OSHA Technical Manual

SECTION II: CHAPTER 1

PERSONAL SAMPLING FOR AIR CONTAMINANTS

Contents:

I. INTRODUCTION

This chapter provides basic information related to sampling air contaminants. Other reference resources are OSHA's Chemical Sampling Information (CSI) file and the OSHA Field Operations Manual (FOM). Sampling and analytical methods that have been validated by either OSHA or the National Institute for Occupational Safety and Health (NIOSH) should be used whenever possible. Sometimes the Salt Lake Technical Center (SLTC) will approve the use of procedures developed by other organizations. Only procedures approved by the SLTC should be used. The use of sampling methods not approved by the SLTC may require resampling with an approved sampling procedure. The SLTC is aware that unique sampling situations will arise during some inspections and it is essential that OSHA Compliance Safety and Health Officers (CSHOs) contact, and work closely with, the SLTC whenever questions arise.

Sampling strategies should be planned for a meaningful evaluation of air contaminants and prudent use of limited resources. Screening techniques and devices, such as detector tubes and direct-reading meters, may provide valuable information when their use and their detection limits are appropriate (see Section II: Chapter 3 Technical Equipment: On-Site Measurements). Knowledge of sampling procedures, including sampling media, recommended air volumes, and sample storage precautions, are essential in planning proper sampling strategies.

Bulk samples are sometimes necessary to support analyses of air samples, to document the source of air contaminants or to identify additional hazards. For example, in conjunction with air sampling for organic dusts, it may also be useful to collect bulk samples for analysis of explosibility and flash point to identify additional safety hazards. Or when air sampling for asbestos, it may also be useful to collect one or more bulk samples of suspect building materials to identify the source(s) of airborne fibers if this is not otherwise evident at the work site. Bulk samples are sometimes used in Hazard Communication inspections (i.e., Safety Data Sheet compliance). Consult OSHA's CSI file to determine when bulk samples are appropriate. Bulk samples often require special shipping and handling.

Ensure that appropriate sample shipping and handling requirements are followed and that the mode of shipment is appropriate for the requested analytical service. For example, "Rush Analysis" requires sample shipment with overnight delivery. If samples are for "Rush Analysis," then concurrence by the Area Director is required. Follow all chain-of-custody protocols. Apply tamper-evident seals (Form OSHA-21) to each sample as shown in Appendix G, and ensure that the chain-of-custody information is not obstructed by the seal. Make certain that samples are properly documented using the sampling worksheet, which is accessed through the OSHA Information System (OIS).

II. PRE-INSPECTION ACTIVITIES

A. REVIEW BACKGROUND INFORMATION

1. Review and follow the inspection procedures in the FOM (CPL 02-00-150).

2. As part of the pre-inspection review, determine whether sampling may be required (and then verify during the on-site walk-around). Also during the pre-inspection review, determine whether exposure to more than one chemical may occur. Refer to OSHA's CSI file for the required sampling media, minimum and maximum sampling volume and flow rate, potential interferences, and handling requirements for individual chemical substances. Contact the SLTC for further guidance if necessary.

   Determine whether there are special handling or shipping requirements prior to sample collection. Refer to OSHA's CSI file. For example, some types of samples need to be shipped back quickly and/or on ice. Sampling media for isocyanates need to be stored refrigerated and protected from light until used, and should be extracted in the field to enhance sample recovery.

3. Refer to Sections III.I. through III.N. for specific sampling requirements for:

   - Total dust
   - Respirable dust
   - Crystalline Silica

- Metals
- Asbestos
- Organic vapors and gases

B. OBTAIN SAMPLING MEDIA, EQUIPMENT AND SUPPLIES

1. The Cincinnati Technical Center (CTC) provides sampling media, supplies and equipment as part of the Agency Expendable Supplies Program (AESP) and the Agency Loan Equipment Program (ALEP). The following are some of the sampling supplies that may be obtained through the AESP:

    - Drager Chip Measurement System (CMS)
    - Detector tubes
    - Filter cassettes (such as preassembled asbestos cassettes)
    - Mixed cellulose ester filters (MCEF)
    - Collar clips and gelbands
    - Sorbent tubes, such as charcoal tubes
    - Tube holders, tube openers, collar clips and manifolds
    - Cyclones
    - Tygon tubing
    - Form OSHA-21 seals
    - Duct tape
    - Calibration gas and accessories
    - Shipping supplies
    - Ventilation smoke tube kits

    A listing of supplies available through the AESP may be found at the following link: https://extranet.osha.gov/dts/LAP/dts/ctc/aesp.pdf.

    CSHOs may place an order for expendable supplies through the CTC via email or fax. The requesting office is charged for the items delivered. When placing an order, please include "AESP ORDER" in the subject line and the following information in the body of the message:

    - CSHO name and telephone number
    - Office name and address
    - For each item ordered:
        - AESP System ID Number (FES #)
        - Supplier Order Number
        - Brief description of the item(s)
        - Quantity

    The ALEP allows field offices to borrow over 250 pieces of specialized monitoring and other equipment from the CTC. The equipment includes items such as air velocity meters for ventilation assessment, dust and fiber aerosol monitors, multi-gas detectors, indoor air quality meters, air sampling pumps and calibrators, and photoionization detectors (PID). The typical loan period is 30 days, which can be extended, if necessary, depending on demand. Equipment can be shipped overnight if the need is urgent.

A list of typical sampling equipment available through the ALEP may be found at the following link: https://extranet.osha.gov/dts/LAP/dts/ctc/alep.pdf. Orders for technical equipment may be made through the same email or fax numbers used for expendable supplies. When placing an order, please include "ALEP ORDER" in the subject line and for each item requested include manufacturer and model, a description of the item(s), and quantity.

2. The SLTC provides some specialized sampling media, such as Carbosieve S-III, passive/diffusive samplers, and pre-weighed filter/cassette units for gravimetric sampling and analysis. Gravimetric filters are weighed at the SLTC and shipped to the field assembled in special cassettes to be used for sampling. The cassette/filter units are returned to the SLTC after sampling for gravimetric determinations and for other analyses. See Appendix A for a discussion of pre-weighed filters. Refer to OSHA's CSI file or to Appendix B for a list of substances for gravimetric determination.

   CSHOs may order sampling media from the SLTC using the order form, which is located on the OSHA Intranet, under CSHO Resources, and which lists media available through the SLTC. Appendix D lists the shelf life of sampling media provided by the SLTC. Appendix E contains a listing of the most frequently requested sampling media from both the SLTC and the CTC.

C. PREPARE PERSONAL AIR SAMPLING EQUIPMENT

1. Active Sampling

   - Assemble filter cassettes prior to the site visit when practical. Verify that the two halves of the cassette are firmly and completely seated against each other to prevent sample material from bypassing the filter. Do not mix brands of cassette components. A hand press can be used to ensure a good seal between the filter and the cassette halves. Examine the assembled cassette to make certain that the joints fit together securely. Use shrink tape or gel bands around the cassette to cover joints.

   - Ensure sampling pump batteries are fully charged. Battery care is discussed in Section II: Chapter 3. Also, refer to the pump manual for specific battery care guidance.

   - Calibrate personal sampling pumps before and after each day of sampling as described in Appendix F. Disconnect the pump from the charger before calibration. Use the same specific type of sample media in line that will be used for sampling in the field (e.g., filter, sorbent tube); but do not use the actual media used for calibration for field sampling. Where more than one pump will be used in the field, label the pumps to avoid mix-up.

   - Calibrate sampling pumps at the temperature and pressure (altitude) at which samples will be collected. If site conditions are substantially above or below room temperature, calibrate the pumps in a clean area at the site, if possible. Give the pump and calibrator electronics time to equilibrate to the temperature conditions at the site. If not possible, refer to manufacturer's guidance in the

equipment manual for temperature corrections and contact the CTC as needed. If sampling will be performed at temperatures below 41° F, check the temperature operating range in the calibrator equipment manual before going to the site, and contact the CTC as needed.

- To avoid sample mix-up, each sample (i.e., cassette, sorbent tube, impinger media) must be labeled with a unique sample number. Either label each sampler before use, or prepare the OSHA-21 seals beforehand by writing in the sample numbers, and then affixing an OSHA-21 seal immediately after removing the sampling device from the pump after post-calibration. OSHA-21 seals are shown in Appendix G. Note that preweighed gravimetric filters have assigned bar code numbers that can be used for sample identification.

- Record presampling calibration data (such as pump serial number and flow rate) and the temperature and pressure of the calibration location using the OIS sampling worksheet. This will also serve as the sample submission document for samples requiring analysis by the SLTC.

2. Diffusive (Passive) Sampling

- Diffusive samplers are convenient air sampling devices that sample gases and vapors and do not require the use of a sampling pump. They are discussed further in section III.N.2 of this chapter. Also refer to the CSI file for diffusive sampling applications and guidance.

- When using diffusive samplers, it is very important to record the sampling site temperature and pressure using the OIS sampling worksheet.

III. ON-SITE INSPECTION ACTIVITIES

A. DEVELOP DOCUMENTATION

- Document accurate and complete sampling pump calibration records and field sampling notes using the OIS air sampling worksheet.
    - Ensure accurate and consistent spelling of the inspected establishment name in order to facilitate future database searches.
    - Refer to the Integrated Management Information System (IMIS) Enforcement Data Processing Manual for detailed sample submission instructions.

- Take photographs and/or videos (as appropriate) and detailed notes concerning sources of airborne contaminants, work practices, potential chemical interferences, movement of employees around the workplace during the performance of their duties, engineering and administrative controls, the use of personal protective equipment (PPE), and other factors to assist in evaluating employee exposures.

- Ventilation and/or smoke tube measurements may be helpful in assessing engineering controls, as described in Chapter 3: Section IV.

- Be certain to observe whether the employee wore the sampling equipment properly. This is sometimes an important issue in litigation. Refer to the FOM for a more thorough discussion of inspection documentation procedures.

B. SAMPLING STRATEGY AND PROTOCOL

As part of the walkthrough, identify the:

- Processes/operations being run
- Tasks performed
- Materials used/materials employees are exposed to
- Work practices used
- Exposure controls in place and how effective they appear to be

Evaluate the chemicals being used. Consider the approximate quantities and utilization rates. For liquids, consider indicators of volatility (e.g., boiling point and vapor pressure). Consider whether handling practices and engineering controls are being used that would increase or decrease exposure. Determine whether exposure is likely to occur as a vapor or an aerosol.

Sample those individuals likely to have the highest workplace exposures (i.e., highest-risk employees) due to the materials and processes with which they work, the conditions in which they work (e.g., distance to exposure source and air movement), the tasks they perform, the frequency of the tasks, and the way in which they perform the tasks (e.g., work habits and employee mobility). For example, in a welding shop, the tall welder who leans over his work may have higher exposures than a shorter welder who is not leaning into the rising plume.

Determine if employees are exposed to more than one chemical, either simultaneously or sequentially. This topic is discussed in Section III.G. Chemical Mixtures.

Determine as soon as possible after the start of the inspection whether air contaminant sampling is required by using the information collected during the walk-around (including any screening samples, such as detector tube results) and from the pre-inspection review. To eliminate errors associated with fluctuations in exposure, conduct representative full-shift sampling for air contaminants when determining compliance with an 8-hour time-weighted average (TWA) permissible exposure limit (PEL). Full-shift sampling is defined as a minimum of the total time of the work shift less one hour (e.g., seven hours of an 8-hour work shift or nine hours of a ten-hour work shift). Make every attempt to sample as much of the work shift as possible, including segments of the greatest exposure. However, no more than eight hours of sampling can be used in the 8-hour TWA calculation (for extended work shifts refer to Section III. E.). A representative exposure sample period may be less than seven hours.

Where relatively high airborne concentrations are anticipated, it may be necessary to replace the sampler during the shift to avoid filter overloading and/or sorbent saturation (refer to Section III.D.5.). Before sampling, check the CSI method to determine flow rate and the minimum and maximum sample volumes needed for each sample. Based on the minimum sample volume and flow rate, determine the minimum duration per sampler.

Equation 1

$$Minimum\ sample\ time = \frac{minimum\ sample\ volume}{flow\ rate}$$

For example, if the minimum sample volume is 240 liters, and the flow rate is 2 liters per minute (L/min), the sampler could be changed out after two hours, and full-shift sampling could be conducted using four two-hour time segments. However, if the minimum sample volume is 600 liters and the flow rate is 2 L/min, a four-hour sample would be insufficient.

And based on the maximum sample volume and flow rate, determine the maximum duration per sampler.

Equation 2

$$Maximum\ sample\ time = \frac{maximum\ sample\ volume}{flow\ rate}$$

For example, OSHA Method ID-100 for ethylene oxide specifies a flow rate of 0.05 L/min and a maximum sample volume of 12 liters. For full-shift sampling it will be necessary to sample in segments of no longer than four hours to avoid exceeding the maximum sample volume (12 liters/0.05 L/min = 240 minutes, or 4 hours).

C. SHORT TERM EXPOSURE LIMITS AND CEILING LIMIT VALUES

Many of OSHA's expanded health standards, such as formaldehyde and methylene chloride, include permissible short term exposure limits (STELs), which are generally 15-minute exposure limits. STEL sampling is conducted by taking a breathing zone air sample of 15 minutes duration in accordance with the applicable sampling method in the CSI file.

Many air contaminants in 29 CFR 1910.1000 have a ceiling limit, either in addition to or instead of an 8-hour TWA PEL. In 29 CFR 1910.1000, Table Z-1, these are noted by a (C), while Table Z-2 contains a separate column for acceptable ceiling concentrations. Ceiling exposures are measured by sampling for a duration sufficient to meet the minimum sample volume in the sampling method in the CSI file.

D. OVERVIEW OF THE SAMPLING PROCESS

1. Select the employees to be monitored and discuss with them the purpose of sampling, how the equipment will be placed, and when and where the sampling equipment will be put on and removed. Stress the importance of not removing or tampering with the sampling equipment. Instruct the employees to notify their supervisors or the CSHO if the sampler requires temporary removal.

2. Place the calibrated sampling equipment on the employee so that it does not interfere with the employee's work performance or safety.

    - Attach the sampling pump to the employee's belt (with the flexible tubing already attached to the pump). Use the minimum length of tubing that is necessary and secure it to the employee to prevent snagging and to avoid interfering with the employee's work. For example, use a collar clip to attach the sampler to the employee's lapel, and tape the tubing to the employee's back between the shoulder blades using duct tape. Collar clips and duct tape are available through the AESP.

- Attach the sampler (filter cassette, charcoal tube, etc.) to the flexible tubing after removing the outlet plug or cap. For flame-sealed sorbent tubes, break open both the ends at this time.

- Attach the sample collection device (use a tube holder for glass sampling tubes) to the shirt collar or as close as practical to the nose and mouth in the employee's breathing zone (i.e., in a hemisphere forward of the shoulders within a radius of approximately six to nine inches). The collection device inlet should be oriented in a downward vertical position to avoid gross contamination from airborne debris falling into the collection device. Air should not pass through any tubing before entering the collection device because otherwise the contaminant of interest may be lost to the walls of any tubing that is placed before the inlet (due to adsorption of vapors or electrostatic attraction of particulates).

- Orient the inlet (vortex finder) to a respirable dust cyclone so that it faces away from the employee.

- For an employee wearing a respirator (including a supplied-air hood for welding or abrasive blasting), place the sampler outside of the respirator. This action is necessary to determine whether the respirator's Assigned Protection Factor (APF) is adequate. For an employee wearing a welding helmet which is not a respirator, the collection device shall be placed under the helmet.

3. Open the inlet to the collection device: e.g., as appropriate to the sampling method, remove the inlet plug and/or face of the filter cassette or plastic end cap for sorbent tubes. Turn on the air sampling pump. After starting, observe the pump operation for a short time to make sure that it is operating correctly. For example, visually check the pump rotameter (if equipped) or digital flow readout, or touch the pump to feel for vibration.

4. Document the sampling pump start time and other required information. For diffusive samplers be sure to record the sampling site temperature and pressure.

5. Strive to sample for at least the **minimum** sampling time or air volume prescribed in the OSHA CSI file. However, this must be balanced against the need to replace the collection medium when overloading of the sampling medium is anticipated or observed during sampling. Overloading is characterized by saturation of the sampling medium. In the case of filters, overloading may be evidenced by the presence of loose material in the filter cassette, darkening of the filter and/or by a reduction in the sampling pump flow rate. For adsorbent media, overloading occurs when the ability of the sampling medium to effectively collect the analyte is compromised. In practice, overloading is difficult to detect and CSHOs should use their observations, experience, and professional judgment to avoid this adverse sampling situation. In general, overloading can be avoided by replacing the collection medium several times during the work shift (once the minimum sample volumes are achieved.)

   If overloading does occur, immediately replace the sampling medium. The sample may still be analyzed, although the reported results are likely to be lower than the actual air concentration.

6. Periodically monitor the employee throughout the workday to ensure that sample integrity is maintained and cyclical activities and work practices are identified. Do not enter areas where sampling is being conducted without the appropriate PPE. Frequent pump checks may be necessary, especially when heavy filter loading is possible. For air sampling filters, verify downward orientation of the sampler inlet and symmetrical deposition of particulate on the filter. There should be no large particles on the filter, since these do not move with the airstream. Check for evidence of tampering with the sample or pump. Ensure that the sampler remains properly assembled and that the tubing does not become pinched or detached from the collection device or from the pump. Check the pump flow readout to be sure the pump is still running. Record any relevant observations. Turn off or remove sampling pumps immediately prior to an employee leaving a potentially contaminated area (such as when he/she goes to lunch or on a break in a clean area). If these areas also appear contaminated and are considered part of the workplace, continue sampling and assess the need for surface contamination measurements (see Section II, Chapter 2, Surface Contaminants, Skin Exposure, Biological Monitoring and Other Analyses). If the pump is turned on and off during the course of the day and/or if the sampling media is changed, document subsequent start/stop times (time on/time off).

7. Before removing the pump at the end of the sampling period, check the pump flow readout (e.g., digital readout or built-in rotameter) to be sure it is still running.

8. Turn off the pump and document the stop time (**time off).**

9. Remove the collection device from the connecting tubing and close both the inlet and the outlet of the collection device as appropriate, for example using caps or plugs.

10. Seal the collection device with a Form OSHA-21 as soon as possible after sampling (see Appendix G regarding Form OSHA-21 seals and sample integrity). The seal should be attached across the sampler inlet and outlet so that evidence of any tampering is visible (see Appendix G, Figures G-1, G-4, and G-5). Appendix G, Figures G-2 and G-3 are photos of **incorrect** applications of Form OSHA-21 seals. Press the seal onto the cassette (or other sampler) to ensure that the adhesive adheres firmly to the cassette/ sampler. Samples with seals that can be removed without obvious evidence of tampering will be identified as "Proper seals not in place" in the SLTC reports of analytical results.

E. EXTENDED WORK SHIFTS

CSHOs can choose one of two approaches for employees who work extended work shifts beyond eight hours. The decision will depend on the nature of the hazardous chemical and the work activity being performed.

- The first approach is to sample what the CSHO believes to be the worst continuous 8-hour work period of the entire extended work shift (e.g., two consecutive four-hour work periods separated by a lunch break).

- The second approach is to collect multiple samples over the entire work shift. Sampling is done so that multiple personal samples are collected during the first 8-hour work period and additional samples are collected for the extended work shift. Unless a CSHO is dealing

with lead, the employee's exposure in this approach is calculated based upon the worst eight hours of exposure during the entire work shift. Using this method, the worst eight hours do not have to be contiguous. Example: for a 10-hour work shift, following the established sampling protocol as per the CSI file, 10 one-hour samples or five two-hour samples could be taken and the eight highest one-hour samples or the four highest two-hour samples could be used to calculate the employee's 8-hour TWA, which would be compared to the 8-hour TWA PEL. Be sure that the sample duration for each individual sample is long enough to meet the minimum sample volume described in the method.

The lead standards for construction (29 CFR 1926.62) and general industry (29 CFR 1910.1025) require PEL adjustments with respect to extended work shifts (workshifts (longer than eight hours). Similarly, under the Cotton Dust standard (29 CFR 1910.1043), the PEL must be proportionately reduced for extended work shifts for the purpose of determining whether, and for how long, respirators must be worn.

F. COMBUSTION AND THERMAL BREAKDOWN PRODUCTS

Certain contaminants are associated with combustion processes. Carbon monoxide (CO) exposures should be suspected whenever combustion-powered equipment, particularly gasoline-powered equipment, is used in areas with limited ventilation. Without a catalytic converter, gasoline-powered equipment typically produces thousands of parts per million (ppm) of tailpipe CO concentrations, as compared to a few hundred ppm produced by propane-powered equipment. The current PEL for CO is 50 ppm. Another combustion byproduct is nitrogen dioxide (NO_2), which has a ceiling value of 5 ppm and is a byproduct of propane-fueled equipment.

Exposures to CO and nitrogen oxides are also associated with welding activities, although such exposures are not usually a concern in open shop welding. CO and NO_2 sampling should be conducted when welding is performed in confined spaces. Ozone is associated with gas shielded metal arc welding. Safety data sheets (SDSs) for welding electrodes, wire and fluxes should be consulted. Contaminants commonly associated with welding include fluorides (if present in the flux-cored electrodes being used), manganese (if present in the electrodes), chromium and nickel oxide (when welding on stainless steel), and zinc (when welding on galvanized metal). "Weldable paints" may thermally degrade to aldehydes, butyric acid, bisphenol A, and numerous other organic molecules. Sampling for welding is discussed in Section III.L., Metals.

Where heated processes are present in the workplace, it may be necessary to sample for thermal decomposition products. In some cases, these are discussed in the SDSs for the products used at the establishment. In other cases, guidance is available from the SLTC for specific industrial processes. For example, in the polymer resin and plastics industries, machining, torch or laser cutting, or overheating of molding equipment may produce toxic decomposition products such as CO or cyanide. The following thermal decomposition products are associated with specific types of plastic: hydrogen chloride from polyvinyl chloride (PVC); styrene from polystyrene; fluoride compounds from polytetrafluoroethylene (PTFE or Teflon®); cyanide compounds from urethanes; and nitrogen-containing compounds from nylon and acrylonitrile. Further information may be found in industrial hygiene references such as Patty's Industrial Hygiene and Toxicology.

G. CHEMICAL MIXTURES

1. Chemical Interactions

Often an employee is exposed to a variety of chemical substances in the workplace simultaneously. In many construction and manufacturing processes, such exposures result in different effects than would be experienced with exposure to only one chemical. This type of exposure can also occur when impurities are present in single chemical operations. When exposure to multiple chemicals occurs, CSHOs should review the health effects information in the CSI to determine whether the chemicals affect the same body organ or physiologic system.

An **additive effect** is one in which the combined health effect of the simultaneous exposures is equal to the sum of the effects of each individual substance alone. For example, the cholinesterase inhibition of two organophosphate pesticides is usually additive when exposure occurs together. Similarly, many solvents have narcotic effects that are considered additive in nature. Below are additional examples of chemicals which have additive effects when exposure occurs together:

- acetonitrile + cyanides
- n-hexane + hexone (methyl isobutyl ketone [mibk]); 2,5 hexanedione or 2,5 hexanediol (all cause peripheral neuropathy)
- carbon monoxide + methylene chloride

A **synergistic effect** is one in which the combined effect of the exposures is much greater than the sum of the individual effects. Classic examples include the synergistic effect of carbon tetrachloride and ethanol on liver toxicity and the synergistic effect on the lungs of smoking and exposure to asbestos.

Potentiation describes a condition in which the target organ toxicity of a particular chemical is markedly increased by exposure to another chemical which does not ordinarily have toxic effects on that organ or system. For example, isopropanol is not a liver toxin, but when combined exposure to isopropanol and carbon tetrachloride (liver toxin) occurs, the liver toxicity is much greater than that due to carbon tetrachloride alone. Ethanol potentiates the toxicity of many other chlorinated hydrocarbons.

Antagonism refers to the situation in which the toxic effects of two chemicals interfere with each other, or the effects of one chemical are actually reduced by exposure to another chemical. This is the basis for many antidotes. Antagonism can occur by several different mechanisms. When chemical antagonism takes place, for example with chelating agents, two chemicals react in the body to a less toxic form. Functional antagonism refers to two chemicals having opposite effects on the same system, such as central nervous system (CNS) stimulants and depressants. Competitive antagonism refers to chemicals acting on the same receptor, such as nicotine and ganglionic blocking agents. Noncompetitive antagonism refers to the toxic effect being blocked by some other means, such as atropine reducing the toxicity of cholinesterase inhibitors.

2. Mixture Formula

OSHA's Air Contaminants standard provides a formula for assessing exposures to chemicals having additive effects [for general industry see 29 CFR 1910.1000(d)(2) and for shipyards see 29 CFR 1915.1000(d)(2)]. This calculation should be used when the components in the mixture pose a combined threat to worker health and components in

the mixture have an effect on the same body (target) organ or physiologic system. This formula can be used for exposures occurring simultaneously or for TWA exposures occurring consecutively within the same workshift.
The mixture calculation is expressed as:

Equation 3

$$E_m = \left(\frac{C_1}{L_1} + \frac{C_2}{L_2}\right) + \cdots \left(\frac{C_n}{L_n}\right)$$

Where:

E_m = equivalent exposure for the mixture (E_m should be less than or equal to 1 for compliance)
C = concentration of a particular substance
L = PEL

Section IV.D. describes sampling and analytical error (SAE) calculations for use of the mixture formula, and example calculations are provided in Appendix H. In addition, an online calculator is available to CSHOs on OSHA's Intranet (in the Directorate of Technical Support's webpage) which will calculate a control limit for any mixture. Simply input the exposures, limits, and SAEs, and the program will calculate a control limit according to the above equation.

Mixture Calculator

The mixture formula may be used to assess employee exposures to chemicals having synergistic effects. However, since the health effects are generally more severe in this scenario, it may be appropriate to apply an increased penalty. As per Chapter 4 of the FOM, all such cases should be discussed with the supervisor and referred to the Regional Administrator. Use the following resource to determine whether there is evidence for synergistic effects: Chemical Mixture Risk Calculation IRSST.

3. Air Sampling for Mixtures (determining what to sample)

The following three examples present portions of SDSs for products containing mixtures and illustrate the process of determining which ingredients should be evaluated for potential employee exposure.

Sample Safety Data Sheet #1

Section 1: *Product Name: Formalin Solution, Buffered 10%*
Section 2: *Composition:*

Ingredient	***CAS No.***	***Percent***	***Hazardous***
Methyl Alcohol	*67-56-1*	*1-1.5%*	*yes*
Formaldehyde	*50-00-0*	*4%*	*yes*
Water	*7732-18-5*	*~95%*	*no*

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Section 8: *Exposure Controls / Personal Protection*

OSHA Permissible Exposure Limits:
Formaldehyde:
0.75 ppm TWA PEL
2.0 ppm STEL
0.5 ppm Action Level

Methyl Alcohol:
200 ppm TWA

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Section 9: *Physical and Chemical Properties:*
Vapor Pressure (mmHg): Essentially the same as water
Evaporation Rate: Essentially the same as water.

Since the SDS does not report the physical properties for the individual ingredients, it is necessary to look at other reference information to determine the relative volatility of the components. Physical properties for specific chemicals may be found in either the CSI file for each chemical, or in the NIOSH Pocket Guide to Chemical Hazards, which can be accessed from links in each chemical's CSI file.

Excerpts from NIOSH Pocket Guide*:*

Methyl Alcohol:
Boiling point: 147ºF
Vapor Pressure: 97 mmHg

Formaldehyde:
Boiling point: -6ºF
Vapor Pressure: > 1atm (1 atm = 760 mmHg)

IDLH: 20 ppm

In comparing the methanol and the formaldehyde, the formaldehyde is present at four times the concentration in the mixture, is considerably more volatile, and has an Action Level which is 1/400th the PEL for methanol. Formaldehyde is a potent irritant with an Immediately Dangerous to Life or Health (IDLH) concentration which is 1/10th the PEL for methanol. Therefore, it is expected that methanol will not make a significant contribution to worker exposure as compared to formaldehyde. Sampling for formaldehyde alone would be considered sufficient. Please note that the CSI states that active sampling, rather than passive badges (diffusive samplers), must be used to sample for formaldehyde where formalin is the source of formaldehyde exposure. Also note that formaldehyde is an OSHA-regulated carcinogen with a substance-specific expanded health standard (29 CFR 1910.1048).

Sample Safety Data Sheet #2

Section 1 *– Product Name: Gravure Ink*

Section 2 *– Composition:*

Ingredient	***CAS No.***	***Percent***	***PEL (ppm)***	***Other Exposure Limits (ppm)***
Toluene	*108-88-3*	*29%*	*200*	*300 ceiling(OSHA)* *500 peak (OSHA)*
1,2-propanediol	*57-55-6*	*5%*	*none*	*not found*
Xylene (mixed)	*1330-20-7*	*31%*	*100*	*150 STEL* *(NIOSH and ACGIH)*

Section 9 *– Physical Properties: % Volume Volatile: 88.6*

Again, the physical properties information on the SDS does not indicate the relative volatility of the components, so it is helpful to refer to the CSI file, including the NIOSH Pocket Guide.

Excerpts from CSI and/or NIOSH Pocket Guide:

Chemical	**Boiling Point**	**Vapor Pressure**
Toluene	232ºF	21 mmHg
1,2-propanediol	188ºC	0.05 mmHg
m-xylene	282ºF	9 mmHg

A review of the CSI file for CAS number 57-55-6 reveals the more common name, propylene glycol. The CSI file states that this material is a Food and Drug Administration (FDA)-approved food additive which is "generally recognized as safe." Due to its low concentration, volatility, and toxicity, sampling for this material is unnecessary.

Sampling for both toluene and the xylenes is recommended if significant quantities are used without adequate local exhaust ventilation. Additionally, toluene and xylenes have similar target organ effects, so the exposures should be evaluated as a mixture using the mixture formula. Toluene and xylenes share the following target organs: central nervous system, eyes, skin, respiratory system, liver and kidneys.

Note that this SDS includes references to non-OSHA occupational exposure limits – in particular, limits set by NIOSH and American Conference of Governmental Industrial Hygienists (ACGIH). NIOSH sets Recommended Exposure Limits (RELs), while ACGIH sets Threshold Limit Values (TLVs). Note that while there is no OSHA ceiling value for xylene, there is a NIOSH/ACGIH STEL. For substances with an 8-hour PEL, but no OSHA ceiling/STEL value, the case should be referred to the Regional Administrator (as described in Chapter 4 of the FOM) if exposure exceeds an ACGIH or NIOSH STEL or ceiling value.

