

# Remediation of a Mercury- Contaminated Fluorescent Lamp Recycling Facility

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## **ABSTRACT**

Mercury contamination present in existing industrial structures creates challenging environmental problems when it comes time to rehabilitate and reuse the facilities. Very little practical knowledge exists to effectively clean and remove mercury from contaminated buildings. The purpose of this thesis was to 1) present decontamination screening methods that can be used to determine the effectiveness of mercury cleaning strategies, and 2) provide clearance sampling methodologies used to evaluate building cleanliness, and support the conclusion that the facility is adequately cleaned with respect to mercury contamination and ready for reuse. This thesis is based on a case-study of a remediation project performed at a mercury-contaminated fluorescent lamp recycling facility in Massachusetts (USA), and presents the strategies developed to clean the building and assess cleanliness. The methods described here showed that properly specified and implemented surface decontamination techniques can adequately reduce airborne mercury contamination by more than three (3) orders of magnitude within the structure. Analysis of mercury sampling results supports the conclusion that the air quality in all areas of the facility was significantly improved, and was nearly at the background levels after decontamination efforts were completed. The thesis presents a variety of practical and reproducible measures to decontaminate and evaluate cleanliness of buildings that have been contaminated through industrial activities.

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## **1.0 INTRODUCTION**

Most existing industrial buildings and structures contain substances which are considered harmful to human health and the environment. Some buildings were originally constructed with materials or components which contain chemicals considered harmful today, e.g., asbestos, polychlorinated biphenyls (PCBs), lead, etc. Other industrial buildings are contaminated with the harmful industrial byproducts and wastes produced by the operation which formerly occupied the building, e.g., mercury, heavy metals, petroleum products, volatile organic compounds (VOCs), etc. The contamination present in existing industrial structures creates challenging environmental problems when it comes time to rehabilitate and reuse these properties.

The purpose of this thesis is to develop and present a systematic and comprehensive approach to the decontamination and evaluation of the cleanliness of buildings and structures which have been subject to mercury contamination.

The particular project which serves as the subject of this thesis is a building rehabilitation involving the characterization, decontamination and cleanliness confirmation of an industrial facility which formerly operated as a fluorescent lamp processing / recycling operation. During its operational lifetime this facility received shipments of waste fluorescent lamps and other mercury-contaminated materials from a variety of sources, and processed these items to remove, recover and/or properly dispose of the hazardous mercury material. Despite the controlled manner by which the fluorescent lamps were recycled at the facility, various inefficiencies in these controls allowed mercury to accumulate throughout the interior of the building over the course of its 20+ year operational history.

The major problems encountered in an industrial facility remediation project, such as the one described above, are the following:

1. There are very few recommended or guideline techniques or technologies for conducting thorough decontamination of contaminated building components with respect to mercury contamination,
2. There are no agreed upon testing methodologies for characterizing and quantifying the level of hazardous mercury contamination in structural matrices thus making the ultimate determination of “cleanliness” problematic.

The existing environmental hazardous material decontamination literature almost exclusively addresses remediation within the “natural” environment – that is, soil, water, waste and, to a more limited extent, air. The techniques established to decontaminate and characterize these types of “standard” media cannot be directly applied to the structural matrices encountered in a building environment (IAEA 2001). Nevertheless, as part of a sustainable, environmentally-oriented approach to urban renewal and property redevelopment, it is important to develop systematic solutions to these problems (Sanchez 2004). This thesis serves to present various decontamination, sampling and cleanliness determination methodologies applicable to a building environment with respect to mercury contamination.

## **1.1      *THESIS OBJECTIVES***

The following are the primary objectives of this thesis:

1. Present decontamination screening methodologies which can be used to determine the effectiveness of cleaning strategies, and

2. Provide clearance sampling methodologies and techniques used to evaluate building cleanliness, and support the conclusion that the facility is adequately cleaned and ready for reuse.

The thesis provides a thorough and reproducible approach to removing mercury contamination from a facility, thus allowing the structure to be reused and reoccupied without limitation, restriction or reservation. The alternative to decontamination would be to demolish the mercury contaminated facility and manage the debris as a hazardous waste. Such an option should not be the desired outcome.

## **1.2 ABOUT THE PROJECT**

The subject facility underwent decontamination and closure between February 2013 and August 2014, and it was the task of the project's consulting team to provide third-party oversight and cleanliness validation for the facility's operator (henceforth, the "owner") throughout the decontamination and closure process. The consulting team completed the following with regard to the decontamination and closure of the facility:

1. Provided a scientific basis for establishing cleanliness acceptance criteria values (see Appendix B);
2. Conducted a detailed review of the material handling and recycling activities performed at the facility (see Appendix C);
3. Conducted representative characterization investigative sampling to evaluate the level of mercury contamination present in the facility at the time of closure (see Appendix D);

4. Developed detailed cleaning and decontamination procedures, and regularly observed that these procedures were performed properly by the decontamination contractors (henceforth, the “contractors”) (see Appendix E);
5. Conducted necessary decontamination verification sampling (i.e. screening testing) to evaluate the effectiveness of a combination of cleaning techniques, and to ensure that all areas of the facility were sufficiently decontaminated (see Section 3.1, page 26 and Section 4.1, page 42);
6. Conducted clearance sampling and assessed the results to verify that post-closure levels of residual mercury contamination were reduced to values considered non-hazardous and/or essentially eliminated (see Section 3.2, page 34 and Section 4.2, page 67); and
7. Issued endorsed consulting reports to the applicable regulating authorities, and received final clean-closure approval.

The procedures, methodologies and challenges associated with these activities are described throughout this thesis. Based on the above mentioned efforts, at the conclusion of closure activities the facility was effectively cleaned and decontaminated by the contractors, and was essentially free of any hazardous levels of mercury contamination.

The facility, which served as the basis for this thesis, operated as a regulated waste processing and storage facility for more than 20 years. In addition to mercury-contaminated wastes (i.e. fluorescent lamps), the facility handled various “other” types of hazardous and universal wastes throughout its operational history; namely, polychlorinated biphenyls (“PCB”), lead-acid batteries and consumer

electronics waste. In addition to mercury, the facility was contaminated with many other toxic compounds that were potentially associated with the facility's other waste handling processes, these compounds included: PCBs, arsenic, cadmium, chromium, lead, barium, silver, selenium, antimony and yttrium. The facility decontamination and closure with respect to these other compounds should be considered outside the scope of this thesis, and as such, only the decontamination efforts related to mercury contamination are presented here.

The facility decontamination and closure efforts related to mercury merit special consideration because of the unique properties of elemental mercury and the general lack of scientific literature addressing this topic (OSPPERA 2002). Elemental / inorganic mercury (i.e. the main species of mercury encountered at this facility) is relatively volatile at room temperature, and amalgamates readily with many metals, such as copper, zinc, aluminum, nickel, tin, cadmium and gold. The substance's volatility and formation of amalgams makes the decontamination process more complicated. These complications are further compounded by the fact that elemental mercury has a very low solubility in water, rendering typical water washing techniques ineffective (Ebabian 2001).

## **2.0 BACKGROUND**

The following sections provide a summary of the background information associated with the facility decontamination objectives and the primary pollutant of concern (i.e. mercury). These sections are not intended to be an exhaustive survey of background requirements, or the chemical and toxicological data available for mercury; rather the purpose of the following sections is to present a brief summary of the relevant information and literature sources which informed the decontamination of the facility.

### **2.1 MERCURY BACKGROUND**

#### **2.1.1 Physical and Chemical Properties**

The heavy metal mercury has an atomic number of 80, an atomic mass of 200.59, a liquid density of 13.55 g/cm<sup>3</sup>, and a vapor density of 8.4 kg/m<sup>3</sup> (20 °C, 101.3 kPa, water liquid density = 1.0 g/cm<sup>3</sup>, air vapor density = 1.2 kg/m<sup>3</sup>). Although mercury is a metal, it is unique in that it is a liquid at normal room temperatures (i.e. 20 °C). Elemental, or metallic mercury is fairly common in the environment due in part to its unique physical and electro-chemical properties (Baughman 2006; Gochfeld 2003; Risher 2007). In its elemental form, mercury is a heavy, shiny, silver metallic liquid at room temperature with relatively high vapor pressure (i.e. 0.002 mm Hg at 77 °F [25 °C]). This means the metal can easily evaporate from liquid to vapor at room temperature. Mercury vapors are colorless and odorless.

Mercury exists in three (3) main oxidation states, Hg(0), Hg(I) and Hg(II). In pure form, expressed Hg(0), it is known as “elemental” or “metallic” mercury. Mercury

can be bound to many other compounds as monovalent (i.e. Hg(I), known as mercurous) or divalent mercury (i.e. Hg(II), known as mercuric), but most inorganic and organic mercury is formed from Hg(II). Common inorganic mercury salts include: mercuric sulfide (HgS), mercuric oxide (HgO) and mercuric chloride (HgCl<sub>2</sub>) (UNEP 2002). Organic mercury consists of a covalent bond between Hg(II) and carbon atom(s). Organic mercury compounds, such as methylmercury and dimethylmercury, react with biologically important ligands and can easily cross biological membranes, and are generally considered more toxic than elemental / inorganic mercury (Faulconer 2012).

Decontamination for different types of mercury compounds may require different techniques. Therefore, a thorough understanding of forms of mercury present at the facility was required. Organic mercury was not processed or produced at the facility, and therefore this thesis only addressed elemental and inorganic mercury compounds. Under ambient conditions, silver, gold copper, zinc and aluminum readily form amalgams in the presence of liquid or gaseous elemental mercury (Andren 1979). As a result, liquid or gaseous mercury can cause galvanized metal, aluminum and certain steel and copper alloy materials to become corroded with mercury-laden rust (Ebadian 2001). If this is the case, more aggressive decontamination (i.e. rust removal) is required.

### **2.1.2 Bioavailability and Absorption**

Bioavailability refers to the ability of an organism to extract mercury from the environment (i.e. external bioavailability) (Gochfeld 2003). Bioavailability depends on the properties of the environmental matrix contaminated with mercury and the form of mercury. Unfortunately, there are relatively few studies of the bioavailability

of different forms of mercury in different materials, so for risk assessment purposes it is assumed that there is 100% transfer efficiency from environment to human (NJMTF 2002).

External bioavailability is mainly a property of the matrix, whereas absorption (i.e. internal bioavailability) is mainly a property of the organ (Gochfeld 2003). Exposure to elemental (metallic) mercury is almost exclusively through inhalation of vapor (see Table 1). Other forms of inorganic mercury salts (i.e. not elemental / metallic) are not shown to pose a significant risk by the inhalation pathway. The next most significant route of exposure is from oral exposure to inorganic mercury salts (e.g. mercuric chloride, mercuric sulfide, etc.) (see Table 1).

**Table 1 – Absorption of Mercury by Exposure Route**

| Route of Exposure | Rate of Absorption |   |
|-------------------|--------------------|---|
|                   | Elemental Mercury  | Inorganic Mercury Salts (e.g. mercuric sulfide) |
| Oral              | <0.1%              | 10-30%  |
| Dermal            | Negligible         | Negligible                                      |
| Inhalation        | 70-90%             | Insufficient Data                               |

(Adopted from ATSDR 1999, Gochfeld 2003 and Risher 2007)

There are many sources of non-occupational exposure to inorganic mercury, as summarized in the following table.

**Table 2 – Sources of Non-Occupational Exposure to Mercury**

| Home / School / Office  | Medical   | Ethnic / Folk   |
|---|---|---|
| Broken thermometers<br>Broken barometers<br>School science labs<br>Thermostat switches<br>Fluorescent lamps<br>Paints | Dental amalgams<br>Skin-lightening creams<br>Ear drops<br>Diuretics<br>Laxatives<br>Immunizations | Santeria<br>Voodoo<br>Espiritismo<br>Palo Mayombe<br>Chinese folk use<br>Mexican folk use |

(Adopted from Risher 2007)

The primary route of exposure to mercury is through inhalation of vapor which yields almost complete absorption of the chemical through the lung tissue (see Table 1, page 8) (Risher 2007). Infants and children, with breathing zones closest to the floor, are at greater risk of significant exposure following spills of elemental mercury, since mercury vapor is heavy and tends to form layers close to the floor (Clarkson 2003).

Dental amalgams constitute the chief source of exposure to elemental mercury for some individuals. Dental amalgams, or silver-mercury fillings, consist of approximately 50 percent elemental mercury, 35 percent silver, and a mixture of other metals such as copper. Through the normal chewing process, mercury vapor volatilizes from the amalgams and builds in the oral cavity at concentrations higher than those deemed safe by most health guidelines. The World Health Organization (“WHO”) estimates that dental amalgams contribute approximately 10 micrograms (“µg”) of mercury exposure per day to humans who have such fillings (WHO 1991). It is important to note that no credible evidence exists which suggests the mercury exposure associated with dental amalgams represents a health risk. Furthermore, studies have found no association between mercury

amalgam exposure and neurologic or renal dysfunction in children (Bellinger 2006; DeRouen 2006).

A less acknowledged / quantified source of exposure to inorganic mercury among the general population is from its use in primitive ethnic, religious or folk practices. Latin American, Caribbean, South American, and Chinese religions sometimes use mercury ceremonially / medically to ward off “evil spirits” or disease (Risher 2003).

### **2.1.3 Toxicity**

The literature on the health effects of mercury is extensive. However, the human and animal data are generally limited to inhalation exposure to elemental mercury vapors and oral exposure to inorganic mercury compounds (ATSDR 1999).

The toxicity of mercury depends on its chemical form and route of exposure, and thus signs and symptoms are rather different. Elemental and inorganic mercury poses minimal risk of severe toxicity through ingestion or dermal contact; however, mercury vapors are readily absorbed when inhaled (ATSDR 1999; Ellis 2009). Inhaled mercury vapor easily penetrates the blood-brain barrier and is a well-documented neurotoxicant (ATSDR 1999; EPA 2000; UNEP 2002).

Acute (i.e. short-term) inhalation human exposure to high levels of elemental mercury can result in central nervous system effects such as: tremors, mood changes, and slowed sensory and motor nerve function. At room temperature, short-term health effects from mercury exposure are infrequent, however, heating mercury increases its evaporation rate. This can cause very high vapor concentrations and severe acute effects. A case report in Michigan detailed the

results when four (4) adults melted down tooth fillings to recover the silver. These fillings contain about 50% mercury. After one (1) day all four people developed difficulty breathing. Despite medical care, all four patients died. The home where the fillings were melted was so contaminated that it had to be destroyed (Baughman, 2006).

Chronic (i.e. long-term) exposure to elemental mercury also affects the central nervous system, with impacts ranging from: erethism (increased excitability), irritability, excessive shyness, and tremors. One study associated chronic exposure of 10 – 40  $\mu\text{g}/\text{m}^3$  with neurologic effects in children (Tauger 1991), but the threshold for such effects is uncertain. In workers, one study associated chronic exposure of 26  $\mu\text{g}/\text{m}^3$  with neurologic effects. However, some studies reported no neurologic effects at slightly higher concentrations (ATSDR 1999).

Acute oral exposure to inorganic mercury salts may result in effects such as nausea, vomiting, and severe abdominal pain. The major effect from chronic oral exposure to inorganic mercury is kidney damage. Factors such as age, sex, nutritional state, and exposure route are likely to affect the relationship between dose and effect response. Human studies are limited and inconclusive regarding the link between elemental mercury and cancer, while certain inorganic mercury salts (e.g. mercuric chloride) have been shown to result in forestomach, thyroid and renal tumors in animals (ATSDR 1999; EPA 1997; EPA 2000; UNEP 2002; WHO 1991).

#### **2.1.4 Use in Fluorescent Lamps**

Fluorescent lamps consist of a sealed glass tube coated with powdered phosphor material and filled at low pressure with argon gas and mercury vapor. Tungsten

coils coated with an electron-emitting material form electrodes at either end of the lamp, and when voltage is applied, electrons pass through the tube, striking the argon atoms and releasing electrons. The electrons then strike the mercury atoms, causing the orbital electrons to jump into an excited state, and upon relaxation, the mercury atoms emit a photon of ultraviolet light, which strikes the phosphor atoms, causing it to fluoresce photons in the visible light spectrum (Lucas 2006). Fluorescent lamps are significantly more energy-efficient than incandescent light bulbs, and they are also more cost-effective since they can last up to ten (10) times longer than incandescent bulbs (Ramroth 2008). However, waste fluorescent lamps have the potential to release significant amounts of mercury into the environment. In the United States alone, approximately 600 – 620 million fluorescent lamps are discarded annually (Aucott 2004; EPA 1994), which accounts for approximately six (6) tons of elemental mercury potentially released to the environment – assuming the average lamp contains 10 mg of mercury (NEWMOA 2008).

In light of this potential environmental impact, recycling and recovery of the mercury from fluorescent lamps is the desired outcome, in that the amount of mercury ultimately released to the environment is reduced. The mercury recovery process begins with the crushing of spent fluorescent lamps in a controlled manner to extract the phosphor powder, which contains the bulk of the mercury. This powder is then put into a mercury retort to vaporize, condense and recover most of the elemental mercury (EPA 1994).

Despite the controlled manner by which the fluorescent lamps were crushed / retorted at the facility, various inefficiencies in the controls allowed mercury to accumulate throughout the interior of the building over the course of the facility's

20+ year operational history. These sources of uncontrolled mercury emissions included, but were not limited to, lamps which were accidentally broken outside the crushing machines, spills of liquid mercury when emptying retort devices and inefficiencies in the building's air filtration systems (OSHA 2012).

## **2.2 PROJECT BACKGROUND**

### **2.2.1 Decontamination Purpose and Objectives**

The desired end result of the cleaning / decontamination and clearance sampling effort was to ensure that, upon final closure, the facility would receive a certificate of clean closure with no restriction or reservation with regard to future tenant use which was endorsed by the applicable State and Federal regulatory agencies.

The main objective of the facility closure activities was to decontaminate and clean all structural surfaces to a point where they were free of any mercury contamination. By extension then, the idealized goal of decontamination effort would be to select sampling methods with very low limits of detection ("LOD") for the contaminant; and after decontamination, collect post-clean samples which had results that were below these analytical LODs. Although this was essentially the goal for the facility closure, it was generally considered not practical, nor possible, to clean every surface of the building such that this ideal scenario was met – that is, all cleanliness verification sampling results below their respective LODs. However, cleaning to a "non-detect" standard should be considered infeasible and not necessary for a successful "clean" declaration. Especially considering that mercury is pervasive in the environment due to volcanic eruptions and is expected to be present in measureable amount within any building. Accordingly, a set of stringent mercury decontamination "acceptance criteria" values (see Table 3) were

developed at the outset of the project, which, if met, were determined to be sufficiently protective of the environment and human health to allow for a “clean” designation. See Appendix B for description of the development methodology for the project-specific acceptance criteria shown below.

**Table 3 – Clearance Sampling Acceptance Criteria**

| Analyte <sup>[1]</sup> | Sample Type <sup>[2]</sup>       | Acceptance Criteria <sup>[3]</sup> |
|------------------------|----------------------------------|------------------------------------|
| Mercury                | Indoor Air Quality Concentration | 3.0 µg/m <sup>3</sup>              |
|                        | Surface Wipe Concentration       | 30 µg/1,000cm <sup>2</sup>         |

Table 3 Footnotes:

<sup>[1]</sup> Mercury was the primary pollutant of concern during the closure of the facility. Additional hazardous / toxic compounds (e.g. PCB, arsenic, cadmium, chromium, lead, barium, silver, selenium, antimony and yttrium) were also analyzed to ensure that after decontamination all types of pollutants potentially associated with the owner’s operation were reduced to levels which were considered insignificant (i.e. non-hazardous).

<sup>[2]</sup> Cleanliness acceptance utilized various types of sampling methodologies to verify facility decontamination. Additional types of sampling, which will be discussed in the thesis, were performed as semi-quantitative screening tests and were only informally compared to acceptance criteria (and background levels).

<sup>[3]</sup> Appendix B of this thesis provides a discussion of the basis for establishing these values as acceptance criteria for non-hazardous designation.

Unit of Measure Notes:

µg/m<sup>3</sup> = micrograms per cubic meter

µg/cm<sup>2</sup> = micrograms per thousand square centimeter

**2.2.2 Facility Background**

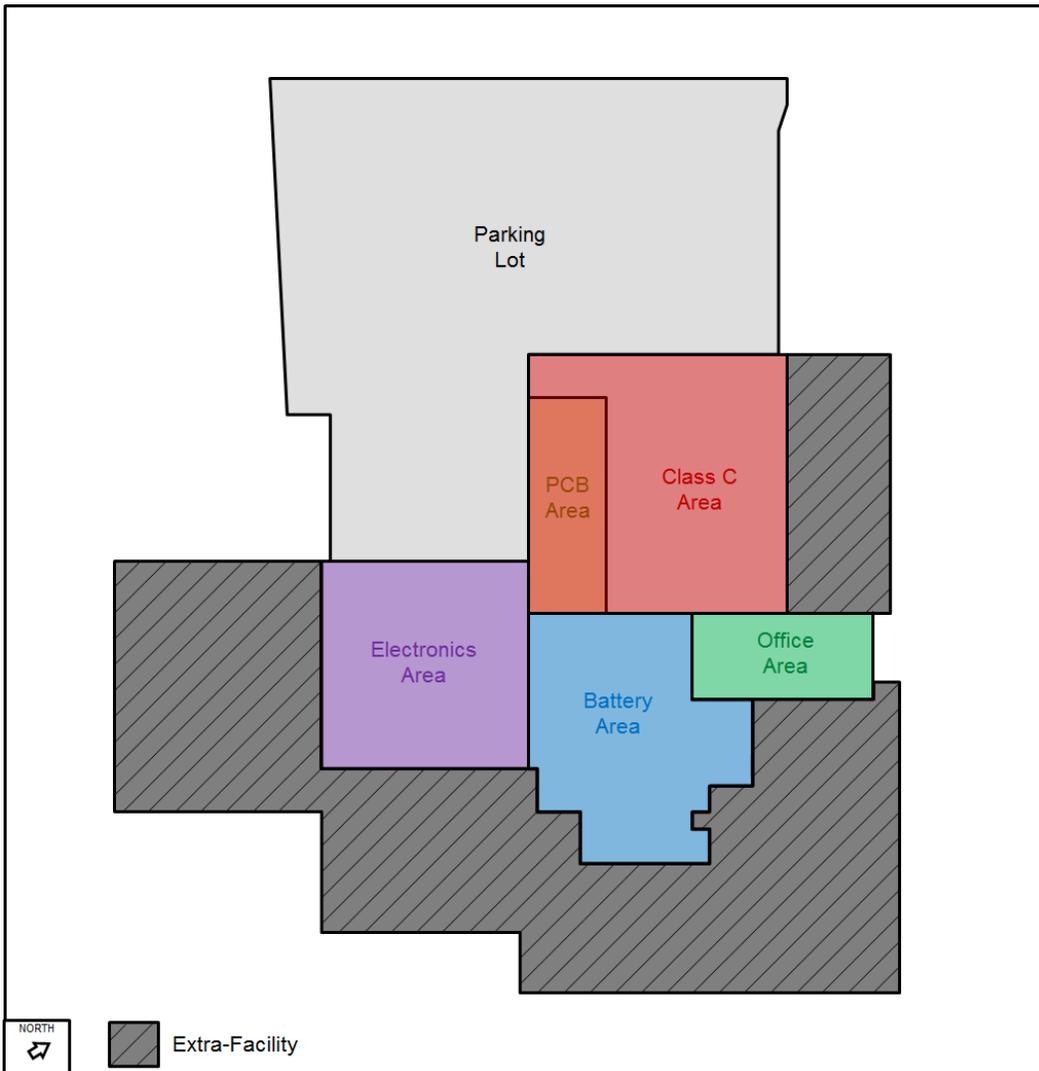
The subject facility was formerly used for processing and recycling mercury-containing fluorescent lamps and other mercury-containing devices (i.e. high-intensity discharge lamps, thermometers, barometers, switches). The facility also operated as a storage and processing facility for capacitors and lamp ballasts containing PCBs, lead-acid batteries and consumer electronics waste (“E-waste”). As mentioned previously in Section 1.0 (page 1), the facility was decontaminated

and confirmed clean for various other toxic compounds in addition to mercury. However, facility decontamination and closure with respect to these other compounds is outside the scope of this thesis, and as such, only the decontamination efforts and closure activities related to mercury contamination are presented below.

A plan overview diagram of the entire facility and the individual process areas is provided in Figure 1.

It should be noted that all figures and pictures contained in this thesis were produced by the author (Andrew Roland). All photographs were taken by the author at the subject facility during the various phases of decontamination (i.e. between February 2013 and August 2014).

**Figure 1 – Facility Overview Diagram**



The main mercury processing area of the facility – herein referred to as the Class C Area – was the location where the majority of processing, recovering and storing the mercury-related materials occurred (see Appendix C). However, due to the volatile nature of elemental mercury, it was believed likely that contamination migrated into other process areas at the facility (this belief was confirmed via pre-clean characterization surface wipe sampling, see Appendix D).

The property on which the facility was located was owned by a third-party, and the mercury recovery operations areas were operated by the owner within a leased space inside the footprint of a surrounding building. As part of the terms of lease, and in accordance with project requirements, the owner agreed to properly clean and decontaminate all areas of the building formerly occupied by the mercury recovery operation before vacating the property and returning it back to the third-party owner. The goal of the decontamination was to assure that all areas of the facility, formerly occupied by the owner's operation (and only the areas occupied by the owner's operation), were sufficiently decontaminated of any hazardous material to allow for future occupancy without restriction or reservation.

The following is a listing of each of the individual areas at the facility. A more complete description of the facility is presented in Appendix C.

- Class C Area
- Battery Area
- Office Area
- Extra-Facility (outside the owner's control)
- PCB Storage Area
- Electronics Area
- Parking Lot

### **2.2.3 Contamination Characterization**

Prior to developing and implementing mercury-specific decontamination methodologies, the existing level of mercury contamination inside the facility at the time of closure was assessed and quantified. This initial characterization was conducted using a variety of sampling techniques.

The purpose of the characterization sampling was to ensure that the extent of contamination at the facility was adequately known before specifying and commencing decontamination operations. It should be noted, that the entire facility was not completely characterized prior to decontamination. At the outset, it was assumed that the building was contaminated with mercury from the facility's operational history. The characterization sampling was a confirmation of that assumption and established a baseline. The characterization sampling was conducted before the contractors began significant decontamination activities. Table 4 provides a brief listing of the various characterization sampling techniques employed to initially evaluate the facility. A more complete description of these methodologies and the results of the characterization sampling are provided in Appendix D.

**Table 4 – Characterization Sampling Methodologies**

| Characterization Sample Method Name | Purpose and Description  |
|-------------------------------------|--|
| Dust Composition Sampling           | <ul style="list-style-type: none"> <li>• Determine the composition (i.e. percent by weight [%w] mercury) of process dust spread throughout the facility.</li> <li>• Vacuumed dust onto match weighed filter cassette, and analyzed using OSHA's Method ID-145.</li> <li>• Results indicated that process dust had average mercury concentration of 0.04%w.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul> |
| Pre-Clean Surface Wipe Sampling     | <ul style="list-style-type: none"> <li>• Determine extent of mercury contamination which could be wiped off various surface types throughout the facility.</li> <li>• Wet-wiped 100 square centimeter (100cm<sup>2</sup>) surfaces, and analyzed the wipe using OSHA's Method ID-145.</li> </ul>   |

| Characterization Sample Method Name | Purpose and Description  |
|-------------------------------------|--|
|                                     | <ul style="list-style-type: none"> <li>• Only 5 of 25 sample results had a mercury concentration under the 30 µg/1,000cm<sup>2</sup> acceptance criteria limit.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul>  |
| Floor Joint / Crack Vapor Testing   | <ul style="list-style-type: none"> <li>• Identify areas of the floor which might require more focused attention and/or complete removal. Also, provided basis for locating subsurface soil sampling locations.</li> <li>• Utilized real-time direct-read mercury vapor monitor.</li> <li>• Results indicated mercury-laden dust had become concentrated at certain locations along the interior floor joints.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul>            |
| Subsurface Soil Sampling            | <ul style="list-style-type: none"> <li>• Determine whether or not mercury had penetrated the floor joints, and delineate the extent of the subsurface mercury contamination.</li> <li>• Used standard subsurface soil sampling techniques and methods.</li> <li>• Results indicated that mercury was present in the upper few inches to few feet of soil directly beneath the interior floor joints in the Class C Area.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul> |
| Excavation Trench Vapor Testing     | <ul style="list-style-type: none"> <li>• After initial floor joint excavation was performed, a detailed direct-read mercury vapor survey was conducted along the exposed surface at the bottom of the excavation trench. The post-excavation survey was designed to identify areas which required additional soil excavation to completely eliminate mercury contamination.</li> <li>• Utilized real-time direct-read mercury vapor monitor.</li> </ul>  |

| Characterization Sample Method Name      | Purpose and Description  |
|--|--|
|  | <ul style="list-style-type: none"> <li>• Results identified areas of the trenches which required additional excavation.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul>  |
| Post-Excavation Subsurface Soil Sampling | <ul style="list-style-type: none"> <li>• Confirm that the excavation adequately removed mercury from the soil below the floor joints in the Class C Area.</li> <li>• Used standard soil sampling techniques and methods.</li> <li>• Results indicated that subsurface was adequately remediated.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul>   |
| Wastewater Vault Vapor Testing           | <ul style="list-style-type: none"> <li>• Identify and delineate areas of soil in small crawl-space area which housed a wastewater collection tank which might require additional remediation.</li> <li>• Utilized real-time direct-read mercury vapor monitor.</li> <li>• Two (2) rounds of soil excavation was sufficient to sufficiently reduce mercury vapor levels directly above the soil to background levels.</li> <li>• See Appendix D for complete methodology description and sample results.</li> </ul> |

#### **2.2.4 Decontamination Methodologies**

The following section briefly lists the procedures used for decontaminating all areas of the facility impacted by mercury contamination. These decontamination procedures were partially developed based on the results of the characterization sampling. A more complete description of these procedures is provided in Appendix E. Prior to implementing the procedures summarized below, the proposed decontamination procedures were presented to the owner and cleaning

contractors via technical memoranda, which presented detailed standard procedures and cleanliness expectations. Additionally, before commencing decontamination, the contractors attended a project-specific training session presented by the project engineer. The training covered: overall project objectives, closure / clearance expectations, roles and responsibilities, and appropriate health and safety training so that all personnel working on the project understood all hazards associated with the work and the expected decontamination procedures.

Throughout the project, all appropriate precautions were implemented to prevent the release of hazardous contaminants into the surrounding environment or underlying structure and soils during cleaning and decontamination activities. During cleaning and other remediation efforts, all contamination was fully contained within the facility using structured plastic-sheet (“poly”) barriers and negative air ventilation systems equipped with high-efficiency particulate arrestance (“HEPA”) filters with 99.97% removal efficiency of particles that have a size of 0.3 microns ( $\mu\text{m}$ ), and 2 inch (in) activated carbon filter media (see Appendix F for specification sheet of ventilation units and mercury adsorption efficiency associated with activated carbon). Additionally, throughout the decontamination effort the necessary engineering controls were installed to control and prevent the cleaned areas from being recontaminated during the cleaning of other areas within the facility. That is, all interfaces between the cleaned areas and other areas of the facility were sealed and the cleaned areas were placed under positive (static pressure) with respect to all adjacent areas, thereby preventing migration of contamination into the cleaned areas. These steps were

taken while still observing proper Life Safety Code – for escape from all building areas.

Table 5 provides a chronological listing and short description of each phase of decontamination. A more complete description of the decontamination strategy employed at this facility is presented in Appendix E.

**Table 5 – Decontamination Methodologies**

| Decontamination Stage                      | Description   |
|--|---|
| Inventory / Equipment Removal and Disposal | <ul style="list-style-type: none"> <li>• Removed all inventoried hazardous waste / recyclable material in an organized manner.</li> <li>• Consolidated and shipped off-site bulk lots of waste material, appropriately (i.e. manifested).</li> <li>• Decontaminated reusable equipment (inside and outside) and enclosed in tight wrap plastic sheeting before transport.</li> <li>• Appendix E provides photographic summary of equipment which were cleaned, packaged and shipped for continued use.</li> </ul> |
| Office Area Decontamination                | <ul style="list-style-type: none"> <li>• Office Area constructed within an old timber-frame structure (original to site), unlike the rest of the facility, which was pre-fabricated steel (i.e. Butler building).</li> <li>• Required asbestos containing material (“ACM”) abatement prior to implementing mercury decontamination.</li> <li>• Appendix E provides photographs depicting various stages of Office Area demolition and decontamination</li> </ul>  |
| Non-Essential Building Component Removal   | <ul style="list-style-type: none"> <li>• All non-essential, or highly contaminated porous material were demolished in a planned and deliberate manner to control dust generation.</li> <li>• Demolition was conducted “top-to-bottom” with the necessary partitions in place to minimize migration of dust throughout the facility.</li> </ul>  |

| Decontamination Stage                           | Description   |
|---|---|
|   | <ul style="list-style-type: none"> <li>• Waste material generated was characterized, consolidated and shipped off-site, appropriately (i.e. manifested).</li> <li>• Appendix E provides a photographic summary of non-essential building component demolition.</li> </ul>   |
| Class C Area Floor Joint Removal and Excavation | <ul style="list-style-type: none"> <li>• Sub-concrete soil sampling and mercury vapor testing indicated that mercury-laden material had become concentrated in the Class C Area floor joints (i.e. where floor slabs met).</li> <li>• Joints (and major cracks) in the concrete floor were removed and the soil underneath was excavated.</li> <li>• Joint removal and soil excavation was conducted with the Class C Area completely isolated from the surrounding facility with poly-sheet containment barriers (and controlled ventilation units).</li> <li>• Waste material generated was characterized, consolidated and shipped off-site, appropriately (i.e. manifested).</li> <li>• Appendix E provides a photographic summary of the floor joint removal and soil excavation conducted in the Class C Area.</li> </ul> |
| Wastewater Vault Remediation                    | <ul style="list-style-type: none"> <li>• Unfinished (i.e. dirt-floor) crawl-space area contained sanitary wastewater collection tank and submersible pump.</li> <li>• Removed collection system and piping and excavated the soil underneath.</li> <li>• Waste material generated was characterized, consolidated and shipped off-site, appropriately (i.e. manifested).</li> <li>• Appendix E provides a photographic summary of the wastewater vault remediation efforts.</li> </ul>  |
| General Surface Decontamination                 | <ul style="list-style-type: none"> <li>• All exposed surfaces (i.e. ceiling, wall, and floor) were thoroughly vacuumed.</li> <li>• All surfaces in the facility were wet-wiped multiple times to removal all visible dust and debris.</li> </ul>  |

| Decontamination Stage                    | Description  |
|--|--|
|  | <ul style="list-style-type: none"> <li>• General surface wet-wipe cleaning utilized tri-sodium phosphate (“TSP”) cleaning solution.</li> <li>• Surfaces which showed noticeable signs of corrosion were cleaned with dilute muriatic acid (“HCl”) to strip out layers of rust.</li> <li>• Extensive decontamination effectiveness testing was conducted to ensure that the prescribed techniques were adequate to remove mercury contamination (see Section 3.1, page 26).</li> <li>• Appendix E provides a photographic summary of the general surface cleaning being performed by the contractor.</li> </ul>         |
| Aggressive Surface Remediation / Removal | <ul style="list-style-type: none"> <li>• Surfaces which were heavily corroded, damaged or to highly contaminated were decontaminated using enhanced techniques.</li> <li>• Enhanced techniques included: sandblasting, scarification and/or complete removal.</li> <li>• Containment barriers were erected to isolate areas of aggressive decontamination to prevent material from re-contaminating the rest of the facility.</li> <li>• Appendix E provides a photographic summary of areas before and after the aggressive surface remediation.</li> </ul>   |
| Floor Decontamination                    | <ul style="list-style-type: none"> <li>• Engineer recognized that mercury had the ability to “seep” into porous building materials, such as concrete floors.</li> <li>• Entire floor surface was cleaned using an industrial-sized floor buffer with TSP detergent and at least two (2) applications of Hg-X® decontamination agent.</li> <li>• Extensive decontamination effectiveness testing was conducted to ensure the prescribed decontamination techniques were adequate (see Section 3.1, page 26).</li> <li>• Appendix E provides a photographic summary of floor decontamination being conducted.</li> </ul> |

### 3.0 TESTING METHODOLOGIES

The following are the sequence of testing conducted as part of this decontamination project: 1) document the level of cleanliness within the facility before decontamination, 2) to prescribe and evaluate the effectiveness of decontamination, and 3) to collect clearance samples to confirm decontamination was completed successfully. The following sections describe the screening (i.e. during decontamination, or pre- and post-clean), and clearance (i.e. post-decontamination) testing methodologies and procedures that were utilized.

As stated in Section 1.0 (page 1), the major problems encountered when dealing with any industrial facility remediation project, such as the one presented in this thesis, are the following:

1. There are no recommended or guideline techniques or technologies for conducting thorough decontamination of contaminated building components with respect to mercury contamination,
2. There are no agreed upon testing methodologies for characterizing and quantifying the level of hazardous mercury contamination in structural matrices, and making the ultimate determination of “cleanliness”.

Table 6 provides listing of the individual sampling methodologies and how they were employed in this thesis, and ultimately how they address the above mentioned challenges.

**Table 6 – Sampling Methods and Categorizations**

| Sample Type                                    | Sampling Method Name  |
|--|---|
| Screening Sampling<br>(during decontamination) | <ul style="list-style-type: none"><li>• General Area Direct-Read Vapor Survey</li><li>• Pre- &amp; Post-Clean Surface Wipe Testing</li><li>• Pre- &amp; Post-Clean Heated Chamber Testing</li></ul> |
| Clearance Sampling<br>(post-decontamination)   | <ul style="list-style-type: none"><li>• Composite Grid Surface Wipe Sampling</li><li>• Individual Location Surface Wipe Sampling</li><li>• Indoor Air Quality Passive-Badge Sampling</li></ul>      |

The contamination characterization, screening and clearance sampling at the facility was conducted in various stages between March 2013 and June 2014. The sampling methodologies and locations described below represent the full extent of potential mercury contamination within the facility, both horizontally and vertically. The sampling utilized the methodologies and analytical procedures described in the following sections.

The results for all sampling are presented in Section 4.0 (page 42).

### **3.1 SCREENING METHODOLOGIES**

During the course of the decontamination effort, investigative (i.e. screening) testing was conducted to ensure that the cleaning / decontamination techniques were adequate to remove mercury contamination from various surface types. An added purpose of conducting these periodic screening tests was to ensure that cleaning efforts in the facility remained on schedule, and to identify any locations that might require additional cleaning early in the process. Accordingly, these periodic screening samples were NOT compared directly to a specific set of acceptance criteria and were not used to assess final cleanliness. Instead, these

samples were used semi-quantitatively to evaluate the effectiveness of cleaning techniques and safe work practices.

### **3.1.1 General Area Direct-Read Vapor Survey**

Throughout the facility closure project, daily general area direct-read air quality monitoring surveys were performed in order to systematically evaluate and track mercury vapor concentrations in various areas of the facility. The overall objective of these general area direct-read air quality surveys was to ensure worker safety and to assess mercury vapor levels in the facility air as the project proceeded and mercury contamination was removed. Upon completion of the cleaning and decontamination activities the average mercury air concentration inside the facility was expected to be close to the concentration of mercury vapor in the outside air, or background levels.

Table 7 provides a listing of the two (2) types of monitors used to conduct the general area direct-read mercury vapor survey, their respective limits of detection and the dates in which they were in service at the facility (see Appendix F for full equipment specification sheets).

**Table 7 – Direct-Read Instrument Data**

| Make / Model No.               | Limit of Detection      | Dates Used       |
|--------------------------------|-------------------------|------------------|
| Mercury Instruments<br>VM-3000 | 0.1 µg/m <sup>3</sup>   | 4/1/13 – 7/31/13 |
| Ohio Lumex<br>RA-915+          | 0.002 µg/m <sup>3</sup> | 8/1/13 – 2/28/13 |

The following standard procedures were implemented by the contractor and engineer for each direct-read air quality monitoring survey:

1. Turn on the direct-read instrument at a location with a relatively stable mercury vapor concentration (i.e. away from active work areas).
2. Check to ensure that the battery is fully charged and the instrument is operating properly.
3. Allow the instrument to stabilize. That is, allow device to auto-zero at least twice to acclimate to ambient temperature. Do not commence survey until instrument displays consistent background value throughout an entire sampling interval.
4. After instrument stabilization is complete, record survey start time and conduct direct-read survey using the following procedure at each monitoring location:
  - a. Allow instrument to auto-zero at the start of each measurement location.
  - b. Hold the sampling inlet tube at least four (4) feet above the ground.
  - c. For each sampling location record the sampling start time (i.e. the first minute of sample collection) on the survey form.
  - d. Observe the direct-read measurements, and record the approximate mercury concentration value.
5. Move to the next sample location, and repeat procedure.

General area direct-read air quality measurements were not systematically collected at set locations throughout the facility. Instead, the number of samples and the exact locations were adjusted over the course of the project. Each direct-read measurement was categorized by the area of the facility in which it was collected (e.g. Class C Area, Battery Area, etc.). The direct-read measurements for each area collected during a single day were averaged together to get an average daily air quality reading for each area of the facility and the background.

### **3.1.2        *Pre- & Post-Clean Surface Wipe Testing***

During the decontamination phase of the project, various surface types and locations were encountered which warranted further attention to ensure that the prescribed general surface decontamination techniques (see Appendix E) were sufficient to adequately clean the surface. Accordingly, the Engineer conducted several rounds of pre- and post-cleaning surface wipe comparison testing on various surfaces types throughout the decontamination period. Surfaces on which these comparison tests were conducted included:

- Concrete floor
- Galvanized metal walls
- Galvanized ceiling (unoxidized & corroded)
- Painted brick wall
- Sprinkler / steam piping

During each test, at least two (2) sets of surface wipe samples were collected. The first sample was collected prior to conducting any decontamination on the surface (i.e. pre-clean), and the second sample was collected after conducting targeted decontamination (i.e. post-clean). The relative difference between pre- and post-decontamination results were qualitatively assessed and semi-quantitatively

compared with closure cleanliness goals to determine whether or not more aggressive decontamination techniques might be required.

Pre- and post-cleaning surface wipe samples were collected using 100 cm<sup>2</sup> paper templates (i.e. 10 cm by 10 cm) and pre-wetted Ghost Wipe brand wipes. The paper templates were labeled with the proper sample tracking ID, taped to the surface to be sampled, and then the sample was collected by wiping in three (3) directions within the template space, folding the wipe in half after each direction.

All wipe samples were collected in accordance with National Institute of Occupational Safety and Health (“NIOSH”) Method 9100, which is a standard surface wipe sampling method typically used in lead contamination applications (see Appendix F for full method specification). Disposable templates were used to assure the accuracy of the sample size, and were left in place to provide direction for any re-cleaning efforts, as necessary. All wipe samples collected were analyzed for mercury in accordance with the Occupational Safety and Health Administration’s (“OSHA’s”) Method ID-145 (see Appendix F for full method specification). A new pair of gloves was worn for each wipe sample. The sample wipe was placed in a sealed bag, labeled with the proper sample ID, consolidated and shipped to the ESIS Environmental Health Laboratory in Cromwell, CT for analysis. All samples were delivered to the laboratory using proper sample handling and chain-of-custody procedures. A blank wipe sample was collected and sent to the laboratory with each batch of samples.

A total of thirty (30) pre- and post-cleaning surface samples were collected during the course of decontamination. The surfaces sampled included those which exhibited high levels of mercury contamination during characterization testing (e.g.

concrete floors), and visually suspect areas (e.g. oxidized or galvanized metal surfaces). The results of these samples are presented in Section 4.1.2 (page 48).

### **3.1.3        *Pre- & Post-Clean Heated Chamber Testing***

Eight (8) rounds of heated chamber testing was conducted using a one (1) cubic meter (m<sup>3</sup>) volumetric chamber to isolate a one (1) square meter (m<sup>2</sup>) area of floor space in each area of the facility. The chamber testing was used as a screening tool to assess the potential for mercury volatilization from the concrete floor. The goal of the chamber testing was to heat and isolate a prescribed area of concrete in order to replicate conditions that may be encountered during worst-case conditions (e.g. if mercury was present on the floor [or within micro-cracks and pores], more mercury would be expected to volatilize from a warm or hot floor than from a cold one). Any volatilized mercury would accumulate in the airspace of the chamber and be measured with a passive-badge sampler and direct-read mercury vapor analyzer to provide a presumed worst-case measurement of mercury volatilization from the floor.

The heated chamber testing utilized SKC's 520 Series Passive Sampler for Inorganic Mercury (see Appendix F for full sampler specification). The sampler is comprised of a reusable housing (i.e. badge) and a replaceable sorbent capsule. The air sample enters the sorbent medium by positive controlled diffusion. The sorbent was then analyzed at ESIS Environmental Health Laboratory using flameless atomic absorption based on the OSHA ID-140 methods (see Appendix F for full method specification). The Mercury Instruments VM-3000 (pre-clean) and the Ohio Lumex RA-915+ (post-clean) direct-read mercury vapor monitors were

used to collect periodic vapor measurements in order to validate the passive-badge samples (see Appendix F for full equipment specification sheets).

The following standard procedures were developed and followed for each heated chamber test:

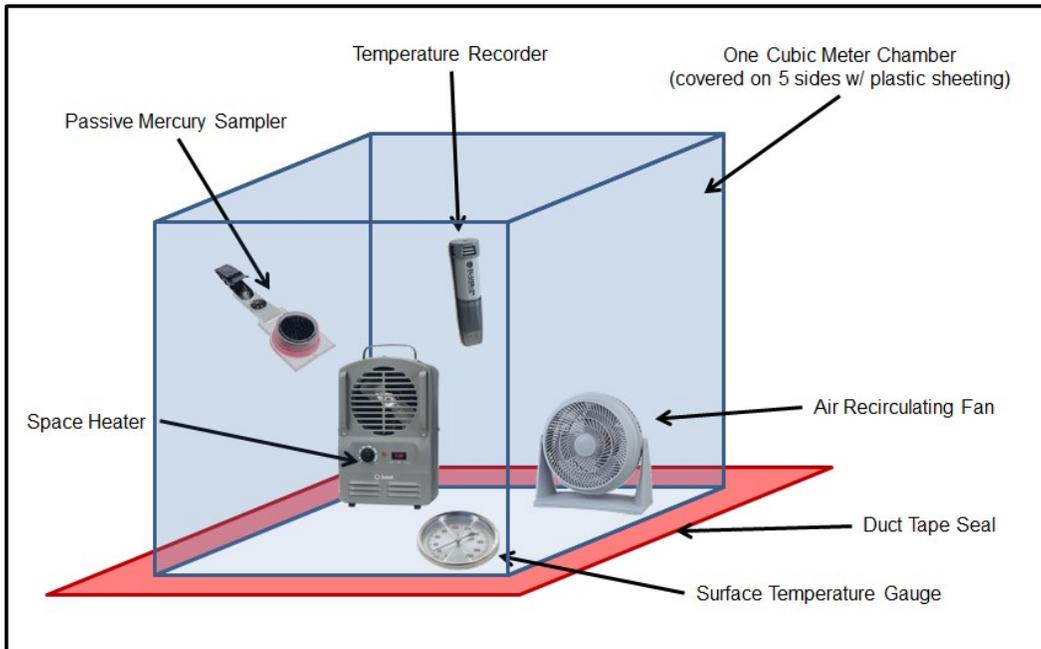
1. Construct a one (1) meter by one (1) meter by one (1) meter (i.e. 1.0 m x 1.0 m x 1.0 m) cubic sample chamber constructed of PVC pipe and encased on five (5) sides with polyvinyl sheeting.
2. Equip the chamber with a small fan to continuously circulate air within the chamber.
3. Equip the chamber with a small heater to raise the air temperature within the chamber to above 80°F in order to simulate a worst-case volatilization scenario.
4. Place a surface temperature gauge on the floor surface inside the perimeter of the chamber. The surface temperature gauge shall be used to determine the temperature of the concrete inside the chamber at the start and end of each sampling period (the average of these values will be considered the temperature of the concrete during the sample period).
5. Place the open end of the sample chamber against the floor surface and seal / isolate the inside from the rest of the environment using adhesive tape.
6. Hang a data-logger equipped temperature probe inside the chamber to record the air temperature during the sample period.
7. Suspend a SKC passive sampling badge in the middle of the chamber, and sample for at least 24 hours.

8. Using a direct-read mercury vapor analyzer, record the mercury vapor concentration at the start and end of each sampling period (this measurement will serve as a validation check to ensure the passive badge analysis is sufficiently accurate).

In the Class C Area, Battery Area and Electronics Area (i.e. areas with concrete floors), the Engineer collected at least two (2) sets of heat chamber testing. The first sample was collected near the beginning of the project prior to conducting floor decontamination, and the second sample was collected after general area decontamination was complete. The relative difference between pre- and post-decontamination heated chamber results were qualitatively assessed and semi-quantitatively compared with closure cleanliness goals to determine whether or not mercury contamination remained within the porous structure of the concrete floor.

Figure 2 provides a schematic illustration and photographs of the chamber sampling setup. Figures A-1 – A-3 in Appendix A show the heated chamber sample locations in the Class C Area, Battery Area and Electronics Area, respectively.

**Figure 2 – Heated Chamber Testing Schematic Diagrams**



### **3.2 CLEARANCE METHODOLOGIES**

At the conclusion of decontamination activities, a visual survey of the entire facility was conducted to confirm that all areas had been adequately decontaminated to meet the *No Visible Dust or Debris* standard (see Appendix E). After the visual survey was performed, final decontamination clearance sampling was conducted in accordance with the methods described in the following sections.

The clearance sample results were compared directly to the acceptance criteria limits (see Table 3, page 14) established at the beginning of the project, and were used to assess final building cleanliness.

The clearance sampling in the facility was conducted in various stages as decontamination was completed, and for various media and analytes on August 18, 2013, September 12, 2013, November 13, 2013, January 28 – 29, 2014, February 13, 2014, and March 7, 2014. The clearance sampling utilized the following methodologies and analytical procedures.

### **3.2.1 Composite Surface Wipe Sampling**

The primary surface mercury wipe sampling protocol consisted of a composite grid surface clearance sampling approach. Under this approach, ten (10) 100 square centimeter (100 cm<sup>2</sup>) surface wipe samples were obtained on various surface types within a designated grid area. Figures A-4 – A-9 in Appendix A provide identification of the composite sampling grids in each area of the facility. The ten (10) discrete wipe samples collected from each grid were composited into a single sample on-site and sent to an accredited laboratory for analysis. This approach resulted in a total surface sample area of 1,000 cm<sup>2</sup>.

Surface wipe sampling was conducted using 100 cm<sup>2</sup> paper templates and pre-wetted Ghost Wipe brand wipes. The paper templates were labeled with the proper sample tracking ID, taped to the surface to be sampled, and then the sample was collected by wiping in three (3) directions within the template space, contacting the surface with a different area on the wipe after each direction. A single wipe was used sample up to five (5) discrete locations, folding the wipe in half after each discrete location. Two (2) to three (3) sample wipes were placed

together into a sample bag, labeled with the proper sample ID, and prepared for transport to the laboratory for mercury analysis. A new pair of gloves was worn for each composite sample. A field blank and duplicate was collected for each group of composite samples taken within the facility to ensure accurate and precise results.

All wipe samples were collected in accordance with National Institute of Occupational Safety and Health (“NIOSH”) Method 9100, which is a standard surface wipe sampling method typically used in lead contamination applications (see Appendix F for full method specification). Disposable templates were used to assure the accuracy of the sample size, and were left in place to provide direction for any re-cleaning efforts, as necessary. All wipe samples collected were analyzed for mercury in accordance with the Occupational Safety and Health Administration’s (“OSHA’s”) Method ID-145 (see Appendix F for full method specification). A new pair of gloves was worn for each wipe sample. The sample wipe was placed in a sealed bag, labeled with the proper sample ID, and prepared for transport to the ESIS Environmental Health Laboratory in Cromwell, CT for analysis. All samples were delivered to the laboratory using proper sample handling and chain-of-custody procedures. A blank wipe sample was collected and sent to the laboratory with each batch of samples.

Information gathered during the cleaning and decontamination activities, and during the *No Visible Dust or Debris* survey, was used to identify discrete wipe sample locations within the facility. Within each grid area, one (1) composite wipe sample was collected by sampling ten (10) of the following types of locations / surfaces, starting from the highest elevation and working downward:

- (2) Roof Truss / Joist – samples collected from horizontal surface.
- (1) Sprinkler Piping / Steam Piping / Electrical Conduit – samples collected from horizontal surface.
- (1) Ceiling Insulation / Roof Peak – samples collected from upper horizontal surface.
- (2) Vertical Surface – one sample collected at elevation greater than 6 ft. above the floor, and the second sample collected within 3 ft. of the floor.
- (3) Floor Surface – one sample collected within 3 ft. of wall, second sample collected at least 3 ft. away from wall, third sample collected in the vicinity of a high-traffic location or cracked surface.
- (1) Low Sill / Ledge / Outlet – sample collected from horizontal surface.
- (#) Unique Surface – samples collected from one or more unaccounted for surfaces, as determined by sampling personnel, if a particular grid did not contain the types of surfaces listed above.

It should be noted that when surfaces were encountered which did not present a continuous 100 cm<sup>2</sup> surface on which to locate the template (e.g. joints, piping, etc.), the wipe area was modified to ensure that at least 100 cm<sup>2</sup> of surface was sampled.

A total of eighty-four (84) composite clearance surface wipe samples were collected from all areas in the facility. The results for these samples are provided in Section 4.2.1 (page 67).

### **3.2.2 Individual Location Surface Wipe Sampling**

In addition to the grid composite surface wipe clearance sampling, unique or visually suspect surfaces were sampled for mercury contamination individually after decontamination was completed. These locations included the following:

- Floor-Only – composite wipe samples collected from the floor in locations identified as having the highest potential for contamination.
- Roof (outside) – samples collected off the outside surface of the roof over the Class C Area, with sample locations concentrated around exhaust points.
- Electrical Closet / Panel – samples collected of the fuse boxes and conduit in the electrical closets.

Figures A-10 – A-15 in Appendix A provide identification of individual surface clearance sampling locations.

The intent of these individual surface samples was to provide analytical data to document the effectiveness of the decontamination / cleaning activities on select “hard-to-clean” surfaces. The individual surface clearance wipe samples were collected from select surface types, and were not considered representative of any particular area as a whole. These samples were intended to supplement the grid composite surface sampling explained in Section 3.2.1 (page 35) and guide any further re-cleaning, as required.

A total of thirty-four (34) individual surface wipe clearance samples were collected from the facility. The results for these samples are provided in Section 4.2.2 (page 78).

### **3.2.3 Indoor Air Quality Passive-Badge Sampling**

To evaluate the air quality within the facility after decontamination with respect to mercury vapor, indoor air quality clearance sampling was conducted. The indoor air quality clearance sampling measured the mercury vapor concentration in breathing zones throughout the facility after the completion of closure activities.

The indoor air quality testing utilized SKC's 520 Series Passive Sampler for Inorganic Mercury (see Appendix F for full sampler specification). Indoor air quality passive-badge samples were analyzed at ESIS Environmental Health Laboratory for mercury using the National Institute of Occupational Safety and Health's ("NIOSH's") Method 6009, which is fully consistent with OSHA's Method ID-140 (see Appendix F for full method specification). A blank passive-badge sample was collected and sent to the laboratory with each batch of samples.

The indoor air quality sampling was conducted using the following procedures:

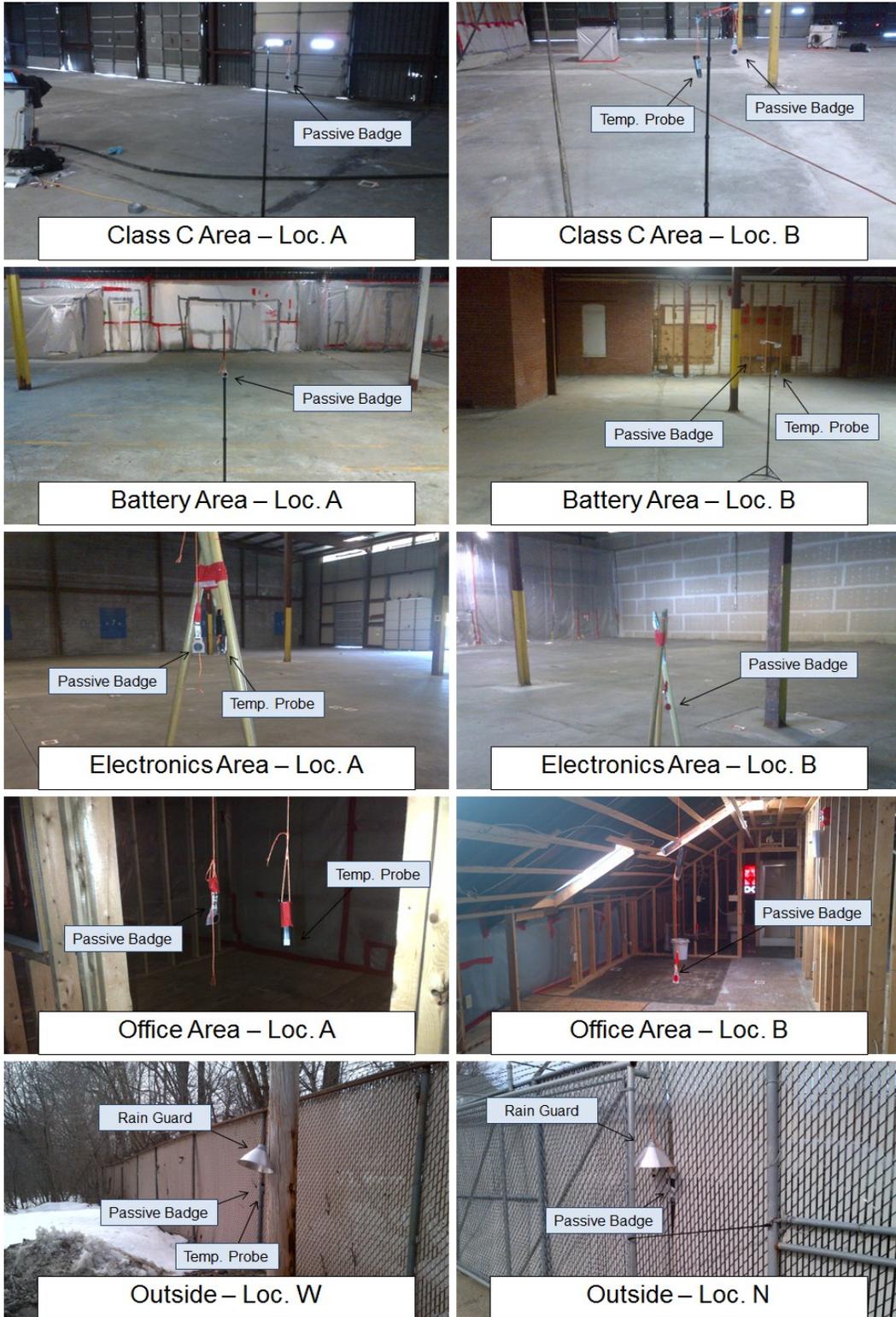
- The Engineer selected representative breathing zone locations within each area of the facility, and equipped those areas with passive-badge sampling devices. The sample badges were placed within four (4) feet of the floor and left undisturbed throughout the sampling period. Figures A-16 – A-20 in Appendix A provide identification of each individual passive-badge indoor air quality sampling location.
- All openings in each area sampled (i.e. doors, windows, exhaust fans) were, to a reasonable extent, sealed / deactivated, and the area was heated (65°F or greater) throughout the sample period. It should be noted that the 65°F temperature was considered an absolute minimum

temperature limit during indoor air quality sampling. The average temperature in each area during the sampling was actually higher.

- Interior fans were put in place to recirculate air within the areas. This light recirculation was necessary to achieve homogenous heating of the area, to simulate normal human occupancy, and to ensure the passive sampling badges operate at their prescribed diffusion rate.
- In addition to the indoor samples, outdoor locations were sampled to collect ambient background mercury data. The outdoor sample badges were placed / sheltered so that they were protected from inclement weather. Figure A-21 in Appendix A depicts the outdoor air quality sampling locations.
- All samples were left to collect mercury vapor concentration data for a period of at least five (5) days (i.e. 120 hours).
- Throughout the sampling period the indoor and outdoor air temperature was recorded using a data-logger equipped thermometer.

See Figure 3 for a photographic summary of the indoor and outdoor air quality sampling setups.

**Figure 3 – Indoor Air Quality Passive-Badge Sampling**



## **4.0 RESULTS AND DISCUSSION**

The following sections provide the findings of this thesis, including a complete listing and analysis of the sampling results.

### **4.1 SCREENING RESULTS**

Investigative testing conducted during decontamination (i.e. screening) was performed in accordance with the methodologies described in Section 3.1 (page 26) of this Report. As stated previously, the purpose of these samples was to ensure that cleaning efforts in the facility were adequate and remained on schedule, and to identify any locations that might require additional cleaning efforts early in the process.

#### **4.1.1 General Area Direct-Read Vapor Survey**

A total of five thousand and thirty one (5,031) individual general area direct-read mercury vapor measurements were collected by the decontamination contractors and the engineer in various locations throughout the facility on two hundred and ninety seven (297) days from February 7, 2013 to March 7, 2014. Direct-read air quality measurements were collected in accordance with the methodologies described in Section 3.1.1 (page 27) of this thesis.

Figure 4, Figure 5, Figure 6, and Figure 7 summarize the results for each daily average direct-read measurement collected during the closure effort in the Class C Area, Battery Area, Electronics Area and Office Area, respectively. These daily averages are easily compared to the average background mercury vapor level. Additionally, the charts display the 10-day moving average of all measurements

collected in each area and compares the trend of these values to the background 10-day moving average.

**Figure 4 – General Area Vapor Survey Results – Class C Area**



**Figure 5 – General Area Vapor Survey Results – Battery Area**

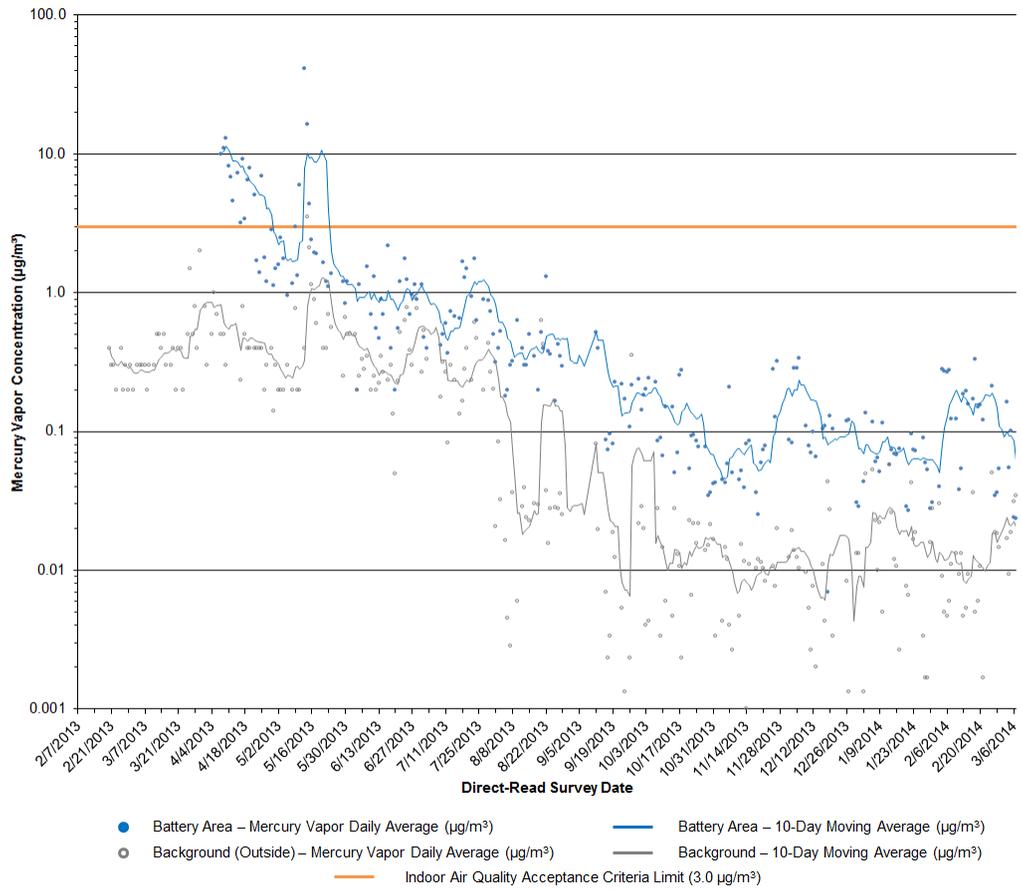
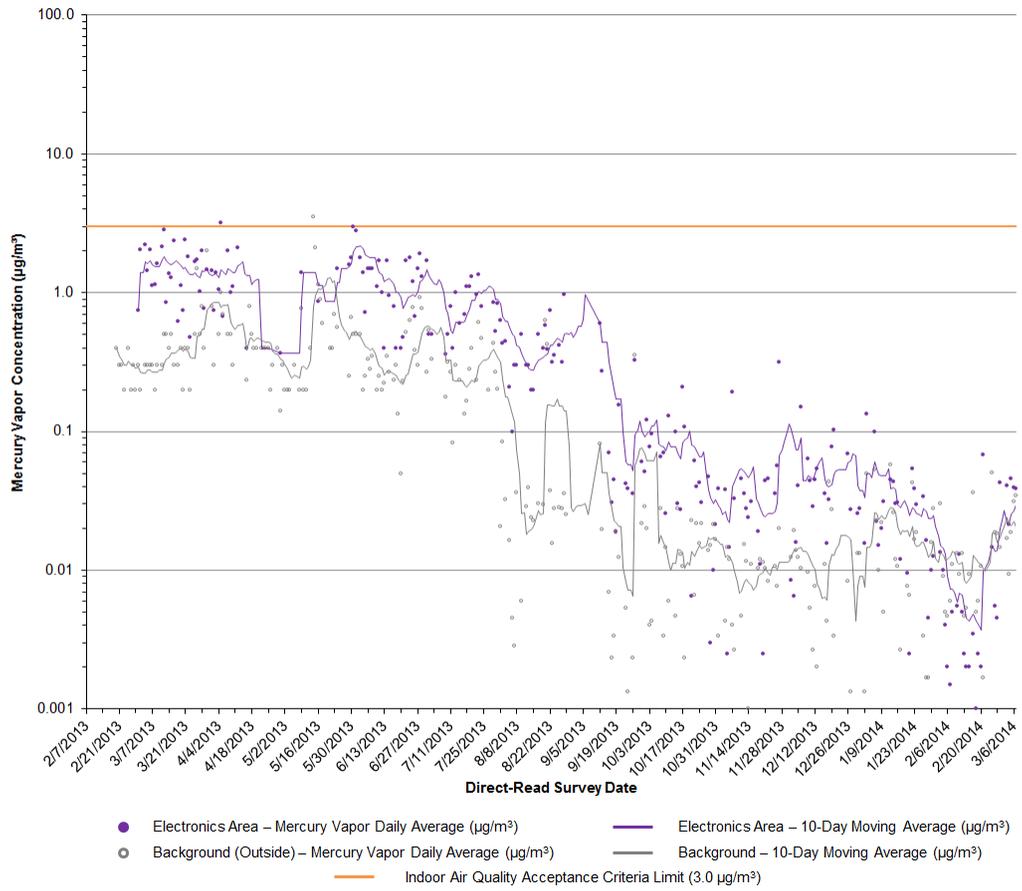


Figure 6 – General Area Vapor Survey Results – Electronics Area



**Figure 7 – General Area Vapor Survey Results – Office Area**



A qualitative analysis of the figures shows that the cleaning / decontamination efforts in the Class C Area effectively reduced the overall indoor mercury vapor levels. This analysis supports the conclusion that the air quality in all areas of the facility was significantly improved, and was nearly at the background level at the end of decontamination efforts. The indoor air quality mercury vapor levels were reduced by approximately three (3) orders of magnitude.

It should be noted that between April 1, 2013 and July 31, 2013 the direct-read air quality monitoring surveys were conducted using the Mercury Instruments USA VM-3000 real-time continuous mercury vapor monitor (see Appendix F for full

equipment specification sheet). Between July 31, 2013 and February 28, 2014 the direct-read air quality monitoring surveys were conducted using the more sensitive Ohio Lumex RA-915+ mercury analyzer (see Appendix F for full equipment specification sheet). The limits of detection for the VM-3000 and Lumex are 0.1  $\mu\text{g}/\text{m}^3$  and 0.002  $\mu\text{g}/\text{m}^3$ , respectively. This change in instrument sensitivity is responsible for the drastic shift in background (outdoor) direct-read vapor measurements before and after this switch. The background measurements collected with the VM-3000 (i.e. 4/1/13 – 7/31/13) were biased high due to the fact that the meter was not capable of measuring mercury vapor concentrations below 0.1  $\mu\text{g}/\text{m}^3$ .

An attempt was made to generate a regression equation which would model surface mercury concentrations (i.e. mercury per wiped area) with direct-read mercury vapor concentrations, but the corresponding data sets were not compatible for developing a useful model. Due to the costs of sampling and laboratory analysis, the surface wipe sampling (i.e. the dependent variable) was conducted much less frequently than the mercury vapor concentration readings in each area of the facility. Consequently, significant gaps in the time series data existed. Additionally, as expected, the daily direct-read mercury vapor readings were highly serially correlated. The sampling methodology selected for this decontamination was not designed with the intended purpose of developing a regression model. Section 5.3.3 (page 94) of this thesis provides a brief discussion of how an alternative sampling plan may have been developed to generate data better suited for modeling this scenario – that is, surface mercury as a function of direct-read mercury vapor.

#### **4.1.2        *Pre- & Post-Cleaning Surface Wipe Testing***

The following Sections (i.e. Sections 4.1.2.1 – 4.1.2.5) summarize the results for each round of pre- and post-cleaning surface testing conducted on various types of surfaces throughout the decontamination process. These tests were conducted in accordance with the methodologies described in Section 3.1.2 (page 29).

##### **4.1.2.1        *Concrete Floor Wipe Testing***

Two (2) rounds of pre- and post-cleaning surface wipe testing was conducted on the concrete floor in the Class C Area of the facility. These samples were motivated by the fact that the pre-clean surface characterization sampling results (see Appendix D) indicated that this surface was likely the most heavily contaminated surface type in the entire facility. Accordingly, to ensure that the proposed floor cleaning techniques (see Appendix E) were adequate, concrete floor wipe testing was conducted.

Between June 5, 2013 and June 7, 2013, the first round of pre- and post-cleaning surface testing was conducted on the concrete floor. The testing was conducted on the floor of the Class C Area near the former location of the Photon C unit (see Appendix C for equipment locations in Class C Area). Not only did this testing evaluate the floor cleaning methodologies, but it also compared the mercury removal efficiencies of two (2) cleaning / chelating solutions, Hg-X® and Mercon-X™. For the first round of testing the two (2) cleaning solutions were allowed to soak side-by-side overnight to evaluate the maximum potential removal efficiency. Each area on which the testing was conducted was cleaned twice, and sampled after each round of cleaning.

Between June 24, 2013 and June 25, 2013, a second round of side-by-side pre- and post-decontamination surface testing was conducted on the concrete floor in the Class C Area. This round of testing was conducted on the floor near the former location of the Hg Pour-Off Area (see Appendix C for equipment locations in Class C Area). Again, the purpose of this testing was to compare the mercury removal efficiencies of Hg-X® and Mercon-X™ cleaning solutions and to confirm / validate the results obtained in the first round of effectiveness testing. Unlike the first round of effectiveness testing, where the cleaning agents were allowed to “soak” on the floor areas overnight, for this second round of testing the Hg-X® and Mercon-X™ were vacuumed up immediately after application. This technique was decided to be a more representative of a worst-case cleaning scenario for the floor in the Class C Area.

Figure 8 provides photographic documentation of the contractors conducting the cleaning on each of the floor areas tested. Table 8 provides a summary of the two (2) rounds of side-by-side pre- and post-cleaning surface wipe testing on the concrete floor. Figure 9 provides a graphical summary of the pre- and post-clean testing.

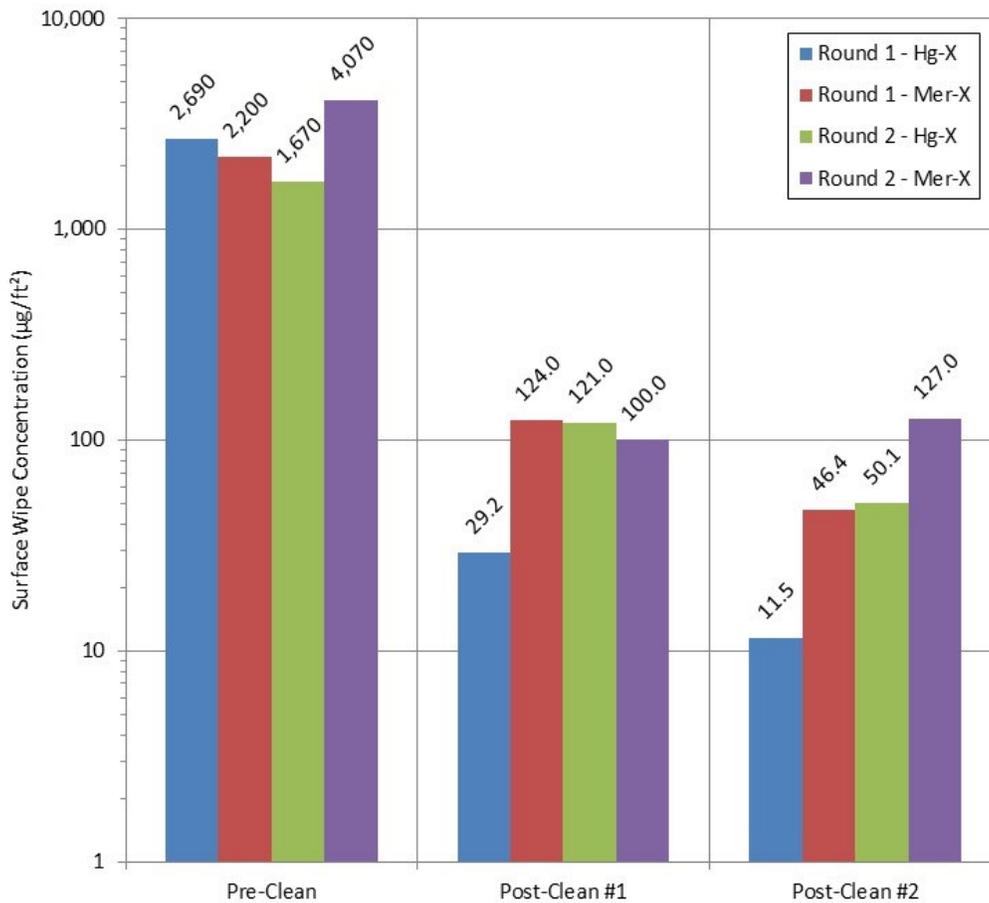
Figure 8 – Pre- & Post-Clean Testing – Floor Cleaning



**Table 8 – Pre- & Post-Cleaning Wipe Testing – Floor Results**

| Test No. | Product   | Surface Wipe Concentration                          |   |   |
|----------|-----------|---|---|---|
|          |           | Pre-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) | Post-1 <sup>st</sup> -Clean Mercury Result (µg/1,000cm <sup>2</sup> ) | Post-2 <sup>nd</sup> -Clean Mercury Result (µg/1,000cm <sup>2</sup> ) |
| 1        | Hg-X®     | 2,690   | 29.2  | 11.5  |
|          | Mercon-X™ | 2,200   | 124   | 46.4  |
| 2        | Hg-X®     | 1,670   | 121   | 50.1  |
|          | Mercon-X™ | 4,070   | 100   | 127   |

**Figure 9 – Pre- & Post-Clean Testing – Floor Results**



The results demonstrated that the proposed floor cleaning methodologies were sufficient to achieve surface mercury acceptance criteria limits. The results also indicated that the Hg-X® performed better than the Mercon-X™ at removing

mercury contamination from the concrete floor in the Class C Area. Additionally, the testing showed that allowing the cleaning / chelating agents to soak overnight was the more effective method of decontamination.

#### *4.1.2.2 Galvanized Metal Wall Wipe Testing*

Two (2) rounds of pre- and post-cleaning surface wipe testing was conducted on the galvanized metal wall in the Class C Area of the facility. This testing was especially important to ensure that mercury contamination had not amalgamated with the zinc coating on the galvanized steel surface, and that the prescribed general surface cleaning techniques were sufficient.

On June 13, 2013, the first round of cleaning effectiveness testing was conducted on the galvanized metal wall in the Class C Area. This test was conducted near the former location of the maintenance area (see Appendix C for description of Class C Area layout).

On June 25, 2013, the second round of pre- and post-cleaning effectiveness testing was conducted on the galvanized wall. This testing was conducted near the former location of the mercury pour-off area (see Appendix C for description of Class C Area layout).

Figure 10 provides photographic summary of the Contractors conducting the cleaning on the galvanized metal wall test areas. Table 9 provides a summary of the two (2) rounds of pre- and post-cleaning surface wipe testing on the galvanized metal walls. Figure 11 provides a graphical summary of the pre- and post-cleaning test results.

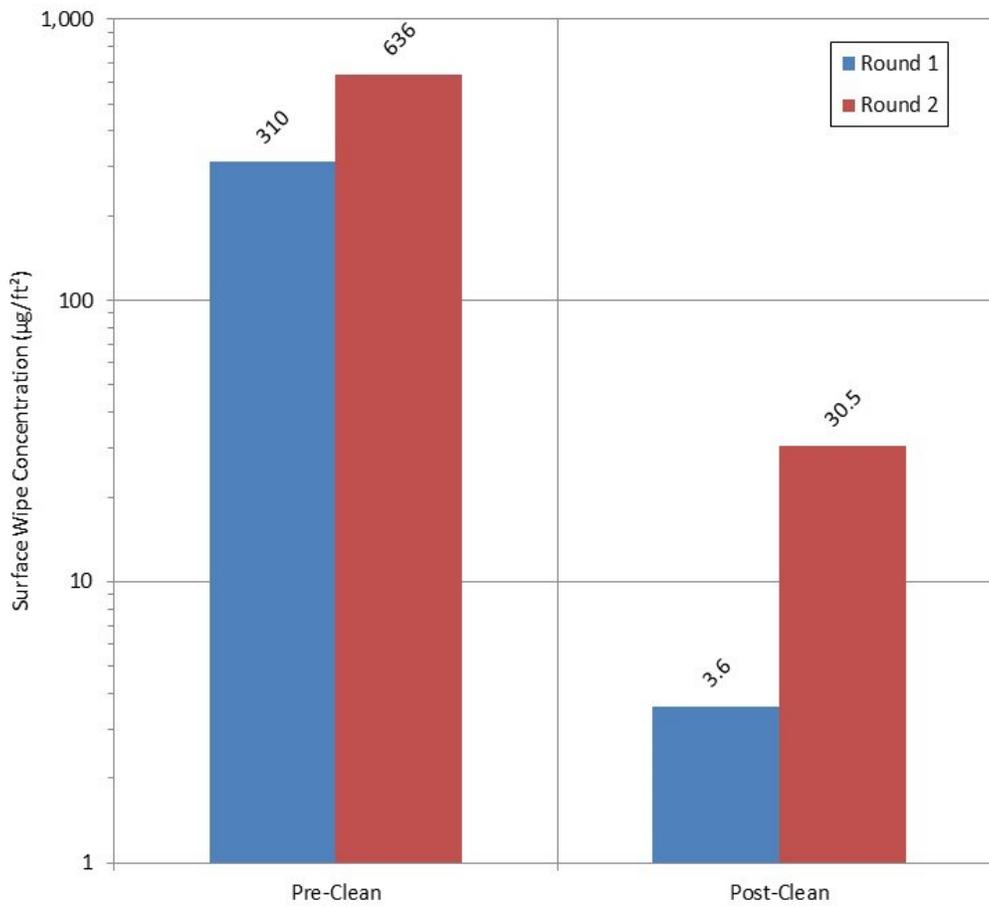
Figure 10 – Pre- & Post-Clean Testing – Galv. Wall Cleaning



**Table 9 – Pre- & Post-Cleaning Wipe Testing – Galv. Metal Wall Results**

| Test No. | Date    | Surface Wipe Concentration                                  |  |
|----------|---------|---|--|
|          |         | Pre-Clean Mercury Result ( $\mu\text{g}/1,000\text{cm}^2$ ) | Post-Clean Mercury Result ( $\mu\text{g}/1,000\text{cm}^2$ ) |
| 1        | 6/13/13 | 310   | 3.6  |
| 2        | 6/25/13 | 636   | 30.5   |

**Figure 11 – Pre- & Post-Clean Testing – Galv. Wall Results**



The galvanized metal wall testing results indicated that the proposed cleaning technique was adequate to reduce the level of mercury contamination to the surface concentration acceptance criteria value, and the results indicated that the

mercury contamination had not amalgamated with the zinc coating on the galvanized steel surface.

#### *4.1.2.3 Painted Brick Wipe Testing*

On September 25, 2013, a round of pre- and post-cleaning surface wipe testing was conducted on the painted brick surface in the Battery Area (i.e. the exterior of the old boiler room at the southeast corner). Again, the purpose of this testing was to evaluate the effectiveness of the prescribed cleaning techniques. Three (3) separate locations on the brick surface were sampled during this test.

Figure 12 provides photos of two (2) the sample locations after cleaning was conducted. Table 10 provides a summary of the pre- and post-cleaning surface wipe testing results for the locations sampled on the painted brick surface. Figure 13 provides a graphical summary of the pre- and post-clean testing results.

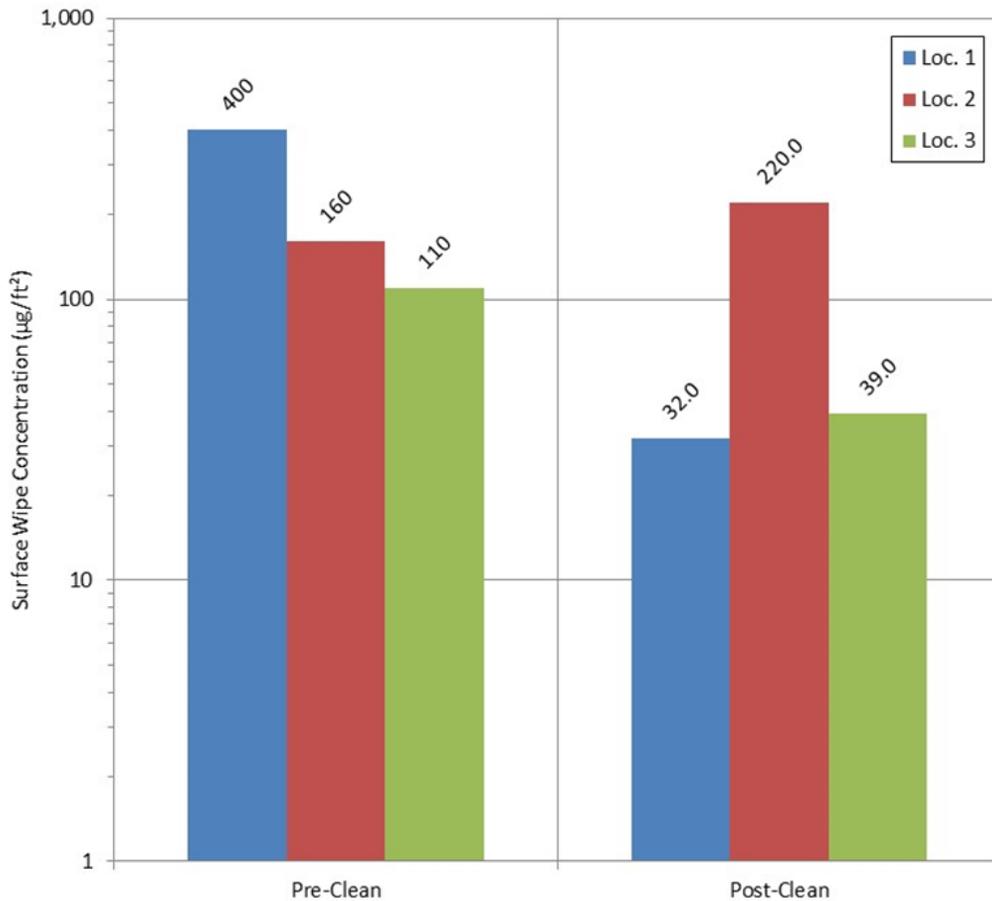
Figure 12 – Pre- & Post-Clean Testing – Paint Brick Cleaning



**Table 10 – Pre- & Post-Cleaning Wipe Testing – Painted Brick Results**

| Test No. | Date    | Loc. ID | Surface Wipe Concentration                          |  |
|----------|---------|---------|---|--|
|          |         |         | Pre-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) | Post-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) |
| 1        | 9/25/13 | 1       | 400   | 32   |
|          |         | 2       | 160   | 220  |
|          |         | 3       | 110   | 39   |

**Figure 13 – Pre- & Post-Clean Testing – Painted Brick Results**



The painted brick testing results were mixed. Two (2) of the three (3) locations showed adequate decontamination, while one (1) of the locations had a measured increase in surface mercury concentration. Given the fact that none of the sample

locations were successfully decontaminated to a level less than the surface acceptance criteria limit (i.e. 30 µg/1,000cm<sup>2</sup>), and that the decontamination contractor reported that the cleaning in these locations was very labor intensive; aggressive surface decontamination techniques were implemented in this area. To expedite the decontamination process the painted brick surfaces were sandblasted to remove the top layers of paint on the brick wall (see Appendix E).

#### 4.1.2.4 *Galvanized Ceiling Wipe Testing*

Pre- and post-cleaning surface wipe testing was conducted on the galvanized metal ceiling in the Battery Area. This testing was designed to determine if mercury contamination had become amalgamated with the zinc coating on the galvanized steel surface under oxidative conditions. Unlike other ceiling areas of the facility, the ceiling in the Battery Area was not covered in fiberglass insulation material (instead the fiberglass insulation was above the metal ceiling in this portion of the building). This lack of protection allowed certain areas of the exposed metal ceiling in the Battery Area to oxidize and corrode over time. This corrosion was especially apparent in the area near of the painted brick boiler room (possibly due to a fire at the facility) (see Appendix C).

On August 22, 2013, the pre- and post-cleaning surface wipe testing was conducted on the unoxidized (i.e. good condition) and oxidized (i.e. corroded) galvanized steel ceiling in the Battery Area.

Figure 14 provides photographs depicting the two (2) sample locations on the galvanized ceiling. Table 11 provides a summary of the pre- and post-cleaning surface wipe testing results for the locations sampled on the galvanized ceiling in

the Battery Area. Figure 15 provides a graphical summary of the pre- and post-clean testing results.

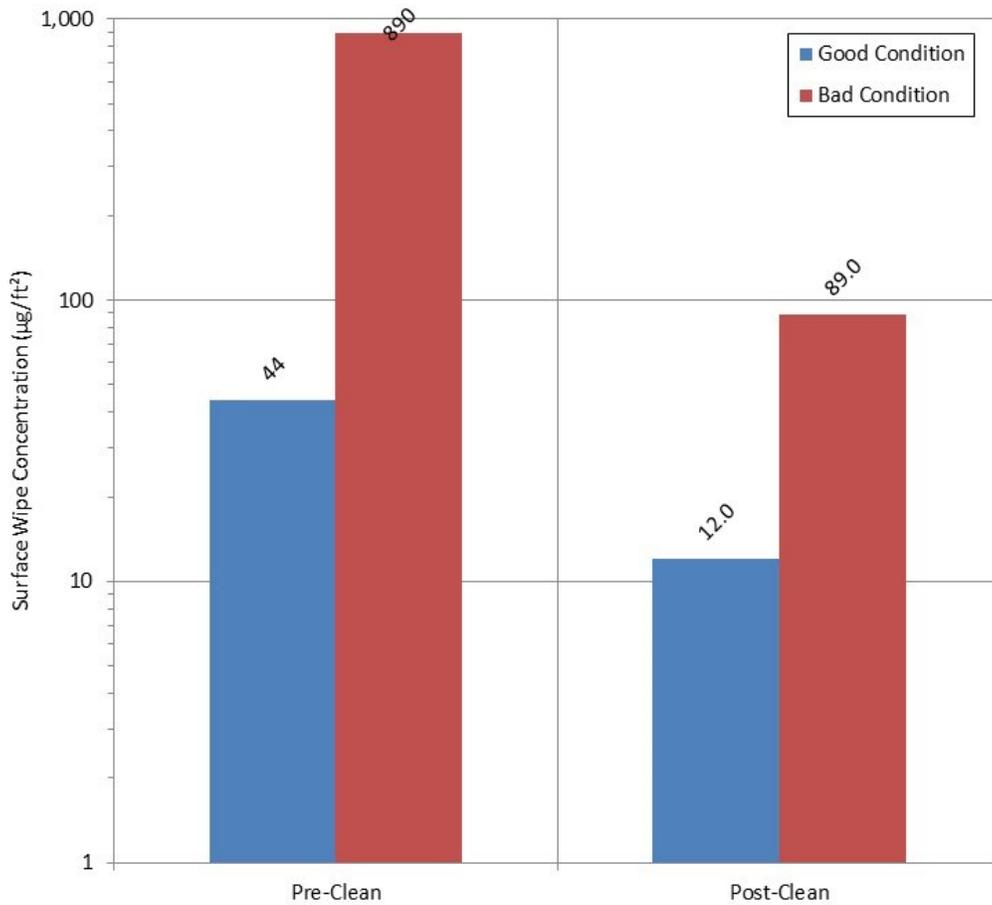
**Figure 14 – Pre- & Post-Clean Testing – Galv. Ceiling Cleaning**



**Table 11 – Pre- & Post-Cleaning Wipe Testing – Galv. Ceiling Results**

| Test No. | Date    | Ceiling Condition | Surface Wipe Concentration                          |  |
|----------|---------|-------------------|---|--|
|          |         |                   | Pre-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) | Post-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) |
| 1        | 8/22/13 | Good              | 44  | 12   |
|          |         | Bad               | 890   | 89   |

**Figure 15 – Pre- & Post-Clean Testing – Galv. Ceiling Results**



Testing of the galvanized ceiling in the Battery Area showed that mercury contamination had become concentrated in oxidized areas of galvanized steel. While traditional decontamination techniques showed promise in reducing the level of contamination on these corroded surfaces, it was decided to aggressively

remediate most of the heavily oxidized ceiling surfaces. To expedite the decontamination process the Engineer recommended that the heavily oxidized galvanized steel ceiling surfaces be completely removed and replaced by the Contractor (see Appendix E).