Sample Safety Data Sheet #3

Section 1 *– Product Name: Indoor/Outdoor Spray Paint – True Blue*

Section 2 *– Composition:*

Ingredient	*CAS No.*	*Percent*	*Exposure Limits*	*Vapor Pressure*
Propane	*74-98-6*	*25%*	*PEL 1,000 ppm*	*760 mmHg*
VM & P Naptha	*8032-32-4*	*12%*	*TLV 300 ppm*	*12 mmHg*
Toluene	*108-88-3*	*15%*	*PEL 200 ppm* *TLV 20 ppm*	*22 mmHg*
Light Aromatic Hydrocarbons	*64742-95-6*	*1%*	*Not available*	*4 mmHg*
1,2,4-Trimethylbenzene	*95-63-6*	*2%*	*PEL 25 ppm*	*2 mmHg*
Acetone	*67-64-1*	*30%*	*PEL 1,000 ppm*	*180 mmHg*
Titanium Dioxide (Total Dust)	*13463-67-7*	*0.1%*	*PEL 15 mg/m^3* *TLV 10 mg/m^3*	*n/a*

Section 5 *– Fire Fighting Measures:*
Flash Point of Propane: <0ºF
LEL 0.7%
UEL 12.8%

The PEL for propane is 1,000 ppm and it constitutes 25% of the mixture. Propane is a "simple asphyxiant," meaning it is nontoxic and acts by displacing oxygen. However, propane is flammable, so it is relevant to monitor for flammable gas.

Among the solvents, the greatest exposures will be to acetone because it is present at the highest concentration (30%) and is very volatile. Toluene should also be sampled since its PEL (200 ppm) is lower than the PEL for acetone (1,000 ppm) and its concentration in the mixture is significantly high (15%). If the spray paint is used in moderate quantities for brief periods outdoors or in a spray booth, the trimethylbenzene would likely not evaporate until after the completion of a brief spray application due to its low volatility. Under those circumstances, it is unlikely that the trimethylbenzene would contribute significantly to the worker's exposure, since it is present at such a low percentage. However, for spray applications of long duration performed without local exhaust controls, the trimethylbenzene should be included because although its concentration in the mixture is low, its PEL is also very low warranting the need to determine the level of exposure. Since these solvents are likely to have similar narcotic effects, the CSI should be reviewed to determine whether they have the same target organs, in which case the mixture calculation should be applied.

The titanium dioxide (TiO_2) is present at a very low concentration, is only a nuisance dust, and would be released in a wetted form as part of an aerosol. Gravimetric sampling for the TiO_2 is neither necessary nor practical. The light aromatic hydrocarbons can be ignored since they are present at such a low concentration.

H. FIELD BLANKS

Field blanks are used by the lab to determine if contamination has occurred before analysis or during sample handling, shipping, or storage. Field blanks (e.g., sorbet tubes, filters, absorbing solution) are clean sample media that are taken and opened in a clean area at the sampling site, but they are not used to take samples. They should be handled, stored and shipped in the same manner as other sampling media used in sampling air contaminants, with the exception that no air is drawn

through them. Field blanks are required for **each** requested analysis and for each lot number of sampling media. Prepare field blanks during the sampling period for each type of sample collected. One field blank will usually suffice for up to 20 samples for any given analysis/sampling period. However, asbestos requires a minimum of two field blanks, even for a single asbestos sample.

Diffusive samplers should be briefly opened in the field in an area on-site where no contamination is expected and then they should be immediately resealed with manufacturer's materials. Diffusive samplers begin to sample as soon as they are opened and continue to sample until they are sealed. Follow sample seal procedures for the field blanks as described in Appendix G.

I. TOTAL DUST

Total dust sampling is used to evaluate exposures to a variety of dusts as shown in Appendix B. Also, use total dust sampling for toxicologically inert, nuisance dusts, whether mineral, inorganic, or organic. These dusts are listed in 29 CFR 1910.1000, Table Z-1 as particulates not otherwise regulated (PNOR) and Table Z-3 as nuisance dust, and in 29 CFR 1915.1000 Table Z as PNOR. Please note that there are both total dust and respirable dust PELs for many PNOR (see Appendix B).

Total dust sampling uses pre-weighed PVC filters to determine the total mass of dust collected during the sampling period. Obtain pre-weighed PVC filters from the SLTC. Use a maximum flow rate of 2 L/min for a maximum sampling time of 480 minutes or eight hours. Visually check the filter during the sampling period to avoid overloading the filter. Overloading may be evidenced by the presence of loose material in the filter cassette, by a darkening of the filter, and/or by a reduction in the sampling pump flow rate. Check for overloading by looking into the inlet of the sampling cassette, using a flashlight if needed.

J. RESPIRABLE DUST

Respirable dust sampling uses a cyclone to separate and capture those particles in the size range which would be deposited in the gas exchange region of the lung. Particles too large to be inhaled are collected in a grit pot in the cyclone. The respirable fraction is captured on a pre-weighed PVC filter for gravimetric analysis. Appendix B lists dusts for which respirable sampling should be performed. Obtain pre-weighed PVC filters from the SLTC.

Collect respirable dust samples using a clean 10 mm nylon Dorr-Oliver® cyclone and a pre-weighed PVC filter at a flow rate of 1.7 L/min for a maximum sampling time of 480 minutes (see Figures 1 and 2 shown below, and Appendix I, Figures I-1 and I-2).

FIGURE 1. MSA SAMPLING TRAIN WITH DORR-OLIVER CYCLONE AND CASSETTE

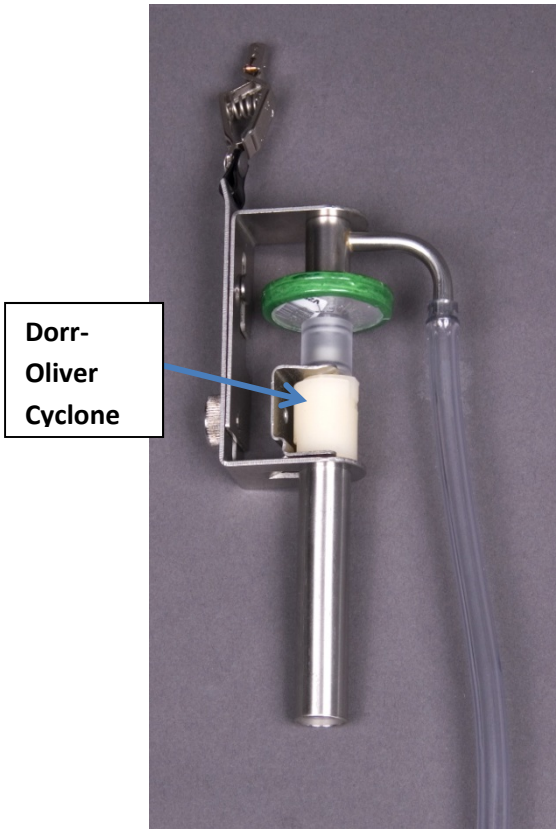
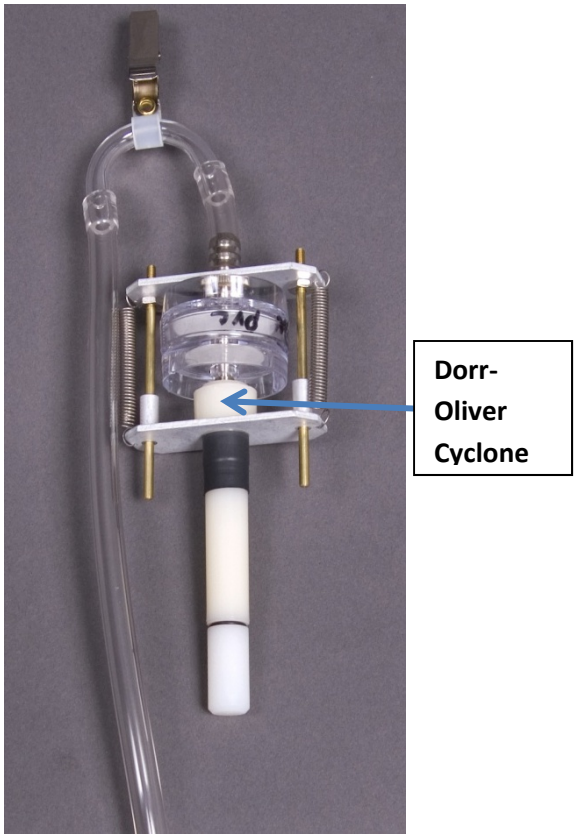


FIGURE 2. SENSIDYNE SAMPLING TRAIN WITH DORR OLIVER CYCLONE AND CASSETTE



The particle size selective characteristics are determined by the type of cyclone used together with the sampling flow rate. A Dorr-Oliver cyclone set to a flow rate of 1.7 L/min can be used in order to meet the specifications described in Table Z-3 (Mineral Dusts) of 29 CFR 1910.1000, footnote "e." Footnote "e" states that both concentration and percent quartz for the application of the crystalline silica and coal dust limits are to be determined from the fraction passing a size-selector with the characteristics shown in Table 1.

TABLE 1. SAMPLING CHARACTERISTICS OF A SIZE SELECTOR

Aerodynamic diameter, μm (unit density sphere)	Percent passing size selector
2.0	90
2.5	75
3.5	50
5.0	25
10	0

Although the criteria in Table 1 were written to meet the Dorr-Oliver performance specifications, any technology that meets this size selective sampling criteria can be used. As OSHA maintains a

significant inventory of Dorr-Oliver cyclones, they remain the primary equipment for respirable mass fraction sampling.

> Note: Adjusting the flow rate of any other sampler design until a 50% cut is achieved at 3.5 µm aerodynamic diameter may not achieve comparable aerodynamic diameters to those specified at the 0, 25, 75, and 90% cut points.

Appendix I contains cyclone assembly and cleaning instructions. Be careful not to overload the filter. Make certain that the cyclone inlet (vortex finder) faces away from the person being monitored.

K. CRYSTALLINE SILICA

1. Air Samples

When employees are exposed to silica during abrasive blasting, air sampling should be done outside the abrasive blasting hood.

Crystalline silica samples are to be collected using a Dorr-Oliver or other suitable cyclone as described for respirable dust samples. A silica sample collected without a cyclone would be a total dust sample and different OSHA PELs apply to respirable and total dust samples. Because of analytical difficulties, CSHOs are discouraged from submitting total dust air samples for silica analysis. The SLTC's silica analysis requires that the particle size distribution of the samples be matched as closely as possible to calibration standards, and this is best accomplished with a respirable sample. If the collected sample is nonrespirable, the SLTC **must** be advised on the air sampling worksheet.

Contact the SLTC if cristobalite or tridymite analysis is required. In general, cristobalite and/or tridymite are produced under conditions involving the high temperature firing of quartz.

X-ray diffraction (XRD) is the preferred silica analytical method because of its sensitivity, its minimum requirements for sample preparation, and its ability to identify polymorphs (different crystalline forms) of free silica. Quartz is initially identified by its major (primary) x-ray diffraction peak. If significant levels of quartz are identified, its presence is confirmed using secondary, tertiary, and/or quaternary peaks to eliminate the possibility of interfering crystalline substances. CSHOs should notify the SLTC if any of the following substances are known to be present in the workplace:

Aluminum phosphate
Feldspars (microcline, orthoclase, plagioclase)
Graphite
Iron carbide
Lead sulfate
Micas (biotite, muscovite)
Montmorillonite
Potash
Sillimanite
Silver chloride

Talc
Zircon (zirconium silicate)

The SLTC results for silica air samples are usually reported under one of four categories:

- Percent quartz and/or percent cristobalite present in the respirable sample. The analysis of tridymite is performed only when requested and results are qualitative only.

- Less than or equal to the percent quartz (and/or cristobalite or tridymite). Less than or equal to values are used when the adjusted 8-hour exposure is found to be less than the PEL, based on the sample's primary diffraction peak. The value reported represents the maximum amount of quartz (or cristobalite) that could be present. However, the presence of quartz (or cristobalite) was not confirmed using secondary and/or tertiary peaks in the sample because the sample results did not show a violation of the PEL.

- Approximate values in units of percent are given for total dust samples. The particle size distribution in a total dust sample is unknown and creates an error in the XRD analysis which limits accuracy to an approximation.

- Nondetected. A sample reported as nondetected indicates that the quantity of quartz (or cristobalite) present in the sample is not greater than the detection limit of the instrument. The detection limit is usually 10 micrograms (µg) for quartz and 30 µg for cristobalite. If less than a full-shift sample was collected, CSHOs should evaluate a nondetected result to determine whether adequate sampling was performed. If the presence of quartz (or cristobalite) is suspected, CSHOs may want to sample for a longer period of time to increase the amount of sample collected.

2. Calculations for Crystalline Silica Exposures

The calculations below are used for determining compliance with the OSHA PELs for crystalline silica. Sample calculations are shown in Appendix J. The Silica Advisor Genius Calculator may be used for general industry (mass-based) calculations. Note that the Advisor Genius is not set up to calculate a "millions of particles per cubic foot" (mppcf) measurement.

Construction and Shipyard Calculations:

Construction and shipyard PELs for silica are measured in units of "millions of particles per cubic foot" (mppcf). The particle count methods are no longer used, and have been replaced by gravimetric (weight) methods. To convert gravimetric results for a respirable dust measurement to mppcf, use the following formula:

Equation 4

$$mppcf = (0.1)(mg/m^3)$$

Before converting mg/m3 to mppcf, the SLTC's SAE must be applied to the severity (see Equation 9) to determine the upper and lower confidence limits.

The construction/maritime PEL for respirable dust containing silica (as quartz) is determined individually for each sample using the following formula:

Equation 5

$$PEL\ (crystalline\ silica, quartz) = \frac{250\ mppcf}{\%\ silica + 5}$$

Conversion factors:

1 *mppcf* = 0.1 *mg/m*^{3} *respirable dust* or
1 *mg/m*^{3} = 10 *mppcf respirable dust*

General Industry Calculations

The general industry PEL for respirable dust containing crystalline silica (as quartz), codified at 29 CFR 1910.1000, is determined individually for each sample using the following formula:

Equation 6

$$PEL\ (mg/m^3) = \frac{10\ mg/m^3}{2 + \%\ respirable\ quartz}$$

The PEL can be calculated either by following the steps below, or by accessing the Advisor Genius online at the OSHA website. The Advisor Genius performs the calculations for a respirable dust sample and yields five values: the PEL for the sample, the respirable dust exposure concentration (mg/m^3), the severity, and the upper and lower confidence limits

To determine the PEL for an air sample containing respirable crystalline silica:

- Obtain the respirable dust concentration for the sample. The weight of the respirable dust in the air sample (expressed as mg or µg) is the net filter weight gain, as determined by the laboratory. The sample air volume is then used to express the concentration of respirable dust in air, as mg of respirable dust per cubic meter of air (mg/m³), as follows:

Equation 7

$$respirable\ dust\ concentration\ in\ air\ (mg/m^3) = \frac{sample\ respirable\ dust\ weight\ (mg)}{total\ air\ volume\ sampled\ (m^3)}$$

- Obtain the percent respirable crystalline silica (e.g., as quartz) in the respirable dust sample, determined analytically by the laboratory and derived as follows:

Equation 8

$$\%\ respirable\ quartz = \frac{weight\ of\ quartz\ (mg\ or\ \mu g) \times 100}{sample\ respirable\ dust\ weight\ (mg\ or\ \mu g)}$$

- Calculate the PEL for the sample, using the reported percent respirable quartz entered as a whole number (e.g., if the % quartz is 7%, use the whole number 7) in Equation 6.

To determine whether there is an overexposure, compare the PEL, calculated using Equation 6, with the sample respirable dust concentration, calculated using Equation 8. The severity ratio is determined by the following formula:

Equation 9

$$Severity\ Ratio = \frac{Sample\ respirable\ dust\ concentration\ (mg/m^3)}{calculated\ PEL\ (mg/m^3)}$$

The equation above is the same as: $Y = \frac{X}{PEL}$

Calculate the Lower Confidence Limit (LCL) by subtracting the SAE from the severity:

Equation 10

$$LCL = Severity - SAE$$

If the LCL is greater than 1, there is a greater than 95% confidence that the sampled employee's exposure exceeded the PEL, and the employee was, therefore, overexposed to respirable dust containing crystalline silica as quartz.

Calculate the Upper Confidence Limit (UCL) by adding the SAE to the severity:

Equation 11

$$UCL = Severity + SAE$$

If the UCL is less than 1, there is a greater than 95% confidence that the sampled employee's exposure did not exceed the PEL.

In the unusual situation where the LCL is less than 1 but the UCL is greater than 1, the employee's exposure relative to the PEL cannot confidently be classified as either over or under and resampling should be considered.

Other factors may have to be considered before arriving at a final exposure value. For example, the TWA calculation may require combining two or more sample results and adjusting to an 8-hour workday. An example is shown in Appendix J.

Where the employee is exposed to combinations of silica dust (i.e., quartz and cristobalite), the additive effects of the mixture will be considered. For the PEL calculation specified in 29 CFR

1910.1000, Table Z-3, the percent silica will be determined by doubling the percentages of cristobalite and tridymite and adding them to the percentage of quartz, according to the following formula:

Equation 12

$$PEL_{mixture} = \frac{10\ mg/m^3}{\%\ quartz + 2\ (\%\ cristobalite) + 2\ (\%\ tridymite) + 2}$$

L. METALS

1. Air Samples

Welding

When sampling for welding fumes, the filter cassette must be placed inside the welding helmet to obtain an accurate measurement of the employee's exposure. Welding fume samples are normally taken using 37-mm mixed cellulose ester filters (MCEF) and cassettes. If these cassettes will not fit inside the helmet, 25-mm MCEF and cassettes can be used. Extra care must be taken not to overload the smaller 25-mm MCEF when sampling.

When a welding helmet or face shield is worn, the sampler is placed on the collar or shoulder so that it is beneath the helmet when the helmet is placed down; it must be located in the breathing zone of the employee (a radius forward of the shoulders and within 6-9 inches of the mouth and nose). Studies have shown that the welding helmet alone results in a reduction in the wearer's breathing zone exposures to welding fume. Placing the sampler under the helmet allows a determination of whether respiratory protection is needed.

Whenever respiratory protection is worn, employee exposure samples must be taken in the breathing zone, but outside the respirator, in order to determine whether the assigned protection factor of the respirator is adequate based on the measured exposures outside the respirator. Some newer styles of negative pressure respirators are designed to fit under a welding helmet. In this case, where an employee is wearing both a welding helmet and a tight-fitting negative pressure respirator, the sampler is placed under the helmet, but outside of the respirator. Where a supplied air welding hood or abrasive blasting hood is worn, the sampler is placed outside the hood, also in the defined breathing zone.

For analysis of welding fume, OSHA Method ID-125G is preferred. This method allows for analysis of several metals on the same filter. Collect metal fumes using a three-stage 37-mm, 0.8-µm MCEF cassette using a maximum flow rate of 2 L/min. Specify the metals of greatest interest in the OIS air sampling worksheet.

Gravimetric determination is required for those substances listed in Appendix B. Use pre-weighed low ash PVC filters obtained from the SLTC as described in Section III.I., Total Dust. Low ash PVC filters may be submitted for metals analysis after the gravimetric determination is performed. See OSHA's CSI file for further detail. Be careful not to overload the filter.

Dust and Fume

When a toxic metal such as lead is present in a workplace as both dust and fume, it may be necessary to sample separately for the dust and the fume. For example, when hot work will be performed adjacent to areas painted with metallic paints, a total dust sample would be collected, as non-respirable particles may be carried out of the lungs by pulmonary clearance mechanisms and then swallowed. The worker would need to wear two sampling pumps, one for dust and one for fume. For total dust, use a preweighed PVC filter obtained from the SLTC. For the fume, use a MCEF filter. In both cases the flow rate is up to 2 L/min. Similarly, vanadium has separate PELs for fume and respirable dust, necessitating the use of two sampling pumps, one with a MCEF cassette for the fume and the other with a cyclone for the respirable dust.

2. Bulk Samples

Bulk samples are sometimes taken to document the source of the material present in the air. Always attempt to take representative samples for bulk analysis. The SLTC analysts will make a reasonable attempt to homogenize samples submitted by CSHOs, however, excessive sample quantities and highly non-homogenous samples complicate this process. Ideally, bulk samples should contain a minimum of approximately 200 mg, but less than a gram, shipped in glass 20-mL scintillation vials with PTFE-lined caps.

3. Metal Analysis

The SLTC is capable of analyzing a variety of metals in specific compatible combinations depending on the ability of the analytical method to simultaneously dissolve the metals of interest in a given acid matrix, and depending on the stability of the metal on the collection filter. In particular, sampling for hexavalent chromium requires use of PVC or treated quartz filters. Some of the current analyte/matrix combinations are listed below and are defined by specific OSHA sampling and analytical methods. Refer to OSHA's CSI file for the most up-to-date analyte/method combinations:

The following combination of 13 metal analytes can be analyzed simultaneously by Inductively Coupled Plasma (ICP) using OSHA Method ID-125G:

Antimony
Beryllium
Cadmium
Chromium (elemental)
Cobalt
Copper
Iron
Lead
Manganese
Molybdenum
Nickel
Vanadium
Zinc

NOTE: The above combination of analytes has been historically referred to as "ICP" for welding fume samples. Where one or more of the analytes are requested for a given filter sample, a full ICP analysis may be conducted, however, CSHOs should specify which metals are of the most interest in the event samples cannot be analyzed by this method or any other multi-element method. Sometimes, alternative types of samples (e.g., samples taken during abrasive blasting operations) may not be analyzed using OSHA Method ID-125G (ICP) because of analytical difficulties encountered with sample characteristics, heavy sample loadings, analyte solubility limitations, or instrumental limitations. Some of these problematic samples and analytes can be analyzed using other multi-element methods listed below or with one of the OSHA Method ID-121 procedures originally designed for individual metal determinations (e.g., Pb, Cd, Fe). Refer directly to OSHA Method ID-121 to interpret the complex choices and compatibilities of a host of assorted analytes and their various preparation techniques. When questions of analytical capabilities arise, CSHOs are encouraged to contact the SLTC spectroscopy experts for further guidance and discussion of analytical options to suit specific compliance monitoring needs.

The SLTC can analyze the following combination of metal analytes, historically referred to as "solder," using OSHA Method ID-206:

Antimony
Beryllium
Cadmium
Copper
Lead
Silver
Tin
Zinc

The following combination of metal analytes can be analyzed by OSHA Method ID-105:

Arsenic
Cadmium
Copper
Iron
Lead
Zinc

The following combination of metal analytes can be analyzed by OSHA Method ID-1006 (air samples only):

Arsenic
Cadmium
Copper
Cobalt
Lead
Nickel

M. ASBESTOS

Collect samples for asbestos using 0.8-µm, 25-mm diameter MCEF cassettes which have been specially designated by the manufacturer for asbestos analysis. The filters must be contained in an electrically conductive cassette assembly that includes a 50-mm extension cowl (see Figure F-5 in Appendix F). An electrically conductive cassette is necessary to prevent loss of fibers to the walls of the cassette due to electrostatic forces. Ensure that the bottom joint (between the extension and the conical black piece) of the cassette is sealed tightly with a shrink band or electrical tape. Make certain that the cassette does not leak. Fasten the (uncapped) open-face cassette to the worker's lapel. Orient the open face downward.

Use a flow rate in the range of 0.5 to 5 L/min. One L/min is suggested for general sampling. For office environments use flow rates up to 5 L/min.

Calibrate as discussed in Appendix F. Do not use nylon or metal (e.g., stainless steel or plated brass) adapters if in-line calibration is done. Do not use the same filter cassette intended to be used for field sampling for sampling pump calibration.

Sample for as long a time as possible without overloading (obscuring) the filter because overloading can lead to an unreadable sample. In a dusty environment, smaller air volumes may be necessary to prevent obscuring the filter (see the discussions on filter overloading in Sections III.D. and III.I.). Instruct the employee to avoid knocking the cassette and, if possible, to avoid using a compressed air source that might dislodge the collected contaminant while sampling. After sampling, replace the face cover and end caps and secure the Form OSHA-21 seal, then post-calibrate the sampling pump.

Approximately 10% of all samples submitted should be blanks, with a minimum of two blanks in all cases.

Where possible, collect and submit a bulk sample of the material suspected to be in the air. Use a wet method for sampling and wear respiratory protection in accordance with regional policy. Submit approximately 0.5 to 1 gram of material in a 20 mL glass scintillation vial with a PolySeal™ cap. Be sure to collect samples from all layers and phases (visually distinct types) of the material. A knife or cork-borer may be used. If possible, make separate samples of each different phase of the material, and place each bulk sample in a separate vial. Ship bulk samples and air samples separately to avoid cross-contamination.

Secure and handle the samples so that they will not rattle during shipment or be exposed to static electricity. Do not ship samples in expanded polystyrene peanuts, vermiculite, paper shreds, or excelsior. Tape sample cassettes to sheet bubbles and place in a container that will cushion the samples without rattling.

Asbestos air samples are analyzed by phase contrast microscopy (PCM) to determine fiber counts. However, PCM does not identify fiber type. List any known fibrous interferences present during sampling in the OIS air sampling worksheet, for example, cellulose (paper, wood), fiberglass, fur, or refractory ceramic. Also, note the workplace operation(s) sampled. Bulk samples are analyzed by polarized light microscopy (PLM) to confirm fiber type. If needed, air samples can be subjected to differential techniques to confirm fiber type and percentage.

For unusual sampling conditions or high flow rates, contact the SLTC for more detailed instructions.

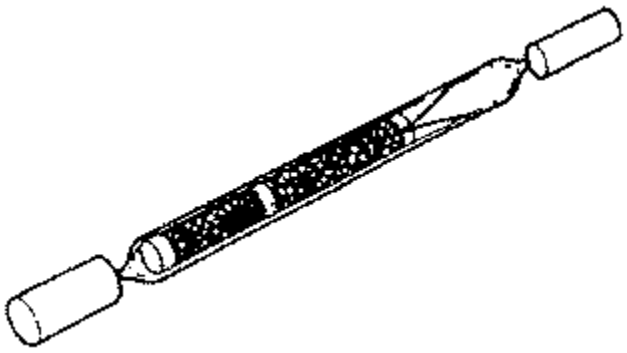
N. ORGANIC VAPORS AND GASES

1. Solid Sorbent Sampling Tubes

   Organic vapors and gases can be collected using several different sampling media including charcoal and other sorbents in sampling tubes (see Figure 3) with low-flow sampling pumps. Refer to OSHA's CSI file for required sampling media, rates, and volumes for specific chemicals.

   Sorbent tube sampling is generally conducted at much lower flow rates than particulate sampling to allow sufficient residence time for the contaminant of interest to adsorb to the sorbent. Sorbent sampling tubes typically contain two sections of sorbent separated by a spacer, such as foam or glass wool. The larger section of sorbent is the primary, and the smaller section is the backup. Orient the back-up section toward the sampling pump. As air is drawn through the sorbent tube, the contaminant of interest will pass into the primary section and bind to the sorbent. When the sorbent in the primary section becomes saturated, contaminant will pass into the back-up section. This is known as **breakthrough**. The lab analyzes the two sorbent sections separately; if greater than 25 %of the contaminant is found in the back-up section, this may indicate that sample was lost due to breakthrough. Breakthrough may result in an underestimation of the employee exposure. The lab should notify the CSHO if breakthrough may have occurred.

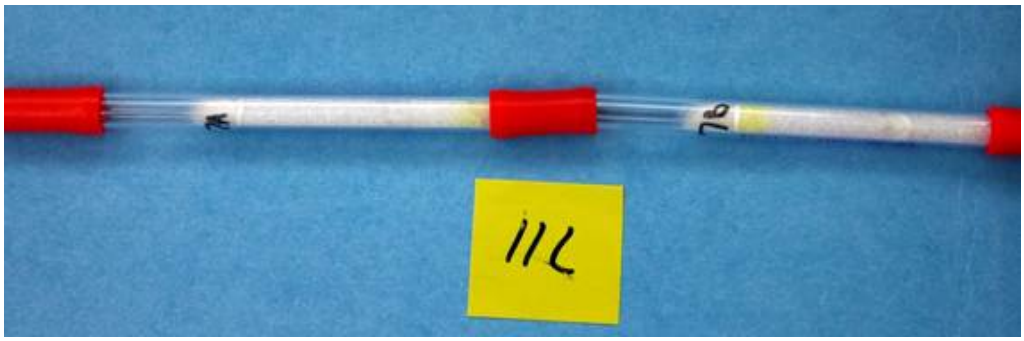
FIGURE 3. CHARCOAL TUBE WITH FLAME-SEALED ENDS AND END CAPS



   Contaminant **migration** may also occur—where contaminant bound in the primary section desorbs and passes into the back-up section after sample collection is completed. There is no way for the lab to distinguish whether material found in the back-up section is the result of breakthrough or migration. To avoid migration, ship samples to the lab without delay. In some cases refrigeration of samples is recommended to reduce migration, for example, in OSHA Method ID-56 for 1,3-Butadiene. Some sampling methods, such as OSHA Method ID-91 for methanol, address the problem of migration by using two sorbent tubes attached in series. The two tubes must be separated from each other and sealed (capped) immediately after sampling.

Note that other airborne contaminants, including moisture, will compete for binding sites on the sorbent. Sample volumes (flow rate and/or sample duration) may need to be decreased under conditions of high humidity (> 90%) or when competing contaminants are present in relatively high concentrations. Check the CSI file for further information.

Figure 4. TWO SORBENT TUBES IN SERIES



Certain situations require use of multiple sorbent tubes, either in series or in parallel (see Figures 4 and 5). As described above, tubes may be used in series to avoid migration of the analyte of interest from the primary to the back-up sections, or to prevent breakthrough by increasing the sampler capacity. Series sampling may also be used where the contaminant of interest must be chemically converted to a more stable form in order to be retained on the sorbent. For example, nitric oxide is sampled using three sorbet tubes connected in series. The front and back tubes contain molecular sieves impregnated with triethanolamine, and the middle or oxidizer tube contains an inert support impregnated with a chromate salt. The middle tube is not submitted to the lab for analysis, but may undergo a color change indicative of depletion of the oxidizer.

FIGURE 5. LARGE PROTECTIVE TUBE COVER FOR SORBENT TUBES IN SERIES (Photo courtesy of NIOSH)

Sampling tubes may also be used in parallel. Sampling in parallel allows simultaneous sampling for multiple chemicals using different sampling media with the same sampling pump. This would generally be done when multiple airborne contaminants are suspected to be present, and either the analytical method does not allow for analysis of more than one of the components from the same sorbent tube or the methods require the use of different sampling media. For example, in ink manufacture, tubes containing different sorbents would be used in parallel. Sorbent tubes are manifolded together using adjustable flow controllers and tube holders available through the CTC AESP. The airflow through each tube must be adjusted separately, and the

combined flow cannot exceed the flow range of the sampling pump. When considering sampling for multiple contaminants operating from the same sampling pump, contact the CTC for further guidance.

Prior to sampling, calibrate the sampling pump as per Appendix F. Do not use the same sorbent tube for pump calibration as will be used for sampling. Immediately before sampling, use a tube opener to break off the ends of the flame-sealed tube to provide an opening approximately half the internal diameter of the tube. Wear eye protection when breaking ends, and be careful not to cut yourself. Do not use the charging inlet or the exhaust outlet of the pump to break the ends of the tube. Insert the sorbent tube into the adjustable low flow controller, slide an appropriate length tube holder over the sorbent tube to shield the sampled person from the sharp ends, and secure the tube holder to the low flow controller. Tube openers (also called tube breakers), holders, and low flow controllers are available through the CTC AESP.

Position the sampling tube vertically so that the opening is pointing downward during sampling. Draw air to be sampled directly into the inlet of the tube. To avoid sample loss, air is not to be passed through any hose or tubing before entering the sorbent tube (except in cases where a very short piece of tubing is used to connect two tubes together that are used in series).

Immediately after sampling, cap the tube with the supplied plastic caps, and seal the tube with a Form OSHA-21 (see Appendix G, Figures G-1 and G-2). The Form OSHA-21 should cover the end caps. If the seal does not cover the end caps because the tube is too long, tape the ends of the seal, using clear plastic tape, so that it is secure and tamper-resistant.

After the samples are properly sealed, post-calibrate the sampling pumps. If the pre- and post- sampling flow rates differ by greater than 5%, note this in the air sampling worksheet. For example, if the pre-calibration flow rate is 50 milliliters per minute (mL/min), the post-calibration flow rate should be between 47.5 and 52.5 mL/min. Likewise, if the pre-calibration flow rate is 200 mL/min, the post-calibration flow rate should be between 190 and 210 mL/min.

Submit the sample for analysis. Do not ship air samples with bulk samples.

2. Diffusive (Passive) Sampling

Diffusive samplers, also known as passive monitors or badges, can be useful for compliance monitoring. The major advantage of diffusive sampling is that no air sampling pump is required. Two common disadvantages are that diffusive samplers are frequently less accurate than active sampling, and that the limit of detection is not always low enough for compliance monitoring, particularly for STEL sampling. As with active sampling, chemical interferences may also be a concern. Figure 6 shows an example of one style of diffusive sampler. Table 2 lists the analytes for which passive diffusive sampling methods have been validated for compliance sampling. Additional airborne contaminants may be identified and quantified by the SLTC, but these analytical results are usually reported as “approximations” and should be used only for screening purposes.

FIGURE 6. DIFFUSIVE SAMPLER

Record the temperature and barometric pressure at the sampling site in the OIS air sampling worksheet. Temperature and pressure are needed for proper calculation of exposure results for diffusive samplers. Results from samples without the sampling site temperature and pressure will have significantly higher sampling and analytical error values. Check the National Oceanic and Atmospheric Administration's (NOAA) website the same day as sampling to obtain the barometric pressure reported with the local weather forecast for that day. The barometric pressure for the time period sampled can sometimes be obtained by contacting the local weather station or airport. If air pressures are obtained by these means, it is necessary to obtain the unadjusted barometric pressure (station pressure) for compliance applications. **If the barometric pressure value cannot be found, note the time and elevation** where the samples were collected**,** and refer to Appendix M, Equation M-4**.**

Specific sampling instructions for each type of diffusive sampler are supplied with the sampler and included in the OSHA methods that permit diffusive sampling (listed below in Table 2). Diffusive samplers should not be opened until just before sampling because they begin to sample as soon as they are opened. To terminate sampling, properly seal the samplers with the manufacturer's packaging materials. Apply the OSHA-21 seal as shown in Appendix G. Send the sealed sampler and all its accessories to the SLTC for analysis. Interfering substances should be noted in the OIS sampling worksheet. Contact the SLTC for further information regarding diffusive sampler availability and use. Consult OSHA's CSI file for new methods as they become available.

TABLE 2. OSHA VALIDATED SAMPLING AND ANALYTICAL METHODS THAT PERMIT DIFFUSIVE SAMPLING

Analyte	Method	Sampler
Benzene	OSHA 1005	SKC 575-002 3M 3520
2-Butanone (MEK)	OSHA 1004	SKC 575-002 3M 3520
Butyl acetate (*n, iso, sec, tert isomers*)	OSHA 1009	SKC 575-002 3M 3520
Ethyl benzene	OSHA 1002	SKC 575-002
Ethylene oxide	OSHA 49	3M 3551
Formaldehyde	OSHA 1007	AT Aldehyde Monitor 571 SKC UMEx 100 Supelco DSD-DNPH
Hexone (MIBK)	OSHA 1004	SKC 575-002 3M 3520
Nitrous oxide	Kem Medical Products Method	Kem Vapor Trak Nitrous Oxide Monitor
Radon	OSHA-208	E-Perm
Styrene	OSHA 1014	SKC 575-006 3M 3520
Tetrachloroethylene	OSHA 1001	SKC 575-002
Trichloroethylene	OSHA 1001	SKC 575-002
Thoron	Contact OSHA SLTC HRT	E-Perm
Toluene	OSHA 111	SKC 575-002 3M 3520
Xylene (*o, m, p isomers*)	OSHA 1002	SKC 575-002 3M 3520

3. Impingers and Bubblers

In many cases, newer methods, such as specially treated sorbents, have been developed that can be used in place of the methods calling for use of an impinger or bubbler. However, in specialized conditions, such as high humidity, methods requiring an impinger or bubbler must still be used. Appendix C lists the chemicals for which the primary method is a bubbler or impinger method. It is always advisable to check the CSI to see if alternative methods can be used.

Examples of a midget impinger (left side) and of a midget bubbler (right side) are shown in Figure 7. The term midget refers to the volume of the sampler flask. The difference between an impinger and a bubbler is that the jet (inlet tube) of an impinger is tapered and sized to allow sufficient velocity for particles to strike the bottom of the flask and become suspended in the liquid, while the stem of a bubbler is fritted to allow collection of vapors in the solution. Bubblers break incoming air into small bubbles to improve collection efficiency of vapors.

The following suggestions should be followed when using impingers and bubblers:

FIGURE 7. MIDGET IMPINGER AND BUBBLER

- Numbers are usually etched into flasks and stems, and matching numbers should be used whenever possible. Take care in preparing impingers and bubblers so that tips or frits are not damaged and so that joints can be securely tightened.

- Rinse the impinger or bubbler with the appropriate collection liquid (absorbing solution) (see OSHA's CSI file). Then add the specified amount of this liquid to the bubbler or impinger flask. Contact the SLTC to obtain the absorbing solutions.

- To prevent overflow, do not add more than 10 mL of absorbing solution to midget impingers or bubblers. Place an empty impinger in series after the impinger (or bubbler) to function as a trap to prevent impinger liquid from being drawn into the air sampling pump. Position this impinger just before the sampling pump; it can be taped to the pump. If an impinger holder or holster is available, tape or secure the holstered impinger to the sampling pump.

- The maximum sampling rate for both midget impingers and bubblers is usually 1.0 L/min, but should be double-checked with the individual sampling method. Because bubblers tend to offer better collection efficiency than impingers, they are preferred over impingers for gas and vapor sampling. Impingers are used only when absolutely necessary for particle counting. Contact the SLTC prior to collecting any samples for particle (dust) counting using impingers.

- The impinger or bubbler can either be hand-held by the CSHO or it can be attached to the employee's clothing using a holster. In either case, it is very important that the impinger or bubbler does not tilt and cause the absorbing solution to flow down the side arm to the hose and into the pump. NOTE: Attach a trap in-line with the pump, if possible.

- In some instances, it will be necessary to add additional absorbing solution during the sampling period to prevent the amount of liquid from dropping below one half of the original amount.

- After sampling, remove the glass stopper and stem from the impinger or bubbler flask. Rinse the absorbing solution adhering to the outside and inside of the stem directly into the impinger or bubbler flask with a small amount (1-2 mL) of the sampling liquid. Pour the contents of the flask into a 20-mL glass vial (preferably a scintillation vial with inert cap and liner). Avoid using metal cap liners or other

materials that may react with the samples. PTFE cap liners with polypropylene caps are inert to most materials. Rinse the flask with a small amount (1-2 mL) of the absorbing solution and pour the rinse solution into the vial. Tape the cap shut by wrapping the tape in the direction of cap closure to prevent it from coming loose due to vibration. If electrical tape is used, do not stretch the tape too much because it could shrink and loosen the cap.

4. Gas Sampling Bags and Canister Samplers

   OSHA uses gas sampling bags to sample carbon dioxide, carbon monoxide, and nitrous oxide. CSHOs can obtain gas sampling bags from the SLTC. Be certain not to fill the bag to more than 75% of its rated volume, and to close the sampling valve after sampling. Place Form OSHA-21 over the valve(s). Transport the gas sampling bag to the SLTC by ground shipment if it contains particularly hazardous materials or if its odor is particularly offensive.

   Gas sampling bags or canisters are sometimes used to collect whole air samples for forensic-type investigations. Call the SLTC for guidance.

IV. POST-INSPECTION ACTIVITIES

A. POST-CALIBRATION

1. Post-calibrate sampling pumps as described in Appendix F.

2. Record results of post-calibration for all pumps used in the OIS air sampling worksheet.

B. COMPLETE DOCUMENTATION

1. Complete the OIS sampling worksheet before sending samples to the lab. CSHOs should be especially diligent in completing the following items:

   - Reporting ID
   - Inspection number
   - Sampling number
   - Establishment name
   - Sampling date
   - Shipping date
   - Person performing sampling
   - CSHO ID
   - Weather conditions
   - Photo(s)
   - Pump checks and adjustments
   - Job location, operation, work location(s), ventilation, and controls
   - Pre-sampling - calibration location temperature and pressure
   - Post-sampling - calibration location temperature and pressure

2. Indicate in the OIS air sampling worksheet if analytical results are to be reported using the actual time sampled (e.g., ceiling or STEL sampling) or if they are to be reported as 8-hour TWA results calculated using zero exposure for non-sampled time portions of the

8-hour period. OSHA TWA-PELs are defined as 8-hour TWA exposures. The SLTC will report sample results using the air volume reported on the OIS sampling worksheet unless otherwise requested by the CSHO.

C. PACKAGE AND SHIP SAMPLES

- Prepare the samples for transport to the SLTC.
- Submit bulk samples and air samples separately to avoid cross-contamination.
- If any submitted materials could be considered hazardous, consult and follow appropriate shipping regulations to assure safe handling during shipment (See internal procedures or contact the SLTC for instructions).
- Pack the samples securely in a box or other sturdy container to avoid any rattle or shock damage. For asbestos samples, do not use expanded polystyrene packing (Styrofoam™) or other static-producing packaging material. Place samples in a plastic bag so that they do not move freely. Use bubble sheeting or other material as packing. Put identifying paperwork in every package. Do not send samples in unpadded envelopes.
- Ensure that you include a printout of the OIS air sampling worksheet and any applicable SDSs with the samples.

D. RECEIVE SAMPLE RESULTS

Calculate the exposure severity, which is the ratio of the sampling results to the PEL. Add the SAE to the severity to determine the upper confidence limit, and subtract the SAE from the severity to determine the lower confidence limit. The SAE is reported by the SLTC on the OIS air sampling worksheet. If there is none listed for a specific substance, contact the SLTC.

For mixtures, the CSHO must determine the SAE as described below in Section IV.D.5. If the PEL violation is confirmed, apply the health effects codes as per Appendix L.

All sampling and analytical methods have some degree of uncertainty. The total uncertainty depends on the combined effects of the contributing uncertainties inherent in sampling and analysis, and has historically been called sampling and analytical error or SAE by OSHA. The SAE is used to determine the upper and lower confidence limits as described below. Correct application of the SAE enables CSHOs to make reliable compliance assessments of sample results. The SAE is especially important when sample results are near the PEL.

Error factors determined by statistical methods shall be incorporated into the sample results to obtain the lowest value of the true exposure (with a stated degree of statistical confidence) and also the highest value of the true exposure (also with a stated degree of statistical confidence).

Confidence limits are values at each end of the confidence interval, which is the probable range of the true value. The lower value is called the lower confidence limit (LCL), and the upper value is the upper confidence limit (UCL). The LCL and the UCL are each termed one-sided because the main concern is with being confident that the true exposure is either less or greater than the PEL.

OSHA applies the LCL and UCL with a 95% statistical confidence limit and they are expressed here as $LCL_{95\%}$ and $UCL_{95\%}$. SAEs that provide a one-sided 95% confidence limit have been developed and are reported out on the Air Sampling Report.

If the $UCL_{95\%} < 1.0$, a violation does not exist.

If $LCL_{95\%} < 1.0$ and the $UCL_{95\%} > 1.0$, classify as possible overexposure.

If $LCL_{95\%} > 1.0$, a violation exists.

The $LCL_{95\%}$ and $UCL_{95\%}$ are calculated differently depending upon the type of sampling method used:

1. Sampling Methods

   Sampling methods can be classified into one of two categories:

   - Full-period, Continuous, Single Sampling. Full-period, continuous, single sampling is defined as sampling over the entire sample period with only one sample. The sampling may be for a full-shift sample or for a short period ceiling determination.

   - Full-period, Consecutive Sampling. Full-period, consecutive sampling is defined as sampling using multiple consecutive samples of equal or unequal duration that, if combined, equal the total duration of the sample period. An example would be taking four two-hour charcoal tube samples. There are several advantages to this type of sampling:

     - If a single sample is lost during the sampling period due to pump failure, gross contamination, etc., at least some data will have been collected to evaluate the exposure.

     - The use of multiple samples should result in slightly lower sampling and analytical errors.

     - Collection of several samples allows conclusions to be reached concerning the manner in which differing segments of the workday affect overall exposure.

     - This practice also allows for monitoring peak and ceiling exposures for the appropriate time. Note that there is some loss of sensitivity with consecutive sampling as compared to continuous sampling.

2. Calculations

   If the initial and final sampling pump calibration flow rates are different, use of the highest of the two calibration flow rates will provide the lowest analytical results for compliance purposes. Generally, sampling is conducted at approximately the same temperature and pressure as calibration, in which case no correction for temperature and

pressure is required and the sample volume reported to the SLTC is the volume actually measured. Where sampling is conducted at a substantially different temperature or pressure than calibration, consult the operating manual for the sampling pump to determine if the air volume needs to be adjusted. If possible, calibrate the equipment at the site. The air volume reported by the CSHO is used in all subsequent calculations.

For particulates, the SLTC reports milligrams per cubic meter (mg/m^3) of contaminant using the actual volume of air sampled at the sampling site as reported by the CSHO.

The SLTC normally does not measure concentrations of gases and vapors directly in ppm. Rather, most analytical methods determine the total weight of contaminant in the collection medium. Using the air volume provided by the CSHO, the lab calculates concentration in mg/m^3 and then converts it to ppm at 25°C and 760 mmHg using Equation M-1 in Appendix M. This ppm result is to be compared with the PEL without adjustment for temperature and pressure at the sampling site. Additional supporting equations are also found in Appendix M.

3. Calculations for Full-Period, Continuous Single Samples

Obtain the full-period sampling result (X), the PEL, and the SAE. The SAE can be obtained from the OIS air sampling worksheet or by contacting the SLTC. Divide the full-period sampling result X by the PEL to determine the exposure severity, Y. From Equation 9:

$$Y = \frac{X}{PEL}$$

Compute the upper confidence level at the 95% confidence level ($UCL_{95\%}$) as follows (from Equation 11):

$$UCL_{95\%} = Y + SAE$$

Compute the lower confidence level at the 95% confidence level ($LCL_{95\%}$) as follows (from Equation 10):

$$LCL_{95\%} = Y - SAE$$

Classify the exposure according to the following classification system:

- If the $UCL_{95\%} < 1.0$, a violation does not exist.
- If $LCL_{95\%} < 1.0$ and the $UCL_{95\%} > 1.0$, classify as possible overexposure.
- If $LCL_{95\%} > 1.0$, a violation exists.

If the results are in the “possible overexposure” category, consider further sampling, taking into consideration the seriousness of the hazard and pending citations. If further sampling is not conducted, or if additional measured exposures still fall into the “possible overexposure” category, the CSHO may wish to carefully explain to the employer and employee representative at the closing conference that the exposed employee(s) may be overexposed, but that there is insufficient data to document noncompliance. The employer should be encouraged to voluntarily reduce the exposure and/or to conduct further sampling to ensure that exposures are not in excess of the PEL.

See Appendix N for an example calculation for a full-period, continuous single sample using the equations above.

4. Calculations for Full-Period Consecutive Samples

The use of multiple consecutive samples should result in slightly lower sampling and analytical errors than the use of one continuous sample because the inherent errors tend to partially cancel each other. The mathematical calculations, however, are somewhat more complicated. The CSHO should first determine if compliance or noncompliance can be established using a calculation method similar to that noted for a full–period, continuous, single sample measurement, following the instructions in the "Compliance/ Noncompliance Method" box below.

Compliance/Noncompliance Method

Obtain the results of consecutive samples taken during the workshift. Let X_n be the concentration for a given sample, and T_n be the sampling duration for that sample, and n be the sample number:

Also obtain the SAE listed in the OIS air sampling worksheet.

1. Compute the TWA exposure, X.

   Equation 13

$$X = \frac{(X_1T_1) + (X_2T_2) \ldots + (X_nT_n)}{480\ min}$$

2. Divide the TWA exposure by the PEL to find Y, the standardized average (TWA/PEL).

3. Compute the $UCL_{95\%}$ as follows:

   $UCL_{95\%} = Y + SAE$ (Equation 11)

4. Compute the $LCL_{95\%}$ as follows:

   $LCL_{95\%} = Y - SAE$ (Equation 10)

Classify the exposure according to the following classification system:

If $UCL_{95\%} < 1.0$, a violation does not exist.

If $LCL_{95\%} < 1.0$, and the $UCL_{95\%} > 1.0$, classify as possible overexposure and recalculate using the more exact calculation found in Equation 14 below.

If $LCL_{95\%} > 1.0$, a violation exists.

When the $LCL_{95\%} < 1.0$ and $UCL_{95\%} > 1.0$, the results are in the "possible overexposure" region and the CSHO must analyze the data using the more exact calculation for full-period consecutive sampling, as follows:

Equation 14

$$LCL_{95\%} = Y - \frac{SAE\sqrt{(T_1X_1)^2 + (T_2X_2)^2 + \cdots + (T_nX_n)^2}}{PEL(T_1 + T_2 + \cdots + T_n)}$$

See Appendix O for an example calculation for a full-period consecutive sampling using the equations above

5. SAEs for Exposure to Chemical Mixtures

As described above in Section III, often an employee is simultaneously exposed to a variety of chemical substances, which may result in additive or synergistic health effects. 29 CFR 1910.1000(d)(2)(i) and 29 CFR 1915.1000(d)(2)(i) specify the computational approach for assessing exposure to a mixture.

Whether using a single PEL or the mixture calculation, the SAE of the individual constituents must be considered before arriving at a final compliance decision. These SAEs can be pooled and weighted to give a control limit for the additive mixture. To illustrate this control limit, the mixture calculation is expressed in the following equation (Equation 3 from above).

$$E_m = \left(\frac{C_1}{L_1} + \frac{C_2}{L_2}\right) + \cdots \left(\frac{C_n}{L_n}\right)$$

Where:

E_m = equivalent exposure for the mixture (E_m should be less than or equal to 1 for compliance)
C = concentration of a particular substance
L = PEL

If $E_m > 1$, indicating that an overexposure has occurred, then the SAE for each substance also needs to be considered:

Exposure ratio (for each substance)

Equation 15

$$Y_n = \frac{C_n}{L_n}$$

Ratio to total exposure

Equation 16

$$R_1 = \frac{Y_1}{E_m}, \ldots R_n = \frac{Y_n}{E_m}$$

The SAEs (95% confidence) of the substances comprising the mixture can be pooled to give the SAE of the mixture using:

Equation 17

$$R_{st} = \sqrt{[(R_1 \times SAE_1)^2 + (R_2 \times SAE_2)^2 + \cdots (R_n \times SAE_n)^2]}$$

Equation 18

$$UCL = 1 + R_{St}$$

Equation 19

$$LCL = 1 - R_{St}$$

If E_m < LCL then no overexposure has occurred at the 95% confidence level.

If LCL ≤ E_m ≤ UCL then the exposure cannot be classified as either under or over the PEL at the 95% confidence level; further sampling may be necessary.

If E_m > UCL then an overexposure has occurred (95% confidence).

See Appendix H for an example calculation.

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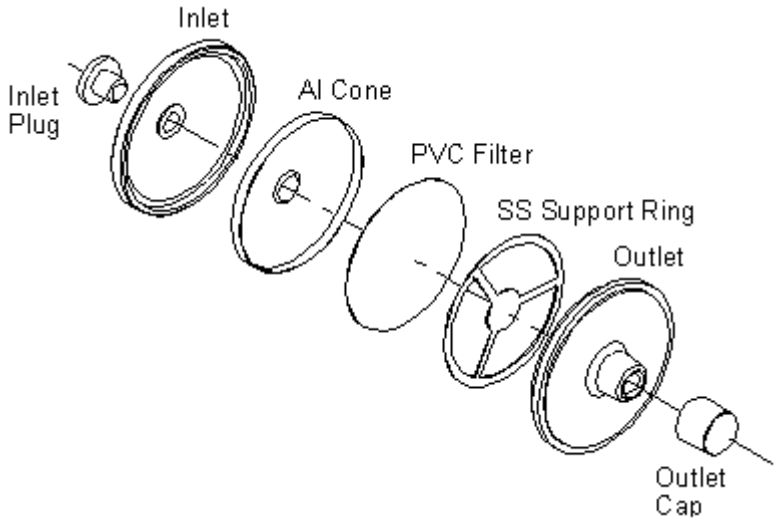
APPENDIX A

PRE–WEIGHED FILTERS

The SLTC provides pre-weighed filters for gravimetric analysis. Filter/cassette units, when assembled in a cassette by the manufacturer, are tested for leaks. These filter/cassette units reduce sample preparation time by CSHOs because the filters are weighed at the SLTC and the units are shipped to the field fully assembled and ready for use. The filter/cassette units are returned to the SLTC for gravimetric determinations and additional analyses as needed. The filter medium is 5-µm, 37-mm diameter, low-ash PVC or PTFE (TEFLON). The PVC filters should be used for silica (quartz) analysis, aluminum, and other appropriate substances having high PELs or requiring gravimetric analysis. The PTFE filters are used for asphalt fumes. The filters may be used with or without a cyclone. Other than for silica, if the gravimetric analysis yields a result less than the PEL for the requested substance(s), no further analysis will be provided unless specifically requested. The filter/cassette unit is shown below in Figure A-1. Appendix B includes a partial listing of substances that should be sampled and analyzed gravimetrically using pre-weighed cassettes.

FIGURE A-1. FILTER/CASSETTE UNIT



Due to the slightly smaller size of the filter, check it frequently to avoid overloading. This can be accomplished by looking into the inlet sampling port of the cassette. Use a flashlight, if necessary. Visual observation of the airborne dust in the workplace may assist in determining how frequently to check the filter for overloading. If used with a cassette, do not lift the cyclone in such a way that particles from the grit pot could be deposited on the filter.

As shown in Figure A-1, the inlet side of the cassette is marked on the polystyrene cassette. This is the side of the filter cassette with the aluminum cone antistatic shield. The stainless steel support (Figure A-2) is visible from the outlet side of the assembly. Each of the filter assemblies is bar coded for weighing purposes (Figure A-4). To aid in tracking the filters, please use the barcode number as the sample submission number when completing the OIS air sampling worksheet. A blank should be included with every set of samples.

FIGURE A-2. STAINLESS STEEL FILTER SUPPORT

FIGURE A-3 OUTLET VIEW OF A FILTER CASSETTE (connect to sampling pump)

FIGURE A-4. INLET VIEW OF A FILTER CASSETTE (open to atmosphere, pointed downward during sampling)

The filter/cassette assembly can be used with both nylon cyclone and holder assemblies currently in field use; however, the standard MSA coupler (used with a standard 2- or 3-piece cassette) will not fit these cassettes. Another coupler available from MSA (part #457391), which is plastic instead of stainless steel, can be obtained from the CTC.

APPENDIX B

SUBSTANCES FOR GRAVIMETRIC DETERMINATION

TABLE B-1. PARTIAL LIST OF SUBSTANCES FOR GRAVIMETRIC DETERMINATION

Substance	IMIS	PEL (mg/m^3)
alpha-Alumina		
Total dust	0160	15
Respirable fraction	A201	5
Aluminum metal (as Al)		
Total dust	A100	15
Respirable fraction	A110	5
Ammonium sulfamate		
Total dust	0185	15
Respirable fraction	A111	5
Barium sulfate		
Total dust	B101	15
Respirable fraction	B104	5
Bismuth telluride Undoped		
Total dust	0370	15
Respirable fraction	B110	5
Boron oxide		
Total dust	0380	15
Calcium carbonate		
Total dust	0505	15
Respirable fraction	C130	5
Calcium hydroxide		
Total dust	0515	15
Respirable fraction	C330	5
Calcium oxide	0520	5
Calcium silicate		
Total dust	C112	15
Respirable fraction	C122	5
Calcium sulfate		
Total dust	C104	15
Respirable fraction	C123	5
Carbon black	0527	3.5
Cellulose		
Total dust	0575	15
Respirable fraction	C124	5
Dicyclopentadienyl iron		
Total dust	0904	15
Respirable fraction	D100	5
Emery		
Total dust	1016	15
Respirable fraction	E102	5
Grain dust (oat, wheat, barley)	G109	10
Glycerin (mist)		
Total dust	1363	15
Respirable fraction	G115	5
Graphite, synthetic		
Total dust	1366	15
Respirable Fraction	G100	5
Gypsum		
Total dust	1367	15
Respirable fraction	G101	5
Kaolin		
Total dust	1568	15
Respirable fraction	K100	5
Limestone		
Total dust	1593	15
Respirable fraction	L100	5
Magnesite		
Total dust	M113	15
Respirable fraction	1615	5

Substance	IMIS	PEL (mg/m^3)
Magnesium oxide fume		
Total dust	1610	15
Marble		
Total dust	1626	15
Respirable fraction	M114	5
Oil mist (mineral)	5010	5
Particulates not otherwise regulated (PNOR)		
Total dust	9135	15
Respirable fraction	9130	5
Pentaerythritol		
Total dust	1987	15
Respirable fraction	P157	5
Perlite		
Total dust	2035	15
Respirable fraction	P101	5
Plaster of Paris		
Total dust	2127	15
Respirable fraction	P102	5
Portland cement		
Total dust	0557	15
Respirable fraction	P104	5
Rouge		
Total dust	2229	15
Respirable fraction	R102	5
Silica Fused		
Total dust		15
Respirable fraction	9013	5
Silicon		
Total dust	2235	15
Respirable fraction	S120	5
Silicon carbide		
Total dust	2236	15
Respirable fraction	S123	5
Starch		
Total dust	2263	15
Respirable fraction	S124	5
Sucrose		
Total dust	2285	15
Respirable fraction	S130	5
Tantalum, metal and oxide dust	2325	5
Titanium dioxide		
Total dust	2440	15
Vegetable oil mist		
Total dust	V126	15
Respirable fraction	V127	5
Zinc oxide fume	2610	5
Zinc oxide		
Total dust	Z102	15
Respirable fraction	Z103	5
Zinc stearate		
Total dust	2616	15
Respirable fraction	Z104	5
Zirconium compounds (as Zr)		
Total dust		15
Respirable fraction	2620	5

APPENDIX C

ANALYTES USING IMPINGER OR BUBBLER AS PRIMARY METHOD (REFERENCE: CSI)

TABLE C-1. IMPINGER METHODS	
Chemical Name	**Chemical Abstracts Service (CAS) Number**
Amitrole	61-82-5
Benzoyl Chloride	98-88-4
Bladex	21725-46-2
Bromacil	314-40-9
Cumene Hydroperoxide	80-15-9
Dibutylamine	111-92-2
Diethylaminopropylamine	104-78-9
Diglycolamine	929-06-6
Diisopropylamine	108-18-9
4-Dimethylaminoazobenzene	60-11-7
N-[3-Dimethylamino) propyl]-N,N',N'-trimethyl-1,3-Propanediamine	3855-32-1
Dinitro-o-cresol	534-52-1
Hexamethylenetetramine	100-97-0
Isopropyl m-Chlorocarbaniliate	101-21-3
Kepone	143-50-0
Lindane	58-89-9
Maleic Acid	110-16-7
beta-Naphthol	135-19-3
Oryzalin	19044-88-3
Pentac	2227-17-0
Pentamethyldiethylenetriamine	3030-47-5
Pipron	3478-94-2
p-Nitrophenol	100-02-7
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9
N,N,N',N'-Tetramethylethylenediamine	110-18-9
Tetranitromethane	509-14-8
Thioglycolic Acid	68-11-1
p-Toluenesulfonic Acid	104-15-4
Tributylphosphorotrithioate	78-48-8

TABLE C-1. BUBBLER METHODS	
Chemical Name	**Chemical Abstracts Service (CAS) Number**
Aldrin	309-00-2
Boron Tribromide	10294-33-4
Boron Trifluoride	7/2/7637
Bromine	7726-95-6
Carbonyl Fluoride	353-50-4
Chlorine	7782-50-5
Chlorine (as Available Chlorine)	7782-50-5 **See note in CSI
Chlorine Dioxide	10049-04-4
Chlorine Trifluoride	7790-91-2
Cyanide (as CN)	57-12-5
1,1-Dimethylhydrazine	57-14-7
Ethyleneimine	151-56-4
Fluoboric Acid	16872-11-0
Fluorine	7782-41-4
Hydrogen Peroxide	7722-84-1
Hydrogen Selenide (as Se)	7/5/7783
Iron Pentacarbonyl (as Fe)	13463-40-6
Isopropylamine	75-31-0
Ketene	463-51-4
Lindane	58-89-9 **See note in CSI
Manganese Cyclopentadienyl Tricarbonyl (as Mn)	12079-65-1
Monomethyl Aniline	100-61-8
Nickel Carbonyl	13463-39-3
N-Nitrosodiphenylamine	86-30-6
Osmium Tetroxide (as Os)	20816-12-0
Pentaborane	19624-22-7
Perchloric Acid	7601-90-3
Perchloryl Fluoride	7616-94-6
Phenylhydrazine	100-63-0
Phosphorus Oxychloride	10025-87-3
Phosphorus Pentachloride	10026-13-8
Phosphorus Trichloride	12/2/7719
Propylene Imine	75-55-8
Rubidium	7440-17-7
Silicon Tetrahydride	7803-62-5
Sulfur dioxide	9/5/7446
Sulfur Monochloride	10025-67-9
Sulfur Tetrafluoride	7783-60-0
Thionyl Chloride	9/7/7719
Triphenylamine	603-34-9

APPENDIX D

SHELF LIFE OF SAMPLING MEDIA

The SLTC will provide an expiration date for sampling media shipped to the field. The date will be printed either on the media itself, on its container, or on its packaging. Return liquid media to the SLTC in the same outer packaging in which it was received.