#### *4.1.2.5 Sprinkler & Steam Piping Wipe Testing*

Pre- and post-cleaning surface wipe testing was conducted on corroded iron piping in the Battery Area. This testing was designed to determine if mercury contamination had become amalgamated with oxidized cast iron surfaces.

On August 22, 2013, the pre- and post-cleaning surface wipe testing was conducted on the oxidized iron sprinkler and steam piping in the Battery Area.

Figure 16 provides photographs depicting the two (2) sample locations on the cast iron piping. Table 12 provides a summary of the pre- and post-cleaning surface wipe testing results for the locations sampled on the cast iron pipe in the Battery Area. Figure 17 provides a graphical summary of the pre- and post-clean testing results.

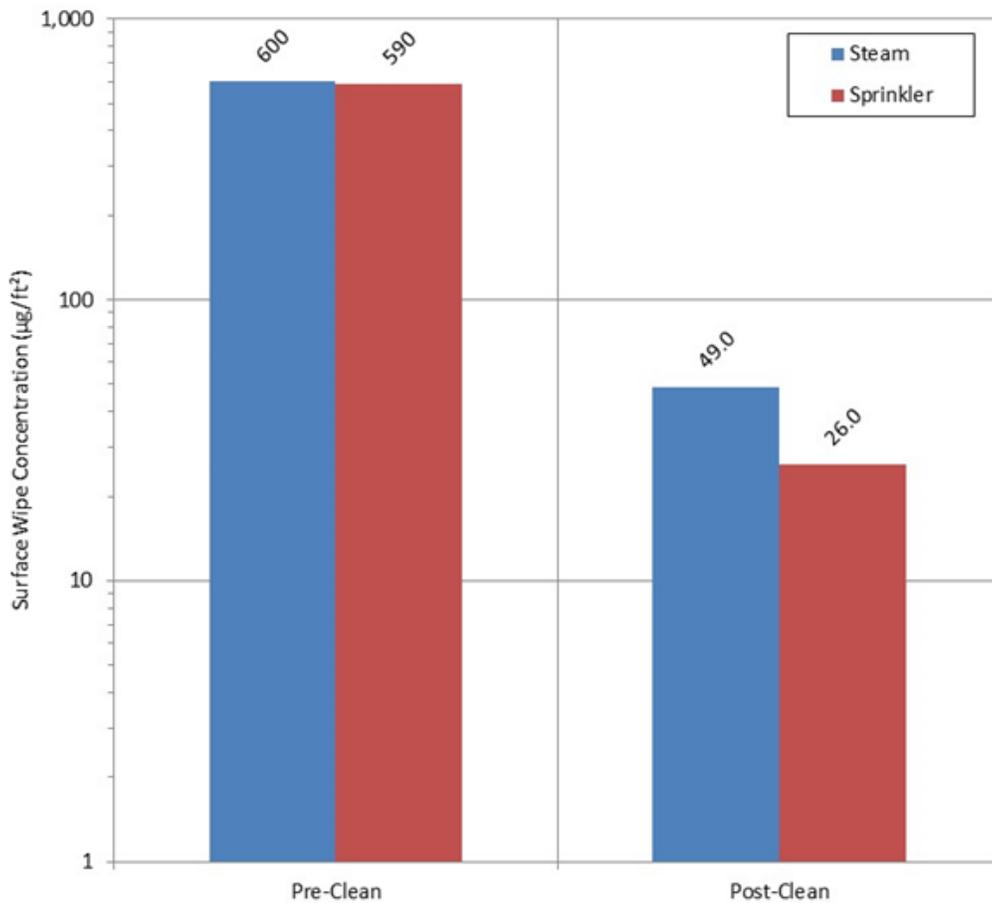
**Figure 16 – Pre- & Post-Clean Testing – Iron Pipe Cleaning**



**Table 12 – Pre- & Post-Cleaning Wipe Testing – Iron Pipe Results**

| Test No. | Date    | Cast Iron Pipe Type | Surface Wipe Concentration                          |  |
|----------|---------|---------------------|---|--|
|          |         |                     | Pre-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) | Post-Clean Mercury Result (µg/1,000cm <sup>2</sup> ) |
| 1        | 8/22/13 | Steam               | 600   | 49   |
|          |         | Sprinkler           | 590   | 26   |

**Figure 17 – Pre- & Post-Clean Testing – Iron Pipe Results**



The cast iron piping testing showed that mercury contamination had become concentrated in the oxidized areas of this material. The standard prescribed decontamination techniques were adequate in reducing the level of contamination on these corroded surfaces. However, it was decided to enhance cleaning on

these surfaces by using a dilute muriatic acid (“HCl”) solution. This acid cleaning technique was performed only on corroded cast iron surfaces to strip the outer layers of rust, which may have resisted initial TSP cleaning. The surfaces were cleaned again with TSP (i.e. after HCl application) to remove any remaining acid residue (see Appendix E).

#### **4.1.3        *Pre- & Post-Cleaning Heated Chamber Testing***

The following section summarizes the results for each round of pre- and post-cleaning heated chamber testing conducted in the facility. These tests were conducted in accordance with the methodologies described in Section 3.1.3 (page 31). Two (2) heated chamber tests were collected from the floors in the Electronics Area and Battery (i.e. a pre- and post-clean chamber tests in each area), and five (5) heated chamber tests were collected from the floor in the Class C Area (i.e. two (2) pre-clean and three (3) post-clean chamber tests). The heated chamber test locations in the Class C Area, Battery Area and Electronics Area are shown in Figures A-1 – A-3 in Appendix A.

Each chamber test generated between one (1) and two (2) passive-badge mercury vapor samples. Most of the pre-clean chamber tests generated one (1) sample which was collected during the second 24-hour test period when the chamber and floor were already up to temperature – that is, during the second day of testing after the floor surface had already been heated under the chamber for 24-hours. The reason for collecting the sample after heating the chamber / floor for 24-hours was to allow for the system to reach equilibrium – that is, to establish an equalized flux between mercury volatilizing from the floor into the air, and mercury condensing from the air onto the floor. In later heated chamber tests, the initial 24-

hour equilibration period was also sampled with a passive-badge. The reason for collecting multiple samples per chamber was to evaluate the type of thermal processes which would liberate mercury from the floor surface and immediate subsurface – gradual heating, or consistently high-temperatures.

The passive-badge heated chamber results were validated using the direct-read mercury vapor analyzer to measure the mercury vapor concentration in the headspace of the chamber at the beginning and end of each sample run. These average direct-read vapor results were then compared to the passive-badge results to ensure consistency. The following tables summarize both the passive-badge heated chamber testing results and the direct-read instrument validation results for the chamber runs.

**Table 13 – Pre-Clean Heated Chamber Testing Results**

| Facility Area | Location ID | Date   | Average Temp. (°F) | Passive-Badge Mercury Result (µg/m <sup>3</sup> ) | Direct-Read Mercury Result (µg/m <sup>3</sup> ) |
|---------------|-------------|--|--------------------|---|---|
| Class C       | AA(1)       | No initial 24-hr sample collected                            |                    |   |   |
| Class C       | AA(2)       | 3/26/13  | 85.7               | 18.5  | 18.8  |
| Class C       | BB(1)       | No pre-clean sample collected at location BB in Class C Area |                    |   |   |
| Class C       | BB(2)       |  |                    |   |   |
| Class C       | CC(1)       | 4/30/13  | 89.3               | 9.94  | 10.0  |
| Class C       | CC(2)       | 5/1/13   | 87.5               | 9.11  | 9.0   |
| Battery       | AA(1)       | No initial 24-hr sample collected                            |                    |   |   |
| Battery       | AA(2)       | 3/21/14  | 82.1               | 6.01  | 10.2  |
| Battery       | BB(1)       | No pre-clean sample collected at location BB in Battery Area |                    |   |   |
| Battery       | BB(1)       |  |                    |   |   |
| Electronics   | AA(1)       |  |                    |   |   |

| Facility Area | Location ID | Date   | Average Temp. (°F) | Passive-Badge Mercury Result (µg/m <sup>3</sup> ) | Direct-Read Mercury Result (µg/m <sup>3</sup> ) |
|---------------|-------------|--|--------------------|---|---|
| Electronics   | AA(2)       | No pre-clean sample collected at location AA in Electronics Area |                    |   |   |

**Table 14 – Post-Clean Heated Chamber Testing Results**

| Facility Area | Location ID | Date  | Average Temp. (°F) | Passive-Badge Mercury Result (µg/m <sup>3</sup> ) | Direct-Read Mercury Result (µg/m <sup>3</sup> ) |
|---------------|-------------|---|--------------------|---|---|
| Class C       | AA(1)       | 3/5/14  | 93.5               | <3.46   | 1.4   |
| Class C       | AA(2)       | 3/6/14  | 90.8               | <4.02   | 0.25  |
| Class C       | BB(1)       | 3/5/14  | 93.8               | <3.58   | 0.60  |
| Class C       | BB(2)       | 3/6/14  | 90.1               | <4.05   | 0.15  |
| Class C       | CC(1)       | 3/11/14   | 93.8               | <3.98   | 0.15  |
| Class C       | CC(2)       | 3/12/14   | 92.8               | <3.73   | 0.20  |
| Battery       | AA(1)       | No post-clean sample collected at location AA in Battery Area |                    |   |   |
| Battery       | AA(2)       |   |                    |   |   |
| Battery       | BB(1)       | 3/26/14   | 90.6               | <3.93   | 0.55  |
| Battery       | BB(2)       | 3/27/14   | 93.7               | <3.91   | 0.45  |
| Electronics   | AA(1)       | 4/8/13  | 92                 | <3.96   | 1.7   |
| Electronics   | AA(2)       | 4/9/13  | 91                 | <3.96   | 1.4   |

The heated chamber testing was used as a screening tool to assess the potential for mercury volatilization from the concrete floor. The goal of the chamber sampling is to heat a prescribed area of concrete in order to replicate conditions that may be encountered during worst-case conditions. The pre-clean heated chamber test results indicate that volatile mercury contamination was present in measurable quantities on the floor surface in the Class C Area and Battery Area

before decontamination was conducted. After decontamination, mercury was not detected in any the chamber samples at a concentration above the passive-badge sample media's limit of detection.

## **4.2 CLEARANCE RESULTS**

Post-decontamination clearance (i.e. verification) sampling was conducted in accordance with the methodologies described in Section 3.2 (page 34) of this thesis. As stated previously, the clearance sample results were compared directly to the acceptance criteria limits (see Table 3, page 14), and were used to assess final building cleanliness.

### **4.2.1 Composite Surface Wipe Sampling**

On March 25, 2013 (Office Area), April 8, 2013 (Electronics Area), August 6-7, 2013 (Battery Area), August 7, 2013 (PCB Area), and January 28-29, 2014 (Class C Area), composite grid surface wipe verification sampling was conducted in each cleaned area to assess the effectiveness of decontamination efforts. Figures A-4 – A-9 in Appendix A provide identification of the composite sampling grids in each area of the facility.

A total of sixty-one (61) composite grids were sampled throughout the facility (Office Area = 18, Electronics Area = 9, Battery Area = 15, PCB Area = 4, Class C Area = 15). The first round of grid clearance sampling collected composite samples from fifty-five (55) of these grids (Office Area = 14, Electronics Area = 8, Battery Area = 14, PCB Area = 4, Class C Area = 15). The first round of sampling demonstrated that 61.8% of the grids were below the acceptance criteria limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) after the first round of general area decontamination (Office Area

= 100%, Electronics Area = 50%, Battery Area 7.1%, PCB Area = 100%, Class C Area = 73.3%). The Office Area and PCB Area were both verified as completely decontaminated after the first round of composite grid surface wipe sampling. The Battery Area was found to have resisted initial decontamination (i.e. only one (1) grid out of the fourteen (14) sampled “passed”). The results indicated that this area would require several more focused rounds of cleaning to be sufficiently decontaminated for mercury. Based on the initial results in the Battery Area, the decontamination techniques were modified to include the aggressive methodologies described in Appendix E.

All grid locations in all areas of the facility which exceeded the acceptance criteria limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) were re-cleaned by the decontamination contractor and re-sampled.

The second round of composite grid surface wipe sampling collected samples from twenty-nine (29) of the re-cleaned composite grids (Office Area = 4, Electronics Area = 5, Battery Area = 15, Class C Area = 5). The results for the first and second round of sampling demonstrated that 96.7% of the grids were below the acceptance limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) (Office Area = 100%, Electronics Area = 100%, Battery Area = 86.7%, PCB Area = 100%, Class C Area = 100%).

A statistical analysis (see below) on all composite sample results was performed, and concluded that the overall facility was sufficiently decontaminated. Since the mercury concentrations in grids F and N in the Battery Area did not exceed the acceptance limit by very much, and considering the built-in conservatism of the acceptance limits, it was concluded that the mercury level did not pose a significant enough health risk to warrant additional cleaning and sampling. The statistical

analysis and reasoning behind this “non-hazardous” decision were based on recommended methodologies developed by the U.S. Environmental Protection Agency’s Office of Solid Waste (EPA 2002).

Table 15 provides a complete summary of the composite grid surface wipe sampling results, and Table 16 provides a summary of the descriptive statistics computed from the final sample results.

**Table 15 – Composite Surface Wipe Sampling Results**

| Facility Area | Grid ID          | Composite Surface Wipe Sampling Results              |         |  |         |
|---------------|------------------|--|---------|--|---------|
|               |                  | Round One  |         | Round Two  |         |
|               |                  | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    |
| Class C       | A                | 6.75   | 1/28/14 |  |         |
| Class C       | B                | 14.9   | 1/28/14 |  |         |
| Class C       | C                | 9.41   | 1/29/14 |  |         |
| Class C       | D                | 0.85   | 1/29/14 |  |         |
| Class C       | E                | 15.6   | 1/28/14 |  |         |
| Class C       | F                | 12.7   | 1/28/14 |  |         |
| Class C       | G                | 16.8   | 1/28/14 |  |         |
| Class C       | H                | 19.9   | 1/28/14 |  |         |
| Class C       | I                | 17.3   | 1/29/14 |  |         |
| Class C       | J                | 29.1   | 1/29/14 |  |         |
| Class C       | K                | <b>32.9</b>  | 1/28/14 | 22.3   | 2/13/14 |
| Class C       | L <sup>[1]</sup> | 27.5   | 1/28/14 | 17.4   | 2/13/14 |
| Class C       |                  | <b>40.1</b>  | 1/28/14 | 12.3   | 2/13/14 |
| Class C       | M                | 8.80   | 1/28/14 |  |         |
| Class C       | N                | <b>38.2</b>  | 1/28/14 | 8.9  | 2/13/14 |
| Class C       | O                | <b>44.8</b>  | 1/29/14 | 24.2   | 2/13/14 |
| PCB           | A                | 6.79   | 8/7/13  |  |         |
| PCB           | B                | 3.21   | 8/7/13  |  |         |
| PCB           | C                | 9.43   | 8/7/13  |  |         |

| Facility Area | Grid ID          | Composite Surface Wipe Sampling Results              |         |  |         |
|---------------|------------------|--|---------|--|---------|
|               |                  | Round One  |         | Round Two  |         |
|               |                  | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    |
| PCB           | D                | 19.9   | 8/7/13  |  |         |
| Battery       | A <sup>[2]</sup> |  |         | 13.1   | 3/12/14 |
| Battery       | B                | <b>59.8</b>  | 8/6/13  | 24.8   | 3/12/14 |
| Battery       | C                | <b>35.3</b>  | 8/6/13  | 12.1   | 3/12/14 |
| Battery       | D                | 18.9   | 8/6/13  | 10.4   | 3/12/14 |
| Battery       | E                | <b>36.1</b>  | 8/6/13  | 19.0   | 3/12/14 |
| Battery       | F                | <b>47.9</b>  | 8/6/13  | 37.8 <sup>[3]</sup>                                  | 3/12/14 |
| Battery       | G                | <b>56.5</b>  | 8/6/13  | 15.6   | 3/12/14 |
| Battery       | H                | <b>140</b>   | 8/6/13  | 19.5   | 3/12/14 |
| Battery       | I                | <b>58.5</b>  | 8/6/13  | 16.5   | 3/12/14 |
| Battery       | J                | <b>31.5</b>  | 8/6/13  | 15.5   | 3/12/14 |
| Battery       | K                | <b>43.4</b>  | 8/6/13  | 12.4   | 3/12/14 |
| Battery       | L <sup>[1]</sup> | <b>91.8</b>  | 8/6/13  | 22.6   | 3/12/14 |
| Battery       |                  | <b>155</b>   | 8/6/13  | 19.7   | 3/12/14 |
| Battery       | M                | <b>272</b>   | 8/6/13  | 17.1   | 3/12/14 |
| Battery       | N                | <b>284</b>   | 8/6/13  | 42.8 <sup>[3]</sup>                                  | 3/12/14 |
| Battery       | O                | <b>89.8</b>  | 8/6/13  | 28.7   | 3/12/14 |
| Electronics   | A                | 17.7   | 4/8/13  |  |         |
| Electronics   | B                | 20.4   | 4/2/13  |  |         |
| Electronics   | C <sup>[2]</sup> |  |         | 7.11   | 8/6/13  |
| Electronics   | D                | <b>98.0</b>  | 4/8/13  | 6.87   | 9/12/13 |
| Electronics   | E                | <b>30.1</b>  | 4/8/13  | 5.81   | 9/12/13 |
| Electronics   | F                | 24.5   | 4/8/13  |  |         |
| Electronics   | G                | <b>73.2</b>  | 4/8/13  | 5.52   | 9/12/13 |
| Electronics   | H                | <b>59.7</b>  | 4/8/13  | 9.46   | 9/12/13 |
| Electronics   | I                | 18.3   | 4/8/13  |  |         |
| Office        | A                | 4.76   | 3/25/13 |  |         |
| Office        | B                | 2.62   | 3/25/13 |  |         |
| Office        | C                | 4.36   | 3/25/13 |  |         |
| Office        | D                | 8.10   | 3/25/13 |  |         |

| Facility Area | Grid ID          | Composite Surface Wipe Sampling Results              |         |  |         |
|---------------|------------------|--|---------|--|---------|
|               |                  | Round One  |         | Round Two  |         |
|               |                  | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    |
| Office        | E                | 1.35   | 3/25/13 |  |         |
| Office        | F                | 3.93   | 3/25/13 |  |         |
| Office        | G                | 2.36   | 3/25/13 |  |         |
| Office        | H                | 2.52   | 3/25/13 |  |         |
| Office        | I                | 4.11   | 3/25/13 |  |         |
| Office        | J                | 1.96   | 3/25/13 |  |         |
| Office        | K                | 6.52   | 3/25/13 |  |         |
| Office        | L                | 2.27   | 3/25/13 |  |         |
| Office        | M                | 4.05   | 3/25/13 |  |         |
| Office        | N                | 2.91   | 3/25/13 |  |         |
| Office        | O <sup>[2]</sup> |  |         | 2.72   | 9/12/13 |
| Office        | P <sup>[2]</sup> |  |         | 8.38   | 9/12/13 |
| Office        | Q <sup>[2]</sup> |  |         | 0.97   | 9/12/13 |
| Office        | R <sup>[2]</sup> |  |         | 17.0   | 9/12/13 |

Table 15 Footnotes:

Values highlighted **RED** indicate that the sample exceeded the acceptance criteria limit (i.e. 30  $\mu\text{g}/1,000\text{cm}^2$ ), and required another round of cleaning and re-sampling.

Values highlighted **ORANGE** indicate that the sample exceeded the acceptance criteria limit (i.e. 30  $\mu\text{g}/1,000\text{cm}^2$ ), but was considered acceptable (i.e. "non-hazardous") when the results were statistically evaluated.

<sup>[1]</sup> Grids sampled in duplicate.

<sup>[2]</sup> Grids not accessible or decontaminated fully during first round of sampling.

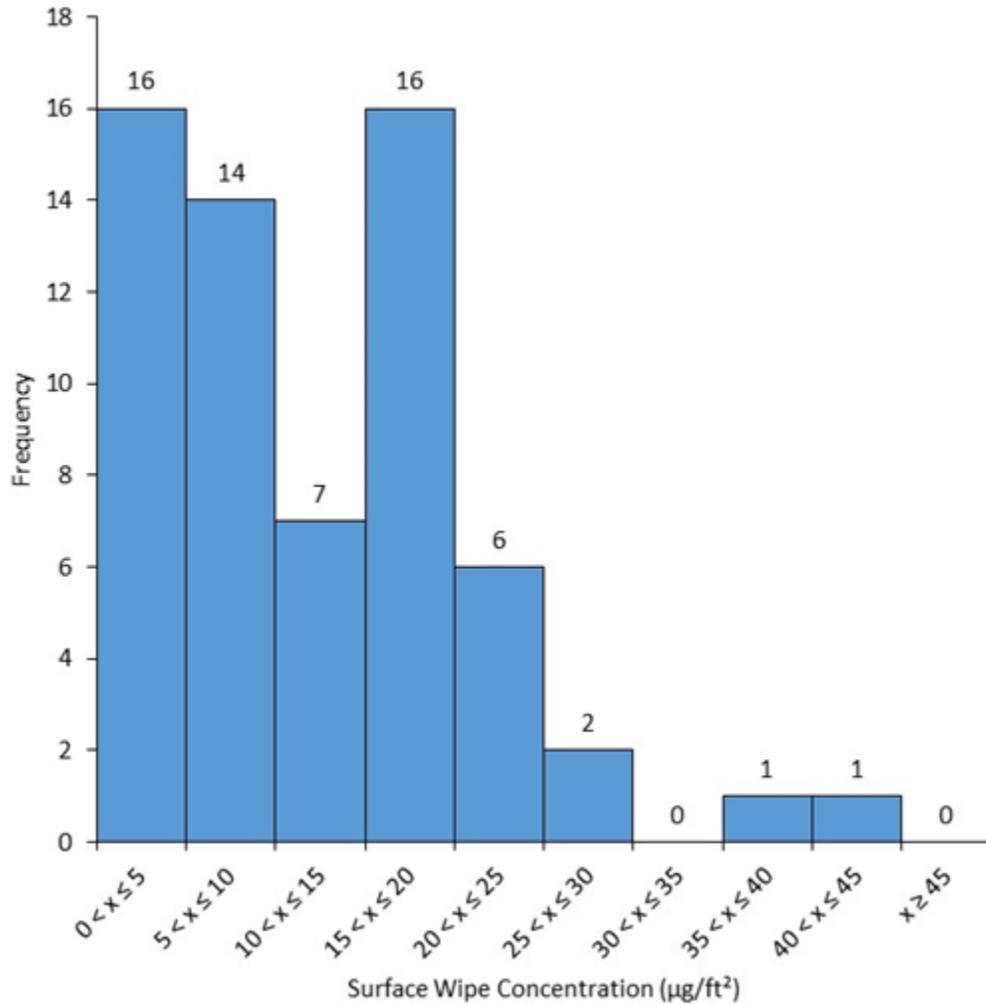
<sup>[3]</sup> Statistical analysis and health risk assessment (see below) concluded that the overall site and the Battery Area was sufficiently decontaminated. Since the mercury concentrations in grids F and N do not exceed the acceptance limit by very much, and considering the built-in conservatism of the acceptance limits, it was concluded that the mercury level did not pose a significant enough health risk to warrant additional cleaning and sampling.

**Table 16 – Composite Surface Wipe Sampling Statistics**

| Sample Set   | Sample Statistic   | Value                        |
|--|--------------------|------------------------------|
| Composite Surface Wipe Clearance Samples Final Results | Mean               | 12.7 µg/1,000cm <sup>2</sup> |
|  | Standard Error     | 1.15 µg/1,000cm <sup>2</sup> |
|  | Median             | 12.1 µg/1,000cm <sup>2</sup> |
|  | Mode               | 15.6 µg/1,000cm <sup>2</sup> |
|  | Standard Deviation | 9.10 µg/1,000cm <sup>2</sup> |
|  | Kurtosis           | +1.07                        |
|  | Skewness           | +0.95                        |
|  | Minimum            | 0.85 µg/1,000cm <sup>2</sup> |
|  | Maximum            | 42.8 µg/1,000cm <sup>2</sup> |
|  | Count              | 63                           |

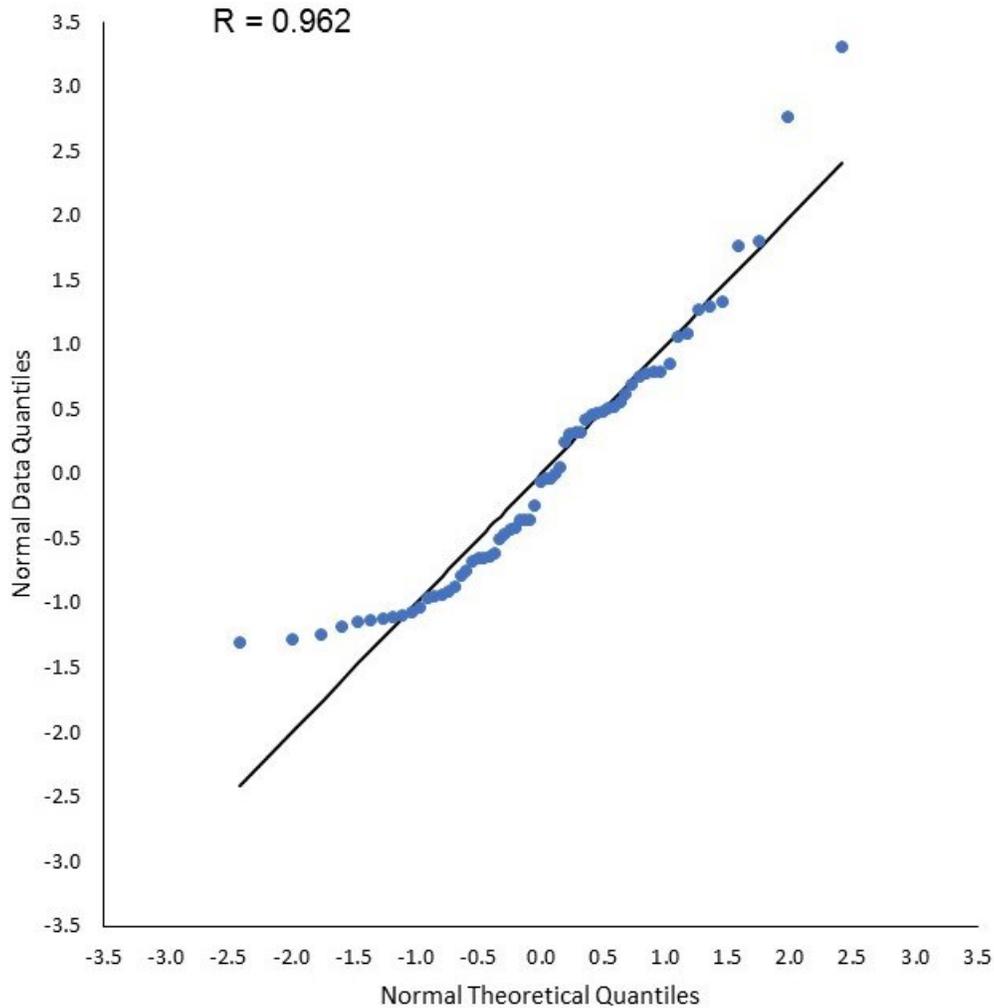
The final composite grid surface wipe sampling indicated that the average (mean) surface mercury concentration in the facility after decontamination was 12.7 µg/1,000cm<sup>2</sup>, and the median concentration was 12.1 µg/1,000cm<sup>2</sup>. The skew was +0.95, suggesting a right skew (i.e. with most values concentrated to the lower end of the range). The histogram shown in Figure 18 confirms this finding.

**Figure 18 – Composite Surface Wipe Sampling – Histogram**



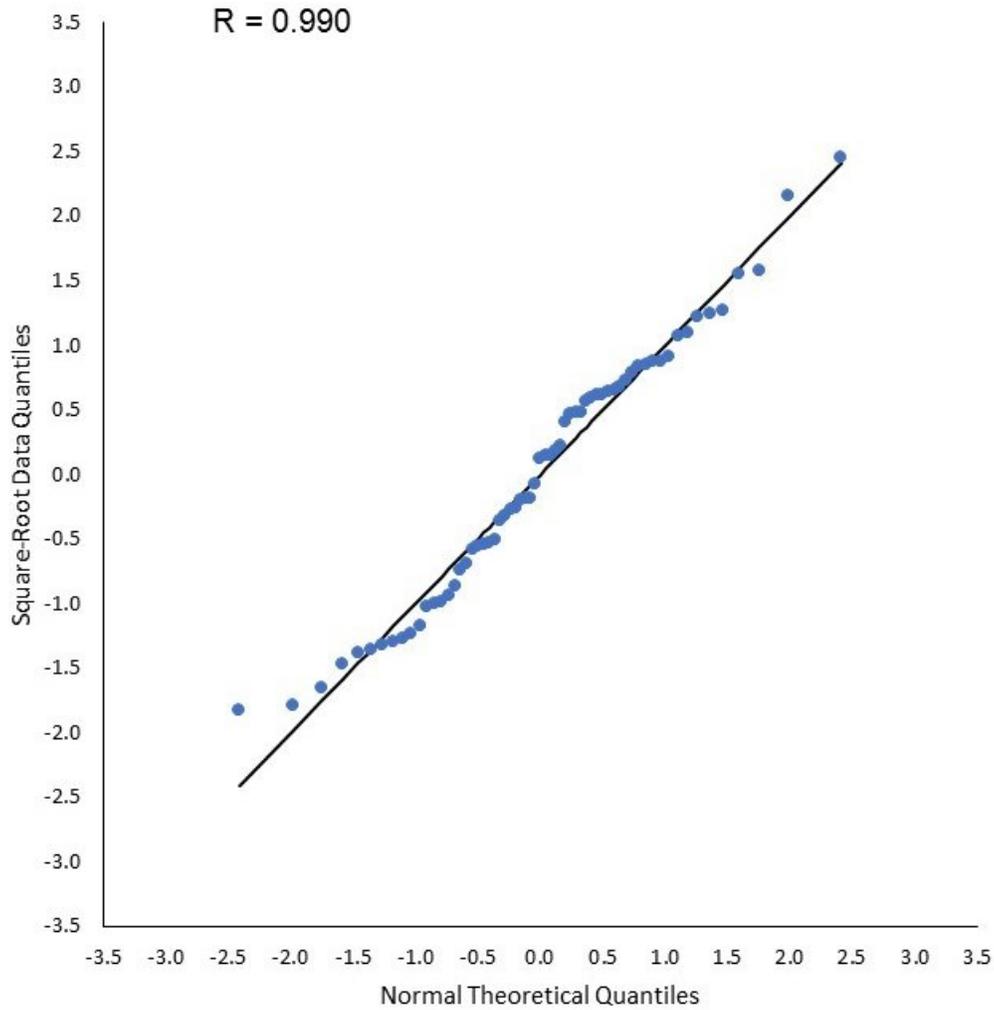
A Q-Q plot for the untransformed composite grid surface wipe data is provided in Figure 19, and indicates that the raw data is probably not normally distributed. Additionally, a Shapiro-Wilk test of normality was conducted and the p-value of this test was less than 0.05, indicating significantly that the untransformed composite grid surface wipe sample results were not drawn from a normally distributed data set.

**Figure 19 – Composite Surface Wipe Sampling – Normal Q-Q Plot**



Due to the non-normality of the data set, the data was transformed using the “ladder of power” method in an attempt to correct for the positive skew. Under a square-root transformation, the skewness was corrected and the data was successfully “linearized”. A Q-Q plot for the square-root transformed composite grid surface wipe data is provided in Figure 20, and indicates high “goodness of fit” to normality. The Shapiro-Wilk test statistic and significance levels for both the untransformed and square-root transformed data are provided in Table 17.

**Figure 20 – Composite Surface Wipe Sampling – Square-Root Q-Q Plot**



**Table 17 – Composite Surface Wipe Sampling Normality Test**

| Composite Surface Wipe Sampling Data Set | Shapiro-Wilk Test |              |
|--|-------------------|--------------|
|  | Statistic         | Significance |
| Untransformed Data                       | 0.925             | 0.001        |
| Square-Root Transformed                  | 0.977             | 0.275        |

Using the square-root transformed data, a statistical analysis was performed on the results to show that when taken as a whole the composite grid surface wipe sampling results support the conclusion that the overall facility was sufficiently

cleaned of hazardous mercury contamination. The table below provides a summary of the basic transformed statistical values which were calculated for this data set.

**Table 18 – Composite Surface Wipe Sampling Square-Root Statistics**

| Sample Set   | Sample Statistic   | Value                                |
|--|--------------------|--------------------------------------|
| Composite Surface Wipe Clearance Samples Square-Root Transformed Results | Mean               | 11.0 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Standard Error     | 1.31 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Median             | 12.1 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Mode               | 15.6 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Standard Deviation | 10.42 $\mu\text{g}/1,000\text{cm}^2$ |
|  | Kurtosis           | +0.11                                |
|  | Skewness           | -0.60                                |
|  | Minimum            | 0.85 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Maximum            | 42.8 $\mu\text{g}/1,000\text{cm}^2$  |
|  | Count              | 63                                   |

Assuming that the square-root transformed data fits a normal distribution and the data set is representative of the entire facility, it was concluded that if another composite grid sample were collected at random somewhere in the facility there would be a 96.6% probability that the sample would be less than the 30  $\mu\text{g}/1,000\text{cm}^2$  surface acceptance criteria limit. This value was calculated using the cumulative distribution function (CDF) for the normal distribution and the square-root transform statistical parameters.

As previously stated, the original goal for decontamination was to have all surface sampling results be less than the 30  $\mu\text{g}/1,000\text{cm}^2$  surface acceptance criteria limit. However, even if all sample results were measured below the acceptance limit,

there would remain a certain probability that if an additional sample were collected it would register above the 30  $\mu\text{g}/1,000\text{cm}^2$  limit. This probability could never be completely eliminated, it could only be minimized.

While there may be some human health risk associated with exposure to mercury on surfaces at 30  $\mu\text{g}/1,000\text{cm}^2$ , it was determined that this risk should be considered so insignificant that the potential for harmful involuntary exposure for any receptor (even sensitive receptors) was adequately minimized. Assuming that risk varies linearly with respect to dose, then the health risk at 60  $\mu\text{g}/1,000\text{cm}^2$  would be expected to be twice (2X) the health risk at 30  $\mu\text{g}/1,000\text{cm}^2$ , which is still very low. The highest exceedance of the acceptance criteria limit was measured in Grid F of the Battery Area, and was only 42.8  $\mu\text{g}/1,000\text{cm}^2$ .

An additional survey of the Battery Area showed that the surface samples that recorded mercury above the 30  $\mu\text{g}/1,000\text{cm}^2$  limit were collected from areas with a lot of structural steel surfaces. Most of these steel surfaces were never painted (only primed) and most of the steel had some level of corrosion / rust / oxidation, or was showing bare steel as a result of cleaning efforts. Mercury does not amalgamate with iron, but it will amalgamate with zinc, copper, tin, sodium, chromium and many other metals used to make the steel or primer coating. The level of oxidation in these areas was minor and had no impact on the structural supports, but it likely provided a site where mercury vapor in the air could condense and then amalgamate with the various metal surfaces, making the removal of mercury more difficult on these types of surfaces. Knowing this, it was recommended that the metal surfaces which showed signs of heavy corrosion (e.g. sprinkler lines, water mains, etc.) be cleaned with a dilute hydrochloric acid ("HCl") solution to strip the outer layers of rust, which may have resisted initial rounds of

cleaning. HCl cleaning was not considered necessary on metal surfaces which showed minor levels of corrosion, because these types of surfaces were not expected to resist TSP cleaning such that they would remain significantly over the 30 µg/1,000cm<sup>2</sup> limit.

Finally, only 3.3% (i.e. 2 out of 61) composite grid locations were found to be above the 30 µg/1,000cm<sup>2</sup> limit, and the highest result was only 1.42 times (42.8 µg/1,000cm<sup>2</sup>) the very conservative mercury surface limit established at the outset of the project.

The aggregate of the composite grid surface wipe sampling results indicated that all surface within the facility were cleaned and that no hazardous level of mercury contamination remained.

#### **4.2.2 Individual Surface Wipe Sampling**

On March 26, 2014 (Office Area), April 30, 2014 (Electronics Area), August 6 & 18, 2013 (Battery Area), August 18, 2013 (PCB Area), and January 28-29 (Class C Area), individual surface wipe clearance sampling was performed in each cleaned area to assess the effectiveness of decontamination efforts on hard to clean and visually suspect surfaces. Figures A-10 – A-15 in Appendix A provide identification of the individual surface sampling grids in each area of the facility.

A total of twenty-four (24) individual surface locations were sampled throughout the facility (Office Area = 6, Electronics Area = 5, Battery Area = 5, PCB Area = 1, Class C Area = 7). The first round of individual surface clearance sampling collected twenty-five (25) samples, including two (2) duplicate samples (Office Area = 6, Electronics Area = 4, Battery Area = 5, PCB Area = 1, Class C Area =

9). The first round of sampling demonstrated that 68% of the individual surface samples were below the acceptance criteria limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) after the first round of general area decontamination (Office Area = 100%, Electronics Area = 50%, Battery Area 40%, PCB Area = 100%, Class C Area = 66.7%). The Office Area and PCB Area were both verified as completely decontaminated after the first round of individual surface wipe sampling. The results indicated that in other areas additional cleaning was required to sufficiently decontaminate for mercury.

All locations in all areas of the facility which exceeded the acceptance criteria limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) were re-cleaned by the decontamination contractor and re-sampled.

The second round of individual surface wipe sampling collected nine (9) samples from the re-cleaned surface locations (Electronics Area = 3, Battery Area = 3, Class C Area = 3). The results for the first and second round of sampling demonstrated that 95.8% of the sample locations were below the acceptance limit (i.e.  $30 \mu\text{g}/1,000\text{cm}^2$ ) (Office Area = 100%, Electronics Area = 100%, Battery Area = 80%, PCB Area = 100%, Class C Area = 100%).

It was concluded that the mercury level measured in the Battery Area location CC did not pose a significant enough health risk to warrant additional cleaning and sampling. Instead, since this sample was collected from inside a floor pit (likely an ash clean-out for the old boiler room), the contractor was instructed to fill all the pits in the Battery Area and seal them with concrete. This effectively eliminated any mercury exposure potential in this location. Since the established acceptance criteria were designed to protect against involuntary (unknown) human exposure, filling and capping these pit locations removed any possibility of contact exposure.

Additionally, it was concluded that the remaining amount of contamination was at trace enough levels to not pose any environmental concern.

Table 19 provides a complete summary of the individual surface wipe sampling results.

**Table 19 – Individual Surface Wipe Sampling Results**

| Facility Area | Surface ID              | Individual Surface Wipe Sampling Results             |          |  |         |
|---------------|-------------------------|--|----------|--|---------|
|               |                         | Round One  |          | Round Two  |         |
|               |                         | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date     | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    |
| Class C       | AA <sup>[1]</sup>       | <b>130</b>   | 1/28/14  | 15.1   | 2/13/14 |
| Class C       |                         | <b>182</b>   | 1/29/14  | 18.6   | 2/13/14 |
| Class C       | BB                      | 16.3   | 1/28/14  |  |         |
| Class C       | CC                      | 13.0   | 1/28/14  |  |         |
| Class C       | DD                      | 22.1   | 1/28/14  |  |         |
| Class C       | EE                      | 17.3   | 1/29/14  |  |         |
| Class C       | FF <sup>[1]</sup>       | 2.35   | 11/13/13 |  |         |
| Class C       |                         | 5.22   | 11/13/13 |  |         |
| Class C       | Elec Box                | <b>201</b>   | 1/28/14  | 1.72   | 2/13/14 |
| PCB           | Elec Box                | 19.4   | 8/18/13  |  |         |
| Battery       | AA                      | <b>45.4</b>  | 8/6/13   | 17.8   | 9/12/13 |
| Battery       | BB                      | 25.2   | 8/6/13   |  |         |
| Battery       | CC                      | <b>102</b>   | 8/6/13   | <b>50.8<sup>[4]</sup></b>                            | 9/12/13 |
| Battery       | Elec Box 1              | <b>31.2</b>  | 8/18/13  | 7.82   | 9/12/13 |
| Battery       | Elec Box 2              | 16.0   | 8/18/13  |  |         |
| Electronics   | AA                      | 8.00   | 4/30/13  |  |         |
| Electronics   | BB                      | <b>30.4</b>  | 4/30/13  | 17.1   | 8/7/13  |
| Electronics   | CC                      | 9.36   | 4/30/13  |  |         |
| Electronics   | DD                      | <b>87.6</b>  | 4/30/13  | 19.8   | 8/7/13  |
| Electronics   | Elec Box <sup>[2]</sup> |  |          | 7.11   | 8/7/13  |

| Facility Area | Surface ID | Individual Surface Wipe Sampling Results             |         |  |      |
|---------------|------------|--|---------|--|------|
|               |            | Round One  |         | Round Two  |      |
|               |            | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    | Mercury Result<br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date |
| Office        | AA         | 7.90   | 3/26/13 |  |      |
| Office        | BB         | <6.00 <sup>[3]</sup>                                 | 3/26/13 |  |      |
| Office        | CC         | <6.00 <sup>[3]</sup>                                 | 3/26/13 |  |      |
| Office        | DD         | <6.00 <sup>[3]</sup>                                 | 3/26/13 |  |      |
| Office        | EE         | <6.00 <sup>[3]</sup>                                 | 3/26/13 |  |      |
| Office        | FF         | <6.00 <sup>[3]</sup>                                 | 3/26/13 |  |      |

Table 19 Footnotes:

Values highlighted **RED** indicate that the sample exceeded the acceptance criteria limit (i.e. 30  $\mu\text{g}/1,000\text{cm}^2$ ), and required another round of cleaning and re-sampling.

Values highlighted **ORANGE** indicate that the sample exceeded the acceptance criteria limit (i.e. 30  $\mu\text{g}/1,000\text{cm}^2$ ), but was considered acceptable (i.e. "non-hazardous") when the results were statistically evaluated.

<sup>[1]</sup> Grids sampled in duplicate.

<sup>[2]</sup> Grids not accessible or decontaminated fully during first round of sampling.

<sup>[3]</sup> Sample results less than analytical limit of detection (LOD). Result reported as "less than" LOD.