TABLE D-1. SHELF LIFE OF SAMPLING MEDIA PROVIDED BY THE SLTC

Sampling medium	Shelf Life	Comments
Sodium hydroxide	1 year	Same for all normalities
Hydrochloric acid Sulfuric acid Methanol in water	1 year	Same for all concentrations
Solution for bis-chloromethyl ether (BCME) and chloromethyl methyl ether (CMME)	2 months	Prepared on request*
Hydroxylammonium chloride solutions (for ketene collection)**	2 weeks	Prepared on request*
Hydroxylammonium chloride-sodium hydroxide mixed solutions (for ketene collection)	Stable only 2 hours	CSHO must prepare solution from two component solutions just before use*
Folin's reagent	5 days	Prepared on request*
Diffusive samplers	As per manufacturer	Must be used before the expiration date printed on the monitor package
Nitrogen oxides collection tubes	2 years as per manufacturer	Should be stored in a refrigerator
Sampler for ozone (Nitrite-treated filter collection device)	28 days	Prepared on request*
Coated filter sampler for diisocyanates (MDI, HDI, TDI, etc.)	1 year	Prepared on request*
NaOH coated binderless quartz fiber filters	3 months	Prepared on request*
Treated filter sampler for collection of anhydrides	30 days	Prepared on request*

* Give the SLTC at least two days' notice to allow time for reagent preparation.
**Hazardous goods shipment required both from the SLTC to the field and from the field to the SLTC; Corrosive Liquid, Toxic, UN 2922, Class 8, PGIII.

APPENDIX E

SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES FROM THE SLTC AND THE CTC (REFERENCE: CSI)

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES

IMIS Code #	Analysis	Media
A624	Acetoin (Acetyl Methyl Carbinol)	Two specially dried Silica Gel Tubes in series; each tube has single 600-mg 20/40 mesh section and glass-fiber filter[1]
0040	Acetone	Carbosieve S-III Tube (130/65 mg sections, 60/80 mesh)
A100	Aluminum (as Al), Metal (Total Dust)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm diameter
		Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0170	Ammonia	Sulfuric Acid-Impregnated Carbon Bead (Supelco ORBO-77 tube or equivalent)
0230	Antimony and Compounds (as Sb)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Wipe: Whatman Smear Tab Filter; Solvent: distilled water
0260	Arsenic, Inorganic	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Wipe: Whatman Smear Tab Filter; Solvent: distilled water
9020	Asbestos (All Forms)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm (open face), 25-mm cassette with 50-mm conductive cowl
		Wipe: Do not use Whatman or other paper filters; bulk samples preferred
		Bulk: Collect bulk in 20 mL scintillation vial
0320	Benzene	Charcoal Tube (100/50 mg sections)
		Diffusive Sampler
		Wipe: Charcoal pad from 3M 3500 or 3520 Organic Vapor Monitor; Solvent: none
0726	Benzo [a] Pyrene	Pre-cleaned Glass Fiber Filter (GFF) 37-mm
		Bulk: Limit bulk to one gm or one ml
0360	Beryllium and Beryllium Compounds (as Be)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0430	2-Butanone	Anasorb CMS
		Diffusive Sampler
		Carbosieve S-III Tube (130/65 mg sections, 60/80 mesh)
		Two Silica Gel Tubes in series (150/75 mg sections, 20/40 mesh)
		Anasorb 747 (150/75 mg sections, 20/40 mesh)
0435	2-Butoxyethanol	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Wipe: Charcoal pad; Seal in glass vial for shipment
0440	n-Butyl Acetate	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Diffusive Sampler
0460	n-Butyl Alcohol	Charcoal Tube (100/50 mg sections, 20/40 mesh)
C141	Cadmium	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0527	Carbon Black	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 5 µm, closed face

[1] Filter faces forward when sampling (SKC 226-183, or equivalent). Use opaque tube holder or wrap tubes with aluminum foil or other opaque material while sampling.

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES		
IMIS Code #	**Analysis**	**Media**
C730	Carbon Monoxide (by COHb)	Determined by calculation based on COHb measurements provided by medical professionals (calculation performed and peer-reviewed by trained SLTC staff)
0686	Chromic Acid and Chromates (as CrO_3)	Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm or 25-mm diameter in polystyrene cassette
		Wipe: 37-mm PVC filter or 37-mm binderless quartz fiber filters
		Bulk: Solids require approximately 10 gm, liquids 10 mL; place in 20-mL glass vials with PTFE-lined caps
0689	Chromium (VI) (Hexavalent Chromium)	Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm or 25-mm diameter in polystyrene cassette; collect chromium plating samples on low-background PVC filters or quartz fiber filters coated with sodium hydroxide
		Wipe: 37-mm PVC filter or 37-mm binderless quartz fiber filters
		Bulk: Solids require approximately 10 gm, liquids 10 mL; place in 20-mL glass vials with PTFE-lined caps
0685	Chromium, Metal and Insoluble Salts	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0692	Chrysene	Pre-cleaned Glass Fiber Filter (GFF) 37-mm
		Bulk: Limit bulk to one gm or one mL
0700	Coal Tar Pitch Volatiles (Benzene Soluble Fraction)	Pre-cleaned Glass Fiber Filter (GFF) Gelman Type A/E
		Bulk: Limit bulk to one gm or one mL
0720	Cobalt, Metal, Dust and Fume (as Co)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0725	Coke Oven Emissions	Pre-cleaned Glass Fiber Filter (GFF) 37 mm
		Bulk: Limit bulk to one gm or one mL
E200	Combustible Dust (%)	Call the SLTC for instructions (bulk analysis)
0731	Copper Fume (as Cu)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
0810	Cyclohexane	Charcoal Tube (100/50 mg sections, 20/40 mesh)
D740	Diacetyl	Two specially dried Silica Gel Tubes in series; each tube has single 600-mg 20/40 mesh section and glass-fiber filter[2]
		Two Silica Gel Tubes in series (150/75 mg sections, 20/40 mesh)[3]
1030	Ethanolamine	Coated XAD-2 Tube (80/40 sections, 20/60 mesh); coated with 10% (w/w) 1-Naphthylisothiocyanate (NITC)
1040	Ethyl Acetate	Charcoal Tube (100/50 mg sections, 20/40 mesh)
1060	Ethyl Alcohol	Two Anasorb 747 Tubes (First Tube 400 mg / Second Tube 200 mg)
		Charcoal Tube (100/50 mg sections, 20/40 mesh)
1080	Ethyl Benzene	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Diffusive Sampler
1100	Ethyl Butyl Ketone	Charcoal Tube (100/50 mg sections, 20/40 mesh)
1190	Ethylene Oxide	Coated Carbon Beads Tube (100/50 mg sections, 20/40 mesh); coated with HBr

[2] Filter faces forward when sampling (SKC 226-183, or equivalent). Use opaque tube holder or wrap tubes with aluminum foil or other opaque material while sampling.

[3] Use opaque tube holder or wrap tubes with aluminum foil or other opaque material while sampling.

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES		
IMIS Code #	**Analysis**	**Media**
		Coated Petroleum Base Charcoal Tube (100/50 mg sections, 20/40 mesh); coated with HBr
		Ethylene Oxide Monitor
		Two Charcoal Tubes in Series (100/50 mg sections)
E101	Explosion Severity	Call the SLTC for instructions (bulk analysis)
1280	Fluorides (as F)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Wipe: Whatman Smear Tab Filter; Solvent: deionized water
1290	Formaldehyde	Coated XAD-2 Tube (150/75 mg sections, 20/60 mesh); coated with 10% (w/w) 2-(Hydroxymethyl)piperidine
		Diffusive Sampler
8120	Fungi	Call the SLTC for instructions
1361	Glutaraldehyde	Two Coated Glass Fiber Filters (GFF) (Open Face) in one cassette separated by a spacer; filters coated with 2,4-Dinitrophenylhydrazine (DNPH) and Phosphoric Acid
1371	Heptane (n-Heptane)	Charcoal Tube (100/50 mg sections, 20/40 mesh)
1377	Hexamethylene Diisocyanate	Glass Fiber Filter (GFF) (37-mm open face); coated with 1.0 mg 1-(2-pyridyl)piperazine
		Bulk: Limit bulk to one gm or one mL
H130	1,6-Hexamethylene Diisocyanate Homopolymer	Glass Fiber Filter (GFF) (37-mm open face); coated with 1.0 mg 1-(2-pyridyl)piperazine
1380	Hexane (n-Hexane)	Charcoal Tube (100/50 mg sections, 20/40 mesh)
1385	Hexone	Anasorb CMS
		Diffusive Sampler
		Charcoal Tube (100/50 mg sections, 20/40 mesh)
1430	Hydrogen Chloride	Specially Cleaned Silica Gel Tube (400/200 mg sections with glass fiber filter) (Supelco, ORBO-53; SKC, 226-10-03; or equivalent)
		Wipe: Whatman Smear Tab Filter; Solvent: deionized water
1460	Hydrogen Fluoride (as F)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm; filter spacer (SKC 225-9001); and Na_2CO_3 Impregnated Backup Pad in 3-piece cassette
I200	Iron (Bulk)	Bulk: 1) a high volume (> 1,000 liter) Mixed Cellulose Ester Filter (MCEF) sample of the workplace area; 2) a representative settled dust (rafter) sample; or 3) a sample of bulk material in the workplace[4]
1520	Iron Oxide Fume	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
1534	Isobutyl Acetate	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Diffusive Sampler
1560	Isopropyl Alcohol	Two Anasorb 747 Tubes (First Tube 400 mg / Second Tube 200 mg)
		Charcoal Tube (100/50 mg sections, 20/40 mesh)
1591	Lead, Inorganic (as Pb)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Wipe: Ghostwipe, Whatman Smear Tab Filter; moistened with distilled water
1620	Manganese Fume (as Mn)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
1631	Mercury (Vapor) (as Hg)	Hydrar or Hopcalite tube (200 mg) SKC brand with a prefilter/cassette

[4] Transfer bulk material or filter into a 20-ml scintillation vial and seal with vinyl or electrical tape.

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES		
IMIS Code #	**Analysis**	**Media**
1660	Methyl Alcohol	Two Anasorb 747 Tubes (First Tube 400 mg / Second Tube 200 mg); separate tubes and seal each after sampling
		Silica Gel Tube (520/260 mg sections, 20/40 mesh)
1675	Methyl (n-amyl) Ketone	Charcoal Tube (100/50 mg sections, 20/40 mesh)
1774	Methyl Methacrylate	Coated Charcoal Tube (110/55 mg sections; 20/40 mesh); coated with 10% (w/w) 4-t-Butylcatechol
		XAD-2 Tube (400/200 mg sections, 20/50 mesh)
1073	Methylene Bisphenyl Isocyanate	Coated Glass Fiber Filter (GFF) (37-mm open face); coated with 1.0 mg 1-(2-Pyridyl)piperazine
		Bulk: Limit bulk to one gm or one mL
1730	Methylene Chloride	Carbosieve S-III Tube (130/65 mg sections, 60/80 mesh)
		Charcoal Tube (350/350/350 mg sections, 20/40 mesh)
M104	Moisture Content	Call the SLTC for instructions (bulk analysis)
1790	Molybdenum (as Mo), Insoluble Compounds (Total Dust)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter
1810	Naphthalene	Chromosorb 106 Tube (100/50 mg sections, 60/80 mesh)
1840	Nickel, Metal and Insoluble Compounds (as Ni)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
1860	Nitric Acid	Treated Silica Gel Tube (Supelco, ORBO-53; SKC, 226-10 or equivalent)
		Wipe: Whatman Smear Tab; Solvent: deionized water
1957	Octane	Charcoal Tube (100/50 mg sections, 20/40 mesh)
5010	Oil Mist, Mineral	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm Diameter
1980	Ozone	Two Impregnated Glass Fiber Filters (37-mm polystyrene cassette); coated with a solution containing $NaNO_2$, K_2CO_3 and Glycerol in water
9130	Particulates Not Otherwise Regulated (Respirable Fraction)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm Diameter, preceded by 10 mm Nylon Cyclone
9135	Particulates Not Otherwise Regulated (Total Dust)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm Diameter
2037	Petroleum Distillates (Naphtha) (Rubber Solvent)	Charcoal Tube (100/50 mg sections, 20/40 mesh)
2040	Phenol	XAD-7 Tube (100/50 mg sections, 15/50 mesh)
		Bulk: Limit bulk to one gm or one mL
2085	Phosphoric Acid	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Treated Silica Gel Tube (Supelco ORBO-53; SKC, 226-10-03 or equivalent)
		Wipe: Whatman Smear Tab; Solvent: deionized water
P125	Polymeric MDI (PAPI)	Coated Glass Fiber Filter (GFF) (37-mm open face); coated with 0.1 mg 1-(2-Pyridyl)piperazine
2170	n-Propyl Alcohol	Charcoal Tube (100/50 mg sections, 20/40 mesh)

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES		
IMIS Code #	**Analysis**	**Media**
R251	Refractory Ceramic Fibers	Call the SLTC for instructions
S103	Silica (Quartz, Total)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 37-mm diameter[5]
9015	Silica, Crystalline Cristobalite, Respirable Dust	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 5 µm, preceded by 10 mm Nylon Cyclone
		Bulk: High volume or settled dust sample is preferred; any sample weight between 0.10 mg and 5.0 mg is acceptable (0.5 to 3.0 mg is preferred)
9010	Silica, Crystalline Quartz (Respirable Fraction)	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 5 µm, preceded by 10 mm Nylon Dorr-Oliver Cyclone
		Bulk: High volume area or settled dust sample is preferred. Collect at least 5 gm of dust if submitting high volume sample; for settled dust, any sample weight between 0.10 mg and 5.0 mg is acceptable (0.5 to 3.0 mg is preferred).
2240	Silver, Metal and Soluble Compounds (as Ag)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
2260	Sodium Hydroxide	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Wipe: Whatman Smear Tab Filter; Solvent: deionized water
S777	Soil	Call the SLTC for instructions
2270	Stoddard Solvent	Charcoal Tube (100/50 mg sections, 20/40 mesh)
2280	Styrene	Coated Charcoal Tube (100/50 mg sections, 20/40 mesh); coated with p-tert-Butylcatechol
		Diffusive Sampler
2290	Sulfur Dioxide	Mixed Cellulose Ester Filter (MCEF) followed by a cellulose filter coated with sodium carbonate (SKC 225-9005, or equivalent)
		Special sampling tube containing uncoated glass fiber filter (GFF), followed by sodium carbonate coated glass fiber filter, followed by two beds of silver nitrate coated silica gel (200/200 mg) (SKC 226-177, or equivalent)
		Impregnated Activated Beaded Carbon (100/50 mg sections) (SKC 226-80, or equivalent)
		Mixed Cellulose Ester Filter in series with Midget Fritted Glass Bubbler (MFGB) containing 15 mL 0.3N hydrogen peroxide
2310	Sulfuric Acid	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Treated Silica Gel Tube (Supelco, ORBO-53; SKC, 226-10-03 or equivalent)
		Wipe: Whatman Smear Tab Filter; Solvent: deionized water
2020	Tetrachloroethylene (Perchloroethylene)	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Diffusive Sampler
2430	Tin, Inorganic Compounds (Except Oxides) (as Sn)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
2460	Toluene	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Anasorb 747 (140/70 mg sections)
		Diffusive Sampler

[5] Note: Lab does not recommend taking non-respirable (total) quartz air samples. Total quartz sample results are reported only semi-quantitatively.

TABLE E-1. SAMPLING MEDIA FOR MOST FREQUENTLY REQUESTED ANALYSES		
IMIS Code #	**Analysis**	**Media**
2470	Toluene-2,4-Diisocyanate (TDI)	Coated Glass Fiber Filter (GFF) (37-mm open face); coated with 1.0 mg 1-(2-Pyridyl)piperazine
T177	Toluene-2,6-Diisocyanate	Coated Glass Fiber Filter (GFF) (37-mm open face); coated with 1.0 mg 1-(2-Pyridyl)piperazine
T405	1,3,5-Triglycidyl Isocyanurate	Coated Glass Fiber Filter (GFF) (37-mm); coated with Hydrobromic Acid
2505	Trimethylbenzene (mixed isomers)	Charcoal Tube (100/50 mg sections, 20/40 mesh)
V125	Vanadium	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
2571	Vanadium Fume (as V_2O_5)	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
		Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 5 µm
V109	VM and P Naphtha	Charcoal Tube (100/50 mg sections, 20/40 mesh)
2590	Xylene	Charcoal Tube (100/50 mg sections, 20/40 mesh)
		Diffusive Sampler
Z100	Zinc	Mixed Cellulose Ester Filter (MCEF) 0.8 µm
2610	Zinc Oxide Fume	Tared Low-Ash Polyvinyl Chloride (LAPVC) filter, 5 µm

APPENDIX F

CALIBRATION

A. Sampling Pump Calibration

Calibrate personal sampling pumps before and after each day of sampling using one of the techniques described below. Assure that the calibration equipment is within its prescribed calibration interval, and record the serial number of the calibration equipment in your case file and the OIS air sampling worksheet. The SLTC's chemists sometimes use sampling pump calibration data to verify air sample volumes.

If the sampling pump is equipped with a rotameter or digital flow readout, record the reading in the OIS air sampling worksheet. Bear in mind that the accuracy of a pump rotameter is only approximate; it is intended primarily to facilitate setting the flow rate for calibration.

Most of the following examples in this appendix use filter cassettes as the sampling media, but the examples are generally applicable to adsorbent tubes as well.

NOTE: Precision rotameters are no longer used by OSHA for calibration due to the potential for measurement error (e.g., tests with precision rotameters have indicated significant error due to pump pulsation). Inverted burets may still be useful, but their use is discouraged because they are no longer considered a primary calibration standard.

Before pre-calibration, replace or recharge sampling pump batteries as needed. Check the rechargeable Ni-Cad batteries in older pumps before use under load (i.e., turn pump on and check voltage at the charging jack with the sampling device in-line).

Place the same **type** of sampling media in-line during sampling pump calibration that will be used to sample in the field. Do not use the actual cassette and filter intended for sampling use to perform calibration.

B. Pump Calibration for use with Cyclone

The "Jarless Cyclone Calibration" procedure is the recommended method for calibrating a cyclone. A one-liter jar should no longer be used due to technical issues such as leakage of the jar lid.

The purpose of the procedure is to determine whether the sampling pump will be able to maintain the required flow rate as the drop in static pressure grows due to particulates loading up on the filter. The typical pressure drop across a clean 5-µm filter is 2 inches of water pressure. The additional pressure drop from the cyclone is approximately 0.25 inches. As a filter loads up, the additional pressure drop may be as high as 20 inches of water pressure.

The procedure is demonstrated in the video "Jarless Cyclone Calibration Method" on the OSHA intranet.

Below is a summary of the basic steps of the procedure:

- Adjust and calibrate the pump to a flow rate of 1.7 L/min with a light load attached;
- Increase the load to 25–35 inches and check to be sure the flow rate is within +/- 5%;
- Remove the load and attach the cyclone to the sampling pump, then verify that the load is at between 2 and 5 inches of water pressure;

Detailed Step-By-Step Instructions

1. Connect the sampling train:

    - Connect the sampling pump to a Tee fitting.
    - Connect the Tee to a pressure gauge and the light load (i.e., a clean 5-µm filter or an adjustable bonnet valve).
    - Connect the load to the air outlet of the pump calibrator (bubble meter).
    - Turn on the sampling pump.
    - If a bonnet valve is used, adjust to create a load of 2–5 inches of water pressure. If a 5-µm filter is used, verify that the pressure drop is 2–5 inches of water pressure. If not, this may indicate leakage around the filter.
    - Set the pump flow rate to 1.7 L/min.
    - Take at least three flow readings and record the average flow rate. Readings should be within +/- 2% of each other.

2. Increase the load:

    - If a bonnet valve is used, adjust to increase the load to 25–35 inches of water pressure. If a 5-µm filter was used for the light load, remove it and replace it with a set of six 0.8-µm filters connected in series (i.e., sandwiched in a four-piece cassette with four backup pads). If the load is not at least 25 inches of water pressure, ensure the cassette is tightly compressed to prevent air from bypassing the filters.
    - Turn on the pump, and then check and record the average flow rate. If the flow is not within +/- 5% under increased load, return the pump to the CTC for repair with a note explaining the problem.

3. Add the cyclone to the sampling train:
    - Disconnect the pump calibrator and remove the load.
    - Attach the cyclone with a clean 5-µm filter in place of the load.
    - Turn the pump on and confirm that the pressure drop is 2–5 inches of water pressure with the cyclone attached.

Refer to the cyclone leak test and cyclone cleaning procedures as described in Appendix I.

C. Electronic Flow Calibrators

The Gilian Gilibrator® I and II by Sensidyne® (see Figure F-1) are electronic bubble flow meters, used to calibrate sampling pumps, that provide instantaneous air-flow readings and cumulative averaging of multiple measurements. These calibrators measure the flow rate and display the results as volume per unit of time (e.g., mL/min) and can be used to calibrate most air sampling pumps. Different flow cells are used to accommodate different flow ranges. The middle-sized flow cell is typically used for personal sampling for particulates, while the largest cell is used for high volume area sampling and the smallest cell may be needed for certain low flow sorbent tube methods. The total range with the different flow cells is from 1 mL/min to 30 L/min. Gilibrators **should not** be left plugged into the charger for extended time periods because doing so will decrease the service life of the battery.

Another wet-cell calibrator available in some OSHA field offices is the miniBuck™ as shown in Figure F-2. Its operation is similar to the Gilibrator.

The Bios Defender™ shown in Figure F-3 is an electronic dry-piston flow meter used to calibrate sampling pumps that provides immediate and average readings. The device can be used to calibrate either pressure (labeled inlet) or vacuum (labeled outlet) flow sources. The vacuum port is used to calibrate sampling pumps, and the pressure port is used to calibrate the outlet of sampling pumps used to fill gas sampling bags. The Bios Defender has a lead-acid battery and can be left on charge for an indefinite time without damaging the battery. Different models of the instrument cover an optimum flow range of 5 mL/min to 30 L/min.

FIGURE F-1. GILIAN GILIBRATOR PUMP CALIBRATOR

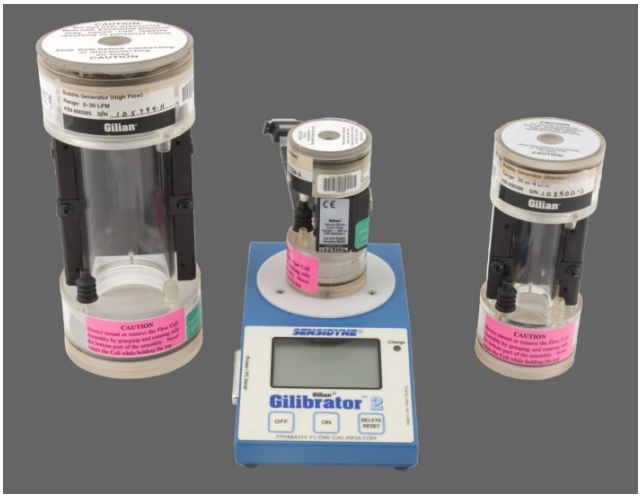


FIGURE F-2. MINIBUCK PUMP CALIBRATOR

If using a Bios Defender to calibrate an MSA Escort® ELF pump, use an isolating flow restriction providing at least 5 inches of water column pressure between the pump and the flow meter. For example, use air sampling media (cassette or sorbent tube) with a Gemini variable orifice. Failure to use such an isolation technique may result in +/- 2% calibration inaccuracy.

The CTC recommends that the Bios Defender not be used in a very dusty environment because dust that flows through the calibrator piston area has the potential to scratch the glass and piston inside the calibrator. The CTC also recommends that neither the Gilibrator nor the Bios Defender flow calibrator be used in corrosive or otherwise contaminated environments.

FIGURE F-3. BIOS DEFENDER PUMP CALIBRATOR

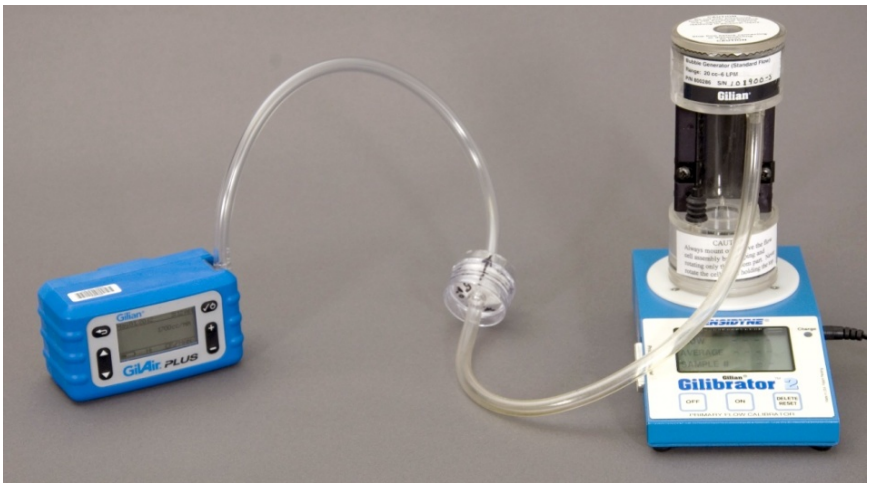
Properly functioning and calibrated Gilibrators and Bios Defenders have an accuracy of approximately 99%. Use the appropriate Gilibrator flow cell or the Bios Defender model with the appropriate range of airflow for the pump airflow to be calibrated.

It is recommended that the flow rates obtained from these devices be reported to three significant figures. For example, a flow rate shown as 1.006 L/min should be reported as 1.01 L/min.

D. Procedures

NOTE: The following instructions and figures were written for the Gilian Gilibrator flow calibrator as shown in Figure F-4, however, the Bios Defender and miniBuck calibrator can be substituted in most cases (for use with MSA Escort ELF pumps, the isolating flow restrictor must be used as described above).

FIGURE F-4. CASSETTE ATTACHED TO ELECTRONIC BUBBLE METER FOR PUMP CALIBRATION



1. Perform the calibration at the pressure (altitude) and temperature where the sampling is to be conducted. If this is not possible, consult the operating manual for the sampling pump to determine if the air volume needs to be adjusted for temperature and pressure. Allow the pump to run for one to five minutes before voltage check and calibration. Consult the CTC regarding correction factors if sampling must be performed at freezing temperatures.

2. Connect the collection device, tubing, pump, and calibration apparatus as shown in Figure F-4 for the cassette (or sorbent tube) sampler. Note that cassette adapters (e.g., plastic or metal Luer taper adapters) should not be used. Luer adapters in front of a filter in a calibration train can potentially generate significant back pressure for which some pressure regulating pumps may not be able to compensate, resulting in inaccurate results. Luer adapters behind filters can affect sample distribution across an open-face cassette, and some Luer adapters are long enough that they may even make contact with the backup pad in the cassette. For this reason their use is not recommended. There are commercially available filter cassette holders with integrated connectors that do not have an adverse effect on back pressure.

3. Visually inspect all plastic tubing connections. Be certain that there are no leaks.

4. Gilibrator: Assemble the Gilibrator as per the equipment manual. Introduce soap solution into the flow cell through the air inlet boss. Add enough soap solution until the angled edge at the bottom of the bubble generator ring is immersed in the solution. After connecting the sampling pump and turning it on, push the button several times to wet the inside of the electronic flow cell with the soap solution.

   Bios Defender: No preparation required.

FIGURE F-5. BUBBLE ACTUATOR BUTTON ON GILIBRATOR

5. Turn on the pump and adjust the pump rotameter and/or digital flow display (if so equipped) to the appropriate flow rate.

6. Gilibrator: Press the button on the electronic bubble meter. Visually capture a single bubble and electronically time the bubble. The accompanying printer will automatically record the calibration reading in L/min.

   Bios Defender: Press and release the Read button for a single measurement. Press and hold the Read button for consecutive measurements.

7. Adjust the sampling pump to the correct flow rate using the calibrator results. Adjust the sampling pump while it is running.

8. Confirm that the sampling pump is adjusted properly and take additional calibrator readings. Three or more consecutive readings should be taken and should be within about 2% of each other and then averaged.

9. Repeat the procedures described above for all pumps to be used for sampling. The same cassette and filter may be used for calibrations involving the same sampling method. Do not use the actual cassette and filter intended for sampling use to perform calibration.

FIGURE F-6. GILIBRATOR DISPLAY PANEL SHOWING FLOW RATE, SIDE BY SIDE WITH GILAIR SAMPLING PUMP WITH DIGITAL FLOW READOUT

E. Instructions for Calibrating MSA Escort ELF Pumps with "Dry" Piston-Type Calibrators

When calibrating Escort ELF pumps with piston-type calibrators, extra steps must be taken to ensure that the pumps are calibrated accurately. The design of Escort ELF pumps make them susceptible to calibration inaccuracies due to pressure spikes created by the mechanical action of Bios International piston-type calibrators, such as the Defender series models. The rubber-walled pulsation dampeners incorporated into the Escort ELF pump design do not sufficiently compensate for the pressure spikes from the Bios calibrators; as a result, these pressure impulses can produce an uncertainty of over 4% (± 4%) in the calibration accuracy of Escort ELF pumps. **THE ESCORT ELF PUMPS SHOULD NOT BE CALIBRATED USING THE BIOS INTERNATIONAL PISTON TYPE CALIBRATORS BECAUSE THEY CAN PRODUCE AN UNCERTAINTY ERROR OF OVER 4%** (compared to the desired margin of error of ±1%). No other type of pumps are affected by this phenomenon, nor do the Escort ELF pumps suffer this susceptibility when wet cell bubble-type air flow calibrators are used or when the pumps are deployed with air sampling media or filter cassettes.

The manufacturers recommend that an isolating flow restrictor, such as a 0.030-inch orifice, be placed between the pump and the flow meter. The 0.030-inch orifice was shown at the CTC to create about 20 inches of water column (WC) of additional loading to the sampling pump at 2,000 mL/min. This additional loading causes the pump to speed up to maintain the required flow setting, which, in turn, makes the small changes in loading caused by the action of the calibrator's piston to have a negligible effect on the airflow within the Escort ELF pump. The use of a 0.030-inch orifice will ensure that there will be a sufficient load on the Escort ELF pump to mitigate the pressure spikes from the Bios piston-type calibrator across the entire effective flow-rate range of the pump, thus enabling the operator not to exceed the required 1 percent (± 1 percent) pump calibration accuracy.

F. Calibration Procedures for Open-Face Filters

Open-face cassettes are used for asbestos and certain chemicals such as isocyanates, crotonaldehyde, and glutaraldehyde.

1. The appropriate way to calibrate an open-face cassette is to use the cover section which comes with the cassette and attach the tubing directly from the electronic flow calibrator to the inlet port on the cassette cover. Be certain there are no leaks and do not use a Luer adapter. This set-up will provide the least amount of flow resistance and represent the open-face conditions while actually sampling.

2. Perform the pump calibration at the pressure (altitude) and temperature where sampling is to be conducted. If this is not possible, consult the operating manual for the sampling pump to determine if the air volume needs to be adjusted for temperature and pressure.

G. Calibration of Impingers and Bubblers

1. Set up the calibration apparatus as shown in Figure F-6, but instead of using a cassette, attach an impinger or bubbler filled with the amount of liquid absorbing solution specified in the sampling method. If a prefilter or cassette is described in the CSI file, include the correct filter in line. Include an adsorbing solution trap if one is to be used in air sampling.

2. Connect the tubing from the electronic bubble meter to the inlet of the impinger or bubbler.

3. Connect the outlet of the impinger or bubbler to the tubing to the pump. Be certain there are no leaks.

4. Calibrate the pump to the flow rate specified in the CSI file for the sampling method.

H. Maintenance and Care of Electronic Calibrators

Consult the manufacturer's instruction manuals for complete details. Periodically, compare the calibrator to another unit to make sure that it is functioning properly. Return the calibrator to the CTC annually to be calibrated and serviced.

Gilian Gilibrator:

1. For units that are used daily, connect the short length of storage tubing to the air outlet (upper) boss and the air inlet (lower) boss of the flow cell. This will prevent evaporation and concentration of the soap solution. Store in a clean area.

2. For units that will not be used for more than a week, remove the flow cell by unplugging the power/data cord and then gripping the bottom of the flow cell and rotating it one quarter turn counter-clockwise. Caution: gripping the top of the flow cell before turning it can stress and crack the flow cell. Then tip the cell horizontally and drain the soap solution out through the air inlet (lower) boss. Allow the flow cell to air dry completely before storage. Do not leave the calibrator plugged into the charger for extended time periods because doing so will decrease the service life of the battery. Store in the case to protect from breakage or dust accumulation.

3. Check the unit before use. Wipe the outside with a damp cloth if needed. If stored properly, routine cleaning is unnecessary. If there is excessive soap residue inside the flow cell, disconnect it and rinse with warm water. The acrylic flow cell can be easily scratched. Do not allow the flow cell (center tube, where sensors detect the soap bubble) to be scratched or to get dirty. Never clean the cell with acetone, alcohol or other cleaning solutions.

4. Leak testing. If leakage is suspected, perform a leak test as described in the Gilibrator manual. No leakage should be observed. Never pressurize the flow cell with more than 25 inches of water pressure. The CTC performs a leak check as part of their annual service.

5. Calibrator Calibration. The calibrator is factory calibrated using a standard traceable to the National Institute of Standards and Technology. The calibrator is linear throughout the entire range. The CTC will calibrate the unit as part of their annual service.

6. When transporting the calibrator, especially by air, it is important that one side of the storage tube which connects the air inlet and outlet be removed to equalize internal pressure within the calibrator. Do not transport the unit with soap solution or with storage tubing in place.

7. The calibrator soap is a concentrated and sterile solution formulated to provide a clean, frictionless soap film bubble over the wide, dynamic range of the calibrator. The sterile nature of the soap is important in order to prevent residue buildup in the flow cell center tube, which could cause inaccurate readings. The use of any other soap is not recommended. Proper soap solution is available from the CTC's expendable supplies program.

Bios Defender*:*

1. Do not use liquid solvents or abrasive cleaners to clean the calibrator; wipe only with a cloth lightly dampened with water. Store the instrument in a clean, dry place and with the unit on charge, if possible.

2. Leak testing. Place the manufacturer supplied leak-test accessory (short piece of tubing with a red plug) over the inlet (top port). Press and hold the STOP button and then press the ON button. The display should read “Leak Test, Invert & Push Read.” Invert the unit and push Read. Turn the unit upright and allow it to stand. Make sure that the piston is at the top of the cell. Allow the calibrator to stand until the piston falls; this may take as long as 15–20 minutes. The unit will display “Test OK Press Read” if it passes the test. Repeat the leak test with the leak-test accessory over the outlet (bottom port).

3. Calibration. Bios recommends that the unit be recalibrated by the manufacturer annually. The CTC will calibrate the unit as part of their annual service.

APPENDIX G

HOW TO APPLY FORM OSHA-21 TO SAMPLING MEDIA

FIGURE G-1. CORRECTLY SEALED CHARCOAL TUBE. CHARCOAL TUBE INSIDE FORM OSHA-21

FIGURE G-2. INCORRECTLY SEALED CHARCOAL TUBE. END CAPS CAN BE REMOVED, ALLOWING SAMPLE INTEGRITY TO BE JEOPARDIZED WITHOUT DISTURBING THE SEAL

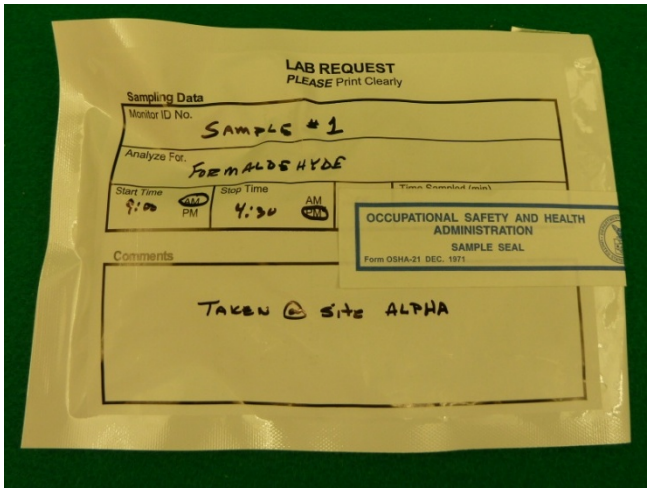
FIGURE G-3. INCORRECTLY SEALED CASSETTE ALLOWS ACCESS TO INLET/OUTLET PORTS AFTER SAMPLE HAS BEEN TAKEN

FIGURE G-4. CORRECTLY SEALED CASSETTE WITH FORM OSHA-21 COVERING INLET/OUTLET PORTS MAINTAINING SAMPLE INTEGRITY

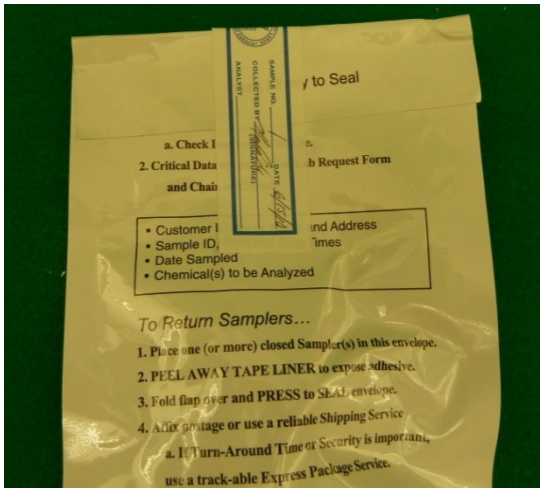
FIGURE G-5. STANDARD ASBESTOS CASSETTE (25mm) CORRECTLY SEALED WITH A FORM OSHA–21

FIGURE G-6. PASSIVE MONITORS CORRECTLY SEALED WITH A FORM OSHA-21

Correctly sealed formaldehyde passive sampler



Backside of correctly sealed formaldehyde passive monitor



Correctly sealed 3M passive monitor

APPENDIX H

EXAMPLE CALCULATIONS FOR MIXTURES

As an example, an exposure to three different substances:

Material	8-hr. Exposure (ppm)	8-hr. TWA PEL (ppm)	SAE
Substance 1	500	1,000	0.089
Substance 2	80	200	0.11
Substance 3	70	200	0.18

Using Equation 3 (from Section III.G.2.):

$$E_m = \left(\frac{C_1}{L_1} + \frac{C_2}{L_2}\right) + \cdots \left(\frac{C_n}{L_n}\right)$$

Where:

E_m is the equivalent exposure severity for the mixture
E_m should be < 1 for compliance
C is the concentration of a particular contaminant
L is the OSHA exposure limit for that substance.

$$E_m = \frac{500}{1000} + \frac{80}{200} + \frac{70}{200} = 1.25$$

Since E_m > 1 an overexposure appears to have occurred; however, the SAE for each substance also needs to be considered:

Exposure severity ratio (for each substance) (from Equation 15 from Section IV.D.5. above)

$$Y_n = \frac{C_n}{L_n}$$

Ratio each to total exposure (using Equation 16 from Section IV.D.5.)

$$R_1 = \frac{Y_1}{E_m}, \ldots R_n = \frac{Y_n}{E_m}$$

The SAEs (95% confidence) of the substances comprising the mixture can be pooled by:

Equation H-1

$$R_{st} = \sqrt{[(R_1)^2 \times (SAE_1)^2 + (R_2)^2 \times (SAE_2)^2 + \cdots (R_n)^2 \times (SAE_n)^2]}$$

which is also equivalent to (using Equation 17 from Section IV.D.5.):

$$R_{st} = \sqrt{[(R_1 \times SAE_1)^2 + (R_2 \times SAE_2)^2 + \cdots (R_n \times SAE_n)^2]}$$

From Equation 18

$$UCL = 1 + R_{St}$$

From Equation 19

$$LCL = 1 - R_{St}$$

If E_m < LCL then no overexposure has occurred at the 95% confidence level.

If LCL ≤ E_m ≤ UCL then the exposure cannot be classified as either under or over the PEL at the 95% confidence level; further sampling may be necessary.

If E_m > UCL then an overexposure has occurred (95% confidence).

Using the mixture data above:

$Y_1 = 500/1{,}000$	$Y_2 = 80/200$	$Y_3 = 70/200$
$Y_1 = 0.5$	$Y_2 = 0.4$	$Y_3 = 0.35$
$R_1 = Y_1/E_m = 0.4$	$R_2 = 0.32$	$R_3 = 0.28$

$$(R_{st})^2 = (0.4 \times 0.089)^2 + (0.32 \times 0.11)^2 + (0.28 \times 0.18)^2$$

$$R_{st} = \sqrt{(R_{st})^2} = 0.071$$

$$UCL = 1 + R_{st} = 1.071$$

$$E_m = 1.25$$

Therefore E_m > UCL and an overexposure has occurred within 95 percent confidence limit.

An executable computer program is available which will calculate a control limit for any mixture. Simply input the exposures, limits, and SAEs and the program will calculate a control limit according to the above equation.

Mixture Calculator

APPENDIX I

CYCLONE ASSEMBLY AND CLEANING INSTRUCTIONS

A. Cyclone Assembly

Inspect the cyclone parts for signs of wear or damage such as scoring, rifling, or a loose coupler. Replace the units or parts if they appear damaged. Figures I-1 and I-2 show the parts for MSA and Sensidyne cyclones, respectively.

FIGURE I-1 MSA CYCLONE ASSEMBLY PARTS

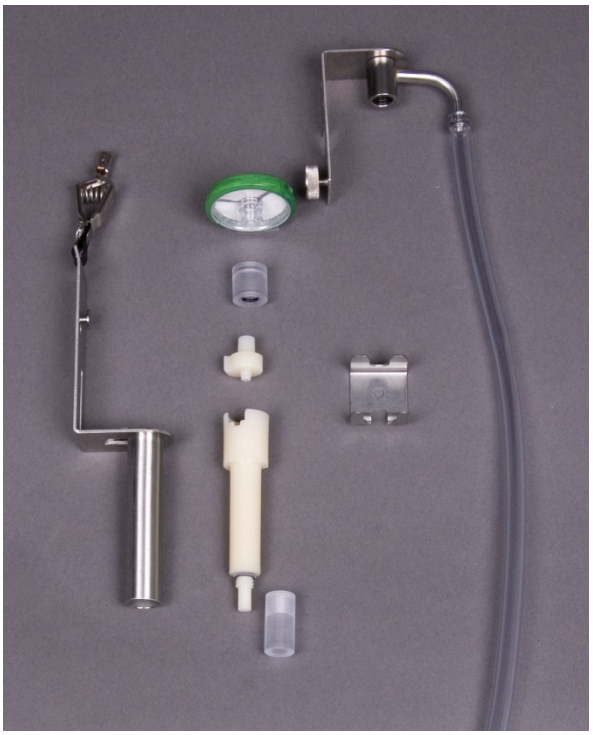
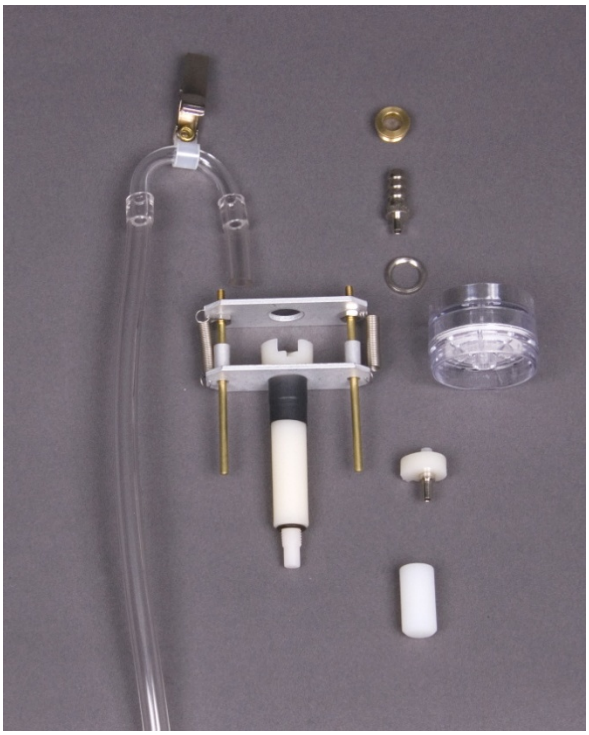


FIGURE I-2 SENSIDYNE CYCLONE ASSEMBLY PARTS



B. Cyclone Leak Test Procedure

Leak test the cyclone before use unless it has been leak tested within the past month. A cyclone leak test kit and cyclone leak test procedure are provided in each Area Office for this purpose.

This section summarizes procedures for leak testing of the Dorr-Oliver cyclone samplers used for collecting respirable dust. Further details on this procedure are contained in the Cyclone Leak Test Procedure (CLTP). CSHOs should review the entire leak test procedure before conducting the leak test as summarized below. See the CLTP for more specific procedures regarding leak tests.

Nylon Part Inspection

- Disassemble the cyclone assembly, clean it, and inspect it for cracks and worn fit between parts. Take care not to scratch the inside surface of the cyclone chamber.

- Replace any worn or cracked units or parts.

O-Ring, Tubing, and Filter Leak Test

- Connect the entire cyclone assembly (minus the cyclone body) to the pressure gauge and aspirator, maintaining the normal spacing between the plastic filter adaptor (coupler) and the vortex finder.

- Seal the cyclone vortex finder opening by placing an airtight cap or your fingertip over the hole.

- Hold the cyclone assembly together with one hand.

- With your other hand, squeeze and gently release the aspirator bulb until the pressure gauge reads between 4 inches and 10 inches of water pressure, then fold the tubing halfway between the "Tee" fitting and the aspirator. If the pressure reading is beyond full scale, release the vacuum and try again.

- Observe the pressure gauge reading for 30 seconds. If the pressure drops less than 25%, the leakage is acceptable and the unit passes the leak test. If the pressure drops more than 25%, corrective action is necessary. Sources of leaks include worn or damaged O-rings, cracked or ill-fitting tubing, and leaky pre-weighed filter cassettes.

Note: Leaks between the filter input and the air sampling pump are more disruptive than leaks at the plastic filter adaptor O-rings.

Final Pump-Fault Leak Test

- Connect the cyclone assembly to the pump in the normal sampling configuration with the air sampling pump running at 1.7 L/min.

- Close the inlet to the cyclone with tape or a finger. If the pump bears down and goes into a fault mode, the assembly passes this final, but crude, pump-fault leak test.

C. Cyclone Cleaning

Unscrew the grit pot from the cyclone. Empty the grit pot by turning it upside down and tapping it gently on a solid surface. Clean the cyclone thoroughly and gently after each use in warm soapy water or, preferably, wash it in an ultrasonic bath. Rinse it thoroughly in clean water, shake off excess water, and set aside to dry before reassembly. Never insert anything into the cyclone during cleaning.

APPENDIX J

SAMPLE CALCULATIONS FOR CRYSTALLINE SILICA

Reference Formulas

A. Construction/Maritime PEL for Crystalline Silica (Quartz) (using Equation 5 from Section III.K.2.):

$$PEL\ (crystalline\ silica, quartz) = \frac{250\ mppcf}{\%\ silica + 5}$$

B. General Industry PEL for Crystalline Silica (Quartz) (using Equation 6 from Section III.K.2.):

$$PEL\ (mg/m^3) = \frac{10\ mg/m^3}{2 + \%\ respirable\ quartz}$$

C. OSHA-adopted conversion factor:

$$1\ mppcf = 0.1\ mg/m^3\ respirable\ dust \qquad or$$

$$1\ mg/m^3 = 10\ mppcf\ respirable\ dust$$

D. Combining multiple silica samples (single analyte) with different percentages and mass:

$$Recalculated\ \% = \frac{(Pa\ x\ Wa) + (Pb\ x\ Wb)}{Wa + Wb}$$

Where:

P = Lab reported percentage of silica for each sample
W = Mass of silica reported by the lab for each sample

Example 1: Two consecutive samples were collected to monitor the same employee for a combined exposure to silica dusts for one work shift. The analytical results are shown in Table J-1, Sample Silica Exposure Data.

Table J-1
SAMPLE SILICA EXPOSURE DATA

Sample	Sampling period (min)	Total volume (L)	Respirable weight (mg)	Respirable concentration (mg/m^3)	SLTC results (%)
A	238	405	0.855	2.1	5.2 quartz 2.3 cristobalite ND tridymite
B	192	326	0.619	1.9	4.8 quartz 1.7 cristobalite ND tridymite
Total	430	731	1.474		
Key: ND = Not detectable.					

Calculation of the TWA from the sampling and analytical data:

Step 1. Calculate the percentage of quartz, cristobalite, and tridymite in the respirable particulate collected (using Equation 8 from Section III.K.2.).

$$Quartz: 5.2\left(\frac{0.855}{1.474}\right) + 4.8\left(\frac{0.619}{1.474}\right) = 3.0 + 2.0 = 5.0\%$$

$$Cristobalite: 2.3\left(\frac{0.855}{1.474}\right) + 1.7\left(\frac{0.619}{1.474}\right) = 1.3 + 0.7 = 2.0\%$$

Step 2. Calculate the PEL for the mixture (using Equation 12 from Section III.K.2.):

$$PEL_{mixture} = \frac{10\ mg/m^3}{\%\ quartz + 2(\%\ cristobalite) + 2(\%\ tridymite) + 2}$$

$$= \frac{10}{5.0 + 2(2.0) + 2(0) + 2} = \frac{10}{11.0} = 0.91\ mg/m^3$$

Step 3. Calculate the employee's exposure (using Equation 7 from Section III.K.2.). NOTE: 1L = 0.001 m^3

Equation J-1

$$Exposure = \frac{Sample\ wt.\ A + Sample\ wt.\ B}{Total\ Volume} = \frac{0.855 + 0.619}{0.731} = 2.0\ mg/m^3$$

Step 4. Adjust (where necessary) for less than 8-hour sampling period.

Equation J-2

$$TWA = (2.0\ mg/m^3)\frac{430\ min}{480\ min} = 1.8\ mg/m^3$$

Step 5. Calculate the severity of the exposure (using Equation 9 from Section III.K.2.):

$$\frac{1.8\ mg/m^3}{0.91\ mg/m^3} = 2.0$$

After Step 5, the upper and lower confidence limits would be determined by applying the SAE as described in Section IV.D. of this document, and as shown in Examples 2 and 3 below.

Example 2: A sample is obtained for a construction jackhammer operator using the gravimetric sampling method specified in OSHA Method ID-142. The sample is run for 240 minutes at a flow rate of 1.7 L/min, yielding a total sample volume of 0.408 m^3. The respirable dust collected on the filter is

determined to weigh 0.857 mg, resulting in a respirable dust concentration of 2.1 mg/m^3. The SLTC reports that the sample contains 55% quartz. The SLTC also reports an SAE of 0.20 for the sample.

Step1. Determine the jackhammer operator's 8-hour TWA respirable dust exposure (assuming zero exposure for the unsampled portion of the 8-hour shift) (using Equation J-2):

$$Exposure = 2.1\ mg/m^3\ x \frac{240\ min}{480\ min} = 1.05\ mg/m^3\ respirable\ dust$$

Step 2. Calculate the general industry PEL, assuming the conditions for the jackhammer operator sample containing 55% respirable quartz (using Equation 12 from Section III.K.2.):

$$PEL\ (mg/m^3) = \frac{10\ mg/m^3}{2 + 55} = 0.175\ mg/m^3$$

Step 3. Calculate the Severity Ratio (using Equation 9 from Section III.K.2.):

$$Severity = \frac{sample\ results\ (from\ Step\ 1)}{calculated\ PEL\ (from\ Step\ 2)} = \frac{1.05\ mg/m^3}{0.175\ mg/m^3} = 6.0$$

Step 4. Calculate confidence limits by applying the SAE (Equations 10 and 11 respectively, from Section III.K.2):

$$Lower\ Confidence\ Limit\ (LCL) = 6.0 - 0.20 = 5.8$$

$$Upper\ Confidence\ Limit\ (UCL) = 6.0 + 0.2 = 6.2$$

Step 5. Based on a confidence limit of 5.8, the sample exceeds the 95% confidence limit for overexposure.

Step 6. Apply the OSHA-adopted conversion factor (using Equation 4 from Section III.K.2.) to the jackhammer operator's exposure result from Step 1 and Reference Formula (B) above:

$$Exposure = (1.05\ mg/m^3)\frac{1\ mppcf}{0.1\ mg/m^3} = 10.5\ mppcf$$

Step 7. Calculate the applicable construction PEL for jackhammer operator sample containing 55% respirable quartz (using Equation 5 from Section III.K.2.):

$$PEL = \frac{250\ mppcf}{55\% + 5} = 4.17\ mppcf$$

Step 8. Conclusion. The 8-hour TWA exposure of the jackhammer operator exceeds the construction industry PEL for crystalline silica (quartz).

Example 3: Two samples are obtained for a construction foreman overseeing a concrete drill press operation. Both samples are collected at a flow rate of 1.7 L/min. The duration of Sample A is 238 minutes, yielding a total sample volume of 0.40 m^3. The respirable dust collected on the filter is

determined to weigh 0.855 mg, resulting in a respirable dust concentration of 2.1 mg/m^3. The SLTC laboratory reports that Sample A contains 30% quartz. The duration of Sample B is 192 minutes, yielding a total sample volume of 0.326 m^3. The respirable dust weight is 0.619 mg, resulting in a concentration of 1.9 mg/m^3. The total weight of respirable dust collected on both samples is 1.474 mg. The SLTC laboratory reports that Sample B contains 25% quartz. The SLTC reports an SAE of 0.16 for both samples.

Step 1. Determine the foreman's 8-hour TWA respirable dust exposure (using Equation 13 from Section IV.D.4.):

$$Exposure = \frac{(2.1\ mg/m^3 \times 238\ min) + (1.9\ mg/m^3 \times 192\ \text{min})}{480\ min} = 1.8\ mg/m^3$$

Step 2. Determine average quartz content since the SLTC provided two different percentages of quartz, using Reference Formula D, above:

$$Recalculated\ \% = \frac{(30\%\ x\ 0.855) + (25\%\ x\ 0.619)}{(0.855 + 0.619)} = 28\%$$

Step 3. Calculate the general industry PEL, assuming the conditions for the construction foreman sample containing 28% respirable quartz (using Equation 12 from Section III.K.2):

$$PEL(mg/m^3) = \frac{10\ mg/m^3}{2 + 28} = 0.333\ mg/m^3$$

Step 4. Calculate the Severity Ratio (using Equation 9 from Section III.K.2):

$$Severity = \frac{1.8\ mg/m^3}{0.333\ mg/m^3} = 5.4$$

Step 5. Calculate confidence limits by applying the SAE (using Equations 10 and 11 respectively, from Section III.K.2):

$$LCL = 5.4 - 0.16 = 5.24$$

$$UCL = 5.4 + 0.16 = 5.56$$

Step 6. Based on a severity of 5.4, the sample exceeds the 95% confidence limit for overexposure.

Step 7. Apply the OSHA-adopted conversion factor to the construction foreman's exposure result from Step 1 and Reference Formula C above (using Equation 4 from Section III.K.2.):

$$Exposure = (1.8\ mg/m^3)\frac{1.0\ mppcf}{0.1\ mg/m^3} = 18.0\ mppcf$$

Step 8. Calculate the applicable construction PEL, (using Equation 5 from Section III.K.2.) for the foreman's samples containing an average of 28% respirable quartz:

$$PEL = \frac{250\ mppcf}{28 + 5} = 7.58\ mppcf$$

Step 9. Conclusion. The eight
-hour TWA exposure of the foreman exceeds the construction industry PEL for crystalline silica (quartz).

APPENDIX K

CHAIN OF CUSTODY

The SLTC uses OSHA's established chain-of-custody procedures to track whether official Form OSHA-21 seals were properly used to ensure the integrity of samples collected by OSHA CSHOs. The procedure also tracks the history and control of samples received at the SLTC. The chain of custody includes the following dates: the date the sample was collected, the date the sample was shipped to the SLTC, the date the sample was received at the SLTC, the date the analyst received the sample, the date the analysis was completed, the date the analytical results were checked by another analyst, and the date the sample results were released by a supervisor or his/her representative. It is important to follow chain-of-custody requirements because it documents the proper handling of OSHA samples for litigation purposes.

APPENDIX L

HEALTH EFFECTS CODES

When available, the CSI files contain health effects information, including the applicable Health Effects Codes, for each chemical. The complete list of Health Effects Codes is shown below in Table L-1. The Health Effects Codes indicate the principal health effects of exposure to each substance, and are used to determine the seriousness of a violation and severity of the penalty, based on the guidelines contained in Chapter 4 of the FOM.

Table L-1. HEALTH EFFECTS CODES

Code	Health Effects
HE1	Cancer---Currently regulated by OSHA as carcinogen
HE2	Chronic (Cumulative) Toxicity---Known or Suspected animal or human carcinogen, mutagen (except Code HE1 chemicals)
HE3	Chronic (Cumulative) Toxicity---Long-term organ toxicity other than nervous, respiratory, hematologic or reproductive
HE4	Acute Toxicity---Short-term high risk effects
HE5	Reproductive Hazards---Teratogenesis or other reproductive impairment
HE6	Nervous System Disturbances---Cholinesterase inhibition
HE7	Nervous System Disturbances---Nervous system effects other than narcosis
HE8	Nervous System Disturbances---Narcosis
HE9	Respiratory Effects Other Than Irritation---Respiratory sensitization (asthma or other)
HE10	Respiratory Effects Other Than Irritation---Cumulative lung damage
HE11	Respiratory Effects---Acute lung damage/edema or other
HE12	Hematologic (Blood) Disturbances---Anemias
HE13	Hematologic (Blood) Disturbances---Methemoglobinemia
HE14	Irritation-Eyes, Nose, Throat, Skin---Marked
HE15	Irritation-Eyes, Nose, Throat, Skin---Moderate
HE16	Irritation-Eyes, Nose, Throat, Skin---Mild
HE17	Asphyxiants, Anoxiants
HE18	Explosive, Flammable, Safety (No adverse effects encountered when good housekeeping practices are followed)
HE19	Generally Low Risk Health Effects---Nuisance particulates, vapors or gases
HE20	Generally Low Risk Health Effects---Odor

APPENDIX M

CONVERSION EQUATIONS (mg/m^3 to ppm)

Equation M-1

$$ppm_{NTP} = \frac{(mg/m^3)(24.46)}{MW}$$

Where:

24.46 = molar volume at 25°C (298K) and 760 mmHg
MW = molecular weight
NTP = Normal Temperature and Pressure (25°C and 760 mmHg)
mmHg = millimeters of mercury

CSHOs will not usually need to calculate the exposure concentration in ppm at the sampling site (ppm_{PT}) but, if necessary, it can be calculated from the SLTC's results reported in ppm_{NTP} by using the following equation:

Equation M-2

$$ppm_{PT} = (ppm_{NTP})\left(\frac{760}{P}\right)\left(\frac{T}{298}\right)$$

Where:

P = sampling site pressure (mmHg)
T = sampling site temperature (K)
298 = normal temperature in degrees Kelvin (273 + 25)
760 = normal atmospheric pressure in mmHg

Equation M-3

$$\text{Because } ppm_{NTP} = \frac{(mg/m^3)(24.46)}{MW}$$

$$ppm_{PT} = (mg/m^3)\left(\frac{24.46}{MW}\right)\left(\frac{760}{P}\right)\left(\frac{T}{298}\right)$$

NOTE: When a contaminant concentration is converted from mg/m^3 and expressed as ppm_{PT}, that value cannot be compared directly to the PEL table without first converting it to its corresponding ppm_{NTP} value.

NOTE: The **barometric pressure** for the time period sampled can sometimes be obtained from the NOAA website or by calling the local weather station or airport. If air pressures are obtained by this route, it is necessary to obtain the unadjusted barometric pressure (station pressure) for compliance applications. The barometric pressure information most readily available from weather and aviation

sources is the sea-level adjusted barometric pressure which tends to average about 760 mmHg and does not represent the actual air pressure of worksites much removed from sea level.
If the sources above are not readily available or cannot provide the actual station pressure, then the elevation (Elev) in feet of the worksite can be used to calculate the typical barometric pressure (P) in mmHg using the following equation:

Equation M-4

$$P = 760 \times \left[1 - \frac{Elev \times 1.6470 \times 10^{-3}}{295.20 \times (1 + Elev \times 4.9787 \times 10^{-8})}\right]^{6.3222}$$

Equation M-4 is an adaptation of the atmospheric model equation used in the *U.S. Standard Atmosphere* (1976) using a higher average effective sea-level screen temperature (295.2K) and lower temperature lapse rate (5.4K/km) typically observed over land surfaces within the northern latitudes of the U.S. (19ºN to 61ºN). For most of the U.S., the barometric pressures obtained with this equation are better estimates of observed station pressures than the 1976 model, and deviate from mean annual station pressures by about 0.24% RSD (percent relative standard deviation) for elevations below 4,300 feet and 0.52% RSD for elevations below 30,000 feet. These deviations are insignificant compared to the estimated 1.6% RSD for combined normal seasonal, storm, and diurnal station pressure variations observed at any elevation within the year. The 1.6% RSD may be assumed if the worksite elevation can be estimated to within 100 feet. A global positioning system (GPS) elevation measurement is typically within 100 feet of the actual elevation. GPS elevation measurements should be made outdoors and away from tall structures. Example calculations using the equation give 723.2 mmHg for an elevation of 1,400 feet above mean sea level and 569.5 mmHg for an elevation of 8,000 feet above mean sea level. Due to Alaska's high latitudes, Equation M-4 is biased high for significant elevations in Alaska; therefore, the station pressure of a nearby weather station is necessary to obtain accurate air pressures for most of Alaska.