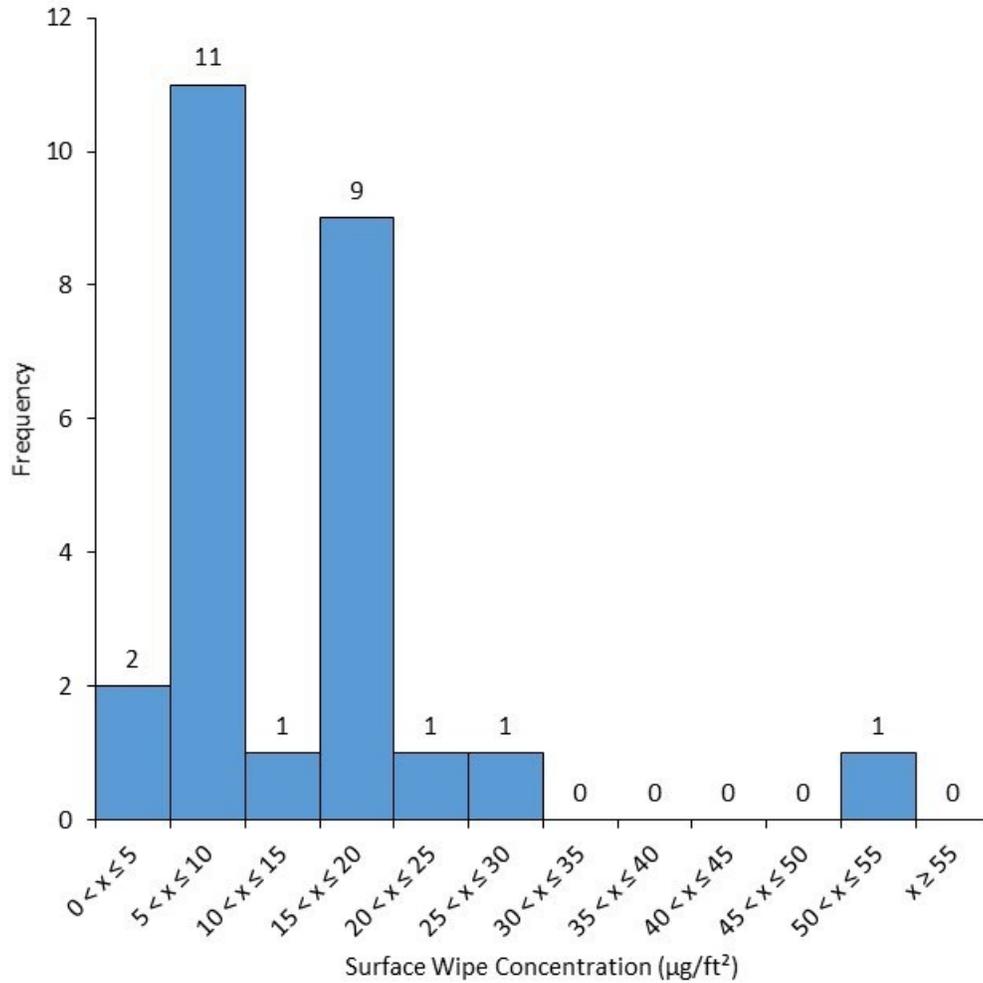
<sup>[4]</sup> Sample location in pit filled and capped to eliminate exposure potential.

**Table 20 – Individual Surface Wipe Sampling Statistics**

| Sample Set  | Sample Statistic   | Value                                |
|---|--------------------|--------------------------------------|
| Individual Surface Wipe Clearance Samples Final Results | Mean               | 13.4 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Standard Error     | 1.97 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Median             | 11.2 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Mode               | 6.0 $\mu\text{g}/1,000\text{cm}^2$   |
|   | Standard Deviation | 10.06 $\mu\text{g}/1,000\text{cm}^2$ |
|   | Kurtosis           | +6.77                                |
|   | Skewness           | +2.10                                |
|   | Minimum            | 1.72 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Maximum            | 50.8 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Count              | 26                                   |

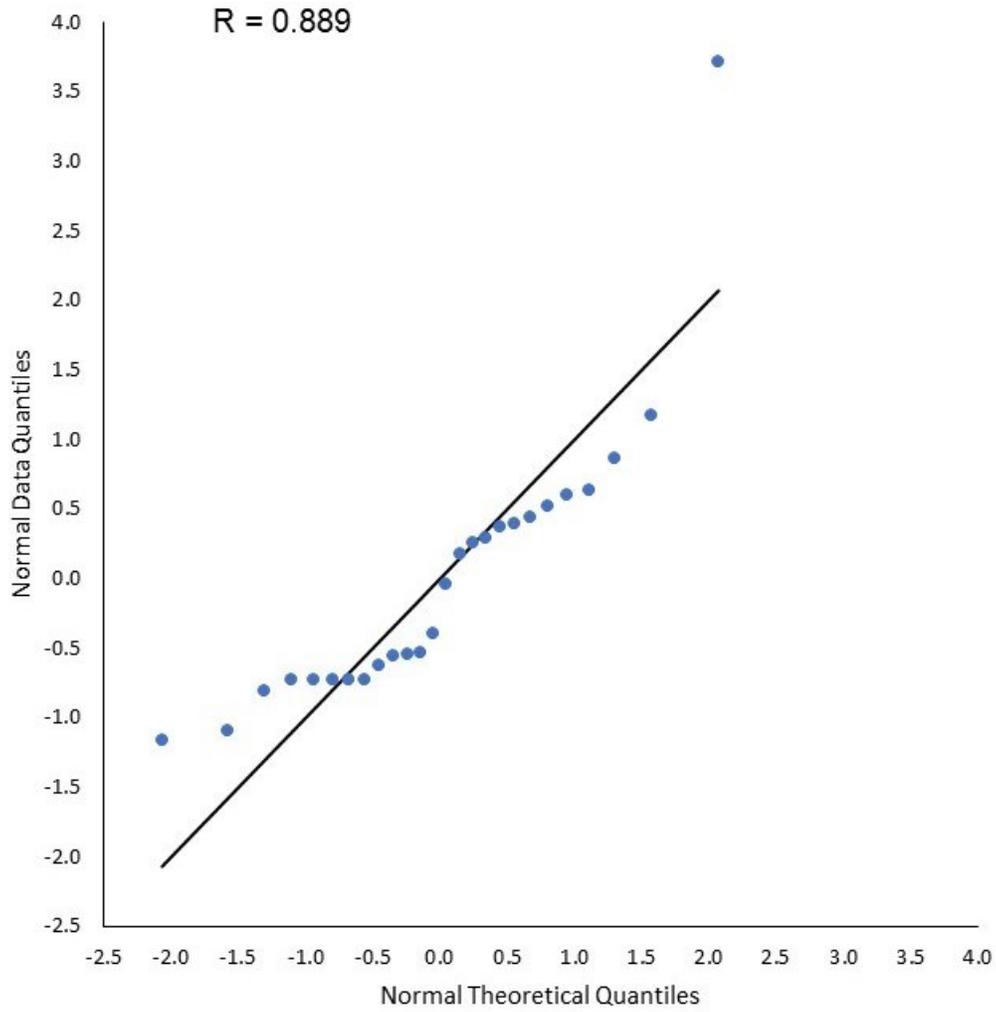
The final individual surface wipe clearance sampling results indicated that the average (mean) hard to clean surface mercury concentration in the facility after decontamination was 13.4  $\mu\text{g}/1,000\text{cm}^2$ , and the median concentration was 11.2  $\mu\text{g}/1,000\text{cm}^2$ . The skew was +2.10, suggesting a dramatic right skew (i.e. with most values concentrated to the lower end of the range). The histogram shown in Figure 21 confirms this finding.

**Figure 21 – Individual Surface Wipe Sampling - Histogram**



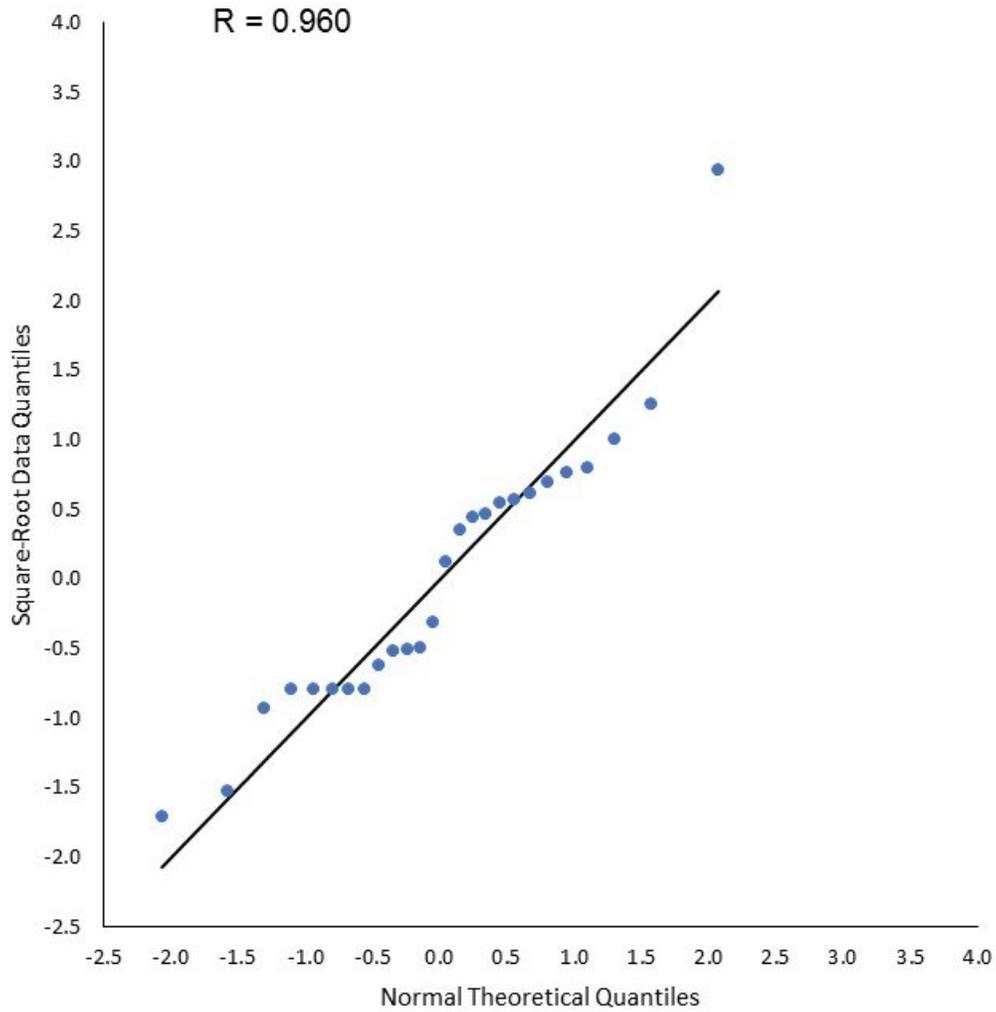
A Q-Q plot for the untransformed individual surface wipe data is provided in Figure 22, and indicates that the raw data is probably not normally distributed. Additionally, a Shapiro-Wilk test of normality was conducted and the p-value of this test was less than 0.05, indicating significantly that the untransformed individual surface wipe sample results were not drawn from a normally distributed data set.

**Figure 22 – Individual Surface Wipe Sampling – Normal Q-Q Plot**



Due to the non-normality of the data set, the data was transformed using the “ladder of power” method in an attempt to correct for the positive skew. Again, under a square-root transformation, the skewness was corrected and the data was adequately “linearized”. A Q-Q plot for the square-root transformed composite grid surface wipe data is provided in Figure 23, and shows “goodness of fit” to normality. The Shapiro-Wilk test statistic and significance levels for both the untransformed and square-root transformed data are provided in Table 21.

**Figure 23 – Individual Surface Wipe Sampling – Square-Root Q-Q Plot**



**Table 21 – Individual Surface Wipe Sampling Normality Test**

| Individual Surface Wipe Sampling Data Set | Shapiro-Wilk Test |              |
|---|-------------------|--------------|
|   | Statistic         | Significance |
| Untransformed Data                        | 0.802             | < 0.001      |
| Square-Root Transformed                   | 0.929             | 0.073        |

Using the square-root transformed data, a statistical analysis was performed on the results to show that when taken as a whole the individual surface wipe sampling results support the conclusion that the overall, hard to clean locations in

the facility were sufficiently cleaned of hazardous mercury contamination. The table below provides a summary of the transformed statistical values which were calculated for this data set.

**Table 22 – Individual Surface Wipe Sampling Square-Root Statistics**

| Sample Set  | Sample Statistic   | Value                                |
|---|--------------------|--------------------------------------|
| Individual Surface Wipe Clearance Samples Square-Root Transformed Results | Mean               | 11.9 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Standard Error     | 2.00 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Median             | 11.1 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Mode               | 6.0 $\mu\text{g}/1,000\text{cm}^2$   |
|   | Standard Deviation | 10.20 $\mu\text{g}/1,000\text{cm}^2$ |
|   | Kurtosis           | +1.51                                |
|   | Skewness           | +0.78                                |
|   | Minimum            | 1.72 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Maximum            | 50.8 $\mu\text{g}/1,000\text{cm}^2$  |
|   | Count              | 26                                   |

Assuming that the square-root transformed data fits a normal distribution and the data set is representative of all hard to clean surfaces at the facility, it was concluded that if another individual surface wipe sample were collected at random somewhere in the facility there would be a 96.2% probability that the sample would be less than the 30  $\mu\text{g}/1,000\text{cm}^2$  surface acceptance criteria limit. This value was calculated using the cumulative distribution function (CDF) for the normal distribution and the square-root transform statistical parameters.

The combined individual surface wipe sampling results indicated that all hard to clean and visually suspect surfaces within the facility were sufficiently cleaned and that no hazardous level of mercury contamination remained.

### 4.2.3 Indoor Air Quality Passive-Badge Sampling

Between October 2 – 7, 2013 (Office Area), October 2 – 7, 2013 (Electronics Area), March 26 – 31, 2014 (Battery Area), and March 7 – 12, 2014 (Class C Area), the indoor air quality passive-badge clearance sampling was performed in accordance with the procedures described in Section 3.2.3 (page 39). Figures A-16 – A-21 in Appendix A provide identification of the indoor air quality sample locations in each area of the facility.

A total of nine (9) indoor and nine (9) outdoor passive-badge air quality samples were collected. All samples were left undisturbed to collect for at least five (5) days.

Table 23 and Table 24 provide a summary of the various passive-badge air quality results. Not a single sample (indoor or outdoor) recorded a measureable level of mercury vapor above the passive-badge analytical limit of detection (“LOD”). All samples had a LOD at most less than 1.0  $\mu\text{g}/\text{m}^3$ . Therefore, it was concluded that decontamination activities had successfully reduced the mercury vapor concentration in the indoor air to less than the established acceptance criteria limit (i.e. 3.0  $\mu\text{g}/\text{m}^3$ ).

**Table 23 – Indoor Air Quality Passive-Badge Sampling Results**

| Facility Area | Location ID | Start Date | Sample Time (hrs.) | Average Temp. (°F) | Passive-Badge Mercury Result ( $\mu\text{g}/\text{m}^3$ ) |
|---------------|-------------|------------|--------------------|--------------------|---|
| Class C       | A           | 3/7/14     | 120.1              | 74                 | <0.85 <sup>[1]</sup>                                      |
| Class C       | B           | 3/7/14     | 120.1              | 74                 | <0.85 <sup>[1]</sup>                                      |
| Class C       | C           | 3/7/14     | 120.1              | 74                 | <0.85 <sup>[1]</sup>                                      |

| Facility Area | Location ID | Start Date | Sample Time (hrs.) | Average Temp. (°F) | Passive-Badge Mercury Result (µg/m <sup>3</sup> ) |
|---------------|-------------|------------|--------------------|--------------------|---|
| Battery       | A           | 3/26/14    | 120.1              | 73                 | <0.85 <sup>[1]</sup>                              |
| Battery       | B           | 3/26/14    | 120.1              | 73                 | <0.85 <sup>[1]</sup>                              |
| Electronics   | A           | 10/2/13    | 123.6              | 67                 | <0.84 <sup>[1]</sup>                              |
| Electronics   | B           | 10/2/13    | 123.4              | 67                 | <0.84 <sup>[1]</sup>                              |
| Office        | A           | 10/2/13    | 123.6              | 73                 | <0.82 <sup>[1]</sup>                              |
| Office        | B           | 10/2/13    | 123.6              | 73                 | <0.82 <sup>[1]</sup>                              |

Table 23 Footnotes:

<sup>[1]</sup> Sample results less than analytical limit of detection (LOD). Result reported as “less than” LOD.

**Table 24 – Outdoor Air Quality Passive-Badge Sampling Results**

| Facility Area | Location ID | Start Date | Sample Time (hrs.) | Average Temp. (°F) | Passive-Badge Mercury Result (µg/m <sup>3</sup> ) |
|---------------|-------------|------------|--------------------|--------------------|---|
| Outdoor       | S           | 3/7/14     | 120.4              | 42                 | <0.93 <sup>[1]</sup>                              |
| Outdoor       | W           | 3/7/14     | 120.4              | 42                 | <0.93 <sup>[1]</sup>                              |
| Outdoor       | N           | 3/7/14     | 120.4              | 42                 | <0.93 <sup>[1]</sup>                              |
| Outdoor       | S           | 3/26/14    | 120.1              | 40                 | <0.94 <sup>[1]</sup>                              |
| Outdoor       | W           | 3/26/14    | 120.1              | 40                 | <0.94 <sup>[1]</sup>                              |
| Outdoor       | N           | 3/26/14    | 120.1              | 40                 | <0.94 <sup>[1]</sup>                              |
| Outdoor       | S           | 10/2/13    | 124.2              | 60                 | <0.85 <sup>[1]</sup>                              |
| Outdoor       | W           | 10/2/13    | 124.6              | 60                 | <0.84 <sup>[1]</sup>                              |
| Outdoor       | N           | 10/2/13    | 124.4              | 60                 | <0.84 <sup>[1]</sup>                              |

Table 24 Footnotes:

<sup>[1]</sup> Sample results less than analytical limit of detection (LOD). Result reported as “less than” LOD.

The combination of indoor air quality passive-badge results and the trends presented by the general area direct-read results (see Section 4.1.1, page 42), indicated that the facility was sufficiently cleaned and that no hazardous level of mercury contamination remained.

## **5.0 CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 CONCLUSIONS**

It was indicated that surface mercury contamination was relatively persistent and resisted the initial rounds of cleaning. However, focused and aggressive decontamination techniques were successful in reducing surface mercury concentrations when implemented properly. The indoor air was shown to improve continuously and considerably as surface decontamination progressed within the facility. This was qualitatively depicted in Figure 4, Figure 5, Figure 6 and Figure 7 in Section 4.1.1, which showed the indoor air quality improve by approximately three (3) order of magnitude.

The purpose of this thesis was to develop and present a variety of practicable measures to identify, decontaminate and evaluate cleanliness of buildings and structures which have been contaminated through industrial activities. This thesis advances the following statements:

- Each site and area poses a unique set of site-specific challenges. These challenges and concerns should be considered before establishing appropriate cleanliness acceptance criteria limits and decontamination procedures.
- The extent of building contamination should be delineated using various types of detection techniques before conducting decontamination.

- Throughout decontamination, field screening methodologies should be conducted to evaluate the effectiveness of various types of cleaning techniques and to monitor the progress of cleanup.
- Decontamination confirmation samples should be collected in a systematic manner throughout all areas potentially impacted by mercury contamination.

## **5.2      *OBJECTIVE COMPLETION***

The objectives of this thesis and a brief explanation of how each objective was completed in this thesis are presented below:

1. Present general decontamination techniques and testing methodologies used to determine the effectiveness of cleaning methods.

### Completion of Objective #1

Decontamination effectiveness screening was conducted during the course of closure in accordance with the methodologies described in Section 3.1 (page 26) of this thesis. A complete summary of the results obtained from this sampling were provided in Section 4.1 (page 42). The screening methodologies were innovative in that there were no established procedures to fully evaluate the effectiveness of mercury decontamination. Several innovative aspects presented in this thesis are: 1) there are no published side-by-side, or pre- and post-clean testing results to compare the effect of alternative cleaning approaches; 2) the heated chamber sampling methodology was the first of its kind for evaluating the potential for mercury volatilization from the semi-porous surface of a concrete floor

(this approach was based on sampling methodologies typically used in wastewater and landfill gas studies); and 3) there were no published works that depict the obvious reduction in ambient air mercury vapor concentrations during the implementation of decontamination as shown by the daily general area direct-read survey results.

2. Provide clearance sampling methodologies and techniques used to determine the extent to which mercury contamination is present, evaluate cleanliness, and support the conclusion that the facility is adequately cleaned and ready for reuse.

#### Completion of Objective #2

Surface mercury and indoor air quality mercury vapor acceptance criteria limits were developed at the outset of the project in accordance with the methodologies described in Appendix B of this thesis. The development of these acceptance criteria limits established defensible standards for the classification of decontaminated buildings as “clean”, with respect to mercury contamination. Clearance sampling was conducted following completion of decontamination activities in accordance with the methodologies described in Section 3.2 (page 34) of this thesis. A complete summary of the results obtained from this sampling, and a statistical analysis to support the “clean” conclusion were provided in Section 4.2 (page 67). The clearance sampling methodologies and results were innovative in that there were no published sampling approaches for determining whether or not a structure is sufficiently “clean” with respect to mercury contamination.

This thesis provides a comprehensive and reproducible approach to removing mercury contamination from a facility. The objective of such decontamination is to allow the structure to be reused and reoccupied without limitation, restriction or reservation. The alternative to decontamination would be to demolish the mercury contaminated facility and manage the debris as a hazardous waste. The combination of characterization, screening and clearance sampling results definitively show that properly specified and aggressively implemented surface decontamination techniques can adequately reduce hazardous mercury contamination within the structural environment. The decontamination techniques presented in this thesis were demonstrated to reduce contamination to a level which is sufficiently protective of human health and the environment so as to be considered non-hazardous.

### **5.3        *RECOMMENDATIONS***

The following sections provide a summary of several aspects of building / structural mercury decontamination which were not addressed by this project, and should be considered recommendations for future research.

#### **5.3.1        *Alternative Decontamination Techniques***

The structural decontamination techniques utilized during this project do not represent all possible mercury decontamination methodologies. Other processes were identified for possible use in the decontamination protocol, but were not pursued or studied. Some of the alternative decontamination techniques considered during this project, but not pursued, include the following:

- Reactive strippable coatings, which use polymer mixtures and are applied to a surface like a paint. The coatings are designed to absorb and bind contaminants during the curing process. Once the coating dries, it can be stripped manually from the surface.
- Iodine lixiviant cleaning, which uses a potassium iodide/iodine (KI/I<sub>2</sub>) solution to oxidize and complex with mercury contamination. Similar to the Hg-X® solution used to clean the floors, the iodine lixiviant reacts with mercury to form a more-stable, water-soluble mercury complex which can be easily cleaned.

### **5.3.2        *Extra-Facility Sampling***

As mentioned in Section 2.2.2 (page 14), this decontamination project only covered areas of the greater project site which were formerly occupied by the owner's waste recycling operation. This meant that the owner agreed only to properly clean and decontaminate all areas of the building formerly occupied by its recovery operation, and only the areas occupied by the owner's operation. This limitation on the extent of decontamination was supported by the property's third-party owner. As a consequence of this arrangement between the recycling operation owner and the third-party owner of the property, no samples were collected in other areas of the facility (i.e. "Extra-Facility) not associated with the owner's operation.

This arrangement posed a significant challenge to fully support the conclusion of clean closure. The inaccessibility of the Extra-Facility was a major and obvious shortcoming of this project. The extent to which mercury contamination was found to have spread throughout the facility certainly left open the possibility that

contamination may have penetrated into the Extra-Facility; however, no obvious route of penetration was identified at any time during the decontamination. Nevertheless, the lack of data from the Extra-Facility should be considered a significant shortcoming of this project, and in future projects characterization sampling should be conducting in all parts of a facility to confirm or refute the possibility of inter-facility contamination.

### **5.3.3        *Regression Model***

As mentioned in Section 4.1.1 (page 42), there was the potential to design the sampling methodology for this project to lend itself towards development of a regression model. The model would be useful for predicting surface mercury concentration as a function of indoor mercury vapor concentration. Since the sampling data presented in this thesis were incompatible for generating a regression model, the following is a discussion of how an alternative sampling strategy may have been developed to generate data better suited for modeling.

An improved method for collecting “better” data from a modeling standpoint would be to adhere to the following general procedure when collecting wipe / direct-read samples:

1. Within each composite grid surface sample location in each area of the facility periodically collect wipe and direct-read mercury samples throughout the decontamination process.
2. Using the direct-read mercury vapor instrument, monitor the mercury vapor concentration directly above the surface at each discrete wipe sample location.

3. Record the surface's status – that is, cleaned or not cleaned.
4. Record the surface type – that is, concrete, metal, wood, etc. and estimate the percentage of the total grid surface area comprised of that type of surface.
5. Collect discrete surface wipe samples from various surface types within the grid and composite into a single sample for that location.
6. Collect general area direct-read mercury vapor measurement within the grid location.

This sampling procedure would generate the following data types:

- Grid status (i.e. boolean variable) – that is, clean or not clean
- Grid surface type breakdown (i.e. % surface type)
- Average grid general area mercury vapor concentration (i.e.  $\mu\text{g}/\text{m}^3$ )
- Average grid surface mercury concentration (i.e.  $\mu\text{g}/1,000\text{cm}^2$ )
- Average “directly-above-surface” mercury vapor concentration (i.e.  $\mu\text{g}/\text{m}^3$ )

This procedure would completely eliminate the time series nature of the regression model and reduce the serial correlation issues between the general area direct-read mercury vapor data points. Additionally, this type of sampling plan would provide direct correspondence between a surface mercury result in an area and a direct-read mercury vapor result in the same area.

The benefit of developing this type of model – that is, one which accurately predicts the surface mercury concentration based on mercury vapor concentration directly above the surface – is the obvious cost benefit of being able to cheaply predict at what point a surface is sufficiently cleaned to “pass” wipe sample clearance testing. Considering that the laboratory analysis fee for a single surface wipe sample can cost more the \$50 (not including the labor to collect), the ability to have an accurate indication of the surface mercury concentration (before collecting the surface wipe sample) would generate an obvious cost savings.

#### **5.4      *DISCLAIMER***

This thesis was developed based on an actual project the author (Andrew Roland) was involved with while employed full-time at the environmental consultancy, AMEC Environment & Infrastructure (“AMEC”) in Chelmsford, Massachusetts. The views and opinions expressed in this thesis are my own, and do not necessarily reflect the views of AMEC, or its employees. Mr. Paul G. Richard, P.E., a Massachusetts licensed Professional Engineer (“P.E.”), and Dr. Michael D. Walters, CIH, a Certified Industrial Hygienist (“CIH”), were integral members of the project team and were responsible for directing and overseeing all project activities and providing expert opinions and advice to the author throughout the project.

## References

- Andren, Aners and Jerome Nriagu. 1979. "The Global Cycle of Mercury." In *The Biogeochemistry of Mercury in the Environment*. (ed.) Jerome Nriagu. Amsterdam, Netherlands. Elsevier/North-Holland Biomedical Press. 1979. 1-21.
- ATSDR. 1999. *Toxicological Profile for Mercury*. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services. Atlanta, GA. March 1999. Web. August 2014.
- ATSDR. 2012. *Chemical-Specific Health Consultation for Joint EPA/ATSDR National Mercury Cleanup Policy Work Group: Action Levels for Elemental Mercury Spills*. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services: Division of Toxicology and Environmental Medicine, Prevention, Response and Medical Support Branch. Atlanta, GA. March 2012. Web. March 2013.
- ATSDR. 2012. *Evaluating Mercury Exposure: Information for Health Care Providers*. Fact Sheet. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services. Atlanta, GA. June 2012. Web. August 2014.
- Aucott, Michael, Michael McLinden and Michael Winka. 2004. *Release of Mercury from Broken Fluorescent Bulbs*. Division of Science, Research & Technology. State of New Jersey Department of Environmental Protection. Trenton, NJ. February 2004. Web. December 2013.
- Baughman, Thomas. 2006. *Elemental Mercury Spills*. Environmental Health Perspectives. February 2006. 114 (2): 147-152.
- Bellinger, David, Felicia Trachtenberg, Lars Barregard, Mary Tavares, Elsa Cernichiari, David Daniel and Sonja McKinlay. 2006. *Neuropsychological and Renal Effects of Dental Amalgam in Children: A Randomized Clinical Trial*. Journal of the American Medical Association. April 2006. 295 (15): 1775-1783.
- Clarkson, Thomas, Laszlo Magos and Gary Myers. 2003. *The Toxicology of Mercury – Current Exposures and Clinical Manifestations*. New England Journal of Medicine. October 2003. 349 (18): 1731-1737.
- Cotsworth, Elizabeth. 1998. *Risk-Based Clean Closure*. Memorandum to RCRA Senior Policy Advisors: EPA Regions I – X. Washington, D.C. 16 March 1998. Web. May 2014.
- Cotton, Albert and Geoffrey Wilkinson. 1980. *Advanced Inorganic Chemistry*. 4th Edition. New York, NY. John Wiley & Sons. 1980. Part 2, Ch. 15: 604.

- De Capitani, Eduardo, Elemir De Souza, Ronan Vieira and Paulo Madureira. 2009. *Contact Dermatitis to Elemental Mercury with Direct Lesion*. *Anais Brasileiros de Dermatologia*. Jan./Feb. 2009. 84 (1): 75-77.
- DeRouen, Timothy, Michael Martin, Brian Leroux, Brenda Townes, James Woods, Jorge Leitao, Alexandre Castro-Caldas, Henrique Luis, Mario Bernardo, Gail Rosenbaum and Isabel Martins. 2006. *Neurobehavioral Effects of Dental Amalgam in Children: A Randomized Clinical Trial*. *Journal of the American Medical Association*. April 2006. 295 (15): 1784-1792.
- Ebadian, M.A., Marshall Allen, Yong Cai and John McGahan. 2001. *Mercury Contaminated Material Decontamination Methods: Investigation and Assessment*. Hemispheric Center for Environmental Technology. Florida International University. Miami, FL. Prepared for: U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology. January 2001.
- Eichholz, Geoffrey, M. Frank Petelka and Robert Kury. 1988. *Migration of Elemental Mercury through Soil from Simulated Burial Sites*. *Water Research*. January 1988. 22 (1): 15-20.
- Ellis, Linda, Michael Mullins, Nancy Gavin and Anthony Scalzo. 2009. *Detection of Elemental Mercury in Abdominal Wall Soft Tissue*. *Journal of Medical Toxicology*. December 2009. 5 (4): 205-209.
- EPA. 1994. *Evaluation of Mercury Emissions from Fluorescent Lamp Crushing*. EPA-453/R-94-018. Control Technology Center. U.S. Environmental Protection Agency. Washington, D.C. February 1994. Web. August 2014.
- EPA. 1995. *Mercury, Elemental*. Integrated Risk Information System (IRIS). U.S. Environmental Protection Agency. Washington, D.C. June 1995. Web. March 2013.
- EPA. 1997. *Mercury Study Report to Congress. Volume V: Health Effects of Mercury and Mercury Compounds*. EPA-452/R-97-007. Office of Air Quality Planning & Standards and Office of Research and Development. U.S. Environmental Protection Agency. Washington, D.C. December 1997.
- EPA. 2000. *Mercury Compounds*. Technology Transfer Network (TTN) – Air Toxics Web Site. U.S. Environmental Protection Agency. Washington, D.C. January 2000. Web. March 2013.
- EPA. 2002. *RCRA Waste Sampling Draft Technical Guidance: Planning, Implementation, and Assessment*. EPA-530-D-02-002. Office of Solid Waste. U.S. Environmental Protection Agency. Washington, D.C. August 2002. Web. January 2015.

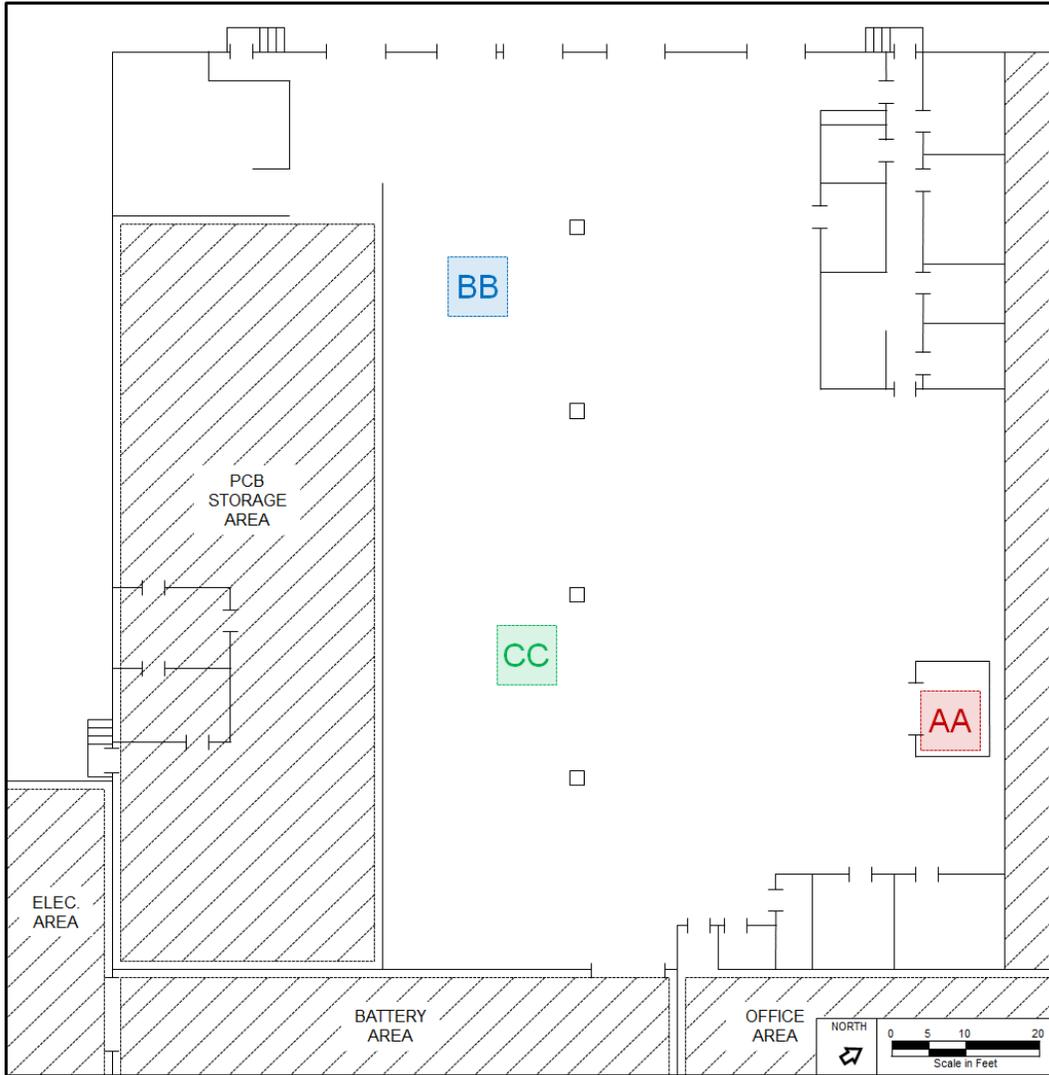
- Erickson, Mitchell. 2001. *PCBs: Recent Advances in Environmental Toxicology and Health Effects*. Edited by Larry W. Robertson and Larry G. Hansen. Lexington, KY: The University Press of Kentucky. 2001.
- Faulconer, Emily. 2012. *Effects of Activated Carbon Surface Chemistry Modification on the Adsorption of Mercury from Aqueous Solution*. Ph.D. Dissertation. University of Florida. George A. Smathers Digital Collection. 2012. Web. September 2014.
- Fawer, R.F., Y. De Ribaupierre, M.P. Guillemin, M. Berode and M. Lob. 1983. *Measurement of Hand Tremor Induced by Industrial Exposure to Metallic Mercury*. *British Journal of Industrial Medicine*. May 1983. 40 (2): 204-208.
- Fields, Timothy and Bruce Diamond. 1991. *Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors."* Memorandum to Waste Management Divisions: EPA Regions I – X. Washington, D.C. 25 March 1991. Web. March 2013.
- Gochfeld, Michael. 2003. *Cases of Mercury Exposure, Bioavailability, and Absorption*. *Ecotoxicology and Environmental Safety*. September 2003. 56 (1): 174-179.
- IAEA. 2001. *Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning of Nuclear Facilities*. From the Technical Reports Series No. 401. International Atomic Energy Agency. Vienna, Austria. May 2001. Web. January 2014.
- Kaiser G. and G. Tölg. 1980. "Mercury." In *The Handbook of Environmental Chemistry: Anthropogenic Compounds*. Volume 3/3A. ed. O. Hutzinger. Berlin, Germany. Springer-Verlag. 1980. 1-58.
- Lide, David. (ed.) 1990. *CRC Handbook of Chemistry and Physics*. 71st Edition. Boca Raton, FL. CRC Press, Inc. 1990.
- Lucas, Alan and Robert Emery. 2006. *Assessing Occupational Mercury Exposures During the On-Site Processing of Spent Fluorescent Lamps*. *Journal of Environmental Health*. March 2006. 68 (7): 30-34.
- Magos, Laszlo. 1975. *Mercury and Mercurials*. *British Medical Bulletin*. 1975. 31 (3): 241-245.
- NEWMOA. 2008. *Mercury Use in Lighting*. Fact Sheet. Northeast Waste Management Officials' Association. Boston, MA. August 2008. Web. August 2014.
- Ngim, C.H., S.C. Foo, K.W. Boey and J. Jeyaratnam. 1992. *Chronic Neurobehavioural Effects of Elemental Mercury in Dentists*. *British Journal of Industrial Medicine*. November 1992. 49 (11): 782-790.

- NJMTF. 2002. *Volume II: Exposure and Impacts*. New Jersey Mercury Task Force. Office of Science. New Jersey Department of Environmental Protection. Trenton, NJ. January 2002.
- OSHA. 2012. *Protecting Workers from Mercury Exposure while Crushing and Recycling Fluorescent Bulbs*. Fact Sheet. Occupational Safety and Health Administration. U.S. Department of Labor. Washington, D.C. June 2012. Web. September 2014.
- OSPPERA. 2002. *Mercury Spill Response & Clean-up Guidance Document*. Ohio Spill Planning, Prevention and Emergency Response Association. Ohio Department of Environmental Protection. Columbus, Ohio. June 2002. Web. January 2015.
- Ramroth, Laurie. 2008. *Comparison of Life-Cycle Analysis of Compact Fluorescent and Incandescent Lamps Based on Rated Life of Compact Fluorescent Lamps*. Rocky Mountain Institute. Boulder, CO. February 2008. Web. December 2013.
- Risher, John, Richard Nickle and Sherlita Amler. 2003. *Elemental Mercury Poisoning in Occupational and Residential Settings*. International Journal of Hygiene and Environmental Health. September 2003. 206 (4-5): 371-379.
- Risher, John and Christopher De Rosa. 2007. *Inorganic: The Other Mercury*. Journal of Environmental Health. November 2007. 70 (4): 9-16.
- Sanchez, Inéz and Erik Lauritzen. 2004. *Integrated Decontamination and Rehabilitation of Buildings, Structures and Materials in Urban Renewal – A European Project for Sustainable City Concept*. Fourth International RILEM Conference on the Use of Recycled Materials in Buildings and Structures. Barcelona, Spain. Vol. 9. November 2004. Web. August 2014.
- Taueg, C., D.J. Sanfilippo, B. Rowens, J. Szejda and J.L. Hesse. 1992. *Acute and Chronic Poisoning from Residential Exposures to Elemental Mercury: Michigan 1989-1990*. Clinical Toxicology. January 1992. 30 (1): 63-67.
- UNEP. 2002. *Global Mercury Assessment*. United Nations Environment Programme (UNEP) Chemicals. Geneva, Switzerland. December 2002. Web. August 2014.
- WHO. 1991. *Inorganic Mercury. Volume 118*. International Programme on Chemical Safety (IPCS). World Health Organization. Geneva, Switzerland. 1991. Web. August 2014.