APPENDIX N

EXAMPLE CALCULATION FOR FULL-PERIOD, CONTINUOUS SINGLE SAMPLE

A single glass-fiber filter and personal sampling pump were used to sample for carbaryl for an 8-hour period. The SLTC reported 6.07 mg/m^3. The SAE for this method is 0.23. The PEL is 5.0 mg/m^3.

Step 1. Calculate the exposure severity (using Equation 9 from Section III.K.2):

$$Y = \frac{6.07}{5.0} = 1.21$$

Step 2. Calculate confidence limits
Calculate the $LCL_{95\%}$ (using Equation 10 from Section III.K.2):

.

$$LCL_{95\%} = 1.21 - 0.23 = 0.98$$

Because the $LCL_{95\%}$ does not exceed 1.0, noncompliance is not established.
Calculate the $UCL_{95\%}$ (using Equation 11 from Section III.K.2):

$$UCL_{95\%} = 1.21 + 0.23 = 1.44$$

Step 3. Classify the exposure.

Because the $LCL_{95\%} < 1.0$ and the $UCL_{95\%} > 1.0$, classify as possible overexposure.

APPENDIX O

EXAMPLE CALCULATION FOR FULL-PERIOD CONSECUTIVE SAMPLING

If two consecutive samples had been taken for carbaryl instead of one continuous sample, and the following results were obtained:

Sample Results		
	A	**B**
Sampling rate (L/min)	2.0	2.0
Time (min)	240	240
Volume (L)	480	480
Weight (mg)	3.005	2.808
Concentration (mg/m^3)	6.26	5.85

The SAE for carbaryl is 0.23

Step 1. Calculate the $UCL_{95\%}$ and the $LCL_{95\%}$ from the sampling and analytical results. Using Equation 13 from Section IV.D.4.:

$$TWA = \frac{(6.26\ mg/m^3)(240\ min) + (5.85\ mg/m^3)(240\ min)}{480\ min} = 6.055\ mg/m^3$$

Using Equation 9 from Section III.K.2:

$$Exposure\ severity\ (Y) = \frac{6.055\ mg/m^3}{PEL} = \frac{6.055}{5.0} = 1.21$$

Using Equation 10 from Section III.K.2:

$$Assuming\ a\ continuous\ sample: LCL_{95\%} = 1.21 - 0.23 = 0.98$$

Using Equation 11 from Section III. K.2:

$$UCL_{95\%} = 1.21 + 0.23 = 1.44$$

Step 2. Because the $LCL_{95\%} < 1.0$ and $UCL_{95\%} > 1.0$, the results are in the possible overexposure region. To document an overexposure, the CSHO must reanalyze the data using the more exact calculation for full-period consecutive sampling (Using Equation 14 from Section IV.D.4.):

$$LCL_{95\%} = (1.21) - \frac{0.23\sqrt{(240\ min)^2(6.26\ mg/m^3)^2 + (240\ min)^2(5.85\ mg/m^3)^2}}{5.0\ mg/m^3\ (240\ min + 240\ min)}$$

$$= 1.21 - 0.20 = 1.01$$

Since the $LCL_{95\%} > 1.0$, a violation is established.

OSHA Technical Manual

SECTION II: CHAPTER 2

SURFACE CONTAMINANTS, SKIN EXPOSURE, BIOLOGICAL MONITORING AND OTHER ANALYSES

Contents:

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)

K_p 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):

$J = (0.0043 \text{ cm/hr}) \times (100 \text{ mg/cm}^3) = 0.43 \text{ mg/(cm}^2\bullet\text{hr)}$(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: $J = (0.0043 \text{ cm/hr}) \times (75 \text{ mg}/10 \text{ cm}^3) = 0.0322 \text{ mg/(cm}^2\bullet\text{hr)}$ (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

TABLE 2. CARBON MONOXIDE (CO) CONCENTRATION VERSUS BLOOD CARBOXYHEMOGLOBIN (COHb) LEVELS*	
CO Concentration (ppm)	**Steady-State Blood COHb Levels (percent)**
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
*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-Oximeter™ 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)"). 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 (H_2S) 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 H_2S 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 H_2S (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 Pyroprobe™, 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.

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APPENDIX A

CHEMICALS NOTED FOR SKIN ABSORPTION (OSHA AND ACGIH DESIGNATED ONLY)

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS

Substance	CAS Number[1]	OSHA PELs[2]		ACGIH TLVs[3]	
		1910	1926/1915	TWA	STEL/C[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	
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;	SAME	0.5ppm	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
		5 mg/m^3			
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 CrO_3); see 1910.1026	1189-85-1				C 0.1 mg/m^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)	
Citral	5392-40-5			5 ppm (IFV)	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
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	
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)	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
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	
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	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
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
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	—	—
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

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
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	
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[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	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
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/m3	
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		
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;	SAME	25 ppm	40 ppm

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
		100 mg/m^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[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)	
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	0.05 mg/m^3 (IFV)	

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
			designation)		
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)	
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

TABLE A-1. OSHA PELS AND ACGIH TLVS WITH SKIN DESIGNATIONS/NOTATIONS					
Substance	**CAS Number[1]**	**OSHA PELs[2]**		**ACGIH TLVs[3]**	
		1910	**1926/1915**	**TWA**	**STEL/C[4]**
Tetramethyl lead (as Pb)	75-74-1	0.075 mg/m^3	0.15 mg/m^3	0.15 mg/m^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)[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[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	
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 (ACGIH BEI AND OSHA EXPANDED STANDARDS ONLY)

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
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 urine[1]	End of shift	—	Nq
		Aniline released from hemoglobin in blood	End of shift	—	Nq
		p-Aminophenol in urine[1]	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 urine[1]	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
Carbon disulfide	75-15-0	2-Thioxothiazolidine-4-carboxylic acid (TTCA) in urine	End of shift	0.5 mg/g creatinine	B, Ns

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
Chemical	**CAS No.**	**Determinant**	**Sampling Time**	**BEI®**	**Notation**
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
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 urine[1]	End of shift at end of workweek	100 mg/g creatinine	Ns
		p-Chlorophenol in urine[1]	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[1]	End of shift at end of workweek	—	Nq, Ns
		Cyclohexanol in urine[1]	End of shift	—	Nq, Ns
Cyclohexanone	108-94-1	1,2-Cyclohexanediol in urine[1]	End of shift at end of workweek	80 mg/L	Ns, Sq
		Cyclohexanol in urine[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	—

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
Chemical	**CAS No.**	**Determinant**	**Sampling Time**	**BEI®**	**Notation**
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
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[1]	End of shift at end of workweek	100 mg/g creatinine	—
Ethyl benzene[3]	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[1]	End of shift	200 mg/L	Ns
n-Hexane	110-54-3	2,5-Hexanedion in urine[2]	End of shift at end of workweek	0.4 mg/L	—
Lead[4]	7439-92-1	Lead in blood	Not critical	30 µg/100 ml	—
Mercury[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[2]	End of shift at end of workweek	0.4 mg/L	—

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
Chemical	**CAS No.**	**Determinant**	**Sampling Time**	**BEI®**	**Notation**
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
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)[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	(—)
N-Methyl-2-pyrrolidone	872-50-4	5-Hydroxy-N-methyl-2-pyrrolidone in urine	End of shift	100 mg/L	(—)
Naphthalene[7]	91-20-3	1-Naphthol[1] + 2-Naphthol[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)[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)

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
Chemical	**CAS No.**	**Determinant**	**Sampling Time**	**BEI®**	**Notation**
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
Phenol	108-95-2	Phenol in urine[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[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
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[1]	End of shift	0.3 mg/g creatinine	B
Toluene diisocyanate[9]	584-84-9; 91-08-7	Toluene diamine in urine[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[2]	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

TABLE B-1. ADOPTED BIOLOGICAL EXPOSURE INDICES (BEIs) – ACGIH (2012)					
Chemical	**CAS No.**	**Determinant**	**Sampling Time**	**BEI®**	**Notation**
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
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.
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.

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.*			
		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) 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.	For currently and/or previously exposed workers, as specified in the standard: • Initial exam • At least annually • 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.

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.*			
1910.1028	Benzene	Complete blood count testing for: • Leukocyte count with differential • Quantitative thrombocyte count • Hematocrit • Hemoglobin • Erythrocyte count and erythrocyte indices After exposure during emergency situations: • Urinary phenol test (to be performed on end-of-shift urine sample within 72 hours of the emergency exposure).	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: • 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.

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.*			
1910.1044	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 After exposure during emergency situations: • Sperm count or above hormone tests if worker has vasectomy or is unable to produce semen.	For workers in regulated areas: • Initial exam • Annually 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.

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.*			
1010.1047	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.

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.*			
1910.1051	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: o At or above the PELs on ≥ 30 days per year for 10 or more years. o At or above the action level for ≥ 60 days per year for 10 or more years. o 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.

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.*			
1910.1052	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[1]) 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.

[1] 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.

- 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 K_{st}.

    - 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.

OSHA Technical Manual

SECTION II: CHAPTER 3

TECHNICAL EQUIPMENT: ON-SITE MEASUREMENTS

Contents:

I. INTRODUCTION

The purpose of this chapter is to provide a broad overview of the types of equipment and instrumentation available for use by OSHA personnel. This information is not a comprehensive resource for specific types of instrumentation, nor is it intended to replace the owner's manual. Rather, its purpose is to provide a broad understanding of the principle of operation for the particular type of equipment and an understanding of the capabilities and limitations of the

equipment. End users should always follow the owner's manual and manufacturer recommendations regarding the specific operation and maintenance of the equipment being used.

The sections which follow discuss various types of instrumentation. Calibration and battery maintenance are discussed in Section II. Section III discusses direct-reading instruments used for assessing chemical and particulate-type air contaminants. Section IV reviews equipment used to support ventilation and indoor air quality (IAQ) assessments. Sections V and VI describe vibration monitors and heat stress monitoring equipment, respectively. Section VII describes instrumentation for detecting nonionizing (e.g., radiofrequency) radiation, which is available through the Cincinnati Technical Center (CTC).

Appendix A provides a useful reference chart which summarizes the various types of instrumentation available and typical applications. Appendices B and C describe specialized tools used to evaluate chemical and biological warfare agents, respectively. Use of these tools is overseen by the Salt Lake Technical Center (SLTC) Health Response Team (HRT) and OSHA's Specialized Response Teams (SRTs). Appendix D describes equipment used for detection of ionizing radiation, which is also overseen by the HRT.

Note that noise monitoring equipment is NOT discussed in this chapter. Chapter 10 contains the discussion of noise monitoring equipment. Also, this chapter does NOT discuss air sampling methods for collection of samples for off-site laboratory analysis. Active and passive (diffusive) personal air sampling methods for air contaminants are discussed in Chapter 1.

NOTE: Any discussion regarding a specific manufacturer's product is not meant to imply an endorsement or approval by OSHA, but merely reflects the need to convey specific information which is pertinent to the particular type and brand of instrumentation available for OSHA personnel.

The CTC serves as a source of technical information for instruments and measurement technology. Much of the equipment and instrumentation discussed in this chapter is available from the CTC through the Agency Loan Equipment Program (ALEP).

Hazardous (Classified) Locations

Certain workspaces may contain a flammable or explosive atmosphere due to the accumulation of flammable gases or vapors, or combustible dusts or fibers, and are termed "Hazardous locations." Hazardous locations are classified into Class and division based on the type and severity of the explosion hazard as described in 29 CFR 1910.307. Sparks from ordinary battery-powered portable equipment commonly used by CSHOs, including cameras, cell phones, tablets and laptop computers, may serve as an ignition source, and must never be brought into a hazardous location.

Nationally Recognized Testing Labs test and approve electrical equipment for use in hazardous locations (see 29 CFR 1910.7) Approved equipment, sometimes referred to as intrinsically safe, must be marked with the Class and Division number for which it is approved. Never bring portable monitoring instruments into a hazardous location without first confirming that the instrument is approved for use in that environment. Use only the type of battery specified on the safety approval label, and replace batteries in a nonhazardous area.

II. EQUIPMENT MAINTENANCE AND CALIBRATION

Service intervals for equipment may be determined by checking the CTC website for Equipment Servicing Information. Repairs are generally conducted by the CTC.

Most equipment is calibrated periodically by the CTC, generally on an annual basis. The CTC applies a calibration sticker which includes the due date for the next calibration. Before using field instrumentation, check the calibration sticker and ensure that the instrument is within its calibration due date. Some equipment must be field calibrated or serviced prior to use. Consult the instrument equipment manual to determine what field calibration is needed. If the equipment fails field calibration, consult the CTC for guidance.

Limitations of Batteries

Proper battery maintenance is essential to ensure proper performance of battery-powered equipment during field use. A variety of battery types are used in different types of portable equipment, as specified by the instrument manufacturer. All battery types will self-discharge to some degree during periods of prolonged storage.

Non-rechargeable batteries need to be removed from the instrument prior to prolonged storage in order to prevent battery leakage which could damage the instrument. Many instruments powered by non-rechargeable batteries will perform a battery life check when first powered on (otherwise, check with a voltage meter before full-shift sampling). If low, replace the batteries as appropriate. Never mix types (alkaline, carbon zinc, etc.), capacity, or age, as this can have negative effects on all the batteries.

Rechargeable batteries should generally be left on trickle charge mode for storage. Overcharging, by charging for too long a time period at a high charge rate, can damage the battery. Conversely, discharging below a minimum voltage can also damage the battery. In general, avoid both overnight discharging and overnight charging at a high charge rate. Closely follow the recommendations in the equipment manual. In some cases an outlet controller (timer) can be used to ensure that batteries are charged for a suitable length of time.

Rechargeable batteries are most reliable when used at least every two to three weeks. Nickel-cadmium (Ni-Cd) batteries are prone to developing "memory" problems, in which the battery will not hold a full charge unless it is fully discharged before recharging. Ni-Cd batteries may need to be reconditioned by charging/discharging two to four times. New batteries should be conditioned in accord with the same process. Nickel metal hydride batteries generally are less prone to memory problems than Ni-Cd, and typically offer longer run time, but they do have a higher self-discharge rate. Lithium ion and lithium polymer batteries typically have higher energy density, lower rates of self-discharge, and are not prone to memory effects.

Be sure to consult the user's manual for proper batter care.

III. DIRECT-READING INSTRUMENTATION FOR AIR CONTAMINANTS

Direct-reading instruments or monitors (also called real-time instruments or monitors) provide information at the time of sampling, thus enabling rapid decision-making. These instruments can often provide the trained and experienced user the capability to determine if site personnel are exposed to airborne concentrations which exceed instantaneous (ceiling or peak) exposure limits for specific hazardous air contaminants. Direct-reading monitors can be useful in identifying oxygen-deficient or oxygen-enriched atmospheres, immediately dangerous to life or health (IDLH) conditions, elevated levels of airborne contaminants, flammable atmospheres, and radioactive hazards. Direct reading instruments are particularly useful for identifying point source contamination or emissions. Periodic monitoring of airborne levels with a real-time monitor is often critical, especially before and during new work activities. Direct-reading instruments are useful for performing screening surveys to determine areas where additional evaluation is warranted. Data obtained from direct-reading monitors can be used to evaluate existing health and/or safety programs and to assure proper selection of personal protective equipment (PPE), engineering controls and work practices.

CSHO Safety

Before bringing monitoring equipment or other electrical devices into an area with the potential for an explosion, always check the Class and Division number marked on the instrument. Use only the type of battery specified on the safety approval label, and replace batteries in a nonhazardous area. Do not assume that an instrument is intrinsically safe. If uncertain, verify by contacting the instrument manufacturer or the CTC.

For atmospheres or work surfaces contaminated with hazardous chemicals, use a plastic bag to cover appropriate parts of equipment to limit contamination. Ensure that the plastic bag is not tightly sealed as this can cause back pressure on the air sampling pump (if equipped). Properly decontaminate all equipment to minimize potential contamination of other persons or objects when sampling is complete. To the extent possible, gross decontamination should be performed onsite.

Before using a direct-reading instrument, review information in the instrument manual regarding the following characteristics:

- Battery life - how long can the instrument run from battery power?
- Datalogging - can the instrument record readings electronically? If so, how is this information retrieved?
- Size and weight - how practical will the instrument be for short-term breathing zone measurements? Will a cart be needed for moving the instrument around?

- Sampling wand - does the unit have a sampling hose and probe to allow for remote sampling, or to allow breathing zone measurements for larger instruments?

- Warm-up time - how long does the unit need to be powered on before it can produce accurate readings?

- Response time (lag time) - how long is the delay between exposing the inlet to a contaminated atmosphere and obtaining an accurate reading?

- Sensitivity - can the analyte be detected, and what is the minimum contaminant concentration that can be reliably measured or detected?

- Specificity - can the instrument discriminate between one contaminant and another?

- Interferences - are there chemicals which, if present, may produce false readings? Are there chemicals, dusts, or other conditions which may damage the sensor?

- Environmental conditions - what is the acceptable temperature and humidity range for use of the instrument? Will temperature and humidity affect the accuracy of the readings? What about altitude? Can the unit be used in a dusty environment without damaging it or requiring factory service? Are there filters available to protect the instrument in these situations?

- Hazardous areas - can the instrument be used in electrical classified areas?

The sections which follow describe the principal types of direct-reading instrumentation. The types discussed include the following:

- Photoionization detectors
- Infrared analyzers
- Gas, oxygen and explosibility (combustible gas) monitors
- Detector tubes
- Mercury analyzers
- Dust/particulate monitors

A. PHOTOIONIZATION DETECTORS

Application and Principle of Operation

Photoionization detectors (PIDs) are used for nonspecific detection of a variety of chemicals, particularly hydrocarbons. PIDs are useful for pinpointing contaminant sources, or for identifying concentration gradients throughout a space, because the readout is proportional to the concentration of contaminant present. However, PIDs cannot positively identify contaminants present in an environment. Where more than one airborne contaminant is present, the instrument may not distinguish one from the other.

PIDs use a high energy ultraviolet (UV) light source to ionize chemicals in an airstream. The charged molecules are collected on a charged surface, which generates a current that is directly proportional to the concentration of the chemical in the air being sampled.

The ionization potential (IP) describes the amount of energy needed to induce ionization in a particular chemical. If the energy of the UV lamp is greater than or equal to the IP of the chemical being sampled, then the chemical will be detected. PIDs may be configured with lamps of different energies. Typical lamp energies are 9.5, 10.6, and 11.7 electron volts (eV). The higher the lamp energy, the greater the number of chemicals that can be detected. For example, benzene (IP 9.25 eV) can be detected with a 9.5 eV lamp, while methylene chloride (IP 11.35 eV) requires use of the 11.7 eV lamp. In general, higher energy lamps have a much shorter lifespan than lower energy lamps. Further, the lamp energy must be lower than background atmospheric gases to be of practical use. For example, the IP of carbon monoxide is 14.01 eV, while the IP of molecular oxygen is 12.08 eV; because the IP of carbon monoxide is higher than for oxygen, a lamp that could ionize carbon monoxide would not be useful for quantifying parts per million (ppm) concentrations of carbon monoxide in the presence of percent concentrations of oxygen (1 percent = 10,000 ppm). Similarly, the IP of many chlorinated hydrocarbons may be too high to be detected by use of a PID.

The amount of electric current (signal response) generated in a PID varies with the chemical to which the PID is exposed, along with the lamp energy. The response factor is the ratio of the detector response for a particular chemical relative to a reference gas, usually isobutylene. The signal response must be multiplied by the response factor to quantify the concentration of the contaminant of interest. Response factors for a large number of chemicals are pre-programmed into the instrument. When sampling in an environment where a single identified gas is known to be present, select the display name for that gas and the readout will be automatically corrected using the response factor for that gas. For chemicals which are not preprogrammed into the instrument, the response factor should be determined by exposing the detector to a known concentration of the gas of interest, by preparing a bag sample (i.e., using a nonreactive Tedlar® bag). Follow the process described in the instrument manual.

Please note that the response factor also depends on the lamp energy. Ensure that the instrument has been set for the energy of the lamp which has been installed. If an incorrect response factor is applied, the displayed reading would significantly under- or over-estimate the concentration of the contaminant in question. The instrument manual includes a table listing the IP and response factor for a variety of common chemicals.

Calibration

PIDs are calibrated using a reference gas, usually isobutylene. Because the response is linear with concentration, a two point calibration is sufficient. Zero gas contains 0 ppm of contaminant, while span gas contains a specified concentration of the reference gas. Use the calibration gases available through the Agency Expendable Supplies Program (AESP) that are specified for the instrument you are using. Calibration gases are typically delivered in nonrefillable 1 liter cylinders. Be sure the gas has not exceeded the expiration date marked on the cylinder. When multiple sensors are present on the same instrument, the right gas mix is necessary to ensure that the span gases for the different sensors do not adversely affect other sensors on the same instrument.

In most cases a calibration check is sufficient, in which the instrument is “zeroed” in fresh air (such as an office environment), then the calibration gas is applied, and if the reading matches the concentration of the span gas, full calibration is unnecessary. Perform a calibration check before each day’s use. If the reading is off, perform a full calibration using zero gas and span gas. Follow the instructions in the manual to enter calibration mode; the unit will auto calibrate, that is, it will internally adjust the signal response so that the displayed reading matches the span gas concentration.

Performing a calibration check using the chemical of interest is recommended where practical, but may not be necessary or possible. In a well-ventilated area, prepare a bag sample of known concentration of the chemical of interest, select that chemical from the instrument library, and ensure that the reading matches the bag concentration.

Special Considerations

Photoionization sensitivity is dependent upon the age of the lamp and cleanliness of the lamp window. Over time, the output of the lamp will be reduced. A spare lamp is sometimes included in the case. Also, the accumulation of organic deposits or buildup of film on the surface of the lamp will reduce sensitivity.

PIDs are also affected by high humidity. For the most sensitive results, it is best to zero the instrument using representative air; that is, zero the instrument in the field in a "clean" area of similar temperature and humidity. The lamp may need to be cleaned more frequently when used in a high temperature, high humidity environment.

Consult the user manual regarding potential interferences. Water vapor, carbon dioxide, methane, and carbon monoxide can all produce a low reading for the gas of interest if present in the air being sampled due to quenching by these non-ionizable gases.

Maintenance

Follow the manufacturer's recommendations for maintaining the detector in optimal condition. This will include routine cleaning of the UV lamp using methanol and frequent replacement of the dust filter. Exercise caution in cleaning the lamp window, as these are fragile. The exterior of the instrument can be wiped clean with a damp cloth and mild detergent, if necessary. Keep the cloth away from the sample inlet and do not attempt to clean the instrument while it is connected to a power source.

B. INFRARED ANALYZERS

Application and Principle of Operation

Infrared (IR) analyzers are useful for measuring a broad range of inorganic and organic chemicals in air. The sensitivity of IR analyzers can be sufficient to quantify chemical concentrations below the OSHA Permissible Exposure Limits (PEL) for many chemicals. IR analyzers can also be used to identify unknown chemicals by using spectral matching. Due to their weight (approximately 10 kg), IR analyzers are most suitable for area sampling rather than personal sampling, although they can be used to analyze a bag sample of contaminated air collected in the breathing zone of a worker (e.g., using a Tedlar® bag). IR analyzers can be used for continuous sampling, although battery life is generally not sufficient for full-shift sampling. Some of the routine applications for IR analyzers include measuring carbon dioxide in IAQ assessments; waste anesthetic gases and vapors including nitrous oxide, halothane, enflurane, penthrane, and isoflurane; and fumigants, including ethylene oxide, ethylene dibromide, chloropicrin, and methyl bromide. IR analyzers are also used in tracer gas studies, such as fume hood performance testing (although these studies are not generally conducted by CSHOs).

IR analyzers operate by passing IR radiation generated from a heated metal source through a gas sample. The IR radiation is absorbed by the chemical at specific wavelengths determined by the

type of bonds present in the molecule. The absorbance is proportional to the concentration of the chemical in the sample. The portable IR analyzer is preloaded with a library of known chemicals; to quantify a known chemical in the environment, the user selects the appropriate wavelength for that chemical from the library. The wave number, or number of wavelengths in one centimeter, is commonly used to describe IR spectra. The wave number is the reciprocal of the wavelength and is expressed in cm^{-1}. The infrared spectrum typically used in infrared analysis ranges from the far infrared region at 400 cm^{-1} (25 micrometers) to the near infrared region 4,000 cm^{-1} (2.5 micrometers).

The sensitivity (detection limit) can be increased by increasing the path length through which the light source travels. The Miran SapphIRe portable ambient analyzer can measure at a path length of either 0.5 meters or 12.5 meters. Generally the response time is slightly slower for the longer path length.

Where multiple chemicals may be present in the environment, interference can be a problem. A unique absorbance wavelength must be identified to distinguish one chemical from another. The instrument may offer more than one wavelength for measuring concentrations of the same chemical, in order to avoid interferences from different chemicals. The user needs to assess what other chemicals are likely to be present and select the wavelength least likely to have interferences. In some instances, a weaker absorbance band at a different wavelength is chosen to measure a chemical in air, if that alternate wavelength is uniquely absorbed by the chemical of interest.

The selected wavelength for analysis of a chemical is chosen both because the chemical of interest has sufficient absorbance at that wavelength and sufficient specificity to exclude the absorbance of other chemicals. For example, acetone in air absorbs IR at both 8.4 and 11.0 micrometers. If methyl acrylate was also known to be present in the air, the 11.0 micrometer IR wavelength would be selected because methyl acrylate absorbs at 8.4 micrometers.

An IR analyzer can be used to identify unknown chemicals by matching measured spectral absorbance with spectra for known chemicals. The Miran SapphIRe ThermoMatch spectrum correlation software includes 150 common industrial chemicals, and additional spectra can be added by the user. Please note that the ThermoMatch feature is NOT intrinsically safe and must not be used in electrical classified areas.

Calibration

The Miran SapphIRe analyzer is pre-calibrated for a list of chemicals which are stored in the instrument library. A calibration check can be performed using the sampling loop kit. The sampling loop kit recirculates a known volume of air and allows the injection of a known amount of a volatile liquid or gas into the IR sampling cell. Instrument zeroing is performed by using a charcoal filter attachment to remove chemicals from the air. Conduct field calibration in accordance with the manufacturer's recommendations.

Special Considerations

Infrared analyzers may not be specific for the chemical of interest because other chemicals present in the work environment air may also absorb at the same wavelength. Cell window degradation will occur if the analyzer is used in the presence of ammonia and many alkyl amines, such as methyl amine.

Maintenance

Field maintenance is limited to replacement of the zeroing filter after a specified number of uses and replacement of the particulate filter in situations where adsorbed particulates or non-volatile liquids may have contaminated the filter surface.

C. GAS, OXYGEN AND EXPLOSIBILITY (COMBUSTIBLE GAS) MONITORS

A variety of hand-held monitors are supported by the CTC for single, dual, or multi-gas monitoring. Single or dual gas monitors are available from the CTC which can monitor carbon dioxide, carbon monoxide, hydrogen sulfide, and a variety of additional toxic gases. Multi-gas monitors incorporate separate sensors for oxygen, combustible atmosphere, and up to three toxic gases in the same hand-held monitor. The sample concentration is displayed in ppm, percent oxygen or percent LEL (Lower Explosive Limit), as applicable. The monitors are available through the Agency Loan Equipment Program ALEP and the Agency Technical Equipment Procurement Program (ATEPP).

Multi-gas monitors typically feature datalogging capability, as well as audible and/or visual alarms that warn of IDLH or time-weighted average toxic gas concentrations, low oxygen levels, LEL conditions, or malfunction. These monitors may operate in passive (diffusive) mode, or in active mode, in which a pump module draws air across the sensors. Active mode speeds the response time on the meter, but care must be taken to avoid drawing particulates into the monitor. Use active mode for remote sampling of a hazardous atmosphere: introduce the extendable wand, or probe attached to the meter by tubing, into the hazardous atmosphere while the user remains outside the hazardous area (e.g., confined spaces).

Calibration gases for both multi and single gases are available through the AESP. Ensure that the calibration (span) gas is intended for the meter make and model you are using. This is particularly important for multi-gas use because some gases in the mixture can adversely affect other sensors in the same meter. Span Gas Cylinder Recycling is available for empty span (calibration) gas cylinders obtained through the AESP.

Order of testing: *Confined spaces, such as sewers and well pits, commonly contain a hazardous atmosphere which may be oxygen deficient and contain a flammable or toxic gas. Many flammable gas sensors are oxygen dependent and will not provide reliable readings in an oxygen deficient atmosphere. Therefore, oxygen content must always be determined before taking combustible gas readings. Flammable gases and vapors are tested second because the risk of fire or explosion is typically more life-threatening than exposure to toxic air contaminants. Monitoring for toxicity is usually conducted last. This monitoring process is greatly simplified by using a multigas monitor containing sensors for oxygen, LEL, and the relevant toxic gases.*

The sections which follow describe in further detail the various sensor types which may be installed on a hand-held monitor. Oxygen sensors are discussed first, followed by combustible gas (explosibility) sensors, and lastly, toxic gas sensors.

1. Oxygen Sensors

Application and Principle of Operation

Oxygen sensors are typically based on electrochemical (galvanic) cells. The generated current in the sensor, which is produced from an oxidation reaction, is directly proportional to the rate of oxygen diffusion into the cell. Most meters are calibrated to measure oxygen concentrations between 0 and 25 percent by volume in air. Normal air contains about 20.9 percent oxygen. Meter alarms are usually set to indicate an oxygen deficient atmosphere at concentrations lower than 19.5 percent and an oxygen rich atmosphere at concentrations greater than 23.5 percent. Oxygen concentrations below 19.5 percent may result in difficulty breathing and impaired judgment. Oxygen concentrations below 16 percent result in rapid heartbeat and headache. Sudden physical exertion in an oxygen deficient environment may lead to loss of consciousness. Oxygen concentrations below 12 percent will bring about unconsciousness rapidly and without warning, and are considered IDLH. Oxygen enriched atmospheres present a fire and explosion hazard because ordinary combustible materials will burn more rapidly.

Calibration

Calibration is typically accomplished using fresh outdoor air (20.9 percent oxygen). Calibrate immediately before testing at or near the temperature of the tested atmosphere.

Maintenance

Oxygen sensors are inherently self-consuming and generally last from six to 12 months. When the unit cannot hold calibration, return it to the CTC for sensor replacement and repair (i.e., complete an Instrument Service Request).