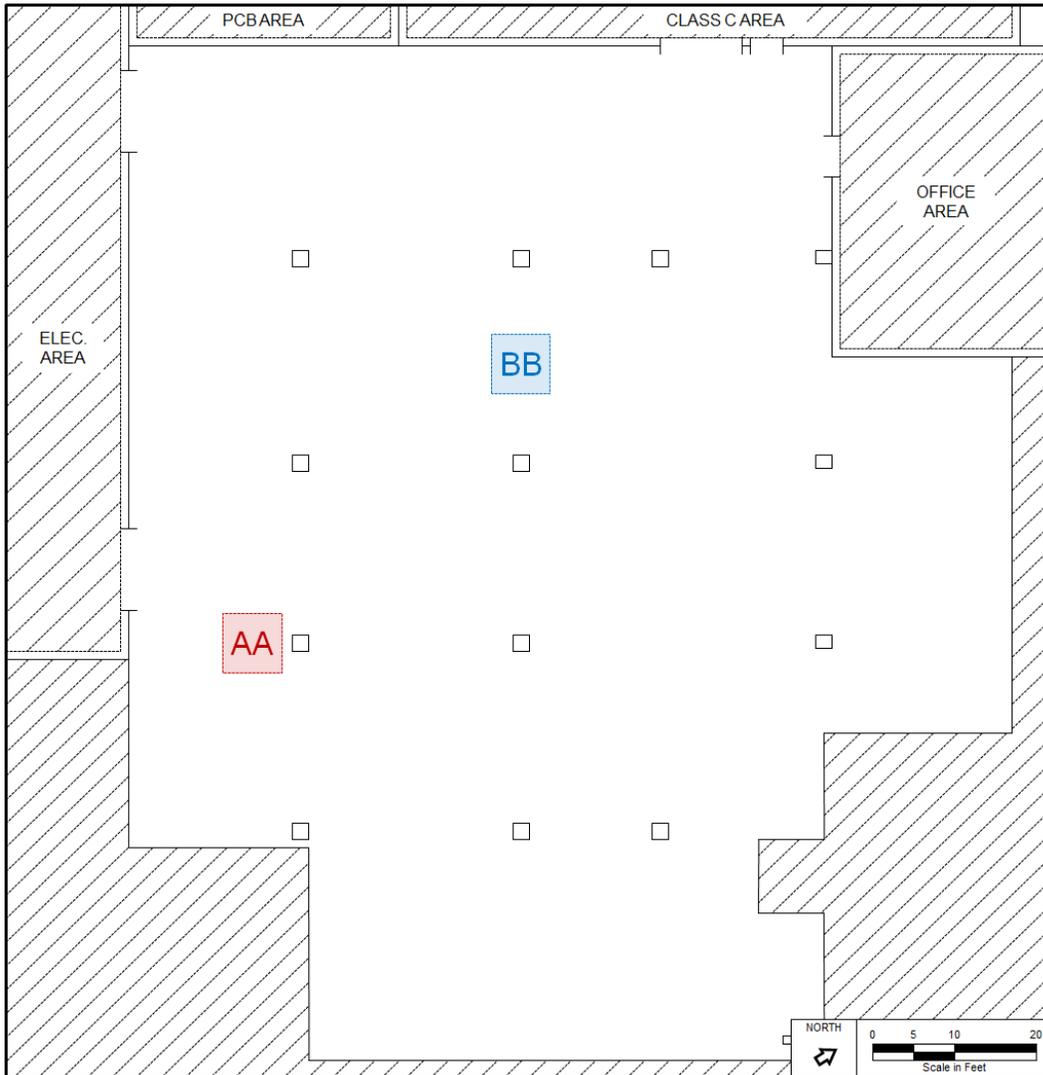
# **APPENDIX A**

## **Testing Location Figures**

**Figure A - 1 – Heated Chamber Test Locations – Class C Area**



**Figure A - 2 – Heated Chamber Test Locations – Battery Area**



**Figure A - 3 – Heated Chamber Test Locations – Electronics Area**

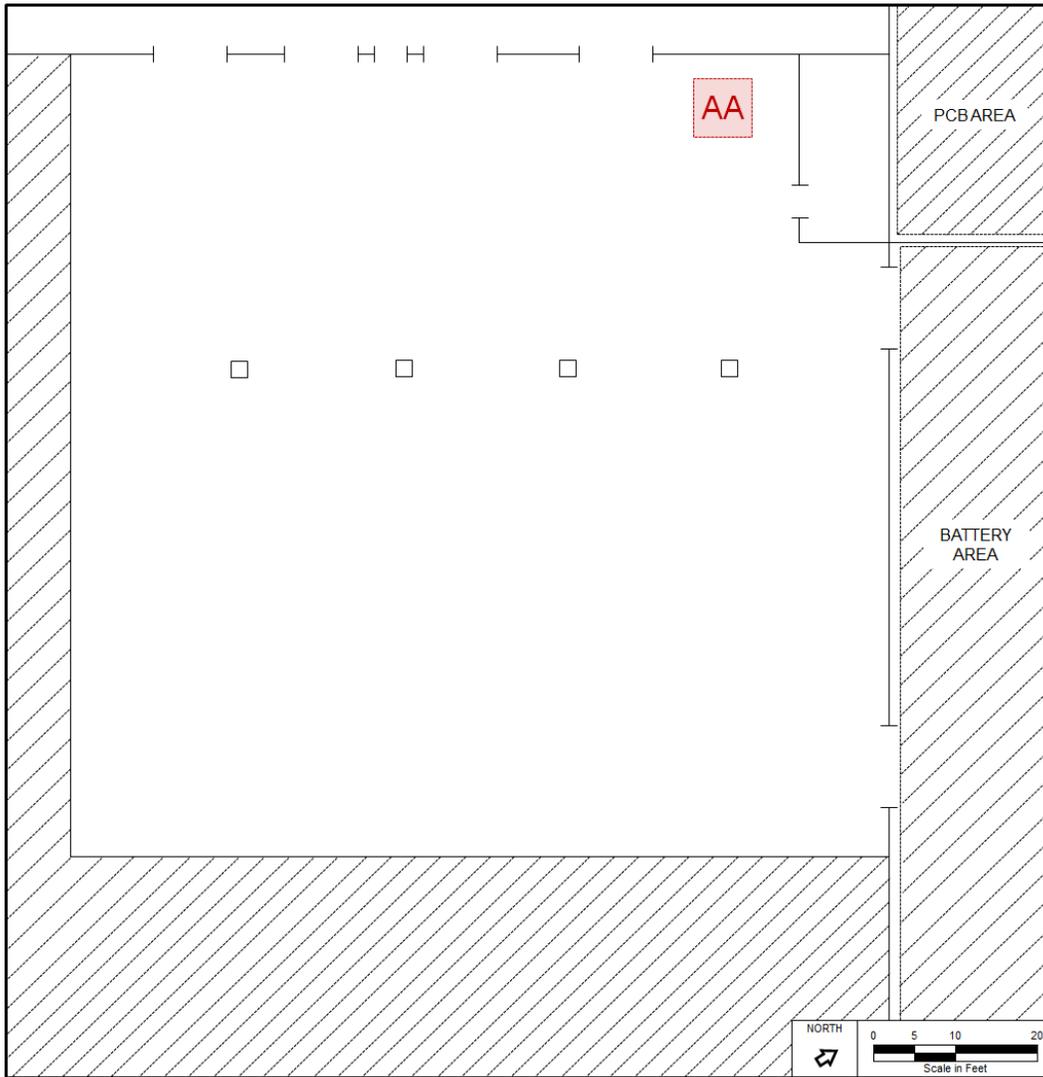


Figure A - 4 – Composite Surface Wipe Locations – Class C Area

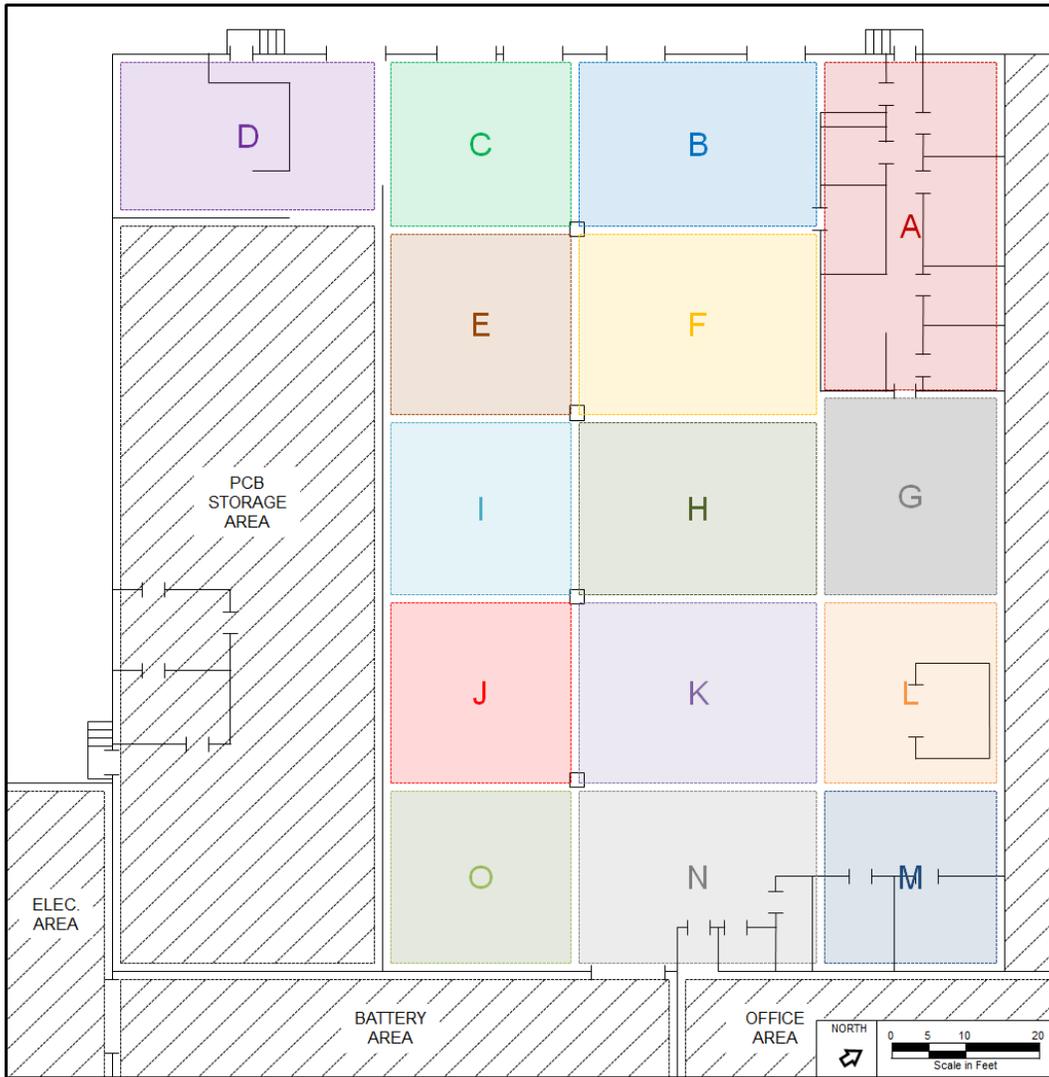
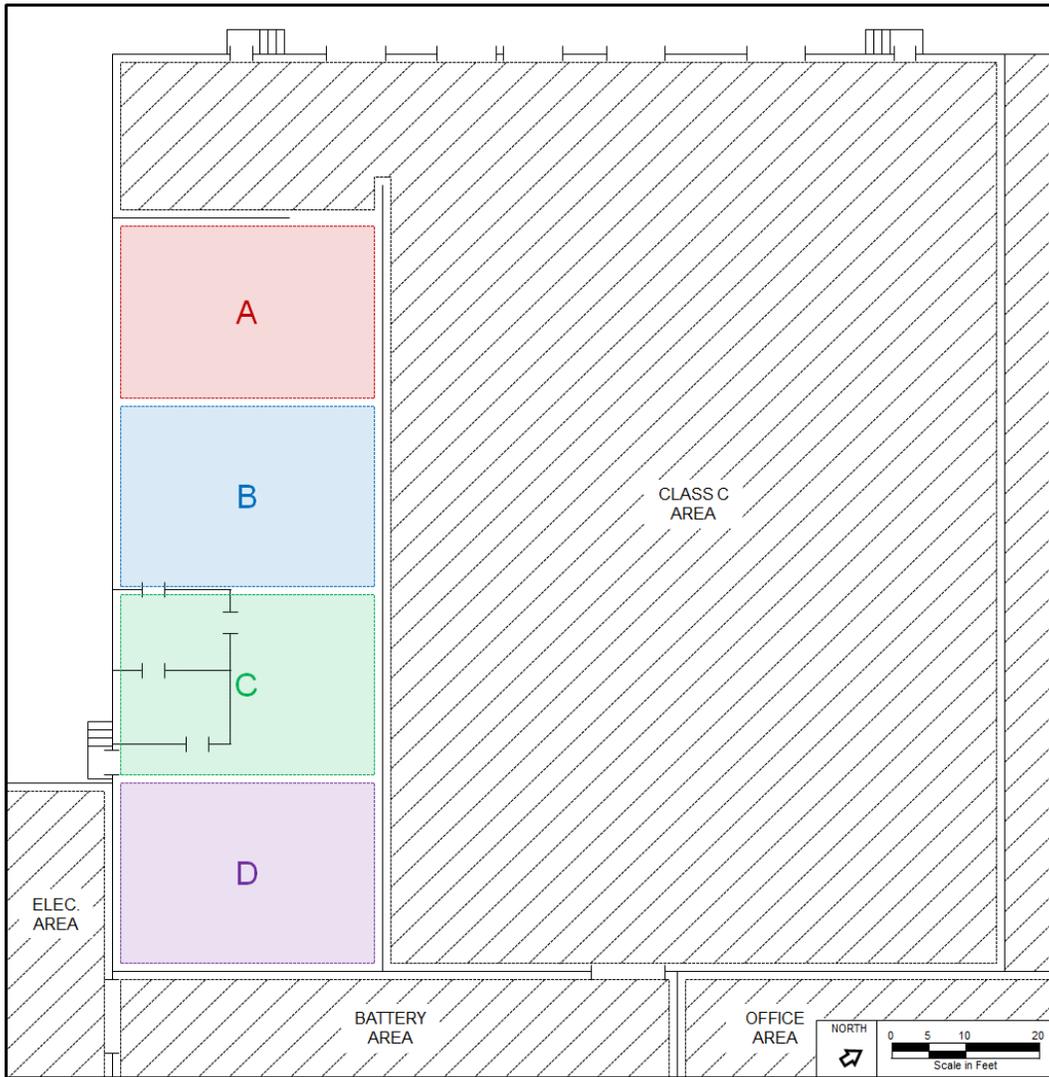


Figure A - 5 – Composite Surface Wipe Locations – PCB Storage Area



**Figure A - 6 – Composite Surface Wipe Locations – Battery Area**

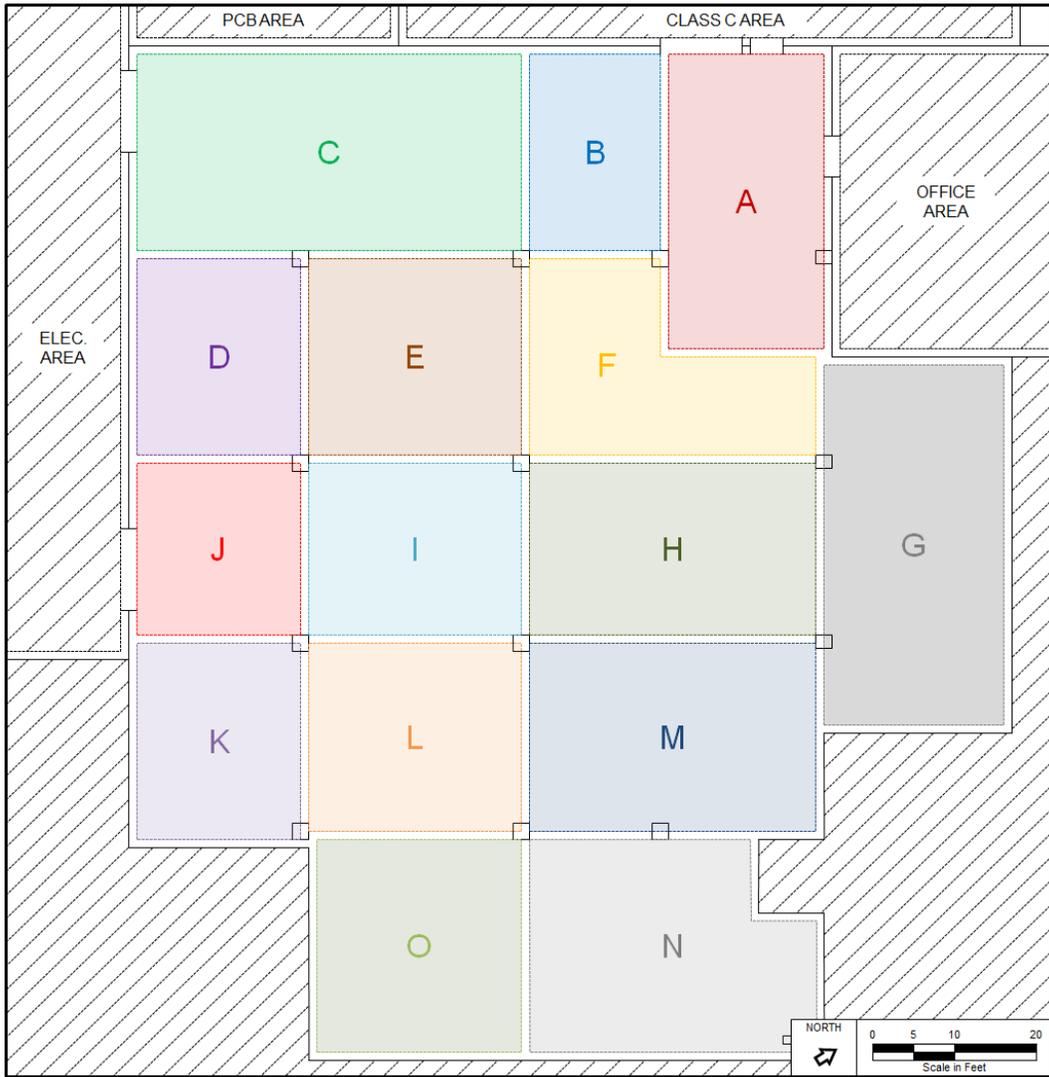
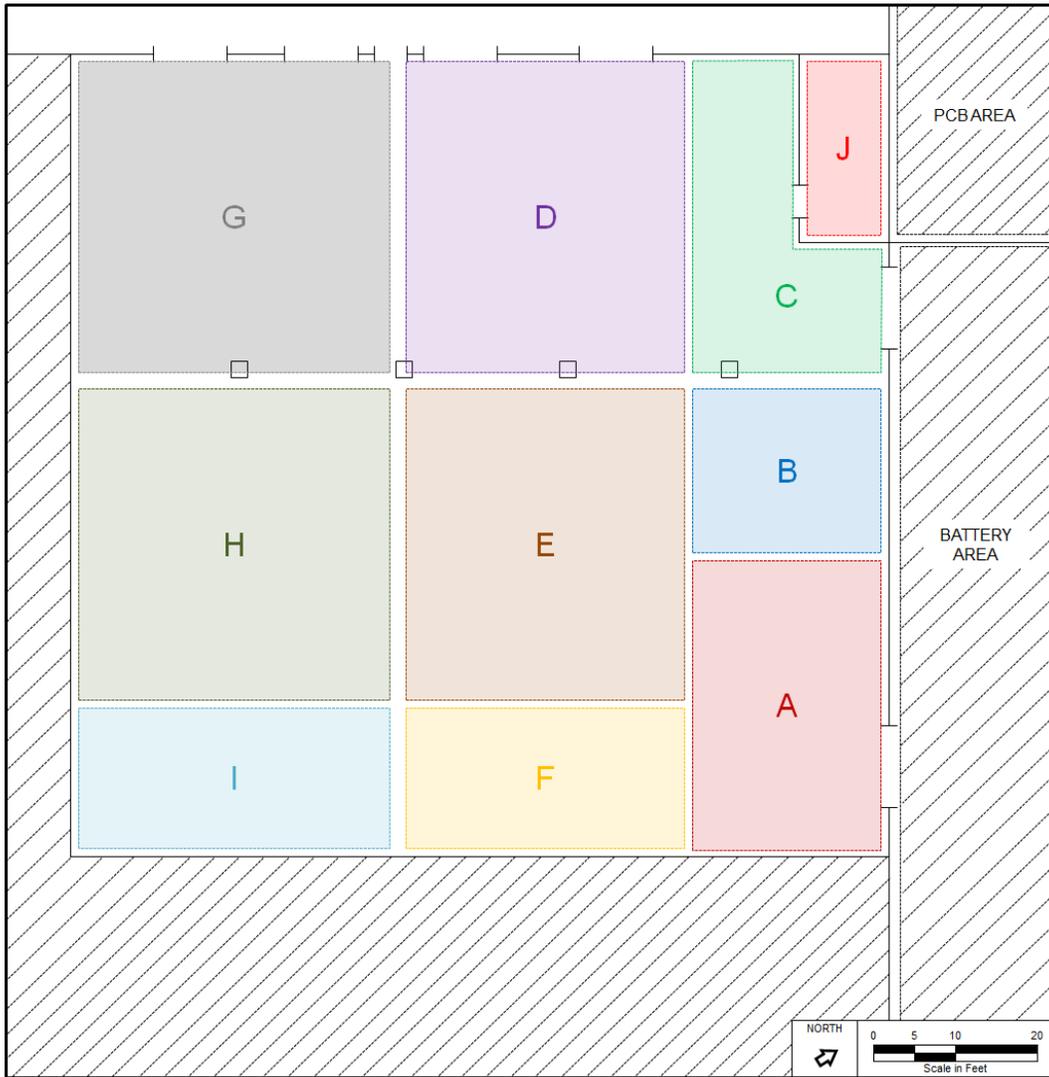


Figure A - 7 – Composite Surface Wipe Locations – Electronics Area



**Figure A - 8 – Composite Surface Wipe Locations – Office Area (3rd Flr.)**

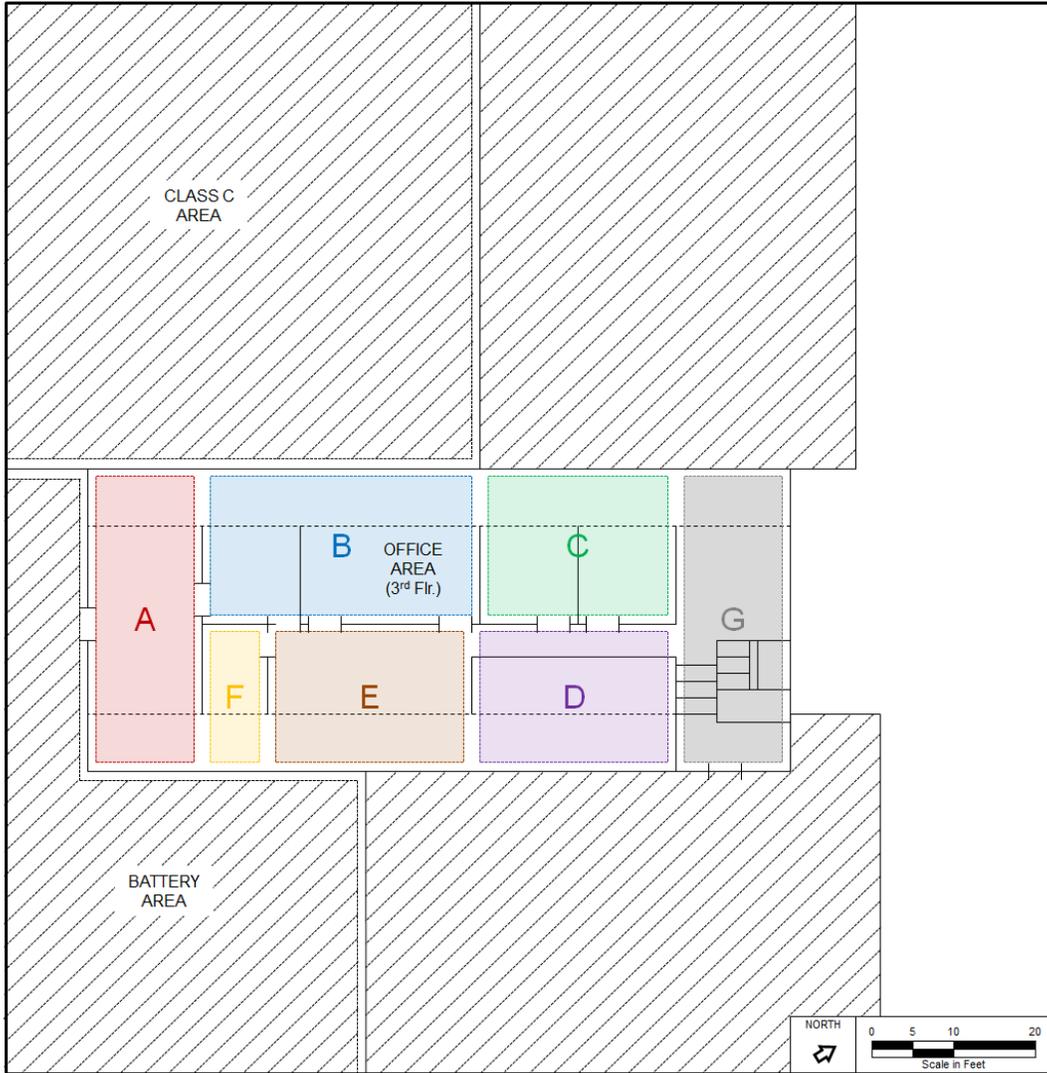


Figure A - 9 – Composite Surface Wipe Locations – Office Area (2nd Flr.)

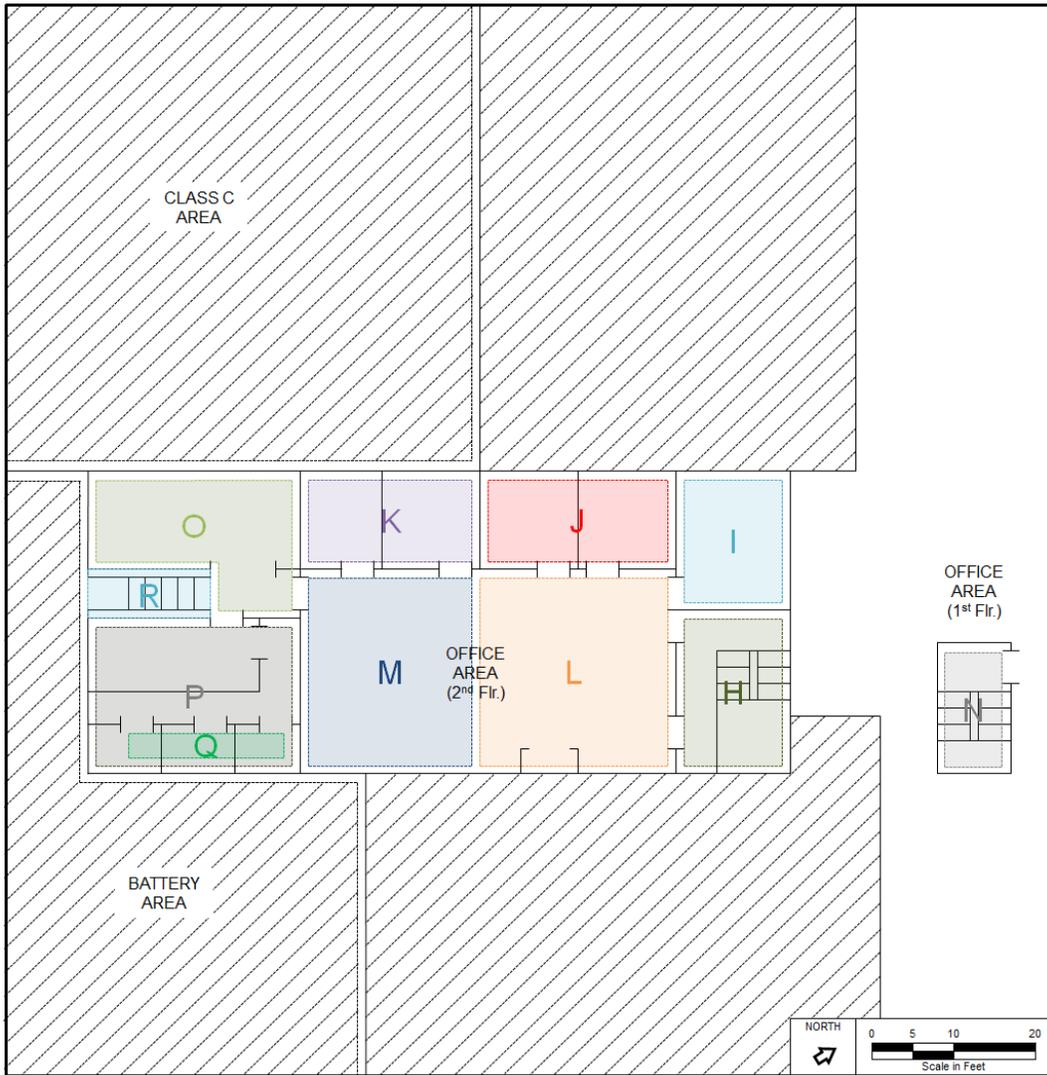


Figure A - 10 – Individual Surface Wipe Locations – Class C Area

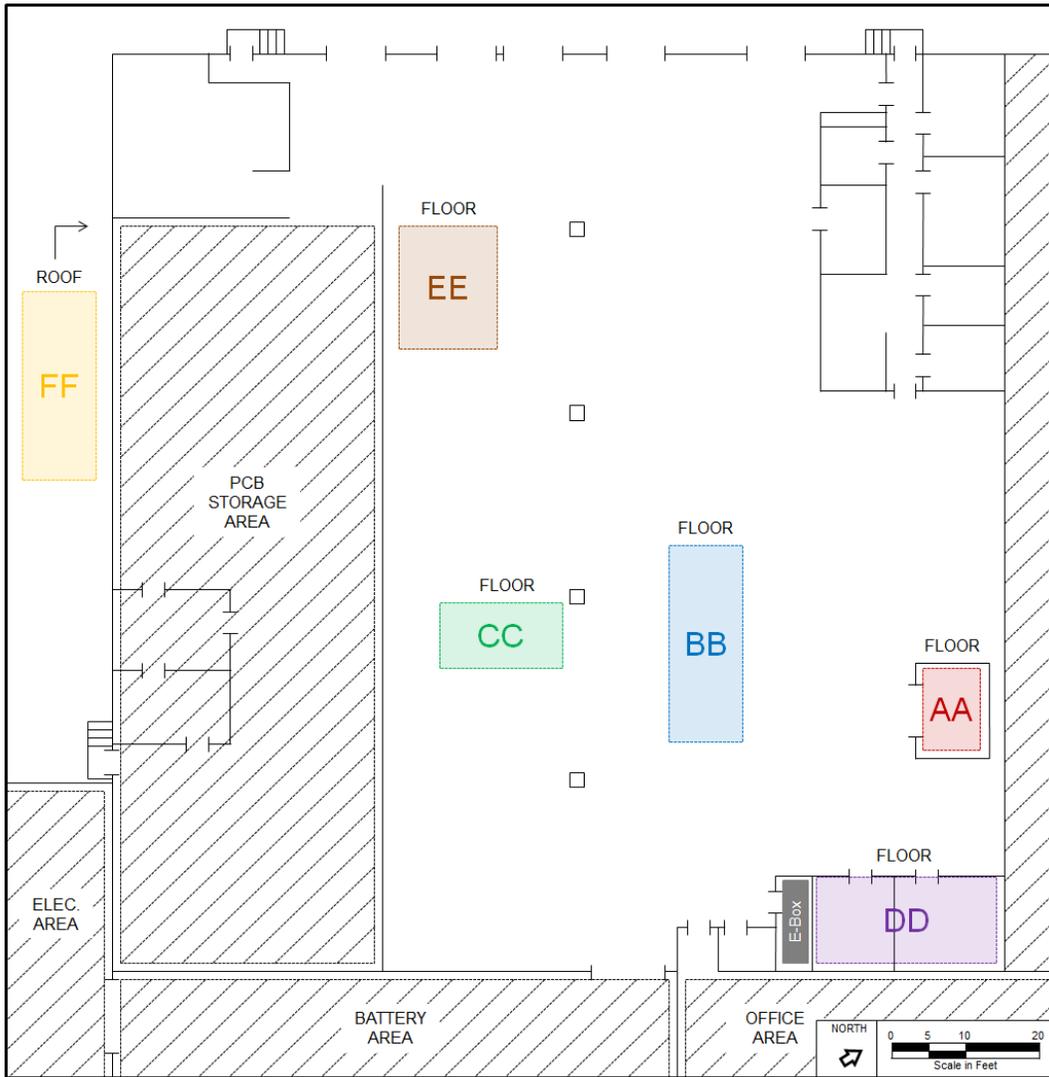
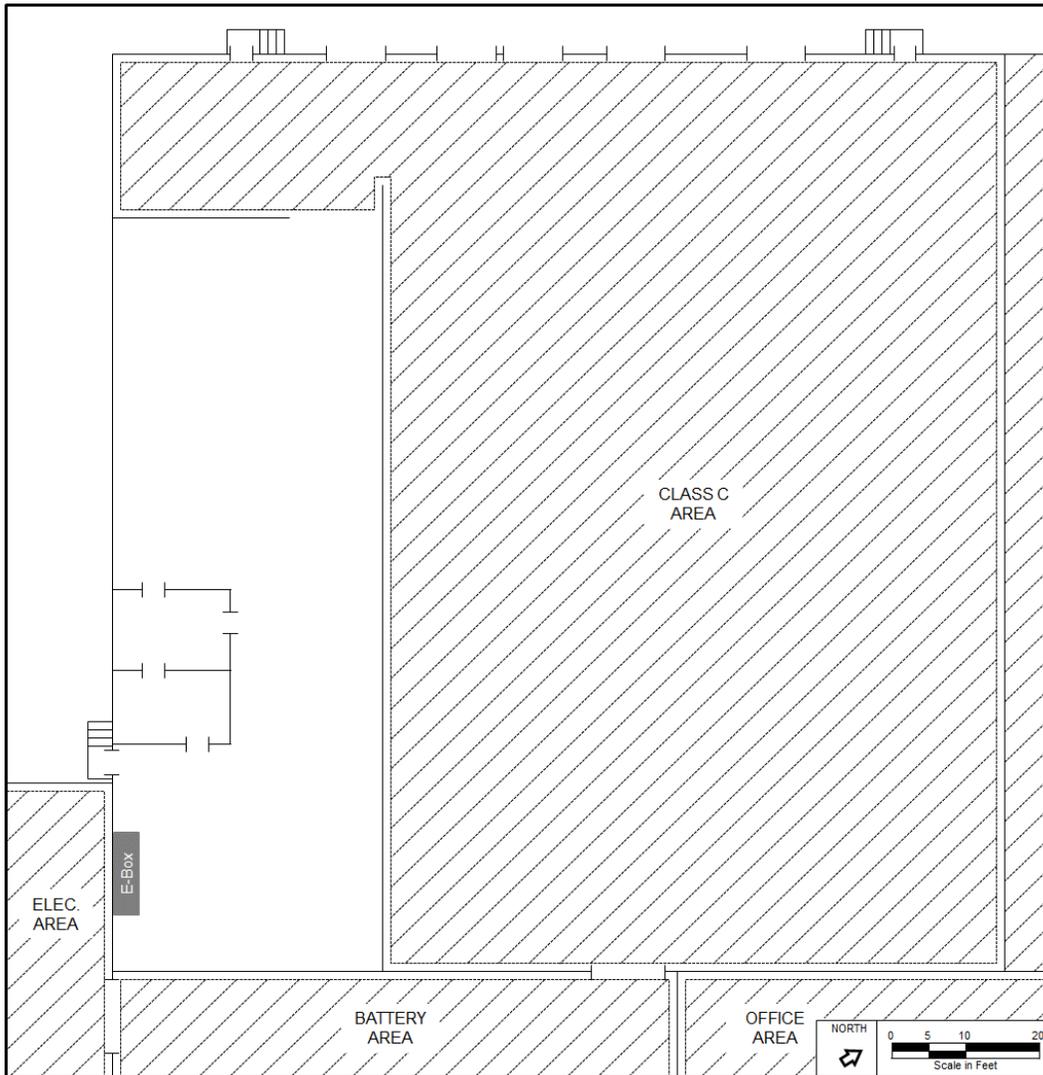
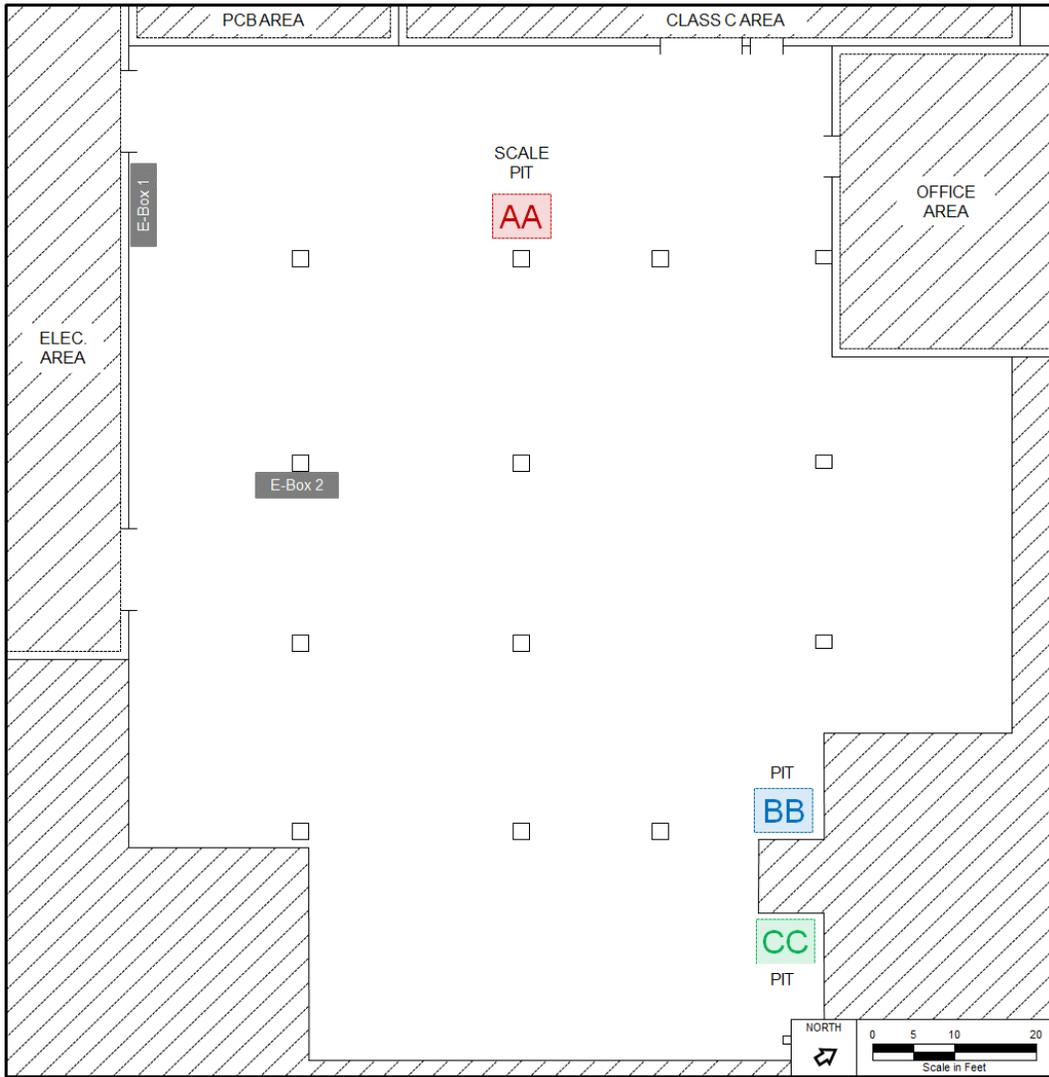


Figure A - 11 – Individual Surface Wipe Locations – PCB Storage Area



**Figure A - 12 – Individual Surface Wipe Locations – Battery Area**



**Figure A - 13 – Individual Surface Wipe Locations – Electronics Area**

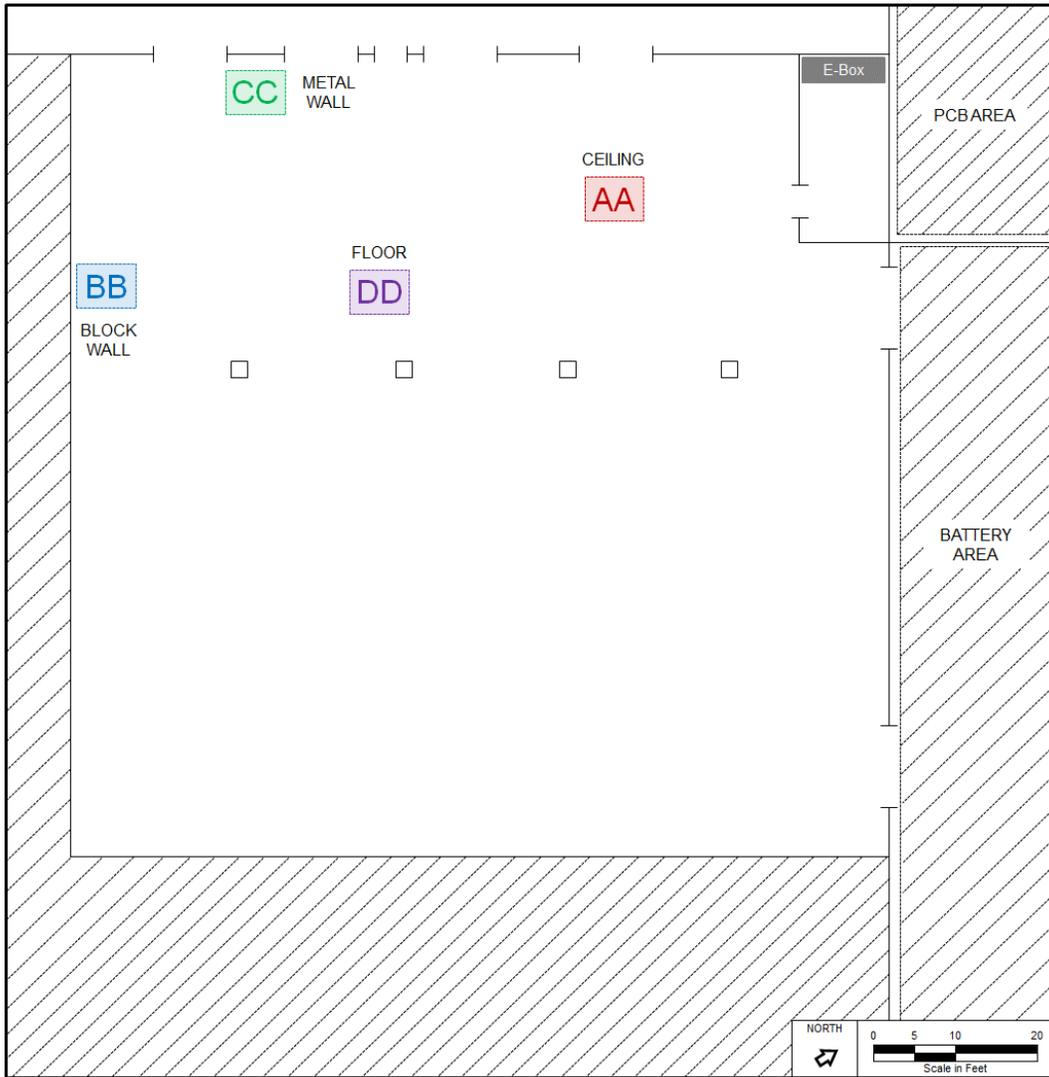


Figure A - 14 – Individual Surface Wipe Locations – Office Area (3rd Flr.)

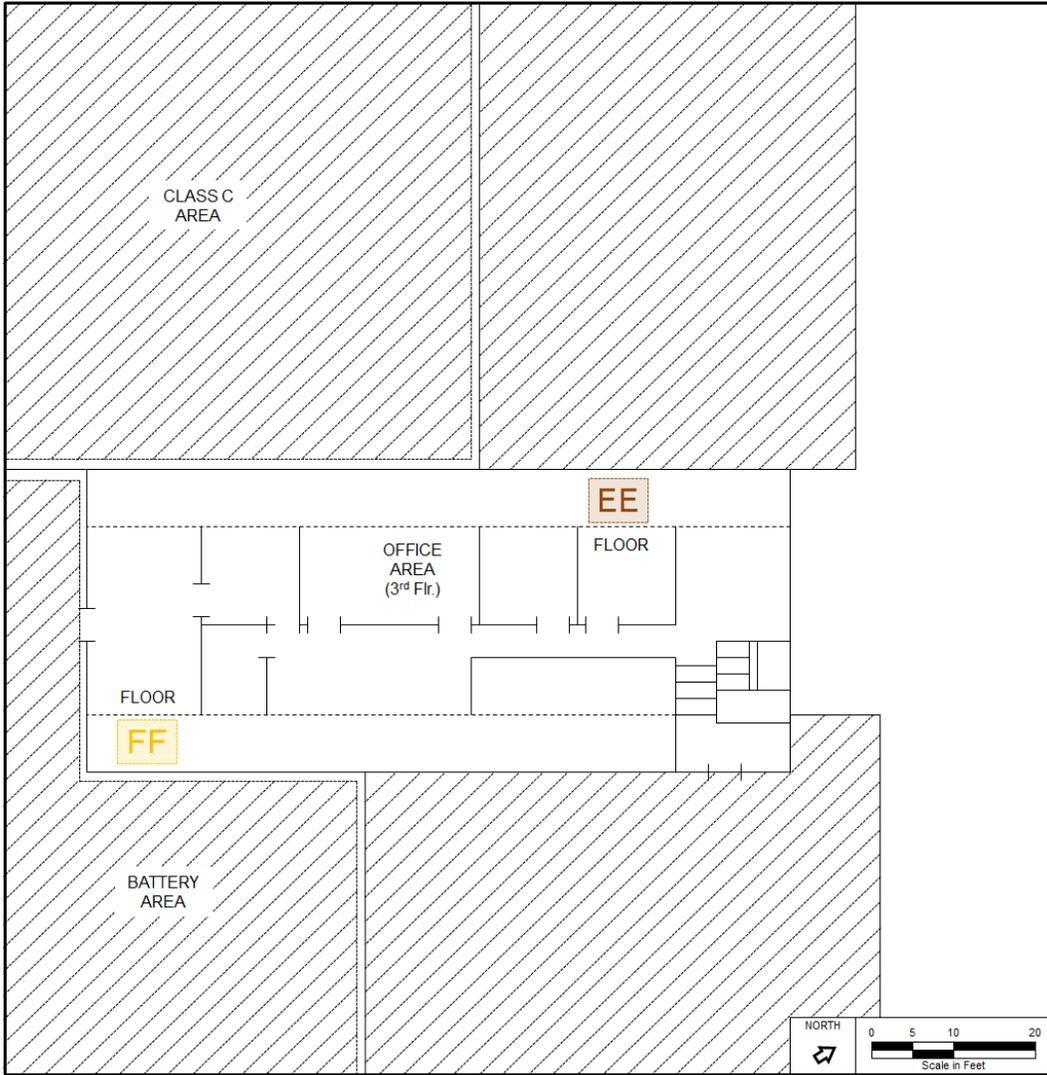


Figure A - 15 – Individual Surface Wipe Locations – Office Area (2nd Flr.)

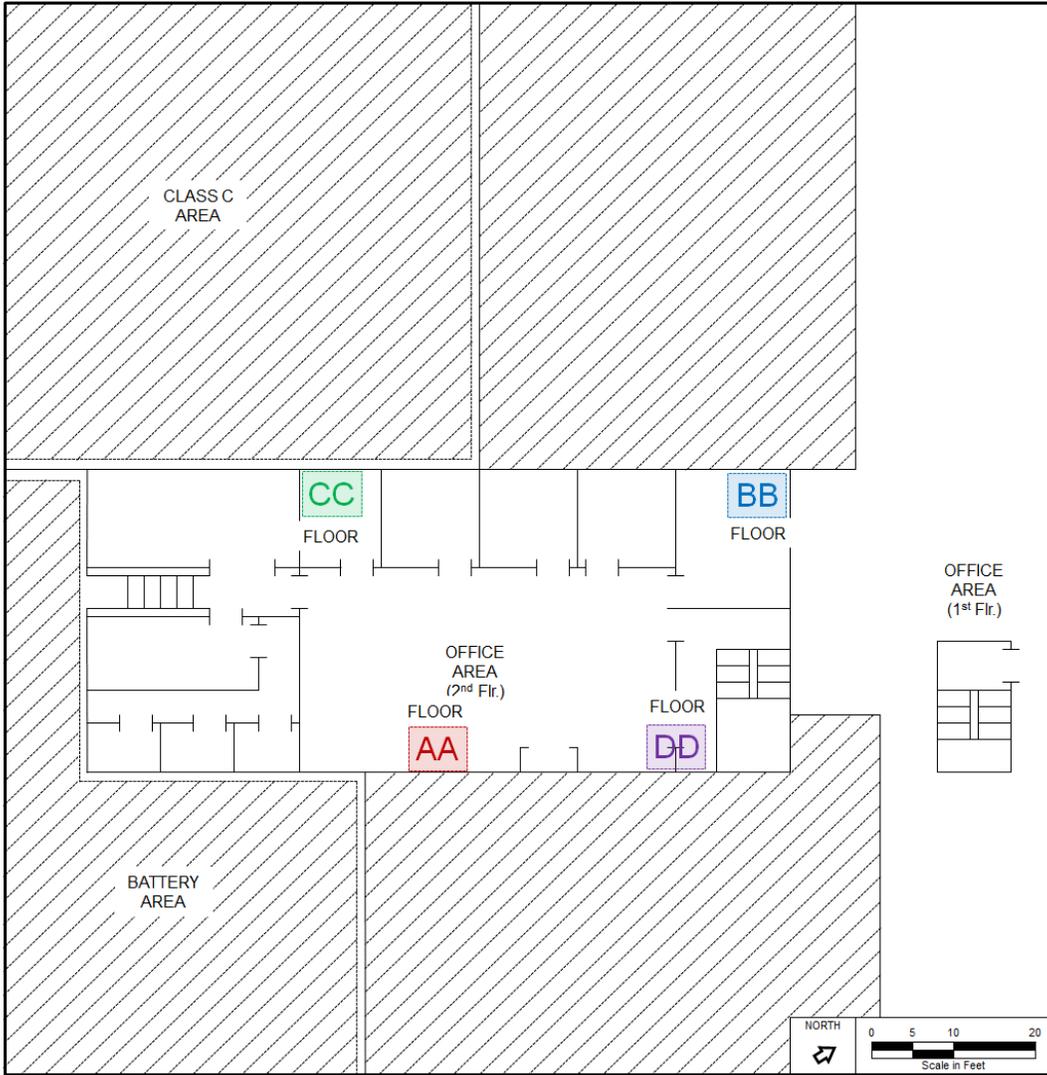
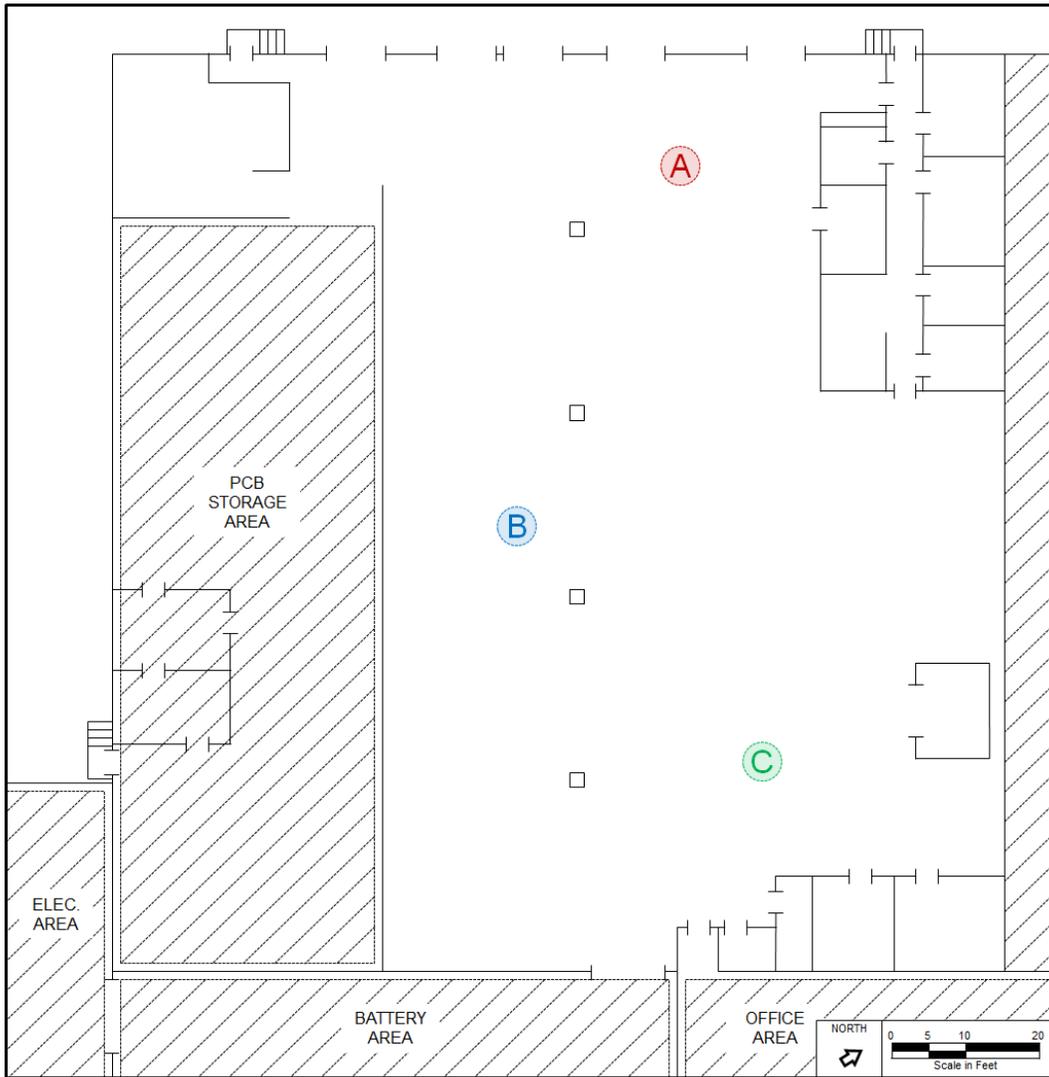
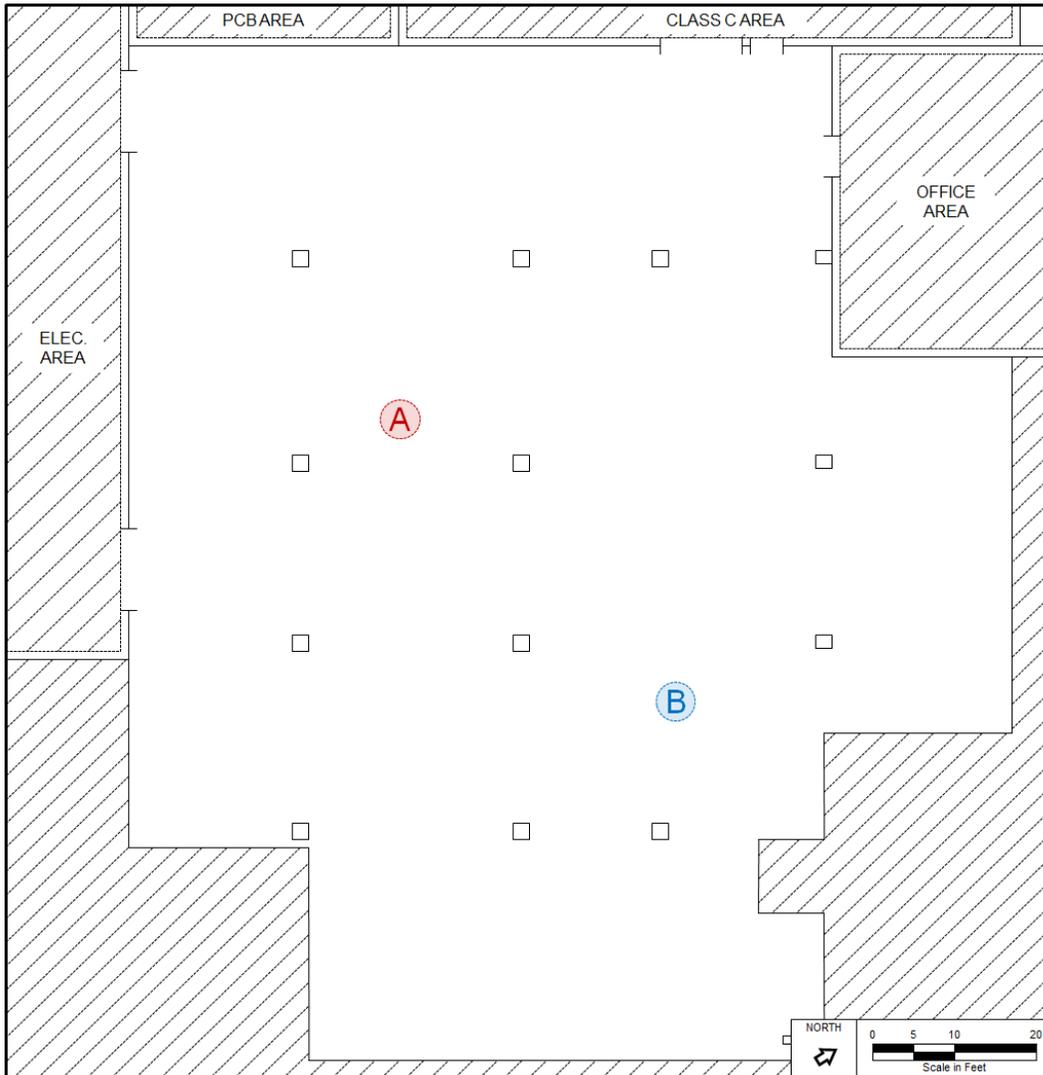


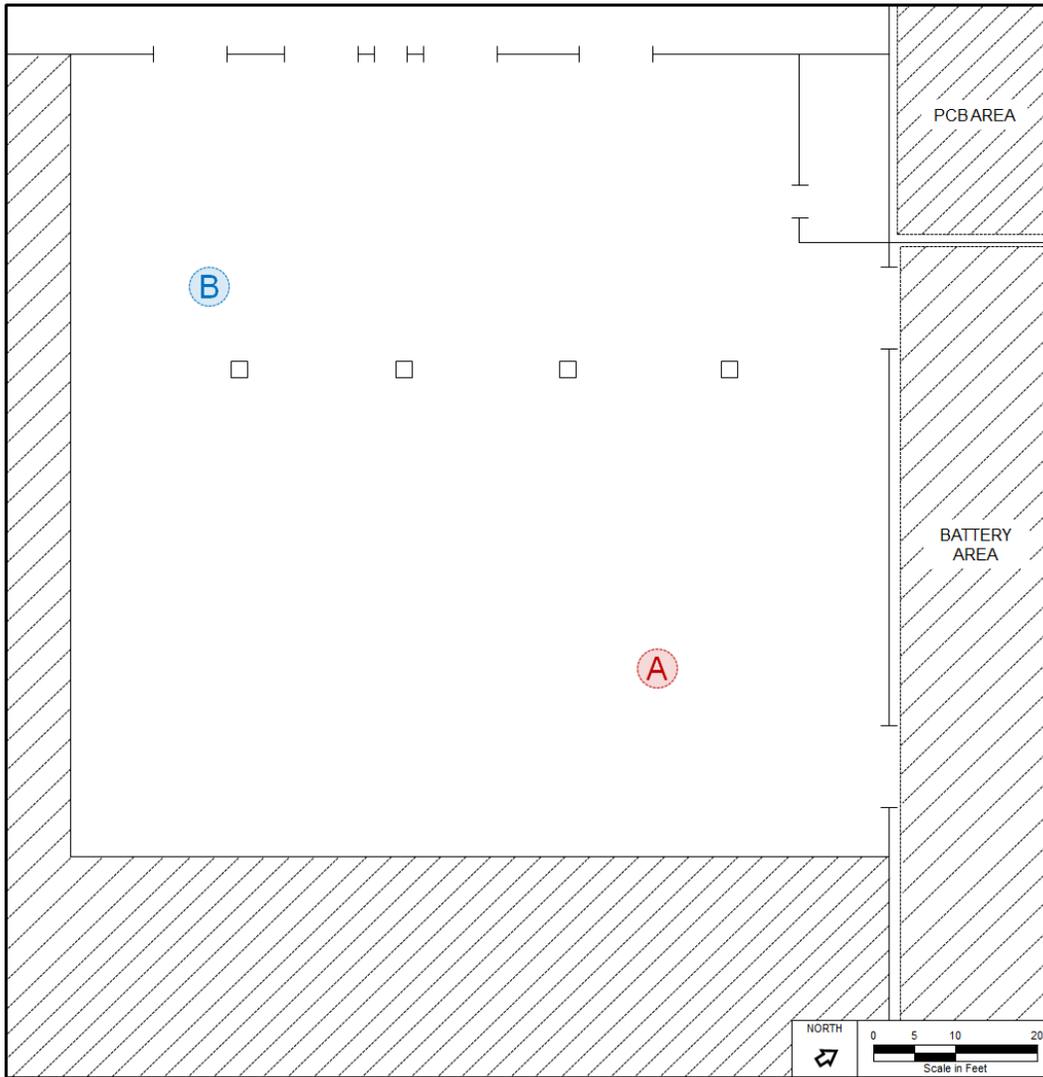
Figure A - 16 – Indoor Air Quality Locations – Class C Area



**Figure A - 17 – Indoor Air Quality Locations – Battery Area**



**Figure A - 18 – Indoor Air Quality Locations – Electronics Area**



**Figure A - 19 – Indoor Air Quality Locations – Office Area (3rd Flr.)**

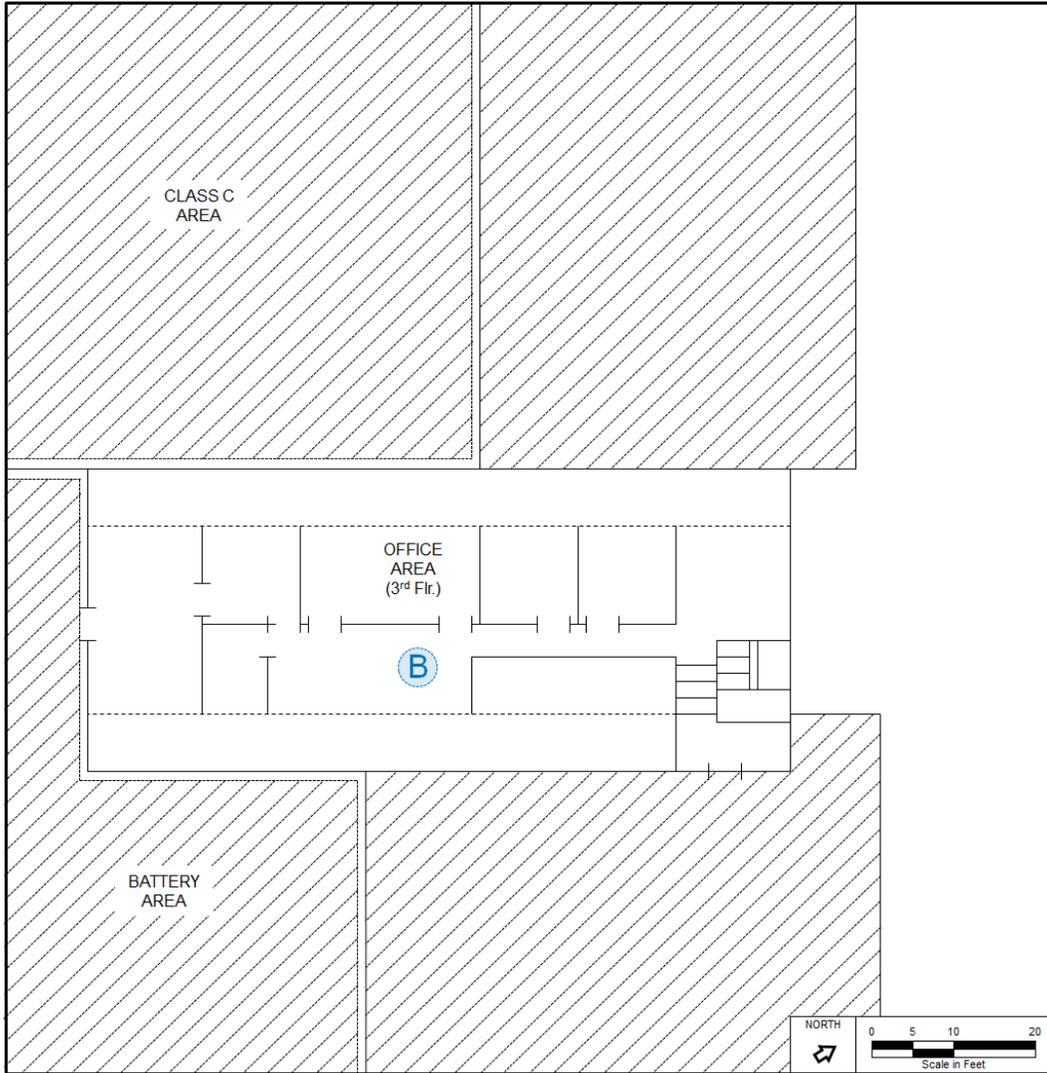


Figure A - 20 – Indoor Air Quality Locations – Office Area (2nd Flr.)

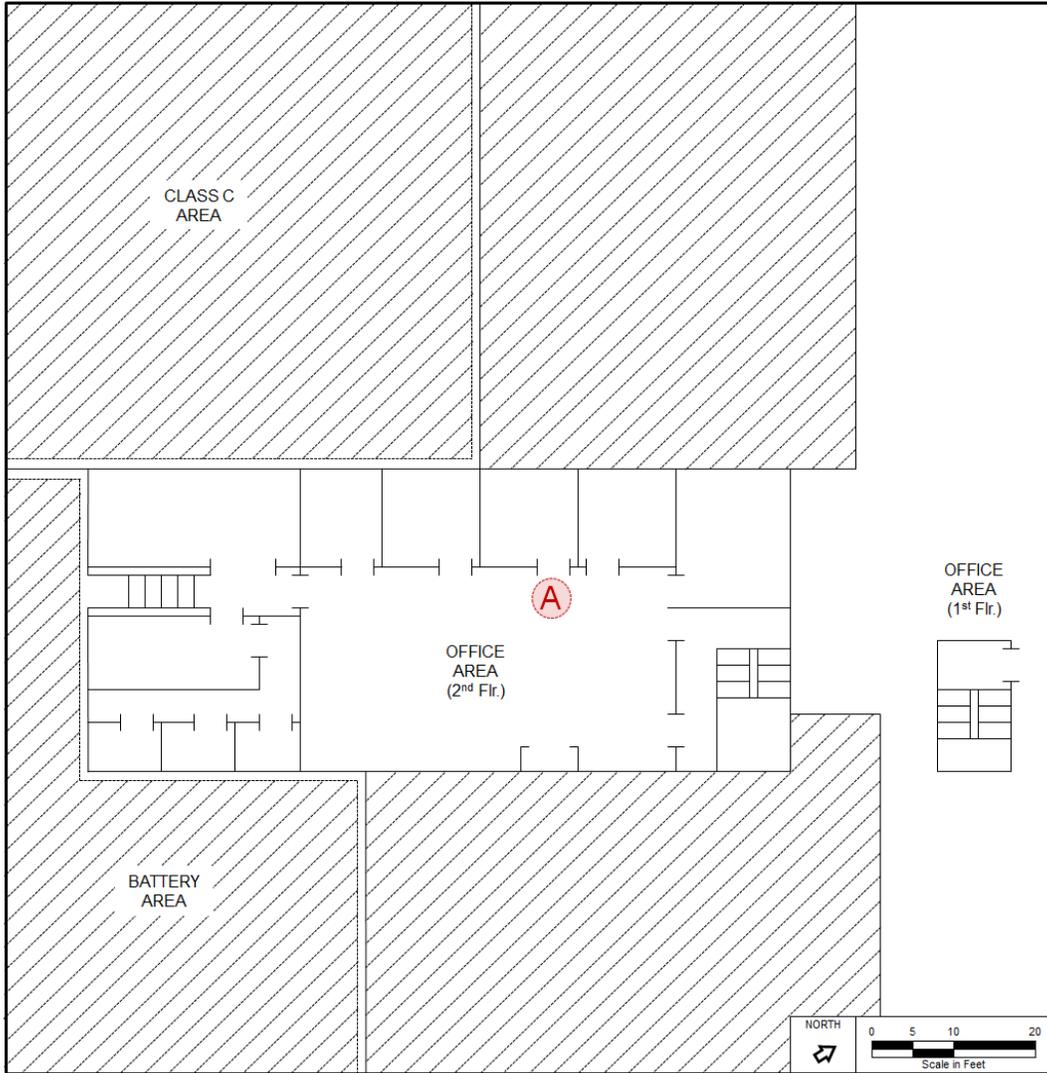
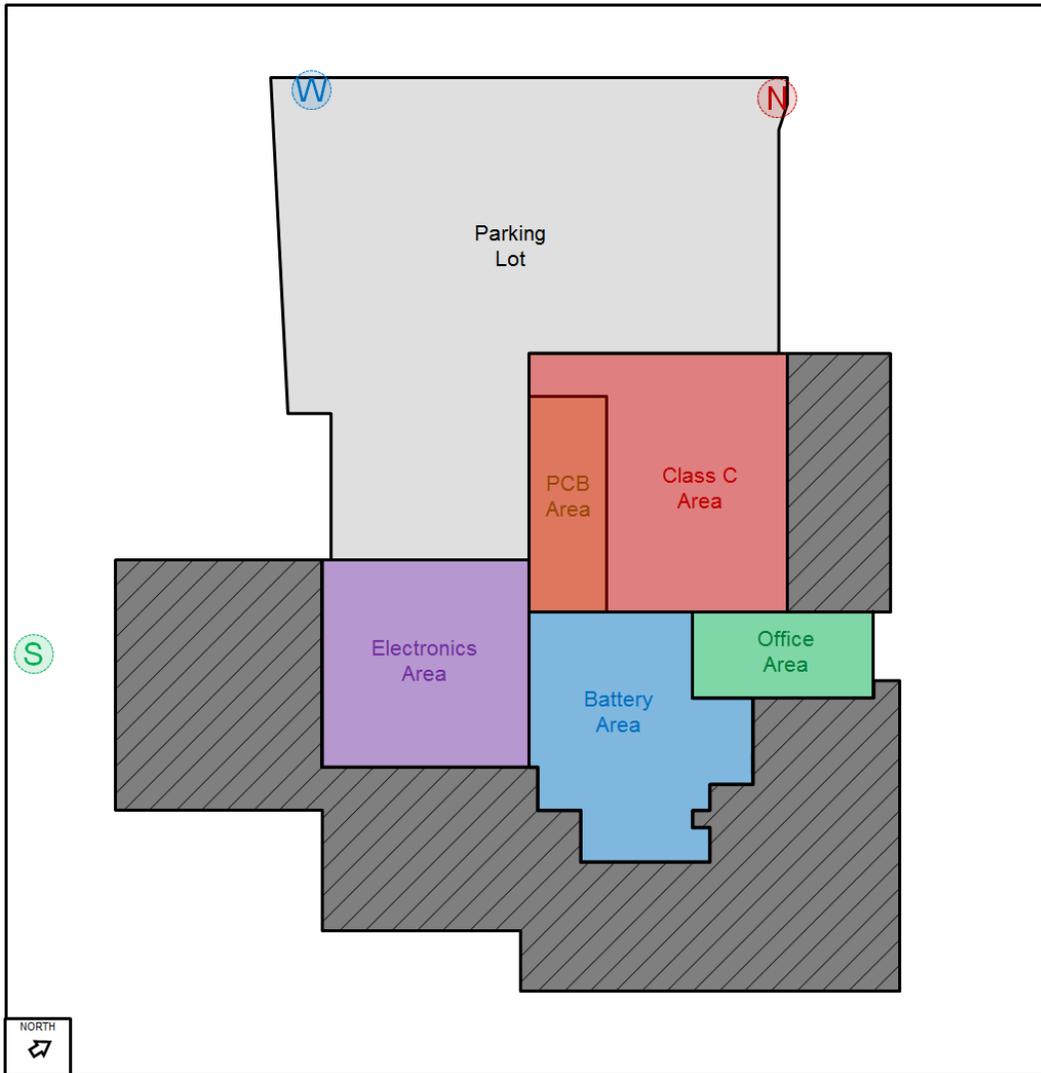


Figure A - 21 – Outdoor / Background Air Quality Locations



## **APPENDIX B**

### **Development of Acceptance Criteria Limits**

## **DEVELOPMENT OF ACCEPTANCE CRITERIA**

The following appendix provides discussion of the selected decontamination and cleanliness clearance limits (i.e. acceptance criteria) established for mercury and presented in Section 2.2 (see Table 3, page 14). In general, the mercury related acceptance criteria values were developed by the Engineer at the outset of the project.

### ***CLOSURE CLEANLINESS OBJECTIVES***

As mentioned in Section 2.2 (page 13), the main objective of the facility closure activities was to decontaminate and clean surfaces to a point where they were free of any hazardous contamination (i.e. clean closure). The premise of clean closure is that all hazardous contaminants have been removed from a given facility and any releases from the facility have been remediated such that further regulatory control is not necessary to protect human health and the environment (Cotsworth 1998) By extension then, the idealized goal of clean closure would be to select sampling methods with very low limits of detection (“LOD”) for the contaminants of concern; and after decontamination, collect post-clean samples which had results that were below these analytical LODs. Although this was essentially the goal for the facility closure, it was generally considered not practical, nor possible, to clean every surface of the building such that this ideal scenario was met – that is, all cleanliness verification sampling results below their respective LODs, or below background levels. Instead, a more realistic and feasible approach for closure was to establish closure acceptance criteria values, which if met, would potentially leave residual contamination in place but at low enough levels to not pose any risk to human health or the environment.

Additionally, when establishing cleanliness objectives, the Engineer considered site-specific concerns and areas of focus. These included the following:

- Type of contamination – that is, elemental and inorganic mercury,
- Form of contamination – that is, surface and indoor air quality,
- Area of most concern – that is, the concrete floor in Class C Area,
- Sampling methods – that is, surface wipe, and direct-read and passive-badge mercury vapor monitoring.

In accordance with these clean closure requirements, the Engineer established acceptance criteria limits which could be achieved in a practical manner by implementing proper and appropriate, albeit labor intensive, cleaning efforts; while allowing for some error and variance in sampling and analysis methods, and still be considered sufficiently protective of the environment and human health. At the outset of this project the acceptance criteria values were reviewed, presented and justified to the regulatory agency with jurisdiction. The project-specific surface contamination limits for the closure of the facility were presented in Table 3 (see page 14). It was the professional opinion of the project Engineer that if decontamination verification sampling results were less than the established acceptance criteria limits, then the facility should be considered sufficiently clean and free of hazardous contamination, such that it could be reoccupied without limitation, restriction or reservation.

Additionally, the Engineer establish other project- and chemical-specific acceptance criteria limits for other toxic compounds that were potentially associated with the Owner's recycling process (in addition to mercury), these

included: PCB, arsenic, cadmium, chromium, lead, barium, silver, selenium, antimony and yttrium. The acceptance criteria for these other compounds were either dictated by regulation (e.g. TSCA *High-Occupancy* PCB Clean-up Levels), or developed by the Engineer in a manner which was analogous to the methodologies described in the following sections for establishing the mercury acceptance criteria. Facility closure with respect to these other compounds is considered outside the scope of this thesis, and as such, the methodologies used for developing the mercury acceptance limits only are presented in the sections below.

### ***INDOOR AIR QUALITY ACCEPTANCE CRITERIA***

When developing the indoor air quality clearance sampling acceptance criteria for this project, the Engineer referred primarily to the information published by the U.S. Department of Health and Human Services: Agency for Toxic Substances and Disease Registry (“ATSDR”), and the U.S. EPA.

The ATSDR established various Minimal Risk Levels (“MRLs”) for different types of mercury exposures. While the MRL for mercury should be considered neither a threshold for toxicity, nor a level beyond which toxicity is likely to occur, it does provide a basis for setting exposure levels at which no health risk to any element of the human population is likely to occur. The ATSDR established a chronic inhalation MRL of 0.2  $\mu\text{g}/\text{m}^3$  for elemental mercury vapor. Assuming a ventilation rate (i.e. breathing rate) of 20  $\text{m}^3/\text{day}$  for an average adult, and assuming complete absorption, exposure at this level would result in a daily dose of 4  $\mu\text{g}$ . This level of exposure is thought to represent no health risk to any element of the human population (ATSDR 1999).

Similarly, the EPA established a Reference Concentration for Chronic Inhalation Exposure (“RfC”) of  $0.3 \mu\text{g}/\text{m}^3$  for elemental mercury vapor (daily dose of  $6 \mu\text{g}$ ). Like the ATSDR’s MRLs, the EPA’s RfC is an estimate of the daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effect during the course of an entire lifetime (EPA 1995).

For comparison purposes, the WHO estimates that dental amalgams contribute approximately  $10 \mu\text{g}$  of mercury per day to humans who have a significant number of fillings (WHO 1991). This equates to breathing a continuous airborne concentration of  $0.5 \mu\text{g}/\text{m}^3$  of elemental mercury vapor, assuming a daily breathing rate of  $20 \text{m}^3/\text{day}$ , which is the EPA’s standard ventilation rate (Fields, 1991). And, no credible evidence exists which suggests the mercury exposure associated with dental amalgams represents a health risk (Bellinger 2006; DeRouen 2006).

Both ATSDR’s and EPA’s “no risk” guideline values (i.e. MRL and RfC) for inhalation of elemental mercury were developed based on a 1983 study of workplace exposures, which presented a Lowest Observed Adverse Effect Level (“LOAEL”) of  $26 \mu\text{g}/\text{m}^3$  for mercury vapor (Fawer 1983). In developing the MRL and the RfC, ATSDR and EPA adjusted the workplace exposure value presented by Fawer from a 40-hour to a 168-hour exposure period, and included additional safety / uncertainty factors to account for potential human variability. The lowest concentration of mercury reported in the scientific literature considered to be associated with adverse was  $10 \mu\text{g}/\text{m}^3$  (Ngim 1992). This study was essentially a survey of dentists, nurses and aides who worked with dental amalgams that contained mercury for 8 – 10 hours per day during a 6-day work week. While both ATSDR and EPA did not use the value present by Ngim in developing their

respective guideline values, both agencies agree that Ngim is an essential supporting study (ATSDR 1999; EPA 1995).

As described in Appendix B, it was generally considered impossible to clean the entire facility in order to make the indoor air concentration meet the MRL or RfC values; as this would require removing virtually every nanoparticle of mercury. Given the extraordinary measures required to remove enough mercury to reach these concentrations, the human health benefit of such a removal action may not always be warranted by the threat (ATSDR 2012). In general, the closer air levels are to the MRL / RfC values, the less likely any exposure is to cause adverse health effects. [MRL = 0.2  $\mu\text{g}/\text{m}^3$  (ATSDR 1999) and RfC = 0.3  $\mu\text{g}/\text{m}^3$  (EPA 1995)]. The closer the air levels are to the lowest concentrations known to cause any level of harm to humans, the more likely any exposure is to cause harm. [LOAEL = 26  $\mu\text{g}/\text{m}^3$  (Fawer 1983) and 10  $\mu\text{g}/\text{m}^3$  (Ngim 1992)].

Historically, ATSDR has recommended 1.0  $\mu\text{g}/\text{m}^3$  as the residential indoor air concentration cleanup level which sufficiently minimizes the risk associated with continuous mercury vapor exposure (ATSDR 2012). However, this concentration was considered unnecessarily stringent for this particular project, as the facility undergoing closure will never conceivably be used as a residential space.

Instead, the Engineer selected ATSDR's 3.0  $\mu\text{g}/\text{m}^3$  recommended indoor air quality cleanup level for school and educational settings as the acceptance criteria level for the facility (ATSDR 2012). The ATSDR's School Acceptance Criteria Value (S-ACV) was selected as the most appropriate indoor air quality cleanup objective because the facility could conceivably operate in the future as an indoor playground or daycare center, which would match the 8-10 hour sensitive person

(i.e. children) exposure expected in a school. The facility would never be considered appropriate for residential space. The ATSDR’s S-ACV is based on the residential action level (i.e. 1.0 µg/m<sup>3</sup>), but adjusted for a workplace exposure – that is, a 24/7 continuous exposure reduced to 8/5 workweek exposure.

The following table provides a summary of how the selected indoor air quality mercury vapor acceptance criteria value of 3.0 µg/m<sup>3</sup> compares to various guideline and regulatory values.

**Table B1 – Mercury Vapor Acceptance Criteria Value Comparisons**

| Criteria Value               | Mercury Vapor Concentration (µg/m <sup>3</sup> ) | Ratio to Project Acceptance Value |
|------------------------------|--|-----------------------------------|
| OSHA PEL CEIL <sup>[1]</sup> | 100  | 33.3                              |
| NIOSH REL <sup>[2]</sup>     | 50   | 16.7                              |
| LOAEL (Fawer) <sup>[3]</sup> | 26   | 8.7                               |
| ACGIH TLV <sup>[4]</sup>     | 25   | 8.3                               |
| LOAEL (Ngim) <sup>[3]</sup>  | 10   | 3.3                               |
| ATSDR S-ACV <sup>[5]</sup>   | 3.0  | 1.0                               |
| <b>PROJECT AIR QUALITY</b>   | <b>3.0</b>                                       | <b>1.0</b>                        |
| ATSDR R-ACV <sup>[6]</sup>   | 1.0  | 0.3                               |
| EPA RfC <sup>[7]</sup>       | 0.3  | 0.1                               |
| ATSDR MRL <sup>[8]</sup>     | 0.2  | 0.1                               |

Table Footnotes:

<sup>[1]</sup> U.S. Occupational Safety and Health Administration (“OSHA”) Permissible Exposure Limit (“PEL”) Acceptable Ceiling Value (“CEIL”) is the legal limit for instantaneous mercury vapor concentration exposure, assessed as a 15-minute time-weighted average (“TWA”) exposure which shall not be exceeded at any time during an 8-hour work day.

<sup>[2]</sup> National Institute of Occupational Safety and Health (“NIOSH”) Recommended Exposure Limit (“REL”) is the TWA indoor air concentration value which is recommended not to be exceeded for up to a 10-hour work day during a 40-hour work week.

<sup>[3]</sup> Lowest Observed Adverse Effect Level (“LOAEL”) is the TWA value based on a chronic occupational exposure found to cause an adverse effect in humans.

<sup>[4]</sup> American Congress of Governmental Industrial Hygienists (“ACGIH”) Threshold Limit Value (“TLV”) is the TWA mercury vapor concentration value recommended not to be exceeded for up to an 8-hour work day during a 40-hour work week.

<sup>[5]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) School Acceptance Criteria Value (“S-ACV”) is the indoor air quality level for mercury vapor at which schools and other educational institutions are recommended to resume normal operations.

<sup>[6]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) Residential Acceptance Criteria Value (“R-ACV”) is the recommended residential indoor air quality cleanup level.

<sup>[7]</sup> U.S. Environmental Protection Agency (“EPA”) Reference Concentration for Chronic Inhalation Exposure (“RfC”) is the mercury vapor concentration thought to represent no health risk to any element of the human population over an entire lifetime of continuous exposure.

<sup>[8]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) Minimal Risk Level (“MRL”) is the mercury vapor concentration thought to represent no health risk to any element of the human population over an entire lifetime of continuous exposure.

### ***SURFACE CONCENTRATION ACCEPTANCE CRITERIA***

It should be noted that some case studies reported dermal irritation after prolonged contact with mercury (De Capitani 2009), however, this dermal irritation was not determined to cause greater levels of elemental or inorganic mercury absorption (ATSDR 2012). Accordingly, the Engineer established a project-specific surface mercury concentration acceptance criteria limit primarily to protect against ingestion exposure, rather than to protect against dermal exposure.

Like the indoor air quality acceptance criteria value, the surface mercury acceptance criteria limit was established using similar assumptions that the ATSDR and EPA used for formulating their MRL and RfC values for mercury, respectively.

The project Engineer used the following line of reasoning when developing the surface mercury acceptance criteria value listed in Table 3 (i.e. 30 µg/1,000cm<sup>2</sup>).

1. Assume all exposed surfaces in the facility are homogenously contaminated to a level equal to the contaminant's acceptance criteria value (i.e. surface mercury concentration equals 30  $\mu\text{g}/1,000\text{cm}^2$ ).
2. Determine the mass of the contaminant that could potentially be ingested if a person were to consume all the mass in one hundred (100) square centimeters ( $\text{cm}^2$ ), or essentially the size of one (1) adult palm, or two (2) child hands (i.e. total palm mercury equals 3  $\mu\text{g}$ ).
3. Assume frequent daily ingestion of this amount of mercury (i.e. ten (10) daily ingestions of 3  $\mu\text{g}$ , or 30  $\mu\text{g}/\text{day}$ ).
4. Conservatively estimate that 50% of the mercury ingested is absorbed (i.e. daily exposure equals 15  $\mu\text{g}/\text{day}$ ). Realistic ingestion absorption rate is less than 30% (see Table 1, page 8).
5. Compare this daily mass exposure rate to various allowable inhalation mass exposure rates when assuming a standard ventilation rate (i.e. breathing rate) of 20  $\text{m}^3/\text{day}$ .

The following table provides a summary of how the selected surface mercury acceptance criteria value of 30.0  $\mu\text{g}/1,000\text{cm}^2$  compares to equivalent surface mercury concentrations extrapolated from various guideline and regulatory values.

**Table B2 – Mercury Surface Acceptance Criteria Value Comparisons**

| Criteria Value               | Mercury Vapor Conc. ( $\mu\text{g}/\text{m}^3$ ) | Daily Mass Exposure <sup>[9]</sup> ( $\mu\text{g}/\text{day}$ ) | Surface Mercury Conc. <sup>[10]</sup> ( $\mu\text{g}/1,000\text{cm}^2$ ) | Ratio to Project Acceptance Value |
|------------------------------|--|---|--|-----------------------------------|
| OSHA PEL CEIL <sup>[1]</sup> | 100  | 2,000   | 4,000  | 133.3                             |
| NIOSH REL <sup>[2]</sup>     | 50   | 1,000   | 2,000  | 66.7                              |
| LOAEL (Fawer) <sup>[3]</sup> | 26   | 520   | 1,040  | 34.7                              |

| Criteria Value              | Mercury Vapor Conc. ( $\mu\text{g}/\text{m}^3$ ) | Daily Mass Exposure <sup>[9]</sup> ( $\mu\text{g}/\text{day}$ ) | Surface Mercury Conc. <sup>[10]</sup> ( $\mu\text{g}/1,000\text{cm}^2$ ) | Ratio to Project Acceptance Value |
|-----------------------------|--|---|--|-----------------------------------|
| ACGIH TLV <sup>[4]</sup>    | 25   | 500   | 1,000  | 33.3                              |
| LOAEL (Ngim) <sup>[3]</sup> | 10   | 200   | 400  | 13.3                              |
| ATSDR S-ACV <sup>[5]</sup>  | 3.0  | 60  | 120  | 4.0                               |
| ATSDR R-ACV <sup>[6]</sup>  | 1.0  | 20  | 40   | 1.3                               |
| <b>PROJECT SURFACE</b>      | -  | <b>15.0</b>   | <b>30.0</b>  | <b>1.0</b>                        |
| EPA RfC <sup>[7]</sup>      | 0.3  | 6.0   | 12   | 0.4                               |
| ATSDR MRL <sup>[8]</sup>    | 0.2  | 4.0   | 8.0  | 0.3                               |

Table Footnotes:

<sup>[1]</sup> U.S. Occupational Safety and Health Administration (“OSHA”) Permissible Exposure Limit (“PEL”) Acceptable Ceiling Value (“CEIL”) is the legal limit for instantaneous mercury vapor concentration exposure, assessed as a 15-minute time-weighted average (“TWA”) exposure which shall not be exceeded at any time during an 8-hour work day.

<sup>[2]</sup> National Institute of Occupational Safety and Health (“NIOSH”) Recommended Exposure Limit (“REL”) is the TWA indoor air concentration value which is recommended not to be exceeded for up to a 10-hour work day during a 40-hour work week.

<sup>[3]</sup> Lowest Observed Adverse Effect Level (“LOAEL”) is the TWA value based on a chronic occupational exposure found to cause an adverse effect in humans.

<sup>[4]</sup> American Congress of Governmental Industrial Hygienists (“ACGIH”) Threshold Limit Value (“TLV”) is the TWA mercury vapor concentration value recommended not to be exceeded for up to an 8-hour work day during a 40-hour work week.

<sup>[5]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) School Acceptance Criteria Value (“S-ACV”) is the indoor air quality level for mercury vapor at which schools and other educational institutions are recommended to resume normal operations.

<sup>[6]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) Residential Acceptance Criteria Value (“R-ACV”) is the recommended residential indoor air quality cleanup level.

<sup>[7]</sup> U.S. Environmental Protection Agency (“EPA”) Reference Concentration for Chronic Inhalation Exposure (“RfC”) is the mercury vapor concentration thought to represent no health risk to any element of the human population over an entire lifetime of continuous exposure.

<sup>[8]</sup> Agency for Toxic Substances and Disease Registry (“ATSDR”) Minimal Risk Level (“MRL”) is the mercury vapor concentration thought to represent no health risk to any element of the human population over an entire lifetime of continuous exposure.

<sup>[9]</sup> Daily mass exposure rate assumes ventilation rate (i.e. breathing rate) of 20 m<sup>3</sup>/day.

<sup>[10]</sup> Surface mercury concentration necessary to produce a daily mass exposure rate equivalent to mass exposure rate via inhalation following the line of reasoning described in Appendix B (page B-7).

## **APPENDIX C**

### **Description of Facility Undergoing Decontamination for Mercury**

## **FACILITY BACKGROUND INFORMATION**

A plan overview diagram of the entire facility and the individual process areas is provided in Figure 1 (page 16) in Appendix A.

The main mercury processing area of the facility – herein referred to as the Class C Area – was responsible for processing, recovering and storing a majority of the mercury-related materials. However, due to the volatile nature of elemental mercury, it was believed likely that contamination migrated into other process areas at the facility (this belief was confirmed via pre-clean characterization surface wipe sampling, see Appendix D).

The property on which the facility was located was owned by a third-party, and the hazardous material recovery operations areas were operated by the Owner from within a leased space contained inside the total building footprint. As part of the terms of lease, and in accordance with project requirements, the Owner agreed to properly clean and decontaminate all areas of the building formerly occupied by its recovery operation before vacating the property and returning it back to the third-party owner. The goal of the decontamination was to assure that all areas of the facility, formerly occupied by the Owner's operation (and only the areas occupied by the Owner's operation), were sufficiently decontaminated of any hazardous material to allow for future occupancy without restriction or reservation.

### ***CLASS C AREA (MAIN MERCURY PROCESSING AREA)***

The Class C Area occupied approximated 15,000 square feet (ft<sup>2</sup>) of the facility space. The Class C Area had four (4) means of entrance: two (2) exterior entryways from the parking lot, and two (2) interior open doorways connected to

the building areas known as the Battery Area and the PCB Processing / Storage Area, respectively. The Class C Area also had five (5) overhead loading dock doors leading to the Parking Lot.

The floor of the Class C Area was constructed of steel-mesh reinforced concrete, approximately 6 inches thick. The majority of the concrete floor in the Class C Area was not epoxy coated (except in the Pour-Off Area), and the floor had several unsealed slab joints. The Class C Area served as the primary fluorescent lamp recycling and processing area, and housed several lamp and mercury processing and support areas, including:

- Loading Dock / Receiving Area – this area was utilized for the shipping and receiving of fluorescent lamps and other mercury-contaminated devices. Containers of inbound and/or outbound mercury-containing materials were staged in this area prior to being placed into the recycling area or shipped off-site. The Loading Dock / Receiving Area was also used for handling PCB and battery waste materials.
- Front Office Area – this area housed several operations offices as well as the employees' locker rooms and cafeteria. The Front Office Area served as the primary point of entry into the facility's main Class C process area.
- Compressor Area – this area housed compressors and other air handling equipment which serviced environmental controls in the Class C Area and PCB Area. The Compressor Area was located in an alcove near the entrance to the PCB Processing / Storage Area.
- High-Intensity Discharge Lamp ("HID") Area – the HID lamp crushing operation was conducted in a specially designed recycling unit located in the Class C Area.

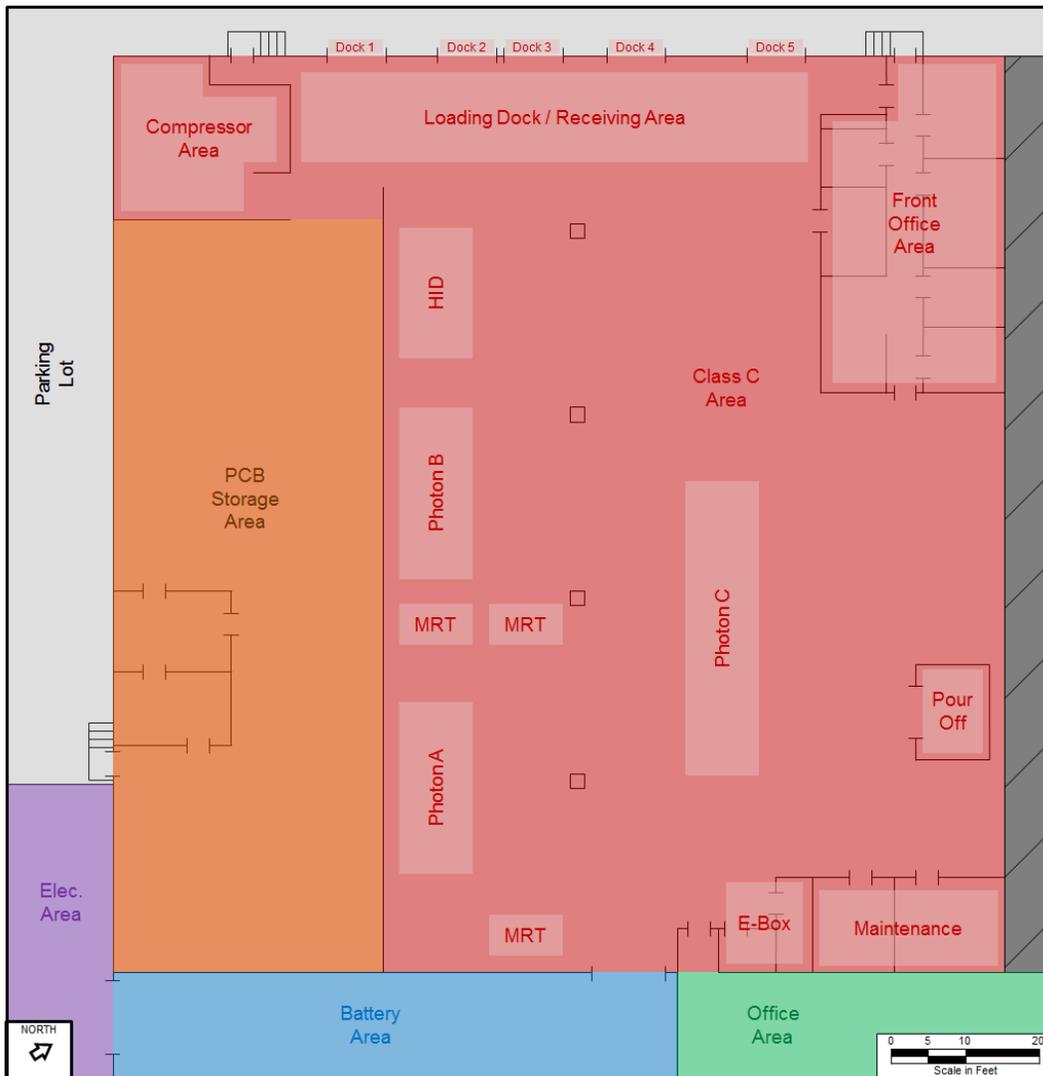
- Fluorescent Lamp Recycling Area(s) – fluorescent lamp (photon) crushing operations were conducted in three (3) specially designed recycling units referred to as Photon A, Photon B and Photon C, which were located throughout the Class C Area.
- Mercury Retort (“MRT”) Area(s) – after lamp crushing was conducted in either the HID or Photon units, the crushed fluorescent lamp phosphor powder was transferred to one (1) of three (3) MRT distillation units. Here the powdered material was heated in order to volatilize the mercury within the powder. The mercury vapor was then condensed in a heat exchanger and collected as elemental mercury.
- Pour-Off Area – after distillation the elemental mercury was collected from the MRT units and stockpiled in bulk containers of varying size in the mercury Pour-Off Area. The concrete floor in the Pour-Off Area was sealed with two coats of epoxy coating.
- Maintenance Area – this area housed various types of maintenance equipment and workstations to perform repairs on the Class C Area recycling equipment and auxiliary machinery.
- Electrical Box Area – this area housed the electrical fuse boxes which serviced the Class C Area.