2. Explosibility (combustible gas) Sensors

Application and Principle of Operation

Combustible gas sensors use an oxidizing catalyst such as platinum or palladium. Combustible gas meters measure flammable gas concentration as a percentage of the LEL of the calibrated gas. When possible, to maximize the accuracy of the combustible gas readings, calibrate the instrument with the gas that will actually be monitored. If monitoring for combustible atmospheres other than the reference gas (i.e., calibration gas) consult the manufacturer's instructions and correction charts/curves to determine a more accurate reading of the true gas concentration. Please note that LEL values for most flammable gases and vapors are a few percent in air (i.e., tens of thousands of ppm) and are NOT appropriate for assessing PEL concentrations of flammable toxic gases.

Calibration

Before using the monitor each day, calibrate it with an appropriate calibration gas as described in the user manual or in consultation with CTC. Follow the instructions in the user manual.

Consult the instruction manual before calibration, and ensure that the calibration gas is introduced at the proper pressure and flow rate, using the appropriate regulator and adaptors. Overpressurization can damage the sensor. For some instruments with an active sampling pump, the pump must be disconnected from the sensor and the span gas flow rate set to match the sampling rate of the pump.

Special Considerations

- Silicone compound vapors and sulfur compounds will cause desensitization of the combustible gas sensor and produce erroneous (low) readings.

- High relative humidity (90 percent to 100 percent) causes hydroxylation, which reduces sensitivity and causes erratic behavior including inability to calibrate.

- Oxygen deficiency or enrichment, such as in steam or inert atmospheres, will cause erroneous readings for combustible gases. Always note the oxygen concentration reading before assessing the LEL reading.

- In extraordinary circumstances, gas concentrations above the Upper Explosive Limit (UEL) may give a false reading indicating a noncombustible atmosphere; be aware that if air is suddenly introduced into such a space, the atmosphere can quickly become explosive.

- Vapors from liquids with flash points above 90°F such as turpentine, diesel fuel, and jet fuel, may not be adequately detected by combustible gas sensors. Use of a photoionization detector may be more appropriate.

- In drying ovens or unusually hot locations, solvent vapors with high boiling points may condense in the sampling lines and produce erroneous (low) readings. Consider taking readings at several different locations around the oven.

- High concentrations of chlorinated hydrocarbons, such as trichloroethylene or acid gases such as sulfur dioxide, will depress the meter reading in the presence of a high concentration of combustible gas.

- High molecular weight alcohols can burn out the meter's filaments.

Maintenance

The instrument requires no short-term maintenance other than regular calibration and recharging of batteries. Use a soft cloth to wipe dirt, oil, moisture, or foreign material from the instrument.

3. Toxic Gas Sensors

Application and Principle of Operation

Available toxic gas sensors include sensors for carbon monoxide, hydrogen sulfide, nitrogen dioxide, sulfur dioxide, chlorine, chlorine dioxide, phosphine, ammonia, hydrogen cyanide and hydrogen. While the toxic gas sensors are interchangeable, these instruments are not easily serviced in the field. Should a different gas sensor need to be installed, return the instrument to the CTC for a change of sensors.

Toxic gas sensors generally use an electrochemical (voltammetric) sensor or polarographic cell to provide continuous analyses. In operation, sample gas is absorbed on an electrocatalytic sensing electrode after passing through a diffusion medium. An electrochemical reaction generates an electric current directly proportional to the gas concentration.

Interference from other gases can be a problem. Before use, consult the user manual to identify interfering chemicals of concern. Some interfering compounds can result in false positive readings. In other cases, the sensor can be damaged, or "poisoned" by exposure to certain compounds, in which case it will need to be returned to the CTC for sensor replacement.

Calibration

Calibration against a known standard is required. Tests have shown the method to be linear; thus, calibration at a single concentration, along with checking the zero point, is sufficient. Calibrate with the appropriate calibration (span) gases before and after each use in accord with the manufacturer's instructions.

The monitor should be calibrated at the altitude at which it will be used. Changes in total atmospheric pressure caused by changes in altitude will influence the instrument's response. The unit's instruction manual provides additional details on the calibration of sensors.

Consult the instruction manual before calibration, and ensure that the calibration gas is introduced at the proper pressure and flow rate, using the appropriate regulator and adaptors.

Overpressurization can damage the sensor. For some instruments with an active sampling pump, the pump must be disconnected from the sensor and the span gas flow rate set to match the sampling rate of the pump.

D. DETECTOR TUBES

Application and Principle of Operation

There is a wide variety of commercially available detector tubes which can be used to measure over 200 organic and inorganic gases and vapors in air. Detector tubes are sealed glass tubes filled with a granular material that is coated with an appropriate indicator chemical that will react with a particular gas or vapor to give a color change. Their operation consists of using a portable pump to draw a known volume of air through a detector tube designed to measure the concentration of the substance of interest. The color change is read in terms of either the length of stain generated inside the tube or the degree of color change. This color change is compared either to a scale printed on the tube or to a reference chart included with the tube kit to determine the airborne concentration.

The pumps can be hand-operated (weight: 8-11 ounces), or they can be an automatic type (weight: about 4 pounds [lbs]) that samples using a preset number of pump strokes. Detector tubes of a given brand are to be used only with a pump of the same brand. A brand of tubes is calibrated specifically for the same brand of pump and may give erroneous results if used with a pump of another brand.

Important considerations for use of detector tubes include measurement accuracy, limits of detection, interferences, temperature and humidity, shelf life, and the time period for which the color stain is stable after the sample is drawn. Always consult the manufacturer's printed

instructions to determine these specifications, along with the required number of pump strokes and the time between pump strokes.

Detector tubes are most useful for screening purposes to determine whether levels of contaminant present in an area warrant further sampling. Several different types and brands of detector tubes have been evaluated for screening use by the SLTC. Information regarding these evaluations can be obtained by contacting the SLTC. Detector tubes can also be used for compliance sampling relative to TWA (8-hour time-weighted average), STEL (short-term exposure limit) and Ceiling limits. For example, the SLTC has documented procedures for use of direct-reading devices, including detector tubes, for the measurement and tracking of methylene chloride exposure. This document discusses the specific detector tubes recommended to determine workplace methylene chloride concentrations based on laboratory studies and includes an example calculation of a methylene chloride TWA exposure. The minimum number of pump strokes required to get a positive response near the STEL is also discussed.

Detector tubes are obtained through the CTC AESP. OSHA's Chemical Sampling Information (CSI) files list specific manufacturer's models of detector tubes for individual gases/vapors. The specific tubes listed are designed to cover a concentration range near the PEL. Concentration ranges are tube-dependent and can be anywhere from one-hundredth ppm to several thousand ppm. The limits of detection depend on the particular detector tube. Detector tube accuracy varies with tube manufacturer and with each detector tube range.

Before use, refer to the manufacturer's instructions for the particular tube type. Determine the measurement precision, which is typically +/- 25-35%, and be sure to record the measurement accuracy when recording the sample result on the Form OSHA-93, Direct Reading Report Form. Also, perform a pump leak test as shown in Figure 2.

To use, break the ends with a tube opener, which is generally part of the manufacturer's sampling kit. Attach the tube to the pump of the correct brand. Tubes generally have a directional arrow printed on each tube. As shown in Figure 1, ensure that the directional arrow is oriented toward the pump. Use the number of pump strokes specified by the manufacturer for that tube type.

FIGURE 1. PROPER INSERTION OF DETECTOR TUBE INTO PUMP.

FIGURE 2. PUMP LEAK TEST.

On each day of use, before taking measurements, perform a pump leakage test as

per the user instruction manual. The general procedure is to insert an unopened detector tube into the pump and attempt to draw in 100 milliliters (mL) of air. After a few minutes, check for pump leakage by examining the pump compression for bellows-type pumps, or return to resting position for piston-type pumps. Automatic pumps should be tested according to the manufacturer's instructions. The leak test procedure is shown in Figure 2.

In the event of pump leakage that cannot be repaired in the field, send the pump to the CTC for repair. Record that the leakage test was performed on the Direct Reading Report Form (OSHA-93).

The Dräger Chip Measurement System is an accurate and reliable hand-held reader based on colorimetric detection which is very useful for spot gas measurements. It combines an electronic-based analyzer with substance specific chips which are available through the AESP. Each chip contains 10 capillaries filled with a reagent system. The results of up to 50 measurements can be stored in a data recorder integrated in the analyzer.

Interferences

A limitation of many detector tubes is the lack of specificity of the chemical indicator. Many indicators are not highly selective and can cross-react with other gases and vapors. Manufacturer's manuals describe the effects of interfering contaminants.

Temperature and Humidity

Temperature, humidity and pressure can also affect detector tube readings. Read and follow the manufacturer's instructions regarding corrections that must be made to sample readings for these factors.

Long-Term Sampling

Most detector tubes only give near-instantaneous measurements, and thus will not reflect time-weighted average (TWA) levels of the hazardous substances present. Some long duration tubes for TWA measurements are available. Some are a diffusive/dosimeter type which requires no pump. Others are used with a portable lightweight pump which continuously draws a measured volume of air through the tube. These tubes can be worn by the worker in a special holder. At the end of the shift, the tube can be evaluated to give a TWA exposure for the working day (e.g., see the SLTC procedure to determine methylene chloride in workplace air by long-term detector tubes).

Another technique which could be used for long-term measurements with detector tubes is to wear a gas sampling bag such as a Tedlar® or Teflon® bag connected to a low flow pump and then periodically measure the concentration of contaminant in the bag (with a detector tube) to get a TWA exposure over the time period worn (e.g., see the SLTC utilization of direct-reading devices for the measurement and tracking of methylene chloride exposure). The sampling bag is connected to the outlet from a portable sampling pump set to a calibrated flow rate such as 0.05 liters per minute (50 cubic centimeters per minute). Once the long-term bag sample is collected, an air sample could be extracted in the field by connecting the bag to a detector tube and hand pump. Massage the bag to ensure good air mixing before extracting the air sample. This technique can only be used for assessing contaminants that would not react over time inside the bag. Consult the sampling pump manual to ensure that atmospheres that may be damaging to the pump are not drawn into it.

Storage and Shelf Life

Detector tubes normally have a shelf life of one to two years when stored at 25°C. Expiration dates are generally printed on the box or on each tube. In general, avoid excessively low (less than 35°F) or high (greater than 78°F) temperatures and direct sunlight which can adversely affect the properties of the tubes. Refrigerated storage prolongs shelf life. Detector tubes should not be used when they are cold. They should be kept at room temperature for about one hour prior to use. Outdated detector tubes (i.e., beyond the printed expiration date) should not be used.

Calibration

Annually or after any repair or maintenance work, send detector tube pumps to the CTC for calibration (volume verification). Calibration in the field is no longer performed. Consult the CTC if there is reason to suspect that a pump may not be operating properly prior to its scheduled calibration due date.

E. MERCURY ANALYZERS

Application and Principle of Operation

Handheld mercury analyzers can be used for compliance sampling and for source and leak detection. These instruments measure airborne mercury vapor by drawing an air sample over a gold film. The mercury adsorbed onto the gold surface changes the resistance of current flow. The change in resistance is a function of the mass of mercury collected on the gold film. The results can be displayed in milligrams of mercury per cubic meter of air (mg/m^3) or total mass of mercury in the air sample collected. Models available through ALEP include the Jerome Model 431X, which has a lower limit of detection of 0.003 mg/m^3 and achieves +/- 5 percent accuracy at 0.1 mg/m^3; and the Jerome 405-0007, which has a lower limit of detection of 0.5 micrograms per cubic meter of air ($\mu g/m^3$) and achieves +/- 5 percent accuracy at 25 $\mu g/m^3$ and +/- 10 percent accuracy at 1 $\mu g/m^3$.

Potential interferences which can produce a positive reading include chlorine, nitrogen dioxide, hydrogen sulfide, high concentrations of ammonia, and most mercaptans. Depending on the model, various filters are available from the manufacturer to remove chlorine, ammonia, and other interfering contaminants upstream of the sensor.

Calibration

Factory calibration is required annually. Because of the gold film/mercury interaction, the instrument should produce stable, accurate readings without the need for frequent recalibration. A calibration check can be performed using the manufacturer's Functional Test Kit.

Special Considerations

The instrument must be zeroed before use at the temperature at which it will be used. Both models have a zero air filter which removes mercury vapor, mercaptans, and hydrogen sulfide.
The instrument should be regenerated before and after use because the gold film sensor becomes saturated with mercury. The meter must be placed on line power and the gold film sensor regenerated at elevated temperature. After regeneration, wait half an hour before taking readings to allow the sensor to equilibrate to room temperature.

Maintenance

Routine maintenance includes periodic replacement of filters and regeneration of the gold film sensor to remove mercury after use of the instrument.

F. DUST / PARTICULATE MONITORS

1. Aerosol Photometers

Application and Principle of Operation

Aerosol photometers operate by detecting scattered light or infrared radiation. The amount of light reaching the detector is proportional to the number of particles passing through the detection chamber. Also known as nephelometers, these instruments are used to monitor particulate matter such as dusts, smokes, mists, and fumes. Some models can be used for monitoring the respirable fraction of dust, and some are small enough to use for personal exposure monitoring. Results are reported in $\mu g/m^3$ or mg/m^3. Some models are also a fibrous aerosol monitor (FAM), which report the number of fibers per volume of air (e.g., these instruments are useful for real-time measurements of airborne asbestos).

Calibration

Annual factory calibration is arranged by the CTC. Field zeroing prior to use is also required.

Special Considerations

Certain instruments have been designed to satisfy the requirements for intrinsically safe operation in methane-air mixtures.

Relative humidity conditions above 80 percent may result in readings which are higher than the actual dust concentration. Follow the manual for any necessary adjustments.

Maintenance

When the photodetector is not being operated, it should be placed in its plastic bag, which should then be closed. This will minimize particle contamination of the inner surfaces of the sensing chamber.

The unit will be cleaned as part of the annual calibration service. Follow the user manual in regards to field servicing. Excessive buildup of particles in the sensing chamber may affect the accuracy of measurements.

After prolonged operation or exposure to particulate-laden air, the interior walls and the two glass windows of the sensing chamber may become contaminated with particles. Although repeated updating of the zero reference following the manufacturer's procedure will correct errors resulting from such particle accumulations, this contamination could affect the accuracy of the measurements as a result of excessive spurious scattering and significant attenuation of the radiation passing through the glass windows of the sensing chamber.

2. Condensation Nuclei Counters

Application and Principle of Operation

Condensation nuclei counters take particles too small to be easily detected, enlarge them to a detectable size, and then count them. Common uses for this technology include quantitative respirator fit-testing and testing the removal efficiency of high efficiency particulate air (HEPA) filters.

Submicrometer particles are grown with alcohol or another liquid vapor as they pass through a heated saturator lined with alcohol-soaked felt. The alcohol vapor becomes super-saturated and condenses on the particles in a cooled condenser. Optics focus laser light into a sensing volume. As the droplets pass through the sensing volume, the particles scatter the light. The light is directed onto a photodiode which generates an electrical pulse from each droplet. The concentration of particles is counted by determining the number of pulses generated. This instrument is sensitive to particles as small as 0.02 micrometers. However, it is non-specific to variations in size, shape, composition, and refractive index.

A counter totals individual airborne particles from sources such as smoke, dust, and exhaust fumes. Common models operate in one of three possible modes, each with a particular application. In the "count" mode, the counter measures the concentration of these airborne particles. In the "test" (or fit- test) mode, measurements are taken inside and outside a respirator and a fit factor is calculated. In the "sequential" mode, the instrument measures the concentration on either side of a filter and calculates filter penetration.

Calibration

Check the counter before and after each use in accordance with the manufacturer's instructions. This procedure usually involves checking the zero of the instrument. Annual calibration is handled through the CTC.

Maintenance

Reagent-grade isopropyl alcohol for use in these types of instruments can be obtained from the CTC AESP. Isopropyl alcohol must be added to the unit after five to six hours of operation under normal conditions. Take care not to overfill the unit.

A fully charged battery pack will normally last for about five hours of operation. Low battery packs should be charged for at least six hours. Battery packs should not be stored in a discharged condition.

To prepare the unit for long-term storage, follow the instructions in the equipment manual. It may be necessary to dry the saturator felt by installing a freshly charged battery pack without adding alcohol. Allow the instrument to run until the LO message (low battery) or the E-E message (low particle count) appears. Some instruments allow you to remove the alcohol cartridge for storage purposes. Remove the battery pack and install the tube plugs into the ends of the twin-tube assembly.

IV. AIR VELOCITY MONITORS/INDOOR AIR QUALITY (IAQ) ASSESSMENT INSTRUMENTATION

NOTE: Always record the barometric pressure and air temperature when using air velocity meters. Refer to the user manual to determine the operating range for temperature and pressure. The measurement uncertainty may be greater when used at temperatures above or below room temperature.

A. FLOW HOODS

Application and Principle of Operation

A flow hood or balometer is an instrument used to measure volumetric air flow from supply or exhaust diffusers and grilles. The benefit of using a flow hood is that accurate measurements with a high degree of precision can be quickly obtained without the necessity of measuring grille sizes and conducting repeated velometer measurements over the face of the diffuser or grille. With the flow hood, the user can measure air volume, check HVAC system balance, verify air flow distribution within and between rooms, and in combination with other data, estimate the percent of outdoor air being supplied to a space. Additionally, if the diffuser area is known or measured, an accurate average linear air velocity can be calculated. Such applications may be important in assessing ventilation controls or conducting IAQ investigations. Other useful applications include determining volumetric airflow for dilution ventilation and evaluating airflow patterns to ensure that contaminants are not being pulled into unintended work areas. For more guidance on the appropriate use of flow hoods, please contact the SLTC.

Calibration

No field calibration is available; CTC handles calibration. Periodic factory calibration or equivalent by a laboratory is essential.

Maintenance

These instruments typically require little field maintenance other than battery pack servicing and zero balancing of the analog scales. Check the manufacturer's user manual for details.

B. THERMOANEMOMETERS

Application and Principle of Operation

A thermoanemometer (hotwire anemometer) is a handheld device with an extendable wand probe used to measure air speed (velocity). Due to their use of a heated wire, they are generally NOT suitable for use in hazardous areas where intrinsically safe equipment is required. Thermoanemometers can be used to monitor the effectiveness of ventilation systems and local exhaust systems. In general, thermoanemometers are appropriate for measuring laminar (nonturbulent) airflow. Multiple readings must be taken at different points in a plane which is perpendicular to the direction of airflow, and then averaged together. They are valuable when evaluating laboratory hoods for adequate face velocity. When the area of the hood face or exhaust diffuser is known (or measured) the volumetric airflow can be estimated by taking multi-point traverse measurements across the face of the hood or diffuser. A thermoanemometer can also be used effectively to assess downdraft/sidedraft tables and slot ventilation, because these all operate by establishing a stable capture velocity in a defined capture plane (e.g., at a specified distance from the slots). They are not useful for assessing snorkel-type local exhaust, due to generally turbulent airflow in the capture zone of a snorkel. Additionally, if a duct has access ports, the interior duct speed can be estimated by taking a multipoint traverse. To ensure accurate readings, a duct traverse should not be taken within three duct diameters of any elbows, branches, fans or transitions due to turbulent airflow in these locations. For more guidance on the appropriate use of thermoanemometers, please contact the SLTC.

"Ventilation smoke" is available through the AESP and is a helpful complement to the thermoanemometer. Smoke released inside an enclosing hood, such as a laboratory fume hood or spray booth, or outside an exterior hood, such as a snorkel, slot ventilation, canopy hood, downdraft table, or side draft hood, will help visualize whether contaminants will be effectively contained and/or captured. Ventilation smoke will also help determine whether supply air turbulence near a hood may compromise the hood's effectiveness.

Calibration

No field calibration is available. Equipment should be sent to the CTC for calibration and document retention. The CTC calibration interval is once every two years.

Special Considerations

While thermal anemometers can be very accurate, their accuracy may be adversely affected by air turbulence, temperature variations, or dirty probes. Note the manufacturer's limitations of use. Thermal anemometers are generally not intended for use in gas mixtures other than air, corrosive atmospheres, or other hazardous gas streams.

Maintenance

These instruments typically require little field maintenance other than battery pack maintenance and zero balancing of analog scales, if applicable. Check the manufacturer's user manual for details.

C. OTHER AIR VELOCITY METERS

Other types of air velocity meters include rotating vane and swinging vane velometers. These are used infrequently, but may be useful in circumstances where a thermoanemometer cannot be used, for example, corrosive atmospheres or hazardous environments. Also, rotating vane anemometers can be used to assess snorkel-type local exhaust ventilation.

D. BIOAEROSOL MONITORS

Application and Principle of Operation

Assessment of bioaerosols may be useful in certain IAQ investigations. A bioaerosol monitor, usually a two-stage sampler, is also a multi-orifice cascade impactor. This unit is used when size distribution is not required and only respirable-nonrespirable segregation or total counts are needed. Ninety-five to 100 percent of viable particles above 0.8 microns in an aerosol can be collected on a variety of bacteriological agar. Trypticase soy agar is normally used to collect bacteria, and malt extract agar is normally used to collect fungi. Blood agar is typically used for collection of Stachybotrys chartarum. Bioaerosol monitors can be used in assessing sick-building syndrome, or buildings which may have source exposures to molds and bacteria which may be exacerbating or causing illness to the occupants. These samplers are also capable of collecting virus particles. However, there is no convenient or practical method for cultivation and enumeration of viral particles.

The SLTC does NOT perform analysis of biological samples in-house. The SLTC coordinates analysis of biological samples by contracted laboratories. When considering biological sampling, contact the SLTC to discuss sampling requirements, technical support, assessment, and analytical coordination. The SLTC staff will review the sampling and analysis plans with the CSHOs and make recommendations where appropriate. The SLTC offers contracting services for analysis of fungi, bacteria (such as Legionella), and endotoxin. Other services can be arranged on a case-by-case basis.

Calibration

Bioaerosol meters must be flow-calibrated before use, using the same type of sampling media in the sampling train as will be used in the field. This can be done using an electronic calibration system with a high-flow cell.

Special Considerations

Prior to sampling, work with the SLTC HRT to determine the type of collection media required, sampling flow rates and times, and the analytical laboratory that will provide analysis. This specialized equipment is available from the HRT with instructions.

Maintenance

The sampler should be decontaminated prior to use by sterilization, or chemical decontamination with isopropanol.

V. VIBRATION MONITORS

The following sections contain a brief discussion of various types of measurements that are of concern when measuring vibration. Human response to vibration is dependent on several factors including the frequency, amplitude, direction, point of application, time of exposure, clothing and equipment, body size, body posture, body tension, and composition. A complete assessment of exposure to vibration requires the measurement of acceleration in well-defined directions, frequencies and duration of exposure. The vibration will generally be measured along three (x, y and z) axes.

A typical vibration measurement system includes a device (accelerometer) to sense the vibration, a recorder, a frequency analyzer, a frequency-weighting network, and a display such as a meter, printer or recorder. The accelerometer produces an electrical signal in response to the vibration. The size of this signal is proportional to the acceleration applied to it. The frequency analyzer determines the distribution of acceleration in different frequency bands. The frequency-weighting network mimics the human sensitivity to vibration at different frequencies. The use of weighting networks gives a single number as a measure of vibration exposure (i.e., units of vibration) and is expressed in meters per second squared (m/s^2).

A. HAND-ARM VIBRATION

Application and Principle of Operation

Hand-arm vibration will generally be measured when using a hand-held power tool. First, one must determine the type of vibration that will be encountered because a different accelerometer will be used depending on whether an impact (e.g., jackhammer or chipper) or non-impact (e.g., chain saws or grinders) tool is being used. The accelerometer will be attached to the tool (or held in contact with the tool by the user) so the axes are measured while the worker grasps the tool handle. The *z* axis is generally from the wrist to the middle knuckle, the *x* axis is from the top of the hand down through the bottom of the hand and wrapped fingers, and the y axis runs from right to left across the knuckles of the hand. The measurement should be made as close as possible to the point where the vibration enters the hand.

The frequency-weighting network for hand-arm vibration is given in the International Organization for Standardization (ISO) standard ISO 5349-1 (Mechanical Vibration - Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration – Part 1: General Requirements). The human hand does not appear to be equally sensitive to vibration energy at all frequencies. The sensitivity appears to be the highest around 8-16 Hz (Hertz or cycles per second), so the weighting networks will generally emphasize this range. Vibration amplitudes, whether measured as frequency-weighted or frequency-independent acceleration levels (m/sec^2), are generally used to describe vibration stress (American National Standards Institute, American Conference of Governmental Industrial Hygienists, ISO, and the British Standards Institution). These numbers can generally be read directly from the human vibration meter used. The recommendations of most advisory bodies are based on an exposure level likely to cause the first signs of Stage II Hand-Arm Vibration Syndrome (white finger) in workers.

OSHA does not have standards concerning vibration exposure. The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for vibration exposure to hand-held tools. The exposure limits are given as frequency-weighted acceleration. The frequency weighting is based on a scheme recommended in ISO 5349-1. Vibration-measuring instruments have a frequency-weighting network as an option. The networks list acceleration levels and exposure durations to which, ACGIH has determined, most workers can be exposed repeatedly without severe damage to the fingers. The ACGIH advises that these values be applied in conjunction with other protective measures, including vibration control.

B. WHOLE-BODY VIBRATION

Application and Principle of Operation

The measurement of whole-body vibration is important when measuring vibration from large pieces of machinery which are operated in a seated, standing, or reclined posture. Whole-body vibration is measured across three (*x*, *y* and *z*) axes. The orientation of each axis is as follows: *z* is from head to toe, *x* is from front to back and *y* is from shoulder to shoulder. The accelerometer must be placed at the point where the body comes in contact with the vibrating surface, generally on the seat or against the back of the operator.

The measurement device is generally an accelerometer mounted in a hard rubber disc. This disc is placed in the seat between the operator and the machinery. Care should be taken to ensure that the weight of the disc does not exceed more than about 10 percent of the weight of the person being measured.

Calibration

Vibration equipment will not generally be calibrated by the user. These devices will generally be sent back to the manufacturer for calibration on an annual basis.

Special Considerations

The most widely used document on whole-body vibration is ISO 2631-1 (Evaluation of Human Exposure to Whole-Body Vibration – Part 1: General Requirements). These exposure guidelines have been adopted as ACGIH TLVs.

The ISO standard suggests three different types of exposure limits for whole body vibration, of which only the third is generally used occupationally and is the basis for the ACGIH TLVs:

1. The **reduced-comfort boundary** is for the comfort of passengers in airplanes, boats, and trains. Exceeding these exposure limits makes it difficult for passengers to eat, read or write when traveling.

2. The **fatigue-decreased proficiency boundary** is a limit for time-dependent effects that impair performance. For example, fatigue impairs performance in flying, driving and operating heavy vehicles.

3. The **exposure limit** is used to assess the maximum exposure allowed for whole-body vibration. There are two separate tables for exposures. One table is for longitudinal (foot to head; *z* axis) exposures, with the lowest exposure limit at 4 to 8 Hz based on human body sensitivity. The second table is for transverse (back to chest and side to side; *x* and *y* axes) exposures, with the lowest exposure limit at 1 to 2 Hz based on human body sensitivity. A separate set of "severe discomfort boundaries" is given for 8-hour, 2-hour and 30-minute exposures to whole-body vibration in the 0.1–0.63 Hz range.

The ACGIH recommendations are based on exposure levels that should be safe for repeated exposure, with minimal risk of adverse effects (including pain) to the back and the ability to operate a land-based vehicle.

Some general considerations for using vibration equipment include:

- Batteries should always be checked prior to use.
- Be careful with electrode cables. Never kink, stretch, pinch or otherwise damage the cables.
- Remove the batteries from any meter that will be stored for more than a few days.
- Protect meters from extreme heat and humidity.

HRT Availability

The HRT maintains the following vibration analysis equipment:

Larson Davis Human Vibration Meter - HVM100

The Larson Davis HVM is a portable multipurpose meter which can be used for measurement of whole-body vibration, hand-arm vibration, hand-tool vibration, vibration severity and product compliance testing. It will collect and analyze data in accord with the most current ISO

requirements for hand-arm vibration and whole-body vibration exposures. It measures three input channels simultaneously, and a fourth channel calculates and stores vector sum information. Single and triaxial accelerometers attach to specialized mechanical mounting adaptors to allow measurement on a wide variety of tools and surfaces.

C. MECHANICAL FORCE GAUGE FOR ERGONOMIC EVALUATIONS

Application and Principle of Operation

Mechanical force gauges are frequently used for a wide range of force testing applications including testing of compressive and/or tensile forces. The gauges may be mounted to a test stand for even greater control and consistent results in repetitive testing applications. An easy to read concentric dial measures clockwise direction only. The dial rotates 360-degrees for tarring. A peak hold button captures peak readings. Usually the gauges are available in pound (lb), kilogram (kg) or Newton units of measure.

Calibration

Gauge accuracy should be checked periodically to ensure that the gauge is within its calibration limits. The calibration can be verified by applying known weight (adjusted for local gravity) to the extension hook. If adjustment is required, the gauge should be returned to the manufacturer for calibration.

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VI. HEAT STRESS INSTRUMENTATION

The following sections contain a brief discussion of various types of instruments that may be used for heat and heat stress monitoring. Refer to the OSHA Technical Manual, Section III: Chapter 4 - Heat Stress for additional information on heat-related injuries and illnesses.

Application and Principle of Operation

There are two types of heat stress monitors available through the CTC. One type is a real-time area monitor that measures environmental conditions that contribute to heat stress, and the other is a real-time personal monitor that measures the wearer's body temperature and/or heart rate. The area monitors (QUEST Model QUESTemp™ 15 or 3M WIBGET™ Model RSS-214) measure indoor and outdoor wet bulb globe temperatures (WBGT). The temperature values can be data logged and the monitor can also be configured to sound an alarm when a predetermined WBGT is reached. The personal monitors provide real-time information on the wearer's physiological condition and work effort by either inserting a probe into the wearer's ear canal to monitor body temperature (QUEST Technologies QUESTemp II™), or wearing a sensor belt around the waist that monitors heart rate and temperature (Metrosonics® hs-383 Personal Heat Stress Monitor). Both personal devices can be programmed to alarm when a predetermined temperature or heart rate is exceeded.

The area monitors work by taking measurements of the ambient temperature, the wet bulb temperature, and the globe temperature, and then using a formula to determine the WBGT. The wet bulb temperature takes into account the effects of humidity on the body's cooling mechanism and the globe temperature accounts for radiant heat on the worker. Outdoors, a WBGT is calculated by multiplying the wet bulb temperature by 0.7, the globe temperature by 0.2, and the dry bulb temperature by 0.1. Because radiant heat from the sun is not a factor indoors (or outdoors without a radiant heat load), the WBGT is calculated differently for indoor environments: the wet bulb multiplier stays the same, the globe temperature is multiplied by 0.3, and the dry bulb temperature

drops out of the formula.

Another personal heat stress monitoring system is available through the HRT. The CorTemp™ personal heat stress monitoring system uses an ingestible temperature sensor that is swallowed by the person being monitored. The capsule transmits the worker's core temperature to a receiver on his/her belt, which also receives a heart rate monitor's reading, and then transmits both signals to a receiver monitored by an observer up to 100 yards away. Because the sensor must be swallowed, the CorTemp™ system is considered a medical device and must be used under the supervision of a physician.

Calibration

Most calibration is done annually by the manufacturer. Certain instruments have simple user calibrations that must be performed before each use. The QUESTemp™ 15 is provided with a calibration module that plugs into the monitor. If the temperatures reported by the module and the monitor differ by more than 0.5°C (32.9ºF), the monitor needs to be returned to the manufacturer for calibration. The QUESTemp™ II personal heat stress monitor is calibrated to the user's body temperature every time it is used or if the ambient temperature changes by 10°C (50ºF).

VII. NONIONIZING RADIATION MONITORS

Survey Meters and Personal Monitors

Application and Principle of Operation

Radio Frequency (RF) survey meters are used to measure both electric and magnetic fields from RF sources. RF meters must be selected based on the frequency of the radiation that is to be measured. Meters typically have interchangeable probes for measuring electric and magnetic fields. Some meters and probes are capable of performing spatial and temporal averaging for multiple frequencies and displaying measurement results in percent of exposure from guidelines recommended by one of several consensus standards.

RF personal monitors are used to measure personal RF exposures. These monitors are worn on the belt and continuously log personal exposures and provide an exposure result using a shaped frequency response.

Induced currents from RF exposure can be measured using a clamp-on induced current meter. Induced currents in the arms and legs can be measured using these devices.

Calibration

No field calibration is available. The CTC arranges for annual calibration.

HRT Availability

Narda 8860

The Narda 8860 personal RF monitor is used to monitor occupational exposures to RF sources within the frequency range of 100 kilohertz (kHz) – 100 gigahertz (GHz). The user can select from multiple alarm settings. The unit continuously logs RF exposure levels and reports results based on a shaped frequency response. Note that the exposure limit for microwave radiation in general

industry, see 29 CFR 1910.97(a)(2)(i), is a 6-minute STEL, and that the primary effect of microwave radiation exposure is heating of body tissues, with the most sensitive organs being the eyes and testes.

APPENDIX A

INSTRUMENT CHART

The information shown in the table below is for reference only. Not every field office will have every type of instrument. Refer to the CTC ALEP for specific information, or to the SLTC.

INSTRUMENT USE		
PHYSICAL MEASUREMENTS		
Type of Instrument	**Measured Substance**	**Application**
Stop time meter	Time	Calibration
Tachometers	Mechanical speed	Flywheels, belts, cylinders, lathes, etc.
Ergonomic testing equipment	Force	Force measurements for ergonomic assessment
Electrical testers and multimeters	Electricity	Electrical circuits
Vibration meters	Vibration	Handheld power tools, bearings, gear trains, housings, walls
Thermoanemometer (air velocity meter)	Airspeed	Ventilation assessments
Detector tubes with hand pumps (bellows or piston style)	Chemical air contaminants	Screening, spot measurements for air contaminants
Pressure gauges	Air Pressure	Compressor air lines
Fibrous aerosol monitors	Fibers in air	Asbestos
Dust monitors (particle or respirable aerosol monitors)	Total dust, respirable dust	Mines, sandblasting, road construction, dusty operations, indoor air quality
GAS & VAPOR METERS		
Type of Instrument	**Measured Substance**	**Application**
Multi-gas meters	Combustible gas (LEL), oxygen (O_2), with specific toxic gas sensors	Confined spaces, underground construction, sewers
Toxic gas sensor, hydrogen sulfide	H_2S	Farms, sewers, underground construction
Toxic gas sensor, hydrogen cyanide	HCN	Industrial facilities, electroplating operations
Toxic gas sensor, sulfur dioxide	SO_2	Paper mills, bleaching operations
Toxic gas sensor, nitric oxide and nitrogen dioxide	NO and NO_2	Combustion sources, particularly from propane fuel
Toxic gas sensor, chlorine and chlorine dioxide	Cl_2 and ClO_2	Bleaching and disinfecting operations, plastics manufacture, chemical synthesis, other industrial operations
Toxic gas sensor, ammonia	NH_3	Industrial refrigeration, fertilizer, animal feed lots
Toxic gas sensor, phosphine	PH_3	Semiconductor manufacture, agricultural pesticides
Carbon monoxide monitor	CO	Garages, warehouses, other combustion sources, indoor air quality

Carbon dioxide monitor	CO_2	Indoor air quality, as a surrogate for other indoor source pollutants
Infrared analyzers	CO, CO_2, organic substances	Area surveys to determine locations with highest concentrations, waste anesthetic gases, fumigants, indoor air, leaks, spills
Photoionization Detectors (PIDs)	Hydrocarbons, other ionizable substances	Area surveys to determine locations with highest concentrations, indoor air, leaks, spills
Mercury vapor meters	Hg	Mercury plants, spills
Ozone Analyzers	O_3	Water or air purification, indoor air
RADIATION METERS		
Type of Instrument	**Measured Substance**	**Application**
Heat stress meters	Ambient (environmental) heat	Foundries, furnaces, ovens and outdoor work locations
Light meters	Light (illumination)	Indoor lighting, UV exposure
Microwave meters	Microwave radiation	Communications, microwaves, heaters
Radiofrequency instruments	Electromagnetic fields	RF heat sealers, VDTs, induction motors
Magnetic field testers	Magnetic Flux Density	Magnetic fields
Electrostatic field tester	Static electric fields	Hazardous locations
Ionizing radiation meters	Ionizing radiation	Nuclear plants, nuclear waste, laboratory and medical settings
BIOLOGICAL MONITORS		
Type of Instrument	**Measured Substance**	**Application**
Microbial sampler	Micro-organisms (microbes)	Indoor air quality

APPENDIX B

CHEMICAL WARFARE AGENT DETECTION

There are several methods and types of instruments that can be used in the detection of chemical warfare agents, such as nerve, blister, blood, and choking agents. However, most of these agents (nerve and blister) have extremely low occupational exposure limits, and nearly all the detection methods lack the sensitivity required to provide results at these low levels. It is important to understand the capabilities, uses, and limitations of each type of detection device or instrument. The manufacturer of each system provides clear and specific use instructions with each kit. Users should familiarize themselves with these instructions, know the limitations of each device or instrument, and practice the use of the kits while wearing appropriate PPE in a non-contaminated environment. The following sections highlight some types of equipment that are used for detection of chemical warfare agents. Generally, use of these detection systems will be limited to specially trained and equipped personnel at the SLTC or other specially trained and equipped OSHA personnel. The following summarizes specialized direct-reading capabilities that OSHA has access to and should be considered informational by all other personnel. These systems should only be used after consultation with the SLTC and under close SLTC guidance.

A. MILITARY DETECTION PAPERS/KITS

1. M8/C8 Detector Paper

The M8 detector paper was developed to detect liquid agents, specifically V- and G-type nerve agents, and H-type blister agents. The C8 paper is equivalent to the M8 paper; the "C" indicates a version manufactured for commercial use. These papers do *not* detect chemical agent vapors. The sheets are impregnated with chemical compounds that change to green, yellow, or red depending on the type of liquid agent encountered. A color chart accompanying the booklet helps determine the type of agent detected. The result is qualitative, but the detector paper has a sensitivity of about 20 microliters (µL) of liquid. Some substances can act as interferences and produce false positives, such as insecticides, antifreeze, and petroleum products.

A similar product, termed "3-way" paper is also available. This detector paper is equivalent to the M8/C8 papers, except that it includes an adhesive backing that can be used to apply the paper to equipment or PPE.

2. M9 Detector Paper

The M9 paper detects the presence of liquid nerve and blister agents by turning a reddish color. It does not distinguish the type of agent, nor does it detect chemical agent vapors. It will detect a liquid agent droplet with a diameter of approximately 100 micrometers (µm). Interfering substances that will produce a false positive include petroleum products, antifreeze, and insecticides. The papers come in a roll and are adhesive-backed.

3. M256A1 Detector Kit

The M256A1 Chemical Agent Detector Kit is designed to detect and identify chemical agent vapors, including blood (AC and CK), blister (H, HN, HD, CX, L), and nerve (V and G series) agents. The test consists of a series of chemical ampoules that are broken and exposed to the air. The reagents in the ampoules react with chemical agent vapors to produce a color change. A color chart and instructions included with the kit are used to determine the type of agent(s) that is/are present. The M256A1 is

relatively sensitive, and can detect some of the agents below the IDLH levels. The kit also includes booklets of M8 paper for detecting liquid agents.

4. C-2 Detector Kit

The C-2 Chemical Agent Detector Kit is used by the Canadian Military for detecting chemical agent vapors. The C-2 kit utilizes various colorimetric detection tubes for identifying nerve, blister, blood, and choking agents. Similar to the M256A1 kit, it will allow detection of some agents below IDLH levels. It also contains a booklet of M8 paper for use with detection of liquid agents.

B. COLORIMETRIC TUBES

Colorimetric tubes are made by several manufacturers, and their function is essentially the same. They contain a series of tubes which can be used to detect airborne chemical agents, as well as toxic industrial chemicals. Conducting a single test with one or more tubes takes two to five minutes to complete. There are some tubes, such as those for blister and nerve agents, which give a qualitative detection of the presence of that family of chemicals up to near IDLH levels. The industrial agents (blood agents and choking agents) can be specifically identified and quantitatively measured in ppm to levels below applicable exposure limits. An example of colorimetric tubes designed specifically for chemical agents is the Dräger Civil Defense Simultest™ (CDS) Kit.

C. PORTABLE CHEMICAL AGENT DETECTORS

Most types of portable, traditional chemical detection equipment, such as photoionization detectors, flame ionization detectors, electrochemical sensors, infrared analyzers, etc. can be used for chemical agent detection. These types of instruments are discussed in other sections of the Technical Manual. However, due to the acute toxicity of chemical warfare agents at very low concentrations, these instruments lack adequate sensitivity and cannot provide detection below IDLH levels. Some instruments have been developed for use specifically with chemical agents, and research is ongoing. Some of the more popular technologies and instruments are discussed below.

1. Ion Mobility Spectrometers

An ion mobility spectrometer (IMS) operates by drawing air into the instrument where it is ionized with a radioactive source. The ionized molecules travel through a charged tube, where they become separated according to their mass and mobility before reaching a collector electrode. An electronic signature is produced for each ion, which gives an indication of the type and relative concentration of agent present. IMS detectors are used mainly to detect nerve, blister, and blood agents. Examples of IMS detectors include the Chemical Agent Monitor (CAM), Improved Chemical Agent Monitor (ICAM), APD 2000 (Advanced Portable Detector), and SABRE 4000.

These instruments will not detect at levels below IDLH for most chemical agents. They are best used for site reconnaissance, or to screen for contamination on equipment or personnel. Some interferents that may cause false alarms with an IMS include the following: cleaning compounds and disinfectants that contain additives such as menthol and methyl salicylate (oil of wintergreen); aromatic vapors, such as perfumes and food flavorings; and exhaust from some motors and fumes from explosives and propellants.

2. Surface Acoustic Wave

Surface acoustic wave (SAW) sensors are comprised of piezoelectric crystals with selective surface coatings. As the mass of a chemical vapor sample flows over the sensors, it is absorbed onto the surface

which results in a change in vibration frequency of the sensor. An internal microprocessor in the instrument measures these changes, providing detection and identification of the chemical agent. Portable instruments utilizing SAW technology are available for detection of nerve and blister agents. Examples of SAW instruments include the HAZMATCAD and SAW MiniCAD. As with IMS detectors, SAW instruments will not allow detection of most chemical agents below IDLH levels. However, SAW detectors are less susceptible to false positive alarms from interfering substances.

D. GAS CHROMATOGRAPHS/MASS SPECTROMETERS

Additional instruments that can be used for chemical agent detection and identification are gas chromatographs (GC) and mass spectrometers (MS). These are generally laboratory-type instruments which require skilled laboratory technicians for operation and interpretation of results. A few have been hardened for use in vans and portable handheld units can be used in the field; however, the technicians normally must collect a sample from the suspect material and bring it to the instrument. Currently, the GC or GC/MS is the only instrument that can verify the concentrations of nerve agents down to levels which are below applicable TWA occupational exposure limits. TWA levels (PEL/TLV). This is important for applications where it is important in determining the appropriate types and levels of PPE or to verify that decontamination is complete.

An example of a portable GC is the MINICAMS Continuous Air Monitor. This instrument is used extensively in Department of Defense depots where chemical agents are stored and used by other agencies in the field. The MINICAMS can provide automatic, quantitative identification of the chemical agents for which it was calibrated.

E. HRT AVAILABILITY

The following equipment is maintained by the HRT for use in chemical agent detection:

1. Military Detection Papers/Kits: M8/C8 paper, M9 paper, M256A1 kits, and C-2 kits.

2. APD 2000; 2 IMS detection units as described above. Each OSHA region is also equipped with a single APD 2000 unit.

NOTE: The HRT also serves as the coordinator for OSHA's SRTs and can provide additional assistance and technical information regarding chemical warfare agent detection. Special precautions, such as PPE and/or other work practices, are also necessary to prevent exposure when working with chemical warfare agents. Contact the HRT for more details.

APPENDIX C

BIOLOGICAL AGENT DETECTION

Sampling and analysis for biological agents is a rapidly growing field. Many techniques and technologies are still under development. There are various factors to consider when sampling for biological agents, such as: method of dispersion for the agent, purpose of the sampling (e.g., to identify the agent, determine extent of contamination, confirm decontamination, etc.), environmental conditions, persistence of the agent, physical state of the agent, area/volume to be sampled, laboratory protocols, and others. It is important to note that biological agents (such as bacteria, viruses, and endotoxins) are particulate matter, and, therefore, detection methods are designed for particulate sampling. The following sections highlight some types of equipment that may be used for sampling and detection of biological agents.

A. SURFACE/BULK SAMPLING

1. Swabs

Swabs have been used frequently when sampling surface areas for the presence of biological agents. Swab tips come in a variety of materials, such as cotton, Dacron™, polyester, rayon, and foam. Shafts can be comprised of either wood or plastic. Generally, synthetic swab tips with plastic shafts are recommended because they are not of biological origin and will not interfere with DNA-based detection systems. Swabs may be used dry or wetted with a buffer solution. In general, studies have shown that wet swabs have higher collection efficiency than dry swabs.

2. Wipes and Sponges

Wipes and sponges are often used because they can sample larger surface areas and have a higher collection efficiency compared to swabs. They can also be used in a dry or wet fashion. Various styles and materials for wipes and sponges are available. As with swabs, synthetic materials are recommended to eliminate potential interference problems with detection systems.

3. Vacuum Methods

Vacuum methods can be used when it is necessary to sample very large surface areas or surfaces which are porous or irregular such as carpeting, where it is impractical to use swabs or wipes. These methods are also useful to gather bulk dust samples for analysis. One method utilizes a HEPA-filtered vacuum equipped with a dust collection filter sock which is used to capture the sample. Large surface areas can be vacuumed, and the dust gathered in the sock is then analyzed for the presence of biological agents. A similar method uses a portable sampling pump equipped with a filter cassette to "vacuum" particulate matter from smaller areas, and at lower flow rates. The filter can then be analyzed for biological agents.

4. Agar Plates

Agar plates, also known as "sticky plates," can be used to sample a surface by contacting the plate directly to the surface. The particles from the surface will adhere to the plate, which can then be analyzed by culture to identify any biological agents. This method has been used by various agencies during investigations of incidents involving biological agents.

B. AIR SAMPLING

Air sampling can be performed to determine the presence of airborne biological particulates. Essentially, a volume of air is drawn through a filter or deposited in another medium, and the captured particulates are then analyzed to identify biological agents. High flow rates are generally desirable because this allows higher sample volumes and increases the likelihood of detecting the suspect agents. However, it should be noted that some organisms are fragile, and the high velocities and impact mechanisms may kill the organism during the sampling process. Consult with SLTC to determine the appropriate flow rate and procedures for your situation.

Low flow air sampling methods consist of traditional personal sampling pumps equipped with capture devices such as filter media or liquid impingers. These low flow methods have the advantage of being small and portable; however, due to their low sample volume they will have a relatively high limit of detection.

Impactors, such as the Six Stage Viable Andersen Cascade Impactor, utilize higher flow rates (around 30 L/min), sample a greater air volume, and, therefore, increase the likelihood of detecting the agent. This and similar types of impactors capture the biological particulate directly on an agar plate which can then be analyzed in a laboratory by culture method.

High volume area samplers are also available for biological agents. These samplers possess flow rates ranging from 200 to 600 L/min, so they are able to sample very large volumes of air. Some instruments deposit the particulate matter on a filter, while others capture it in a liquid solution.

C. GENERIC DETECTION

There are several techniques and instruments available that will allow responders to perform a generic detection for biological agents. These methods will not identify a specific agent, but can be used to determine if a suspect material is of biological origin, and to rule out hoax materials. The following are some examples of equipment types:

1. **Particle Analyzers:** The particle size of a sample can be analyzed and compared to known size ranges for biological materials. If the particle size is too large or too small, biological materials can be ruled out.

2. **Fluorometer:** These instruments will detect the presence of DNA, which is a component of most biological materials. A positive response by the meter for a given sample indicates a biological material, but again, does not identify the material or agent.

3. **Luminometer:** A luminometer operates similarly to a fluorometer, except that it will detect the presence of adenosine triphosphate (ATP) in a sample. ATP is another component of a cellular organism, thereby indicating a biological material.

4. **Colorimeter:** Colorimeters can be used to detect protein from a sample. Again, protein is present in biological organisms, so these instruments can indicate if the material is biological in origin.

5. **Protein Paper:** Similar to a colorimeter, these paper strips can indicate if a given sample contains protein, and is, therefore, biological.

6. **pH Paper:** The pH of a sample is tested with pH paper strips; if the pH range is between 5 and 9, the material *may* be biological. If the pH is outside this range (below 5 or above 9), then biological materials can be ruled out.

D. IDENTIFICATION

1. Immunoassay/Handheld Assay

An immunoassay test, also known as a handheld assay (HHA), can be performed on a sample to identify a specific agent. These HHA tests rely on an antigen/antibody reaction to identify the suspect agent. The test is presumptive, meaning that a given agent must be suspected and then tested with its specific HHA for confirmation. For example, if *Bacillus anthracis* (anthrax) is suspected, the sample is tested using an HHA designed for *Bacillus anthracis*; a positive result confirms the presence of the organism while a negative result indicates that the sample does not contain that specific organism. The HHA units are small, the test can be performed in the field, and they rely on a visual colorimetric change for sample results. Some HHA systems come with an electronic reader to aid in detecting the colorimetric change.

HHAs are under scrutiny due to limitations on sensitivity and specificity; i.e., high rates of false-negative and false-positive results. The results from an HHA test should not be relied upon alone and further confirmatory analysis should always be performed. However, these tests are used widely by first responders as a rapid field test. Although they are presumptive, their results can assist decision makers in taking protective actions, treating potential infections, and involving other authorities as necessary.

2. Polymerase Chain Reaction

Polymerase chain reaction (PCR) is a system that allows identification of an agent based on its DNA. The DNA from the sample is obtained and reproduced rapidly to produce a quantity that is detectable by the instrumentation. For example, after 30 cycles with the PCR system, one copy of DNA from an agent sample can be reproduced until there are one billion copies, which can then be analyzed and identified.

PCR is performed real-time through detection by fluorescence. During the PCR cycle, DNA-specific "probes" with fluorescent dyes are attached to the DNA sample which allows detection. PCR can be performed in a laboratory, or in the field with semi-portable instrumentation. Specific reagents and supplies are necessary to perform the analysis.

PCR has been useful for biological agent detection because it has excellent sensitivity, good specificity, and provides real-time results. Some weaknesses of PCR to consider are the following: potential interferences from other substances in the sample, reagent stability, and sample viability, because PCR will detect the presence of both live and dead organisms, but will not distinguish between the two.

3. Culture

Analysis by culture is considered by many to be the "gold standard" for the identification of biological agents. Samples are sent to a laboratory where they are prepared and applied to an agar plate on which the suspect biological organisms are allowed to grow. After a sufficient period of time (usually 24 hours or more), visible growth can be examined to detect the presence of the biological agent(s). Often, culture is used for the confirmatory analysis of previous detection methods for a given sample (HHAs, PCR). Some disadvantages of culture include delayed results and the procedure will only detect living organisms. Any biological agent that has died before the analysis has begun will not be detected. Note that biological toxins or allergens associated with nonviable/nonculturable agents may still cause health effects.

HRT Availability

The following equipment is maintained by the HRT for use in biological agent sampling and analysis:

- Handheld Assays for the following agents: anthrax, plague, brucellosis, tularemia, Venezuelan equine encephalitis, staphylococcal enterotoxin B, botulinum toxin, ricin, smallpox, and Q fever.
- HEPA Vacuums: Two units with filter socks and other supplies specifically for use with biological agent sampling.
- Andersen Cascade Impactors: Two units.
- Dry Filter Units (DFU): Two units. The DFU is a high-volume air sampler designed for biological agent sampling. It operates at flow rates up to 600 L/min and utilizes a filter pad for capturing the agent.
- Surface/Bulk Sampling: Various wipe, sponge, and swab sampling kits.

NOTE: The HRT also serves as the coordinator for OSHA's biological SRT and can provide additional assistance and technical information regarding biological agent detection. Special precautions such as PPE and/or other work practices are also necessary to prevent exposure when working with biological agents. This information is provided as a reference for specially trained personnel and is not generally intended for CSHO use. Contact the HRT for more details.

APPENDIX D

IONIZING RADIATION MONITORS AND METERS

The following sections contain a brief description of the types of instruments that may be used for monitoring exposures to ionizing radiation and radioactive materials.

A. SURVEY METERS

Application and Principle of Operation

Radiation survey meters are used to locate and quantify sources of ionizing radiation or to quantify the exposure rate from sources of ionizing radiation. To assess the quantity of radioactive materials present, survey meters are typically calibrated to measure counts per minute (cpm). To measure the exposure rate from gamma (γ) or X radiation sources, survey meters are calibrated to measure roentgens per hours (R/h). Most survey meters have either gas filled detectors or scintillation detectors. Not all survey meters are configured to measure all radiation types. Survey meters must be chosen based on the type and energy of the radiation you expect to measure and whether you wish to measure cpm or R/h.

Calibration

Calibration is performed by the manufacturer on a periodic (usually annual) basis.

HRT Availability

1. Ludlum Model 3 with 44-9 Pancake GM Detector

The Ludlum Model 3 is a general purpose survey meter fitted with a pancake Geiger Mueller (GM) detector capable of measuring alpha (α), beta (β), γ, and X radiations. This instrument will measure count rates over a range of 0–500,000 cpm.

2. Ludlum Model 2360 with 43-93 Alpha/Beta Scintillator

The Ludlum Model 2360 is a survey meter capable of measuring and discriminating between α and β radiations. It is fitted with a Ludlum 43-93 alpha/beta scintillation detector. The meter will measure count rates over a range of 0–500,000 cpm.

3. Ludlum Model 192 MicroR™ Meter

The Ludlum Model 192 is a low level (μR/h) γ and X radiation exposure rate meter. The meter has an internal sodium iodide detector capable of measuring dose rates between 0 and 5,000 μR/h.

4. Thermo Scientific® FH40GL Dose Rate Meter with FHZ732GM Pancake Probe

The FH40GL is a stand-alone radiation survey meter equipped with an internal proportional detector capable of measuring γ and X radiation exposure rates from 1 μR/h–10 R/h. The unit is also equipped with an FHX732GM pancake GM detector capable of measuring count rates from α, β, and γ radiations over a range of 0.01–100,000 counts per second.

5. Thermo Scientific® FH40TG Teleprobe™

The FH40TG telescoping probe can be used with the FH40GL to measure γ and X radiation exposure rates over a range of 10 μR/h–1,000 R/h. The probe is equipped with two GM detectors that can be extended up to 13 feet away from the user, allowing exposure rate measurements to be made at a distance from the source.

6. Thermo Scientific® RO-20 Ionization Chamber

The RO-20 is capable of measuring exposure rates from β, γ, and X radiations. The instrument is equipped with an air filled ionization detector capable of measuring exposure rates up to 50 R/h.

7. Thermo Scientific® PM1703M Gamma Pager

The PM1703M is a pager-sized survey meter that can be worn on the belt. The meter contains a cesium iodide scintillator-photodiode detector capable of measuring γ and X radiation. The instrument will measure exposure rates from 0–5,000 μR/h. The PM1703M is a highly sensitive instrument that can be set to alarm when the background varies by a user-set factor. This meter can be used to warn the user that he/she has entered a radiation area that is above background radiation levels.

B. SCALARS

Application and Principle of Operation

Scalars are used to analyze samples of radioactive material and to quantify the amount of material present. They are often used to measure the amount of radioactive material in air samples, wipe samples, and nasal swabs. Scalars use the same detector types used in survey meters. These instruments can typically be set to count a sample for a specified time.

Calibration

Calibration is performed by the manufacturer on a periodic (usually annual) basis.

HRT Availability

1. Ludlum Model 3030 Alpha/Beta Scalar

The Ludlum Model 3030 is a dual alpha/beta scalar used for sample counting. The instrument has a silver-activated zinc sulfide [ZnS(Ag)] coated scintillation detector capable of discriminating between α and β radiations. The readout on the front of the instrument reports both α and β counts for the specified period. Counting time can be set from 0.1–30 minutes.

2. Ludlum Model 2000 Scalar with 43-10 Alpha Sample Counter

The Ludlum Model 2000 scalar with 43-10 sample counter is capable of counting samples for α particle emissions. The sample counter has a ZnS(Ag) scintillation detector. Counting time can be set from 6–990 minutes.

3. Thermo HandECount Scalar

The HandECount is a battery or AC powered sample counter used for determining the α and β activity present in a sample. The instrument is controlled by a Palm™ hand-held computer platform and operating system which communicates with a standard modular detector board to perform all counting operations. All data is automatically logged to a file for later retrieval to a PC. The HandECount will report both α and β counts for a sample.

C. ELECTRONIC PERSONAL DOSIMETERS

Application and Principle of Operation

Electronic personal dosimeters are used to measure the dose received by an individual. They are normally worn on the front of the body in the chest area. Most electronic dosimeters measure the deep dose equivalent (Hp(10)) to γ radiation. Some electronic dosimeters also measure the shallow dose equivalent (Hp(0.07)). Most electronic dosimeters allow the user to set alarms for integrated dose and/or dose rates.

Calibration

Calibration is performed by the manufacturer on a periodic (usually annual) basis.

HRT Availability

1. Thermo Electronic Personal Dosimeter (EPD) Mk.2

The Thermo EPD Mk.2 is an electronic dosimeter capable of measuring Hp(10) (deep dose) and Hp(0.07) (shallow/skin dose). It is sensitive to γ and X radiations for Hp(10) measurements, and is sensitive to γ, β, and X radiations for Hp(0.07) measurements. Alarms can be set for accumulated doses and for dose rates for both Hp(10) and Hp(0.07).

2. Rados RAD-60 Electronic Personal Dosimeters

The Rados RAD-60 is capable of measuring Hp(10) from γ and X radiations. Alarms can be set for both dose and dose rate.

D. SPECTROSCOPY

Application and Principle of Operation

Portable handheld radiation spectroscopy instruments allow the user to identify radionuclides. These instruments typically use a sodium iodide detector with a multichannel analyzer to measure the energy spectrum emitted by a radioactive source. The instrument compares the spectrum to a library of spectra and provides the user with a list of likely sources. Spectra can also be downloaded to a computer if the user wishes to perform the spectral analysis manually or wishes to print the spectra for documentation.

Calibration

Calibration is performed by the manufacturer on a periodic (usually annual) basis.

HRT Availability

EXPLORANIUM™ GR-135N

The EXPLORANIUM™ GR-135N is a handheld isotope identification device. The GR-135N has a sodium iodide detector capable of identifying radionuclides, a GM detector for measuring exposure rate, and a solid state neutron detector. Spectra from the GR-135N can be downloaded to a computer for analysis and printing.

E. ELECTRET-PASSIVE ENVIRONMENTAL RADON MONITORING

Application and Principle of Operation

The Electret-Passive Environmental Radon Monitor (E-PERM) system is a passive integrating detector system for the measurement of radon (^{222}Rn) or thoron (^{220}Rn) concentrations in air. It consists of a charged Teflon® disk (electret), an open-faced ionization chamber, and an electret voltage reader. When the electret is screwed into the chamber, an electrostatic field is established and a passive ionization chamber is formed. The chamber is deployed directly in the area to be measured. Radon gas diffuses passively into the chamber and the α particles emitted from the decay of radon ionize the air molecules. These ions are then attracted to the charged surface of the electret, and the charge on the electret is reduced. The electret charge is measured before and after the exposure with a portable electret voltage reader, and the rate of change of the charge (change divided by the time of exposure) is proportional to the concentration of radon in the area.

Calibration

Calibration factors are provided for each type of electret. Calibration factors are voltage dependant and instructions for calculating the calibration factors are in the E-PERM manual provided by the manufacturer.

HRT Availability

The HRT has 12 E-PERM chambers, electrets, and a voltage reader.

F. RADIATION PPE AND SHIELDING

In radioactively contaminated areas, PPE is typically used in order to prevent workers from becoming contaminated, and to minimize the spread of radioactive contamination. The choice of appropriate shielding for ionizing radiation depends on the type and energy of the radiations to be shielded. Alpha particles have very low penetrating power and travel only a few centimeters in air and will not penetrate the dead outer layer of skin. Shielding is generally not required for alpha particles because external exposure to alpha particles delivers no dose. Where particulates contaminated with alpha particles are present, HEPA-filtered respiratory protection is critical to prevent an internal dose. Beta particles can travel several meters in air and can penetrate several millimeters into the skin. Beta particles should be shielded using an appropriate thickness of low atomic mass (low-Z) materials such as aluminum or plastics (e.g., Plexiglas®). Shielding beta particles with high-Z materials should be avoided as this can result in production of secondary X radiation (i.e., bremsstrahlung radiation). Gamma and X-rays can travel kilometers in air and can penetrate deep into the human body or pass through it entirely. Gamma and X-rays are most efficiently shielded using an appropriate thickness of high-Z materials such as lead or steel, or with an appropriate thickness of concrete. Neutrons are most efficiently shielded using an

appropriate thickness of hydrogenous materials such as paraffin, water, or plastics, or with an appropriate thickness of concrete.

NOTE: The HRT also serves as the coordinator for OSHA's radiation SRT and can provide additional assistance and technical information regarding radiation measurements. Special precautions are also necessary to prevent exposure when working with radioactive materials, such as PPE and/or other work practices. Contact the HRT for more details.