See Figure C-1 for a schematic overview of the Class C Area.

In addition to the Class C Area, the Owner operated several other recycling operations as part of the facility. The “other areas” of the facility were used to handle and recycle PCB contaminated materials, lead-acid batteries, electronics waste (“E-waste”), and other universal wastes. Each of these other areas are described briefly below. Since these other areas were not directly involved in

mercury material handling, they were considered less severely impacted than the Class C Area. Nevertheless, all of these areas were determined to be impacted to some extent by mercury contamination, and were therefore decontaminated by the Owner's cleaning contractors and sampled / certified clean for mercury (and other contaminants) by the Engineer.

**Figure C - 1 – Class C Area Diagram**



### ***PCB STORAGE/PROCESSING AREA***

The PCB Storage / Processing Area (i.e. PCB Storage Area) formerly occupied approximately 3,500 square feet (ft<sup>2</sup>) of building space, and was immediately adjacent to the Class C Area. The PCB Storage Area had two (2) means of entrance: one (1) interior curbed entryway connected to the building area known as the Class C Area, and one (1) separate exterior entrance in the Parking Lot. The PCB Storage Area served as a handling and warehousing space for various types of PCB contaminated wastes including: inbound PCB lamp ballasts waiting to be processed, outbound PCB wastes recovered from dismantling / cleaning operations awaiting shipment for off-site disposal, and recovered / cleaned non-PCB-containing scrap metal components (e.g. transformer cores) awaiting shipment to off-site scrap metal reclamation facilities. The area also housed a small work space, which was used to disassemble and solvent-strip PCB components from certain devices.

The entire PCB Storage Area was located on an epoxy-sealed concrete pad. The floor was constructed of reinforced concrete, approximately 6 inches (inch) thick, and curbed on all sides by a 6 inch containment berm. The entire PCB Area floor and containment berm were covered with two (2) coats of epoxy sealant. The exterior wall of the PCB Storage Area (i.e. wall separating PCB Area from Parking Lot) was constructed half of galvanized metal and half of painted cinderblock. The interior wall of the PCB Storage Area (i.e. wall separating PCB Area from Class C Area) was constructed of 2x4 studs covered with plywood and sheetrock.

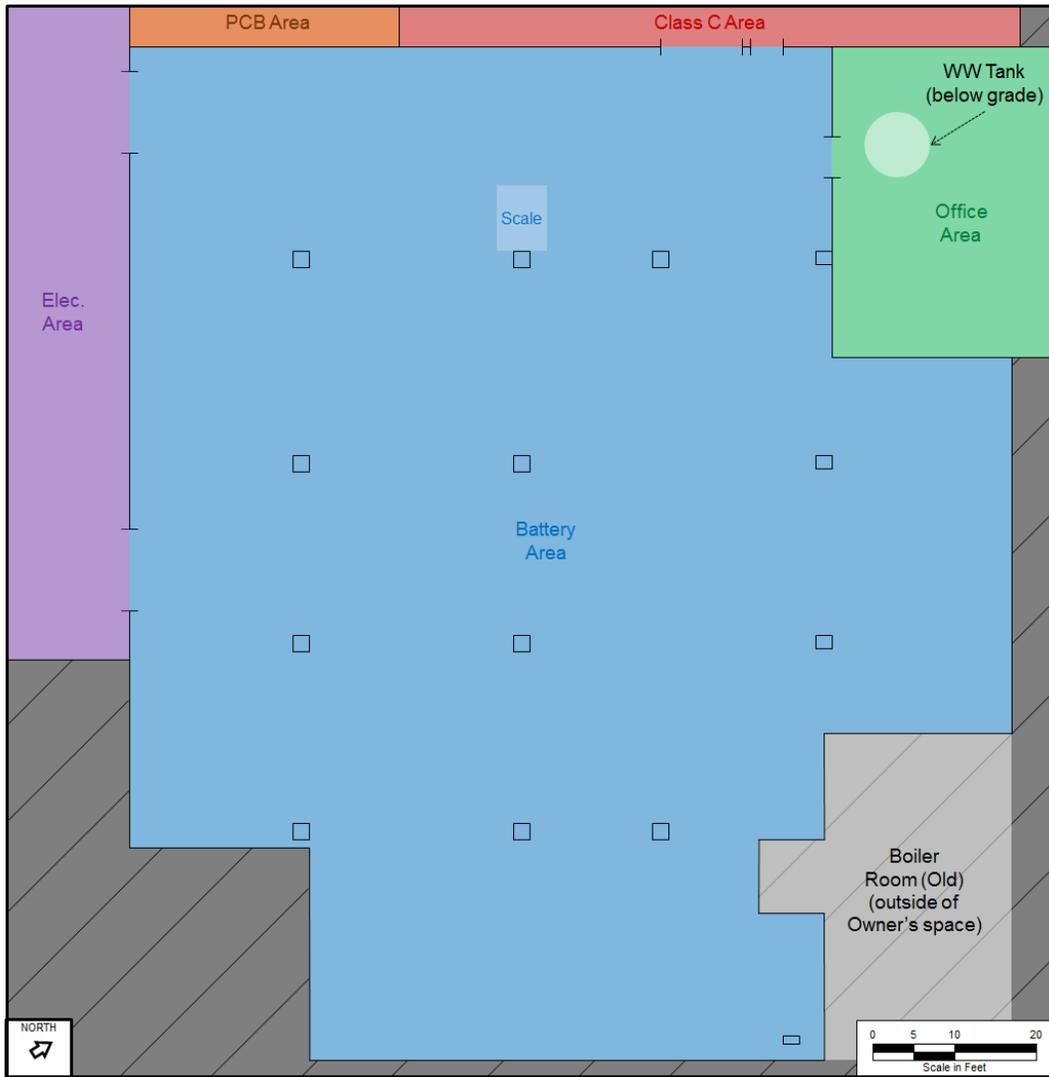
See Figure C-1 for a schematic overview of the PCB Storage Area.

## ***BATTERY AREA***

The Battery Area occupied approximated 11,000 square feet (ft<sup>2</sup>) of the building space, and was adjacent to the rest of the facility. The Battery Area had three (3) means of entrance: two (2) interior open doorways connected to the Electronics Area, and one (1) interior doorway connected to the Class C Area. The Battery Area served as a handling and warehousing space for various types of universal and battery wastes. In general, primary mercury recycling and processing operations were separate and somewhat isolated from the Battery Area.

See Figure C-2 for a schematic overview of the Battery Area.

Figure C - 2 – Battery Area Diagram

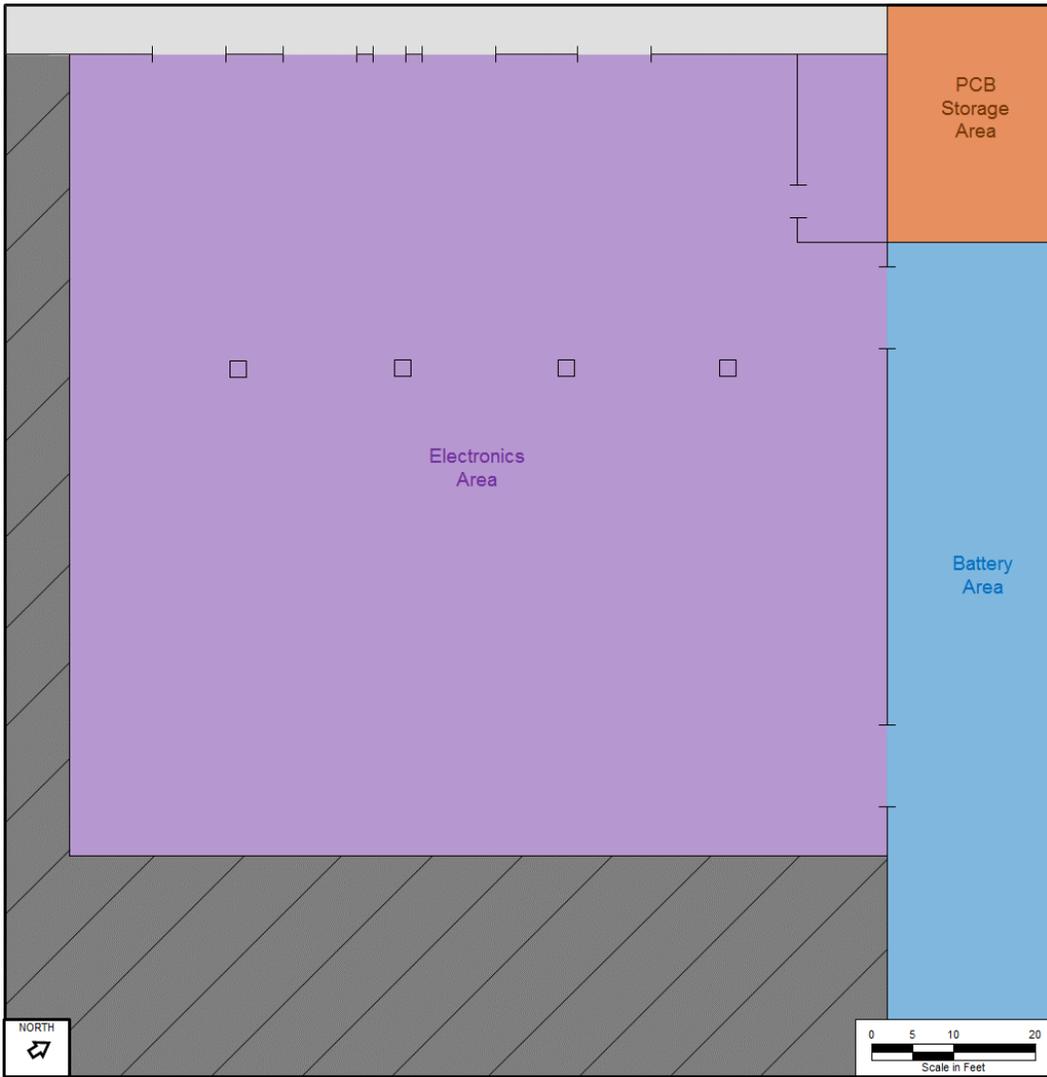


### ***ELECTRONICS AREA***

The Electronics Area occupied approximately 10,000 square feet (ft<sup>2</sup>) of building space, and was immediately adjacent to the rest of the recycling areas. The Electronics Area also had three (3) means of entrance: two (2) interior open doorways connected to the building area known as the Battery Area, and one (1) separate exterior entrance in the Parking Lot. The Electronics Area also had four (4) overhead loading dock doors to the Parking Lot. The Electronics Area served as a handling and warehousing space for various types of universal and electronics waste (“E-waste”) including computers, refrigerators, and other appliances. The area also housed a waste-hopper, which was used to transfer retorted (i.e. heated to remove mercury) crushed glass from the fluorescent lamp recycling operation to waste dumpsters located in the Parking Lot outside the Electronics Area. Otherwise, primary mercury recycling and processing operations were separate and somewhat isolated from the Electronics Area.

See Figure C-3 for a schematic overview of the Electronics Area.

Figure C - 3 – Electronics Area Diagram



## ***OFFICE AREA***

The Office Area occupied two (2) floors of the facility, and was immediately adjacent and above the rest of the much larger facility. The Office Area had two (2) means of entrance: 1) a short hallway and stairway connected to the main process area, and 2) a separate business entrance along the frontage of the main thoroughfare. The Office Area served as a company business office for the overall recycling operations, and included sales, accounting, invoicing and records retention personnel. With the exception of a few employees, the business operation had limited access to the recycling operation areas. Recycling operations and processing were separate and somewhat isolated from the Office Area.

See Figures C-4 and C-5 for a schematic overview of the Office Area.

Figure C - 4 – Office Area (3rd Flr.) Diagram

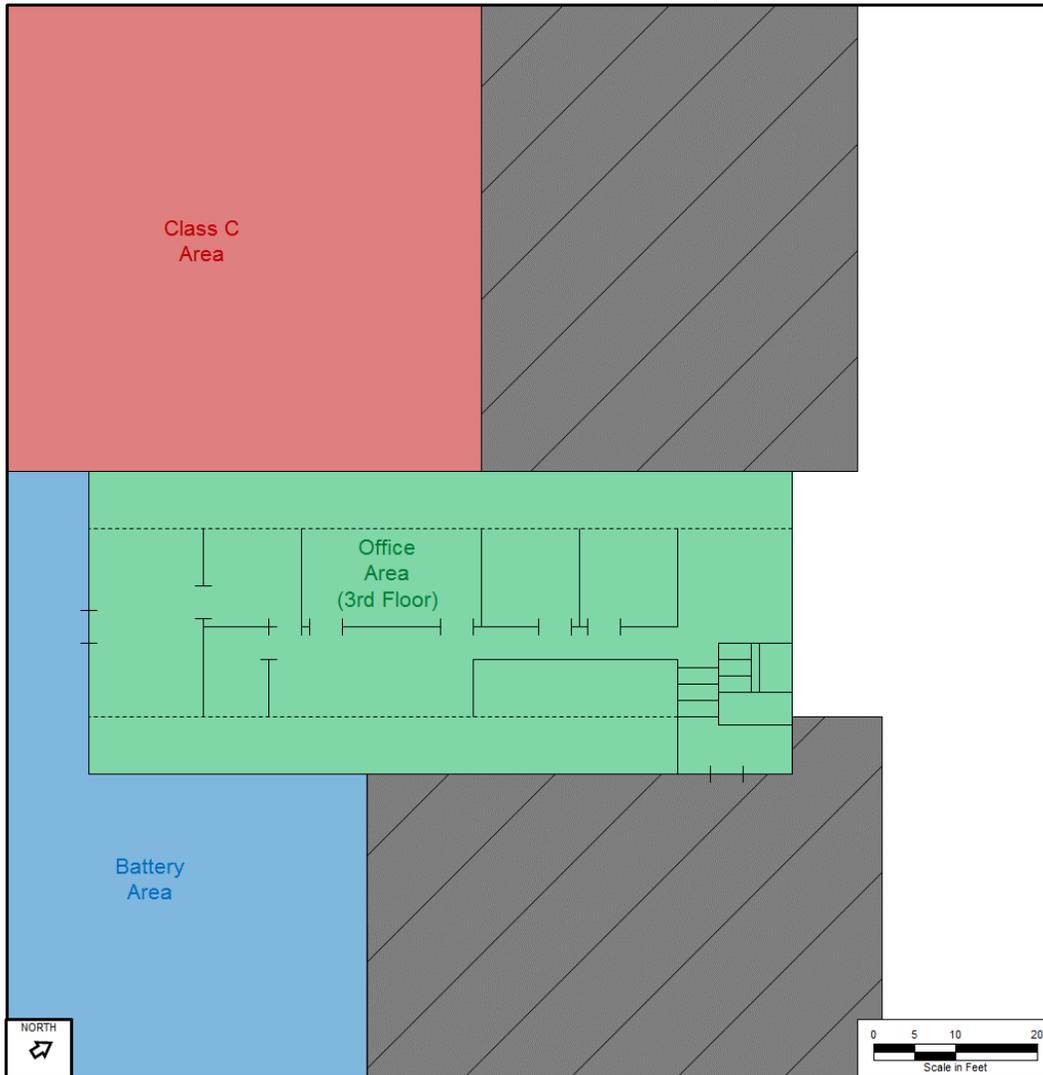


Figure C - 5 – Office Area (2nd Flr.) Diagram



### ***Parking Lot***

The Parking Lot consisted of asphalt paved areas outside the facility including: the area outside five (5) loading dock bays of the Class C Area, along the exterior wall of the PCB Storage Area, and outside the four (4) loading dock bays of the Electronics Area. The Parking Lot also includes the main on-site traffic routes and vehicle parking locations. In total, the paved area outside the facility encompasses an area of approximately 0.87 acres (37,700 ft<sup>2</sup>)

It should be noted that the Parking Lot was not considered to be involved in regulated waste handling activities, but was identified as a likely area where mercury may have been “tracked” outside of the normal processing areas during delivery / removal of mercury-contaminated materials. However, the sampling conducted in the Parking Lot consisted of traditional subsurface soil sampling and analysis for mercury. These samples provided no noteworthy results (i.e. non-detect), and were considered representative of standard environmental sampling of soils which are well understood and regulated. Therefore, discussion of the Parking Lot sampling was not included as part of this thesis.

See Figure 1 (page 16) for a schematic overview of both the entire facility and the Parking Lot.

### ***Extra-Facility***

As mentioned in Section 2.2.2 (page 14), the property on which the facility was located was owned by a third-party, and the hazardous material recovery operations areas were operated by the owner from within a leased space contained inside the larger building footprint (herein referred to as the Extra-

Facility). As part of the project the owner agreed to properly clean and decontaminate all areas of the building formerly occupied by its recovery operation, and only the areas occupied by the owner's operation. This limitation on the extent of decontamination was supported by the property's third-party owner.

See Figure 1 (page 16) for a schematic overview of the facility and the Extra-Facility. Section 5.3.2 (page 93) provides a discussion of this situation.

## **APPENDIX D**

### **Characterization Methodologies and Results**

## **CHARACTERIZATION METHODOLOGIES**

The following Appendix of this Report describes the sampling procedures used to initially assess the level of mercury contamination in the facility. The purpose of the characterization sampling was to ensure that the extent of contamination at the facility was adequately known before specifying and commencing decontamination operations. It should be noted, that the entire facility was not completely characterized prior to decontamination. At the outset, it was assumed that the building was contaminated with mercury from the facility's operational history. The characterization sampling was a confirmation of that assumption and established a baseline. The characterization sampling was conducted before the contractors began significant decontamination activities.

### ***DUST COMPOSITION SAMPLING***

Before decontamination was conducted, several dust composition samples were collected to determine the amount of mercury contamination present within the process dust which covered nearly every surface at the facility.

Total dust composition sampling was conducted using laboratory supplied sampling cassettes equipped with a matched weight 37mm, 0.8 micron ( $\mu\text{m}$ ) mixed cellulose ester ("MCE") filter set. A matched weight filter cassette contains two (2) filters of equal weight, one on top of the other. During sampling, air was drawn through the cassette and dust collected on the top filter only; the bottom filter acted as a blank. Once back at the laboratory, both filters were weighed and the difference provided a measure of the total dust quality. After total dust analysis was completed, the MCE filters were completely digested in an acid solution, which

was subsequently analyzed for mercury in accordance with the Occupational Safety and Health Administration's ("OSHA's") Method ID-145.

A total of three (3) dust composition samples were collected from the Class C Area and Battery Area. The results of these samples are provided in this appendix. The ratio of mercury to total dust provided an indication that mercury contamination was concentrated within the process dust particles.

### ***PRE-CLEAN SURFACE WIPE SAMPLING***

Prior to commencing decontamination, several discrete surface wipe samples were collected to assess the level of surface mercury contamination at the facility.

Surface wipe sampling was conducted using 100 cm<sup>2</sup> paper templates (i.e. 10 cm by 10 cm) and pre-wetted Ghost Wipe brand wipes. The paper templates were labeled with the proper sample tracking ID, taped to the surface to be sampled, and then the sample was collected by wiping in three (3) directions within the template space, folding the wipe in half after each direction. All wipe samples were collected in accordance with National Institute of Occupational Safety and Health ("NIOSH") Method 9100. Disposable templates were used to assure the accuracy of the sample size, and were left in place to provide direction for any re-cleaning efforts, as necessary. All wipe samples collected were analyzed for mercury in accordance with the Occupational Safety and Health Administration's ("OSHA's") Method ID-145. A new pair of gloves was worn for each wipe sample. The sample wipe was placed in a sealed bag, labeled with the proper sample ID, and prepared for transport to the ESIS Environmental Health Laboratory in Cromwell, CT for analysis. All samples were delivered to the laboratory using proper sample handling and chain-of-custody procedures.

A total of twenty (20) pre-clean surface wipe samples were collected from several areas in the facility. The results for these samples are provided in this appendix. These samples served to confirm the assumption that excessive mercury contamination existed within the facility and decontamination of the entire facility was required.

### ***FLOOR JOINT / CRACK VAPOR SURVEY***

The owner conducted an investigation of mercury contamination below the concrete floor prior to closure in March 2012. Mercury was detected at one (1) subsurface sampling location which was located at a joint in the floor where two (2) concrete slabs met.

After ceasing mercury recycling operations and prior to facility decontamination, two (2) rounds of detailed concrete floor joint / crack mercury vapor surveys were conducted using a direct-read mercury vapor monitor. The objective of these surveys was to identify and delineate areas of the floor which might require more focused attention and/or potentially require complete removal. An additional goal of the direct-read survey was to provide basis for identifying additional subsurface sampling locations which would be conducted concurrent with addressing the previously discovered soil issue.

The direct-read mercury vapor surveys were conducted with a properly calibrated Ohio Lumex RA-915+ real-time continuous mercury vapor analyzer (see Appendix F for equipment specification sheet). The following sampling methodology was used to characterize any volatile mercury residues which might remain in the cracks, crevices and pores of the floors which may not normally be detected by traditional surface wipe sampling.

1. Turn on the direct-read instrument.
2. Check to ensure that the battery is fully charged and the instrument is operating properly.
3. Allow the instrument to stabilize. That is, allow device to auto-zero at least twice to acclimate to ambient temperature. Do not commence survey until instrument displays consistent background value throughout an entire sampling interval.
4. Hold sampling probe inlet tube at least four (4) feet above the ground and record background mercury vapor concentration.
5. After instrument stabilization is complete, record survey start time and conduct direct-read survey using the following procedure at each sample location:
  6. Hold the sampling inlet tube at the floor joint / crack, being careful not to collect debris from within the joint / crack.
  7. Observe the direct-read measurements, and record approximate average mercury concentration value.
  8. Move to next sampling location.

The preliminary direct-read mercury vapor survey (i.e. first round) was performed after major demolition activities were complete but decontamination had not been conducted by the contractor. A total of thirty (30) individual floor joint, crack and degraded surface locations were sampled in the Class C and PCB Areas during this preliminary round of direct-read surveying. The next round of direct-read

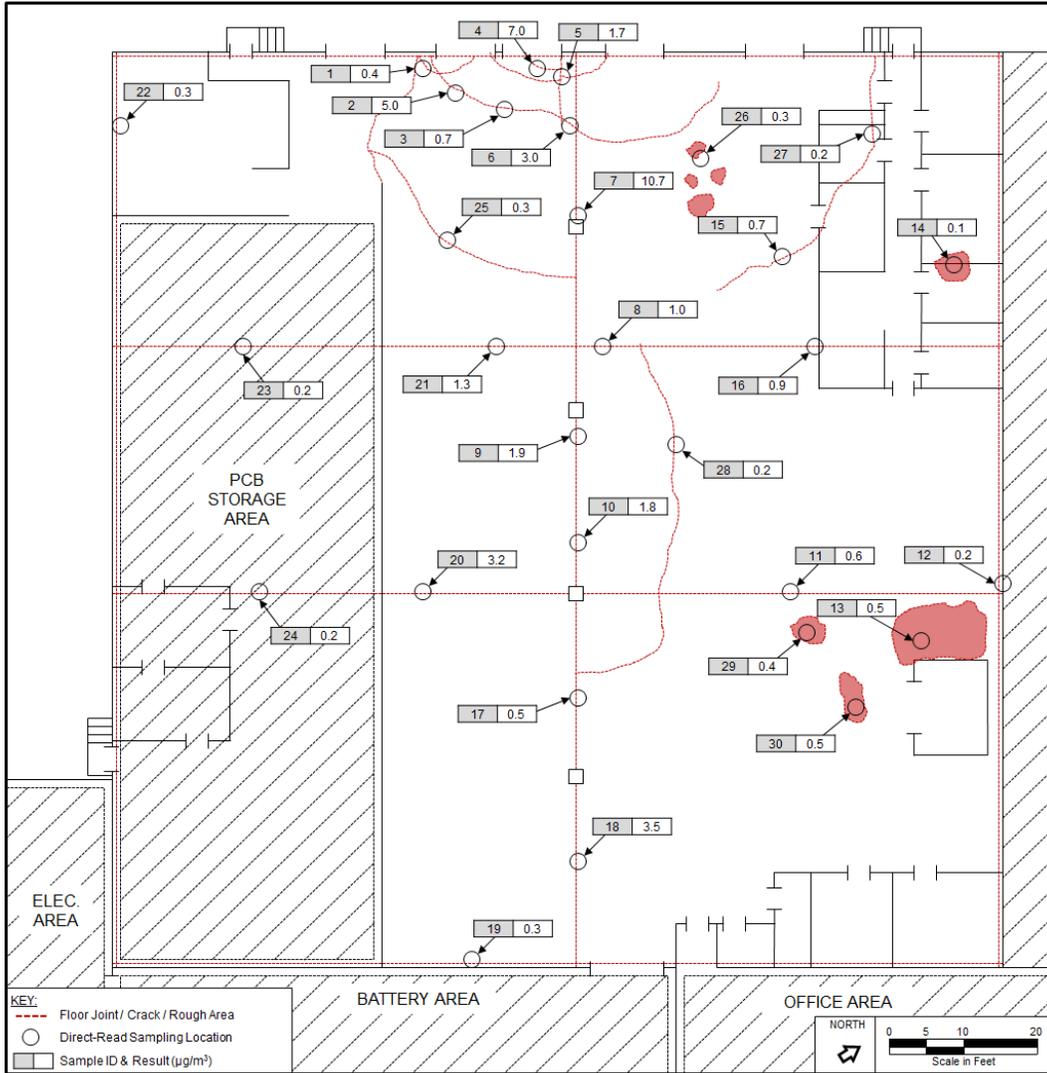
survey (i.e. second round) was performed specifically targeting only the floor joints in the Class C and Battery Areas. A total of three hundred and fourteen (314) individual locations were sampled along the floor joints.

Figures D-1 – D-3 show the floor joint and crack locations which were sampled in the first two rounds of surveys.

Based on the first two rounds of direct-read surveys, it was determined that the small (i.e. minor) cracks did not contain mercury at concentrations which presented a concern for cleaning. Additionally, the floor joints along the outside of the facility (i.e. where the floor slab met the foundation) were well sealed and not heavily contaminated. However, the direct-read surveys did indicate that mercury-laden dust had become concentrated at certain locations along the interior floor joints (i.e. where floor slabs met in the interior of the facility), and in an area near the loading docks where the concrete slab was considerably fractured. Multiple attempts by contractor to completely remove the mercury from within these joints and major cracks in the concrete were not sufficiently successful to achieve the closure goals.

The results of the first two (2) rounds of floor joint direct-read surveys are provided in this appendix.

**Figure D - 1 – Preliminary Floor Joint/Crack Survey Results – Class C Area**







### ***SUBSURFACE SOIL SAMPLING***

After the preliminary and comprehensive floor joint / crack direct-read mercury vapor surveys were completed, extensive subsurface soil sampling was conducted below the concrete floor in the Class C and Battery Areas to determine whether or not mercury had penetrated the floor joints (i.e. wasn't just concentrated near the top of each joint), and delineate the extent of the subsurface mercury contamination. Soil samples were collected from underneath areas which were suspected to have the greatest potential for mercury contamination, namely beneath the joints and major cracks in the concrete floor. This sampling was conducted in August 2013.

Soil samples were collected with a Geoprobe® type direct-push sampling device, which utilizes a hydraulic hammer to advance a small-diameter sample tube into the subsurface to collect each sample. The samples were extracted using a Macro-Core® type sample probe. The Macro-Core® sampler is of open-tube design and measures approximately 2 inches in diameter, and is designed for continuous soil sample collection. All soil samples were collected from underneath the joints / cracks by coring through the concrete floor directly next to the joint / crack at a slight angle back towards the bottom of the joint / crack. It is important that the sample was NOT collected by coring through the floor at the joint / crack in order to avoid transporting potential dust and debris at the top of the joint / crack down into the soil.

Figure D-4 provides a general diagram of how the soil samples were collected.

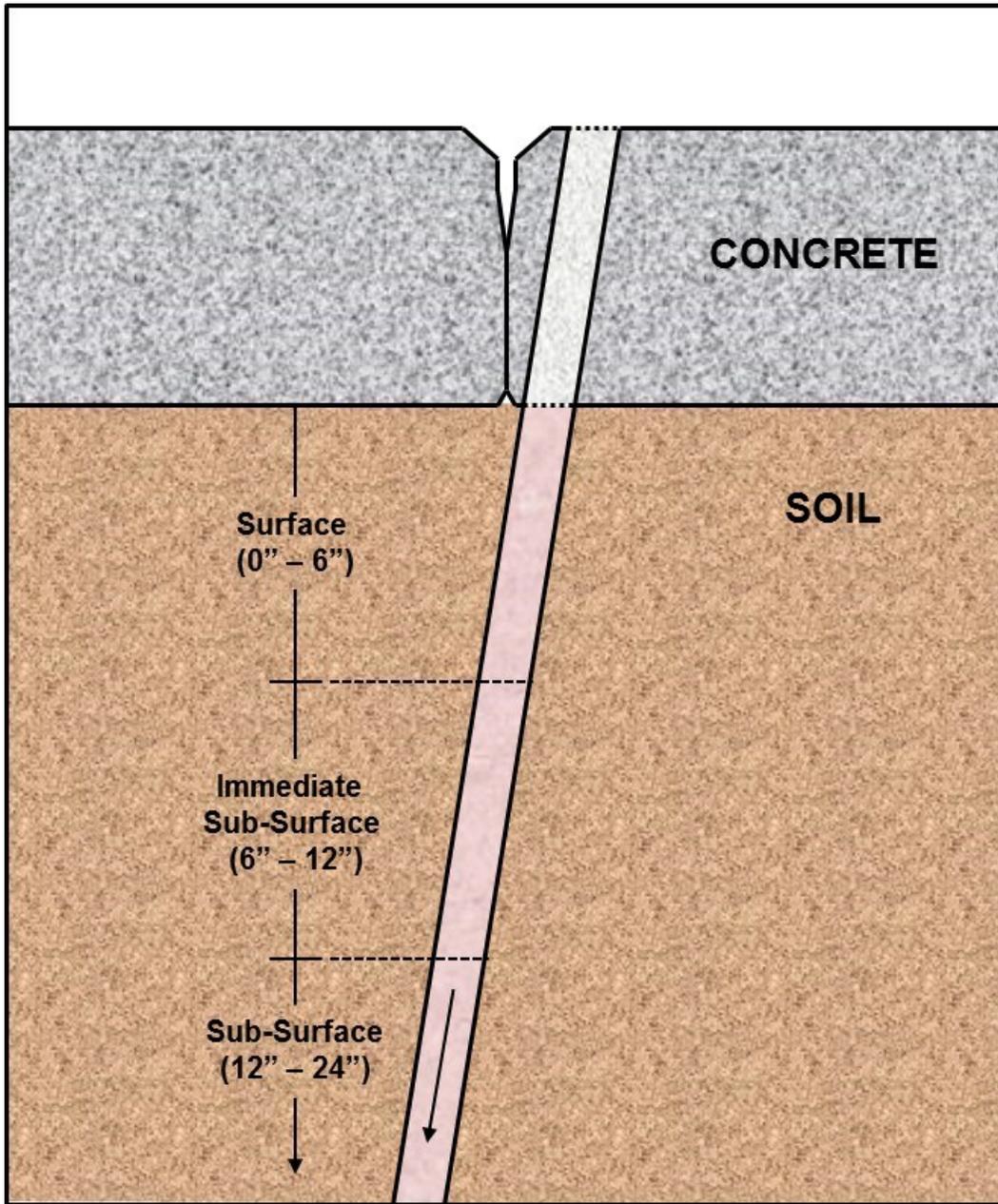
To assist in the removal of the soil sample and to protect the sample integrity, each of the sample devices was fitted with a new acetate liner prior to each use. After

the soil sample was collected, the acetate liner was removed, and carefully opened for visual inspection and soil classification. The sample intervals were removed from the sampling device, homogenized in a decontaminated stainless steel mixing bowl, and placed in laboratory supplied sample containers. The containers were labeled and delivered to an off-site laboratory for mercury content analysis using appropriate chain-of-custody procedures.

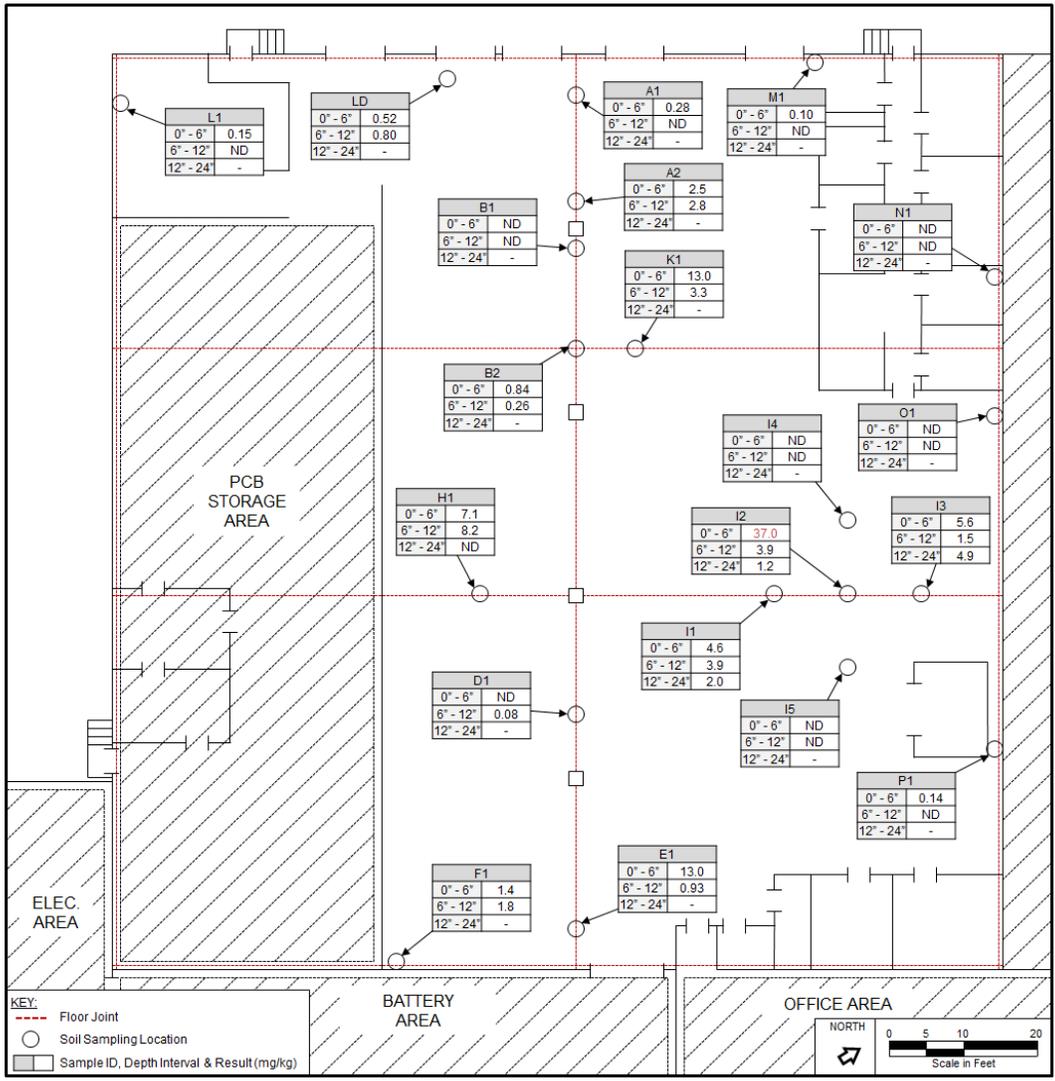
The locations of the August 2013 subsurface sampling are shown in Figures D-4 and D-5. The results from the subsurface soil sampling are provided in this appendix.

The results from the soil investigation indicated that mercury was present in the upper few inches to few feet of soil directly beneath the interior floor joints and major cracks in the Class C Area. The subsurface soil sampling showed that mercury did not penetrate the floor along the exterior floor joints (i.e. where floor slab met the foundation), or in the Battery Area.

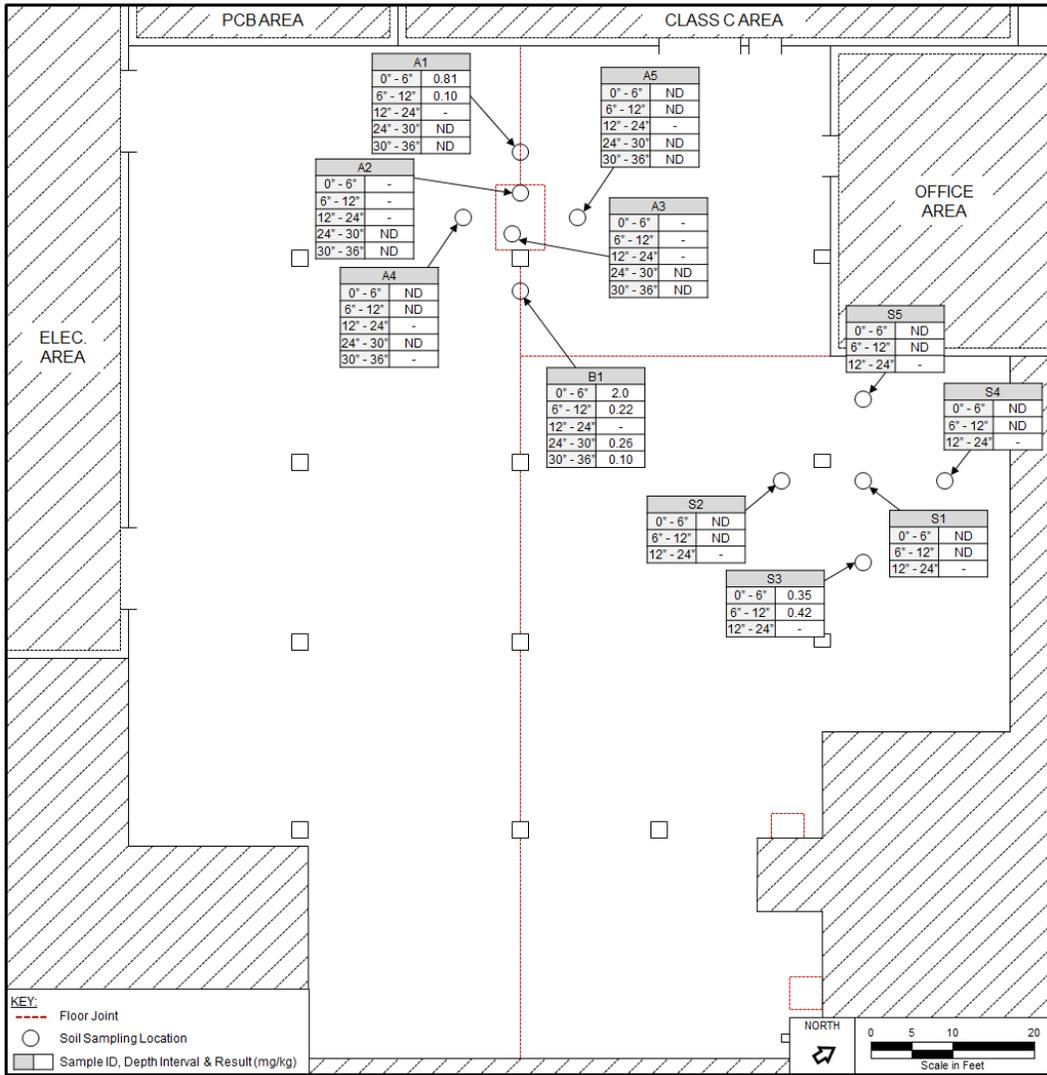
Figure D - 4 – Subsurface Soil Sampling Diagram



**Figure D - 5 – Subsurface Soil Sampling Results – Class C Area**



**Figure D - 6 – Subsurface Soil Sampling Results – Battery Area**



### ***EXCAVATION TRENCH VAPOR SURVEY***

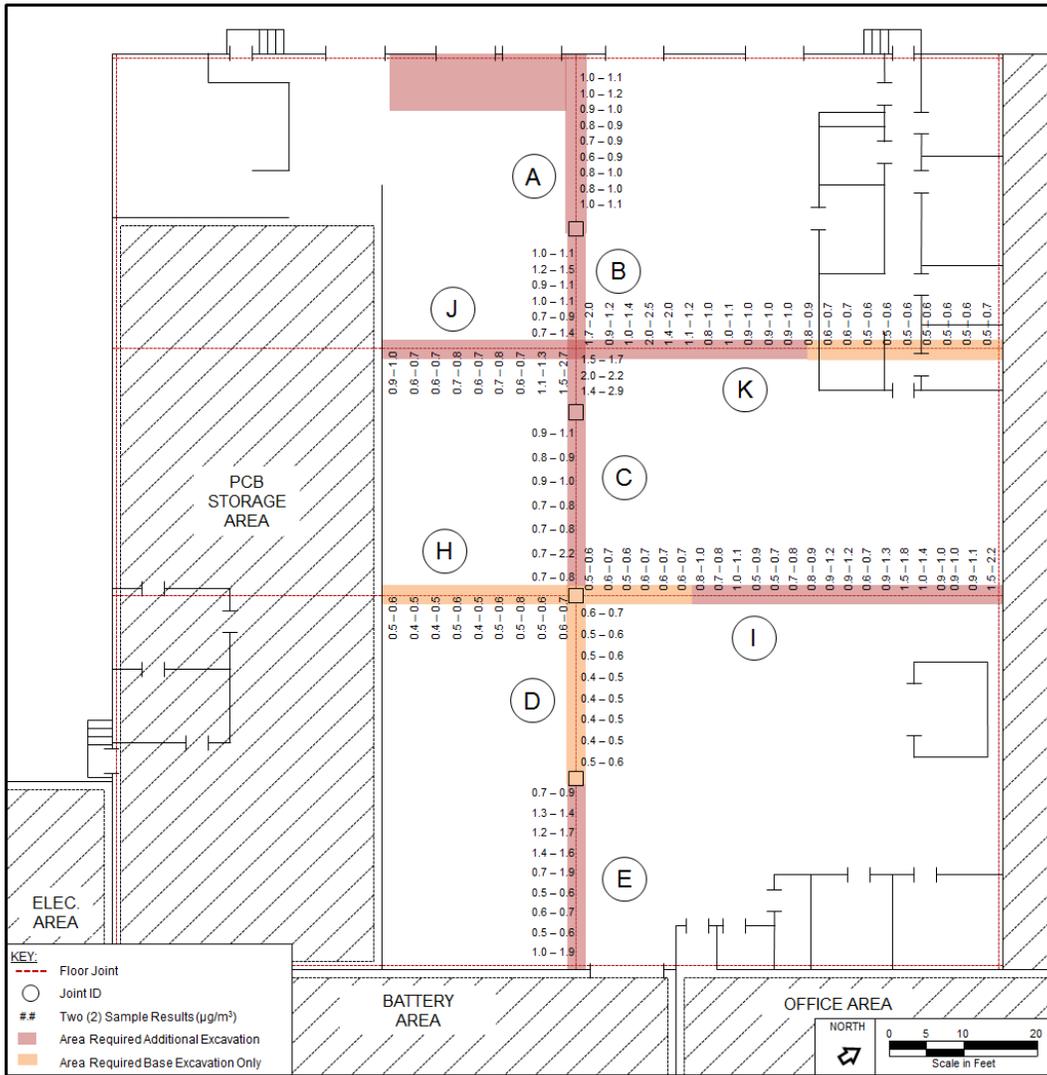
The results of the floor joint direct-read surveys and the subsurface soil sampling indicated that mercury-laden dust had become concentrated along the interior floor joints and major cracks. Joint removal and excavation was conducted along the entire length of all interior floor joints in the Class C Area.

After the initial excavation was performed, another detailed direct-read mercury vapor survey was conducted along the exposed surface at the bottom of the excavation trench. The objective of this post-excavation survey was to identify areas which required additional soil excavation to completely eliminate mercury contamination. The soil at the bottom of the excavation was screened using a direct-read mercury vapor analyzer to confirm the presence or absence of mercury. Where mercury vapor was detected at the soil surface, the decontamination contractor was directed to remove additional soil until the screening yielded mercury vapor values at or very near background concentrations.

The direct-read mercury vapor survey along the bottom of the excavation trenches was conducted using a methodology similar to the methodology described in this appendix. The Ohio Lumex RA-915+ real-time continuous mercury vapor monitor (see Appendix F for equipment specification sheet) was used to sample mercury vapor levels immediately above the soil surface at the bottom of the trench.

The areas of the trenches which required additional excavation are shown in Figure D-7. The depths of the additional excavation areas ranged from 12 to 32 inches below grade of the concrete floor. The results of the excavation trench direct-read survey are provided in this appendix.

**Figure D - 7 – Excavation Trench Survey Results**



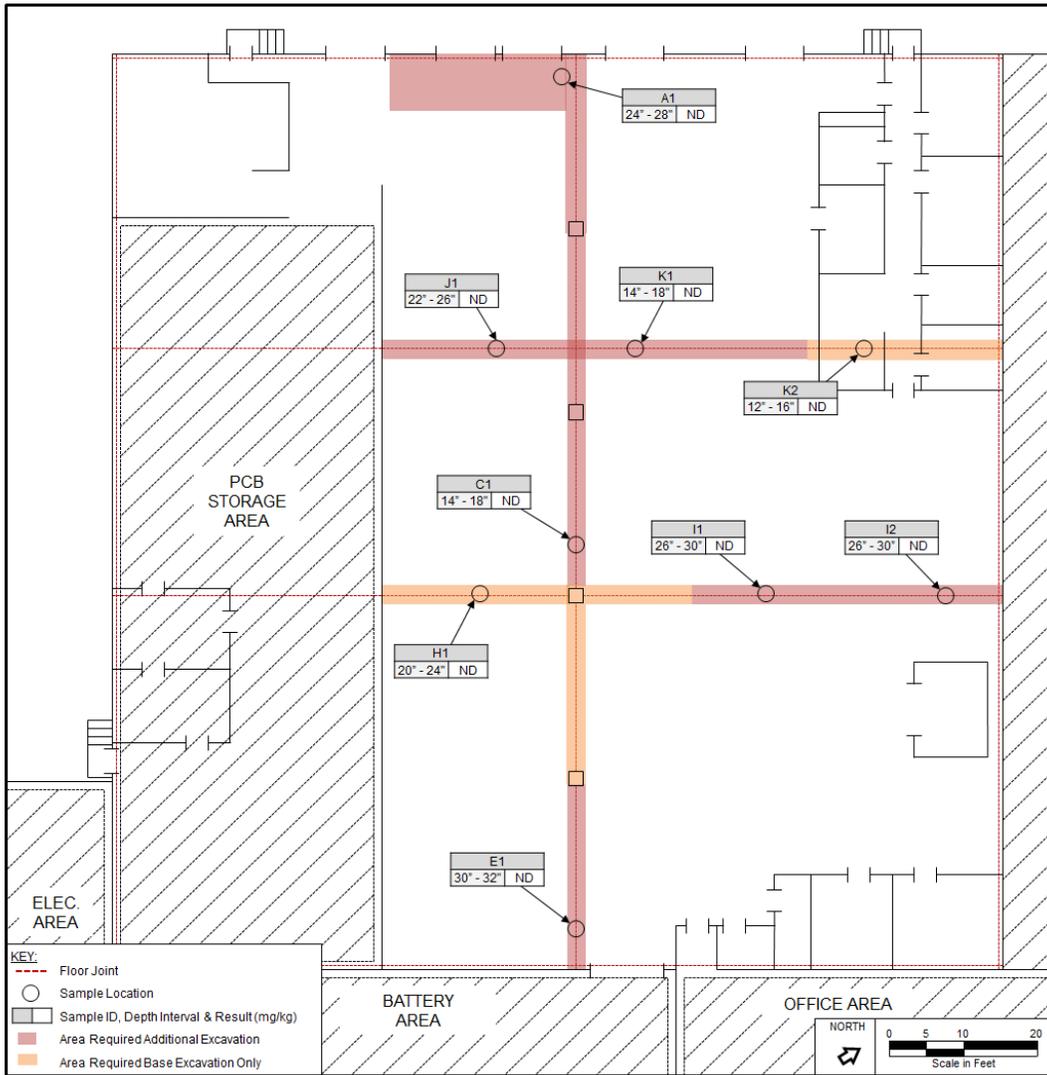
### ***POST-EXCAVATION SOIL SAMPLING***

After all interior joint areas were sufficiently excavated – that is, direct-read mercury vapor screening at the underlying soil surface was at or very near background concentrations – a final post-excavation confirmatory subsurface investigation was conducted in October 2013. The purpose of the post-excavation sampling was to ensure that the excavation adequately removed mercury from the soil below the floor joints in the Class C Area.

Post-excavation soil samples were collected using a stainless steel trowel. The samples were collected from the top four (4) inches of soil at the bottom of the excavation trenches. The samples were homogenized in a decontaminated stainless steel mixing bowl and placed in laboratory supplied containers. The containers were labeled and delivered to an off-site laboratory for mercury content analysis using appropriate chain-of-custody procedures.

The locations of the October 2013 post-excavation soil samples are shown in Figure D-8. The results of the post-excavation soil samples are provided in this appendix.

**Figure D - 8 – Post-Excavation Soil Sampling Results**



### ***WASTEWATER VAULT VAPOR TESTING***

The decontamination of the Battery Area included a small crawl-space area under the Office Area stairwell containing a wastewater collection tank system. Two (2) rounds of direct-read mercury vapor monitor surveys were conducted from the surface of the underlying soil in this area. The objective of these surveys was to identify and delineate areas of soil which might require additional remediation by the contractor.

The preliminary vapor survey was performed after the initial round of demolition and soil remediation was conducted in the wastewater vault area. After some follow-up soil removal was completed, the second round of mercury vapor monitoring was conducted at the surface of the soil.

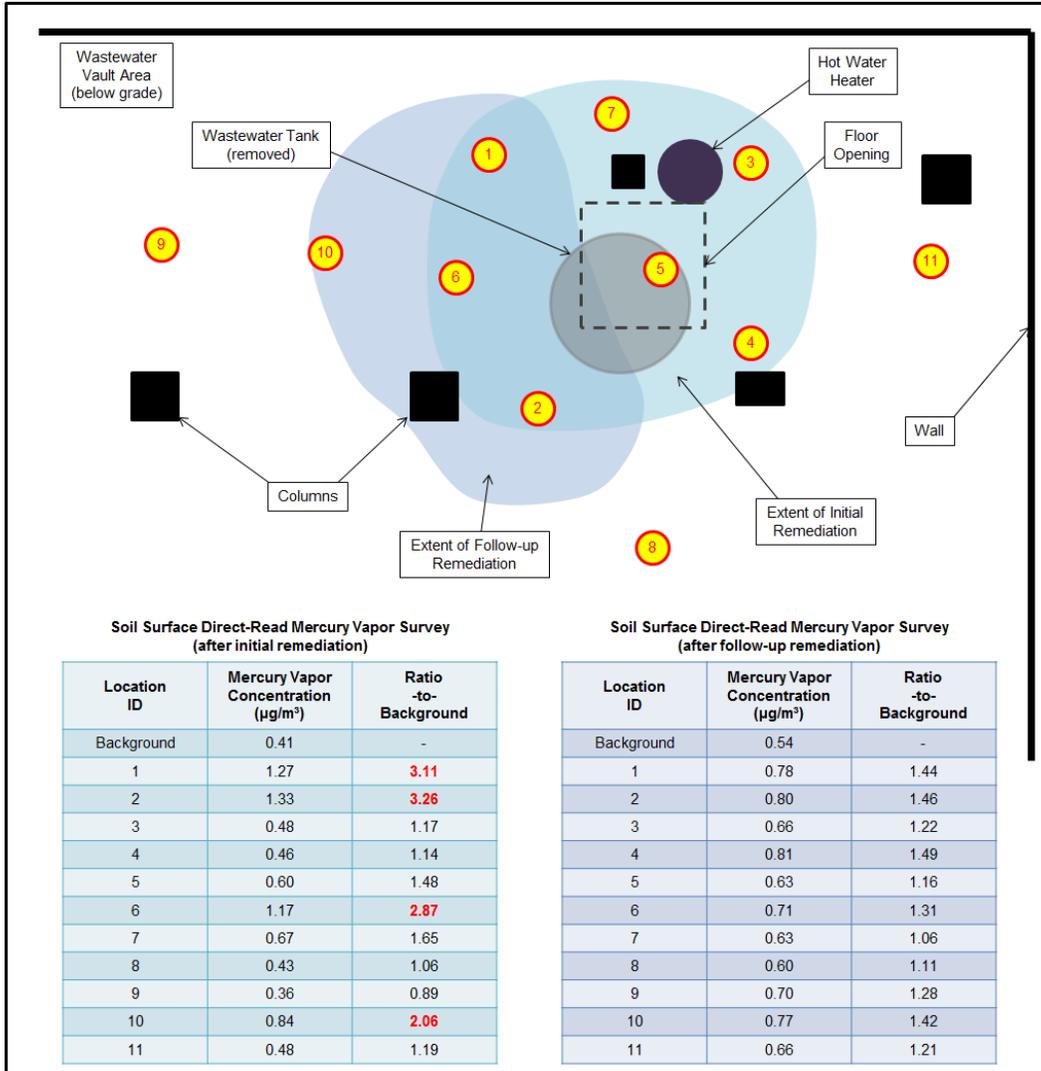
Both wastewater vault surveys were performed using a properly calibrated Ohio Lumex RA-915+ real-time continuous mercury vapor monitor (see Appendix F for equipment specification sheet). The methodology used for surveying the soil at the bottom of the wastewater vault followed the procedures used for addressing mercury vapor at the bottom of the Class C Area floor joint trenches.

The results of the two (2) rounds of wastewater vault vapor testing are provided in this appendix.

Post-remediation soil samples were not collected from the wastewater vault area. This decision was made in light of the fact that the post-excavation soil samples collected from the Class C Area floor joint trenches recorded no detectable amount of mercury (see Appendix E). These trench soil samples served as the “proof of concept” to validate that the direct-read mercury vapor survey methodology from

immediately above the soil surface was a viable, low-cost method for establishing whether or not adequate soil excavation had been performed.

**Figure D - 9 – Wastewater Vault Vapor Survey Results**



## CHARACTERIZATION RESULTS

Pre-decontamination investigation (i.e. characterization) was conducted in accordance with the methodologies described previously in this appendix. The purpose of these characterization tests was to ensure that the extent of contamination at the facility was adequately known before conducting full decontamination.

### *DUST COMPOSITION SAMPLING*

On April 16, 2013, pre-clean dust composition samples were collected in the Class C and Battery Areas to characterize the concentration of mercury within the process dust. A total of three (3) dust composition samples were collected using the methodologies described in this appendix. Results from the dust composition sampling indicated that mercury contamination was concentrated in the process dust with an average concentration of 0.04 percent by weight (%w).

The results of the pre-clean dust composition sampling are provided in the table below.

**Table D - 1 – Dust Composition Sampling Results**

| Facility Area | Location ID | Total Dust Result (µg) | Mercury Result (µg) | Dust Mercury Content (%w) |
|---------------|-------------|------------------------|---------------------|---------------------------|
| Class C       | Loc. 1      | 597,000                | 237                 | 0.040                     |
| Class C       | Loc. 2      | 1,440,000              | 825                 | 0.057                     |
| Battery       | Loc. 3      | 382,000                | 102                 | 0.027                     |

### ***PRE-CLEAN SURFACE WIPE SAMPLING***

On February 6, 2013 (Office Area), March 11, 2013 (Electronics Area), March 20, 2013 (Battery Area) and March 25, April 16, and April 30, 2013 (Class C Area) pre-clean surface wipe sampling was conducted in each area of the facility to characterize the level of surface mercury contamination. A total of twenty (20) individual (i.e. 100 cm<sup>2</sup>) wipe samples were collected using the methodologies described in this appendix. Results from this pre-clean sampling confirmed the Engineer's assumption that the facility was contaminated with mercury, and that the entire facility would require complete decontamination. Out of the twenty (20) pre-clean samples, only five (5) (i.e. 25%) were sampled from surfaces which without cleaning would have passed the acceptance criteria limit (i.e. 30 µg/1,000cm<sup>2</sup>).

The results of the pre-clean surface wipe sampling are provided in the following table.

**Table D - 2 – Pre-Clean Surface Wipe Sampling Results**

| Facility Area | Location ID | Pre-Clean Surface Wipe Sampling Results                   |   |         |
|---------------|-------------|---|---|---------|
|               |             | Mercury Result <sup>[1]</sup><br>(µg/100cm <sup>2</sup> ) | Mercury Result <sup>[1]</sup><br>(µg/1,000cm <sup>2</sup> ) | Date    |
| Class C       | Floor 1     | 1,190   | 11,900  | 3/25/13 |
| Class C       | Floor 2     | 208   | 2,080   | 4/16/13 |
| Class C       | Floor 3     | 484   | 4,840   | 4/16/13 |
| Class C       | Floor 4     | 196   | 1,960   | 4/30/13 |
| Battery       | Floor 1     | 69.6  | 696   | 3/20/13 |
| Battery       | Floor 2     | 38.6  | 386   | 3/20/13 |
| Electronics   | Dry Wall 1  | 5.80  | 58.0  | 3/11/13 |
| Electronics   | Dry Wall 2  | 5.70  | 57.0  | 3/11/13 |

| Facility Area | Location ID                 | Pre-Clean Surface Wipe Sampling Results                           |   |         |
|---------------|-----------------------------|---|---|---------|
|               |                             | Mercury Result <sup>[1]</sup><br>( $\mu\text{g}/100\text{cm}^2$ ) | Mercury Result <sup>[1]</sup><br>( $\mu\text{g}/1,000\text{cm}^2$ ) | Date    |
| Electronics   | Block Wall 1                | 9.82  | 98.2  | 3/11/13 |
| Electronics   | Block Wall 2                | ND <sup>[2]</sup>   | (< 6.0)   | 3/11/13 |
| Electronics   | Ceiling 1                   | ND <sup>[2]</sup>   | (< 6.0)   | 3/11/13 |
| Electronics   | Ceiling 2                   | ND <sup>[2]</sup>   | (< 6.0)   | 3/11/13 |
| Electronics   | Floor 1                     | 56.1  | 561   | 3/11/13 |
| Electronics   | Floor 2                     | 0.97  | 9.7   | 3/11/13 |
| Office        | 3 <sup>rd</sup> Flr, Loc. 1 | ND <sup>[2]</sup>   | (< 6.0)   | 2/6/13  |
| Office        | 3 <sup>rd</sup> Flr, Loc. 2 | 148   | 1,480   | 2/6/13  |
| Office        | 3 <sup>rd</sup> Flr, Loc. 3 | 3.27  | 32.7  | 2/6/13  |
| Office        | 2 <sup>nd</sup> Flr, Loc. 1 | 61.8  | 618   | 2/6/13  |
| Office        | 2 <sup>nd</sup> Flr, Loc. 2 | 44.0  | 440   | 2/6/13  |
| Office        | 2 <sup>nd</sup> Flr, Loc. 3 | 77.5  | 775   | 2/6/13  |

Table D-2 Footnotes:

<sup>[1]</sup> Sample results reported in micrograms per 100 square centimeters ( $\mu\text{g}/100\text{ cm}^2$ ) because each sample was collected from one (1) 100 square centimeter ( $100\text{ cm}^2$ ) template. Results converted to  $\mu\text{g}/1,000\text{ cm}^2$  by multiplying by ten (10).

<sup>[2]</sup> ND = non-detect, result below analytical limit of detection.

### ***FLOOR JOINT / CRACK SURVEY***

The preliminary floor joint / crack mercury vapor survey (i.e. round one) was performed on July 9, 2013, and the comprehensive floor joint survey (i.e. round two) on August 1, 2013. These initial surveys were conducted to assess the level of mercury contamination within crevices in the floor which would resist traditional surface cleaning techniques. The floor joint / crack direct-read surveys were conducted using an Ohio Lumex RA-915+ mercury analyzer in accordance with the methodologies described previously in this appendix.

The results for the direct-read surveys indicated that mercury-laden dust had become concentrated at certain locations along the interior floor joints (i.e. where

floor slabs met) and in the area of heavily cracked floor near the loading docks. Figures D-1 – D-3 show the floor joint and crack locations and graphical sample results for the two rounds of direct-read mercury vapor surveys.

The following tables provides the tabulated results from the floor joint / crack direct read surveys. The sample locations which were determined to require additional investigation and/or complete remediation are highlighted **RED** in the tables below.

**Table D - 3 – Preliminary Floor Joint / Crack Survey Results**

| Facility Area   | Location ID | Location Type    | Mercury Vapor Result ( $\mu\text{g}/\text{m}^3$ ) |
|---|-------------|------------------|---|
| Background Mercury Vapor Concentration <sup>[1]</sup> |             |                  | 0.2 – 0.3   |
| Class C   | 1           | Crack (major)    | 0.4   |
| Class C   | 2           | Crack (major)    | <b>5.0</b>  |
| Class C   | 3           | Crack (major)    | <b>0.7</b>  |
| Class C   | 4           | Crack (major)    | <b>7.0</b>  |
| Class C   | 5           | Crack (major)    | <b>1.7</b>  |
| Class C   | 6           | Crack (major)    | <b>3.0</b>  |
| Class C   | 7           | Joint (interior) | <b>10.7</b>                                       |
| Class C   | 8           | Joint (interior) | <b>1.0</b>  |
| Class C   | 9           | Joint (interior) | <b>1.9</b>  |
| Class C   | 10          | Joint (interior) | <b>1.8</b>  |
| Class C   | 11          | Joint (interior) | <b>0.6</b>  |
| Class C   | 12          | Joint (exterior) | 0.2   |
| Class C   | 13          | Rough Surface    | 0.5   |
| Class C   | 14          | Rough Surface    | 0.1   |
| Class C   | 15          | Crack (minor)    | <b>0.7</b>  |
| Class C   | 16          | Joint (interior) | <b>0.9</b>  |
| Class C   | 17          | Joint (interior) | 0.5   |
| Class C   | 18          | Joint (interior) | <b>3.5</b>  |
| Class C   | 19          | Joint (exterior) | 0.3   |
| Class C   | 20          | Joint (interior) | <b>3.2</b>  |

| Facility Area   | Location ID | Location Type    | Mercury Vapor Result ( $\mu\text{g}/\text{m}^3$ ) |
|---|-------------|------------------|---|
| Background Mercury Vapor Concentration <sup>[1]</sup> |             |                  | 0.2 – 0.3   |
| Class C   | 21          | Joint (interior) | <b>1.3</b>  |
| Class C   | 22          | Joint (exterior) | 0.3   |
| PCB   | 23          | Joint (interior) | 0.2   |
| PCB   | 24          | Joint (interior) | 0.2   |
| Class C   | 25          | Crack (minor)    | 0.3   |
| Class C   | 26          | Rough Surface    | 0.3   |
| Class C   | 27          | Crack (minor)    | 0.2   |
| Class C   | 28          | Crack (minor)    | 0.2   |
| Class C   | 29          | Rough Surface    | 0.4   |
| Class C   | 30          | Rough Surface    | 0.5   |

**Table D - 4 – Comprehensive Floor Joint Survey Results**

| Facility Area   | Joint ID             | Number of Readings along Joint Length | Average Mercury Vapor Result ( $\mu\text{g}/\text{m}^3$ ) |
|---|----------------------|---------------------------------------|---|
| Background Mercury Vapor Concentration <sup>[1]</sup> |                      |                                       | 0.2 – 0.3   |
| Class C   | A                    | 10                                    | <b>3.9</b>  |
| Class C   | B                    | 11                                    | <b>1.7</b>  |
| Class C   | C                    | 11                                    | <b>0.9</b>  |
| Class C   | D                    | 11                                    | 0.3   |
| Class C   | E                    | 10                                    | <b>1.7</b>  |
| Class C   | F                    | 13                                    | 0.2   |
| Class C   | G                    | 13                                    | 0.2   |
| Class C   | H                    | 13                                    | <b>7.6</b>  |
| Class C   | I (a) <sup>[2]</sup> | 12                                    | <b>1.3</b>  |
| Class C   | I (b) <sup>[2]</sup> | 13                                    | <b>0.9</b>  |
| Class C   | J                    | 13                                    | <b>0.9</b>  |
| Class C   | K (a) <sup>[2]</sup> | 12                                    | <b>1.0</b>  |
| Class C   | K (b) <sup>[2]</sup> | 13                                    | 0.2   |
| Class C   | L                    | 22                                    | 0.1   |
| Class C   | M                    | 23                                    | 0.2   |
| Class C   | N                    | 18                                    | 0.1   |

| Facility Area   | Joint ID | Number of Readings along Joint Length | Average Mercury Vapor Result ( $\mu\text{g}/\text{m}^3$ ) |
|---|----------|---------------------------------------|---|
| Background Mercury Vapor Concentration <sup>[1]</sup> |          |                                       | 0.2 – 0.3   |
| Class C   | O        | 15                                    | 0.1   |
| Class C   | P        | 23                                    | 0.4   |
| Battery   | A        | 7                                     | 0.1   |
| Battery   | B        | 9                                     | 0.1   |
| Battery   | C        | 8                                     | 0.2   |
| Battery   | D        | 8                                     | 0.1   |
| Battery   | E        | 11                                    | 0.1   |
| Battery   | F        | 15                                    | 0.1   |

Tables D-3 and Table D-4 Footnotes:

<sup>[1]</sup> General area background mercury vapor value was measured at beginning and end of sampling surveys. Individual joint / crack locations which recorded values greater than or equal to two (2) times background were highlighted **RED** to indicate that the location required further investigation and potential aggressive remediation.

<sup>[2]</sup> Joint I and K in Class C Area were split into two (2) halves due to the length of each joint.

***SUBSURFACE SOIL SAMPLING***

After the preliminary and comprehensive floor joint / crack direct-read mercury vapor surveys were completed, subsurface soil sampling was conducted below the concrete floor in the Class C and Battery Areas to determine whether or not mercury had penetrated the floor joints (i.e. wasn't just concentrated near the top of each joint). Soil samples were collected from underneath areas which were suspected to have the greatest potential for mercury contamination, namely beneath the joints and major cracks in the concrete floor. This sampling was conducted between August 7 – 12, 2013.

The results of the August 2013 soil sampling confirmed the exceedance of RCS-1 reportable concentrations at one (1) sample location (originally measured before closure in March 2012). Additionally, the August 2013 subsurface investigation

revealed measureable concentrations of mercury (below the RCS-1 reportable concentration) at other points along the floor joints throughout the Class C Area.

Figures D-5 – D-6 show the below floor soil sampling locations and graphical sample results for the samples collected both in the Class C Area and the Battery Area. The tables below provide the tabulated results for the subsurface soil sampling. The sample locations with measured soil concentrations above the RCS-1 reportable concentration limit are highlighted **RED** in the tables below.

**Table D - 5 – Subsurface Soil Sampling Results (Class C Area)**

| Facility Area | Sample ID         | Date    | Soil Sample Interval Mercury Result (mg/kg) |                   |                   |
|---------------|-------------------|---------|---|-------------------|-------------------|
|               |                   |         | 0" – 6"                                     | 6" – 12"          | 12" – 24"         |
| Class C       | A1                | 8/7/13  | 0.28  | ND <sup>[1]</sup> | -                 |
| Class C       | A2                | 8/12/13 | 2.5   | 2.8               | -                 |
| Class C       | B1                | 8/12/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -                 |
| Class C       | B2                | 8/12/13 | 0.84  | 0.26              | -                 |
| Class C       | D1                | 8/12/13 | ND <sup>[1]</sup>                           | 0.08              | -                 |
| Class C       | E1                | 8/12/13 | 13.0  | 0.93              | -                 |
| Class C       | F1                | 8/12/13 | 1.4   | 1.8               | -                 |
| Class C       | H1                | 8/12/13 | 7.1   | 8.2               | ND <sup>[1]</sup> |
| Class C       | I1                | 8/7/13  | 4.6   | 3.9               | 2.0               |
| Class C       | I2                | 8/12/13 | <b>37.0</b>                                 | 3.9               | 1.2               |
| Class C       | I3                | 8/7/13  | 5.6   | 1.5               | 4.9               |
| Class C       | I4 <sup>[2]</sup> | 8/7/13  | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -                 |
| Class C       | I5 <sup>[2]</sup> | 8/7/13  | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -                 |
| Class C       | K1                | 8/12/13 | 13.0  | 3.3               | -                 |
| Class C       | L1                | 8/12/13 | 0.15  | ND <sup>[1]</sup> | -                 |
| Class C       | LD <sup>[3]</sup> | 8/7/13  | 0.52  | 0.80              | -                 |
| Class C       | M1                | 8/7/13  | 0.10  | ND <sup>[1]</sup> | -                 |
| Class C       | N1                | 8/12/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -                 |
| Class C       | O1                | 8/12/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -                 |

| Facility Area | Sample ID | Date    | Soil Sample Interval Mercury Result (mg/kg) |                   |           |
|---------------|-----------|---------|---|-------------------|-----------|
|               |           |         | 0" – 6"                                     | 6" – 12"          | 12" – 24" |
| Class C       | P1        | 8/12/13 | 0.14  | ND <sup>[1]</sup> | -         |

**Table D - 6 – Subsurface Soil Sampling Results (Battery Area)**

| Facility Area | Sample ID         | Date   | Soil Sample Interval Mercury Result (mg/kg) |                   |         |                   |                   |
|---------------|-------------------|--------|---|-------------------|---------|-------------------|-------------------|
|               |                   |        | 0"-6"                                       | 6"-12"            | 12"-24" | 24"-30"           | 30"-36"           |
| Battery       | A1                | 8/8/13 | 0.81  | 0.10              | -       | ND <sup>[1]</sup> | ND <sup>[1]</sup> |
| Battery       | A2 <sup>[4]</sup> | 8/8/13 | -   | -                 | -       | ND <sup>[1]</sup> | ND <sup>[1]</sup> |
| Battery       | A3 <sup>[4]</sup> | 8/8/13 | -   | -                 | -       | ND <sup>[1]</sup> | ND <sup>[1]</sup> |
| Battery       | A4 <sup>[5]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | ND <sup>[1]</sup> | -                 |
| Battery       | A5 <sup>[5]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | ND <sup>[1]</sup> | ND <sup>[1]</sup> |
| Battery       | B1                | 8/8/13 | 2.0   | 0.22              | -       | 0.26              | 0.10              |
| Battery       | S1 <sup>[6]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | -                 | -                 |
| Battery       | S2 <sup>[6]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | -                 | -                 |
| Battery       | S3 <sup>[6]</sup> | 8/8/13 | 0.35  | 0.42              | -       | -                 | -                 |
| Battery       | S4 <sup>[6]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | -                 | -                 |
| Battery       | S5 <sup>[6]</sup> | 8/8/13 | ND <sup>[1]</sup>                           | ND <sup>[1]</sup> | -       | -                 | -                 |

Table D-5 and Table D-6 Footnotes:

<sup>[1]</sup> ND = non-detect, sample result below analytical limit of detection (LOD). LOD ranged from 0.06 mg/kg to 0.1 mg/kg depending on sample matrix quality.

<sup>[2]</sup> Samples I4 and I5 in Class C Area collected from middle of floor slab (i.e. not collected from joint) near location of highest concern (i.e. I2). Mid-slab samples collected to confirm that mercury did not penetrate concrete floor or migrate horizontally.

<sup>[3]</sup> Sample LD in Class C Area collected from heavily cracked area in front of loading docks.

<sup>[4]</sup> Samples A2 and A3 in Battery Area collected from bottom of empty scale pit, which was approximately 24 inches below grade of floor slab.

<sup>[5]</sup> Samples A4 and A5 in Battery Area collected from middle of floor slab (i.e. not collected from joint) near location of highest concern (i.e. scale pit). Mid-slab samples collected to confirm that mercury did not penetrate floor or migrate horizontally.

<sup>[6]</sup> Samples S1 – S5 Battery Area collected surrounding a location where pre-closure (i.e. March 2012) sampling indicated mercury contamination may exist.

### ***EXCAVATION TRENCH SURVEY***

After removal of the floor joints and top 6 to 8 inches of soil, several rounds of direct-read mercury vapor surveys were conducted from the bottom of the excavation trench, the results of which were used to direct further excavation. Where mercury vapor was detected at the soil surface, the decontamination contractor was directed to remove additional soil until the screening yielded mercury vapor values at or very near background concentrations.

The results for the excavation trench survey are provided in the table below. The table records the depth of initial excavation for each floor joint removed, the average direct-read mercury vapor reading recorded from the bottom of each trench, the depth of the trench after additional excavation (if necessary), and the final average direct-read mercury vapor reading from the bottom of the trench.

Figure D-7 provides results for each individual location along all of the floor joint trenches. The figure also shows the areas along the trenches where additional excavation was implemented.

**Table D - 7 – Excavation Trench Survey Results**

| Facility Area                          | Joint ID | Depth of Initial Excavation (inches) | Average Initial Mercury Result ( $\mu\text{g}/\text{m}^3$ ) | Depth of Final Excavation (inches) | Average Final Mercury Result ( $\mu\text{g}/\text{m}^3$ ) |
|--|----------|--------------------------------------|---|------------------------------------|---|
| Background Mercury Vapor Concentration |          |                                      |   |                                    | 0.3 – 0.4   |
| Class C                                | A        | 8.0                                  | <b>0.9</b>  | 24.0                               | 0.4   |
| Class C                                | B        | 8.0                                  | <b>1.4</b>  | 20.0                               | 0.2   |
| Class C                                | C        | 8.0                                  | <b>0.8</b>  | 14.0                               | 0.3   |
| Class C                                | D        | 12.0                                 | 0.5   | -                                  | -   |
| Class C                                | E        | 10.0                                 | <b>1.1</b>  | 30.0                               | 0.3   |

| Facility Area | Joint ID             | Depth of Initial Excavation (inches) | Average Initial Mercury Result ( $\mu\text{g}/\text{m}^3$ ) | Depth of Final Excavation (inches) | Average Final Mercury Result ( $\mu\text{g}/\text{m}^3$ ) |
|---------------|----------------------|--------------------------------------|---|------------------------------------|---|
| Class C       | H                    | 20.0                                 | 0.5   | -                                  | -   |
| Class C       | I (a) <sup>[2]</sup> | 20.0                                 | 0.6   | -                                  | -   |
| Class C       | I (b) <sup>[2]</sup> | 20.0                                 | <b>1.0</b>  | 26.0                               | 0.2   |
| Class C       | J                    | 10.0                                 | <b>0.9</b>  | 22.0                               | 0.3   |
| Class C       | K (a) <sup>[2]</sup> | 12.0                                 | <b>1.2</b>  | 14.0                               | 0.2   |
| Class C       | K (b) <sup>[2]</sup> | 12.0                                 | 0.6   | -                                  | -   |
| Class C       | LD                   | -                                    | -   | 24.0                               | 0.2   |

Table D-7 Footnotes:

<sup>[1]</sup> General area background mercury vapor value was measured at beginning and end of sampling surveys. Trench areas which recorded values greater than two (2) times background were highlighted **RED** to indicate that the location required additional excavation.

<sup>[2]</sup> Joint I and K in Class C Area were split into two (2) halves due to the length of each joint.

### ***POST-EXCAVATION SOIL SAMPLING***

After all interior joint areas were sufficiently excavated – that is, direct-read mercury vapor screening at the underlying soil surface was at or very near background concentrations – final post-excavation confirmatory soil samples were collected in October 2013. The purpose of the post-excavation soil sampling was to ensure that the excavation adequately removed mercury from the soil below the floor joints in the Class C Area. This final round of post-excavation sampling confirmed that all mercury contamination had been adequately reduced in the underlying soil. The results for all nine (9) post-excavation soil samples from the bottom of the trenches were below the analytical detection limit for mercury (i.e. non-detect).

A summary of the results from the post-excavation soil investigation are presented in Figure D-8. The table below provides a tabulated summary of the post-excavation soil sampling results.

**Table D - 8 – Post-Excavation Soil Sampling Results**

| Facility Area | Sample ID | Date     | Sample Interval | Soil Sample Mercury Result (mg/kg) |
|---------------|-----------|----------|-----------------|------------------------------------|
| Class C       | A1        | 10/22/13 | 24" – 28"       | ND <sup>[1]</sup>                  |
| Class C       | C1        | 10/9/13  | 14" – 18"       | ND <sup>[1]</sup>                  |
| Class C       | E1        | 10/6/13  | 30" – 34"       | ND <sup>[1]</sup>                  |
| Class C       | H1        | 10/9/13  | 20" – 24"       | ND <sup>[1]</sup>                  |
| Class C       | I1        | 10/9/13  | 26" – 30"       | ND <sup>[1]</sup>                  |
| Class C       | I2        | 10/9/13  | 26" – 30"       | ND <sup>[1]</sup>                  |
| Class C       | J1        | 10/9/13  | 22" – 26"       | ND <sup>[1]</sup>                  |
| Class C       | K1        | 10/9/13  | 14" – 18"       | ND <sup>[1]</sup>                  |
| Class C       | K2        | 10/9/13  | 12" – 16"       | ND <sup>[1]</sup>                  |

Table D-8 Footnotes:

<sup>[1]</sup> ND = non-detect, sample result below analytical limit of detection (LOD). LOD ranged from 0.07 mg/kg to 0.09 mg/kg depending on sample matrix quality.

The post-excavation soil sampling results indicated that after remediation the soil underneath the floor joints (and in the area near the loading dock, which was repaired) was successfully cleaned of mercury contamination.

***WASTEWATER VAULT SURVEY***

After removal of the old wastewater collection system from the wastewater vault area, two (2) rounds of direct-read mercury vapor surveys were conducted from immediately above the soil in the vault. A total of eleven (11) locations were tested. In locations where mercury vapor was detected at a level above two (2) times indoor background, the decontamination contractor was directed to remove

additional soil until the survey yielded mercury vapor values at or very near background concentrations.

The table below provides a summary of the results for the wastewater vault direct-read surveys. The table shows the depth of initial excavation at each sample location, the average direct-read mercury vapor reading recorded at each location, the depth after additional excavation (if necessary), and the final average direct-read mercury vapor reading from immediately above the soil.

Figure D-9 provides a schematic summary of the sample locations, results and extents of initial and follow-up excavation areas in the wastewater vault.

**Table D - 9 – Wastewater Vault Survey Results**

| Facility Area                          | Location ID | Depth of Initial Excavation (inches) | Average Initial Mercury Result ( $\mu\text{g}/\text{m}^3$ ) | Depth of Final Excavation (inches) | Average Final Mercury Result ( $\mu\text{g}/\text{m}^3$ ) |
|--|-------------|--------------------------------------|---|------------------------------------|---|
| Background Mercury Vapor Concentration |             |                                      |   |                                    | 0.4 – 0.5   |
| WW Vault                               | 1           | 6.0                                  | <b>1.3</b>  | 12.0                               | 0.8   |
| WW Vault                               | 2           | 6.0                                  | <b>1.3</b>  | 12.0                               | 0.8   |
| WW Vault                               | 3           | 8.0                                  | 0.5   | 8.0                                | 0.7   |
| WW Vault                               | 4           | 6.0                                  | 0.5   | 6.0                                | 0.8   |
| WW Vault                               | 5           | 10.0                                 | 0.6   | 10.0                               | 0.6   |
| WW Vault                               | 6           | 6.0                                  | <b>1.2</b>  | 12.0                               | 0.7   |
| WW Vault                               | 7           | 8.0                                  | 0.7   | 8.0                                | 0.6   |
| WW Vault                               | 8           | -                                    | 0.4   | -                                  | 0.6   |
| WW Vault                               | 9           | -                                    | 0.4   | -                                  | 0.7   |
| WW Vault                               | 10          | -                                    | <b>0.8</b>  | 8.0                                | 0.8   |
| WW Vault                               | 11          | -                                    | 0.5   | -                                  | 0.7   |

Table D-9 Footnotes:

<sup>[1]</sup> General area background mercury vapor value was measured at beginning and end of sampling surveys. Soil areas in the wastewater vault which recorded values greater than two (2) times background are highlight **RED** to indicate that the location required additional excavation.

## **APPENDIX E**

### **Description of Decontamination Methodologies for Mercury**

## **DECONTAMINATION METHODOLOGIES**

Appropriate selection of decontamination strategies for implementing building rehabilitation can significantly affect project effectiveness. The following sections of this thesis describe the procedures used for decontaminating all areas of the facility impacted by mercury contamination. Prior to implementing the procedures summarized below, they were researched and presented to the owner and cleaning contractors via technical memoranda which presented detailed standard procedures and cleanliness expectations. Additionally, before commencing decontamination, the contractors attended a project-specific training session. The training covered: overall project objectives, closure / clearance expectations, roles and responsibilities, and appropriate health and safety training so that all personnel working on the project understood all hazards associated with the work and the expected decontamination procedures.

Throughout the project, the contractors took all appropriate precautions to prevent the release of hazardous contaminants to the surrounding environment or underlying structure and soils during cleaning and decontamination activities. During cleaning and other remediation efforts, all contamination was fully contained within the facility using structured plastic-sheet (“poly”) barriers and negative air ventilation systems equipped with high-efficiency particulate arrestance (“HEPA”) filters with 99.97% removal efficiency of particles that have a size of 0.3 microns ( $\mu\text{m}$ ), and 2 inch (in) activated carbon filter media. Additionally, throughout the decontamination effort the necessary engineering controls were installed to control and prevent the cleaned areas from being recontaminated during the cleaning of other areas within the facility. That is, all interfaces between the cleaned areas and other areas of the facility were sealed and the cleaned areas

were placed positive (static pressure) with respect to all adjacent areas, thereby preventing migration of contamination into the cleaned areas. This was done while still observing proper Life Safety Code – for escape from all building areas.

### ***INVENTORY / EQUIPMENT REMOVAL AND DISPOSAL***

The first step in the facility closure process was the removal of all hazardous and recyclable materials inventoried at the facility. Whenever possible, recyclable materials and/or hazardous wastes were consolidated into compatible lots for bulk shipment to an appropriately permitted treatment, storage, disposal or recycling facility. Whenever practical, materials in inventory or generated during closure activities were recycled. In the case of materials meeting the definition of hazardous waste, a uniform hazardous waste manifest were used to document the shipment of the material.

At the time of ceasing recycling operations, the facility contained approximately 150,000 pounds of waste material, including 20,000 pounds of containerized mercury-contaminated materials. These materials were removed from the facility by the Owner and transferred to an appropriately permitted facility in April 2013.

In general, all work stations and miscellaneous equipment that was contaminated with hazardous material was dismantled, accumulated in properly sized containers, sampled appropriately, properly classified for waste category, and shipped off-site for disposal at a proper and appropriately licensed facility. However, certain pieces of equipment were scheduled for relocation and reuse at another owner operated facility, or were recycled for scrap value.

All reusable and recyclable equipment (i.e. photon units, MRT units, etc.) were cleaned and decontaminated using aggressive cleaning techniques. Prior to transit, the equipment was totally and securely enclosed in tight-wrap plastic material before being removed from the facility to ensure that contaminants would not be released into the environment during transport.

Figure E-1 provides a photographic summary of the various pieces of equipment which were cleaned / packaged / shipped for continued use or recycling.

Figure E - 1 – Equipment Decontamination



### ***OFFICE AREA DECONTAMINATION***

The Office Area of the facility was deconstructed and decontaminated separately from the rest of the facility – that is, during inventory removal and non-essential building component demolition was performed in the rest of the facility. This was done because of the fact that the Office Area posed a different set of structural decontamination challenges than the rest of the facility. Where the other areas of the facility were newer construction pre-fabricated steel framed additions (i.e. Butler building), the Office Area was built within an old timber frame barn-like structure, original to the site.

Considering the Office Area's age, prior to implementing demolition and cleaning activities in the Office Area, a survey was conducted for the presence of asbestos containing material ("ACM"). All walls and structures where ACM was identified were abated by a licensed asbestos removal contractor, who installed all the necessary containment structures prior to performing abatement services. During ACM abatement, full-shift indoor air quality sampling was conducted to ensure abatement personnel were not exposed to dangerous concentrations of asbestos. After ACM abatement, the asbestos contractor's containment structures were left in place so that decontamination personnel could utilize these structures to complete demolition. This methodology eliminated the potential for contaminated dust to be reintroduced into other areas of the facility.

After completing ACM abatement and general area demolition, the contractor used general area decontamination methodologies analogous to the procedures used in the rest of the facility and described elsewhere in this appendix.

Figure E-2 provides photographs depicting various stages of Office Area demolition and decontamination.

**Figure E - 2 – Office Area Decontamination**



### ***NON-ESSENTIAL BUILDING COMPONENT DEMOLITION AND REMOVAL***

In general, all non-essential, or highly contaminated porous structural material in the facility was demolished in a planned and deliberate manner using hand-tools (e.g. hammers, crowbars, etc.), collected, appropriately managed and disposed of accordingly off-site at an approved facility. All essential structural material (i.e. ceiling, walls, floor coverings etc.) in the facility were identified and scheduled to be cleaned and decontaminated in-place as part of the general facility surface cleaning activities.

At the time of closure, the facility housed several interior, non-structurally essential building components (i.e. Class C Front Office, Maintenance Area, Pour-Off Area, and PCB Storage Area partition wall, etc.). These building components were demolished using a “top-to-bottom” type approach by first removing and demolishing all non-essential structural material, including the interior plywood/sheetrock wall, corroded metal wall, insulation, and the floor coating. The demolition debris were removed from the facility and collected in appropriate containers. Throughout the demolition process the contractors took care to implement all necessary control techniques to minimize the generation and migration of dust throughout the facility.

Pre-clean dust composition sampling results (see Appendix D) indicated mercury contamination was concentrated within process dust particles, and therefore it was extremely important that during each phase of the building component demolition adequate controls were in place to control dust generated. The contractors were instructed to minimize dust generation throughout the decontamination process.

All demolition debris were removed from the facility, sampled for TCLP-Hg, appropriately characterized, and prepared for transport by the Owner's personnel using proper waste handling and manifest procedures. Figure E-3 provides a photographic summary of non-essential building component demolition.

**Figure E - 3 – Non-Essential Building Component Demolition**



### ***FLOOR JOINT / CRACK SOIL EXCAVATION AND REMOVAL***

Prior to facility closure, and as part of the closure decision making process, the owner conducted an investigation of mercury contamination below the concrete floor in the facility (March 2012). Mercury was detected at one (1) subsurface sampling location at a level in excess of the applicable Level-1 Reportable Concentrations for Soils (“RCS-1”), that is, greater than 20 mg/kg. This soil exceedance sample was located at a joint in the floor where two (2) concrete slabs met. After conducted several rounds of follow-up mercury vapor and soil testing (see Appendix D), it was determined that subsurface remediation was required for the interior floor joints and major cracks in the Class C Area of the facility. These surveys indicated that mercury-laden dust had become concentrated along the interior floor joints (i.e. where floor slabs met). Multiple attempts by contractor to completely remove the mercury from within these joints / cracks in the concrete were not sufficiently successful to achieve the closure goals.

Joint removal / remediation entailed cutting the concrete approximately 10-12 inches along both sides of the joint, exposing an approximately 20- to 24-inch wide swath of soil along the entire length of all interior floor joints in the Class C Area. Additionally, the contractor removed a portion of the slab in the area of the loading docks because the concrete in this area was heavily cracked. Once the soil was exposed, a mini-excavator and hand digging was used to remove the top 6 to 8 inches of soil. During this phase of decontamination the Class C Area was completely isolated from the surrounding facility using poly-sheet containment barriers equipped with negative air handling units to control and prevent dust migration to the rest of the building, other tenant spaces and/or to the environment. The negative air units were equipped with disposable pre-filters to capture large

dust particles, HEPA filters to collect sub-micron sized particles, and activated carbon filters to adsorb any vapors. The ventilation was sufficiently controlled so that the concrete cutting and excavation areas were negative (static pressure) with respect to all adjacent building areas and the outside.

After removal of the floor joints and top 6 to 8 inches of soil, several rounds of direct-read mercury vapor surveys were conducted from the bottom of the trench (see Appendix D), the results of which were used to direct further excavation.

Concrete and soil cuttings that were removed from the floor joint excavations were staged on-site, within the Class C Area, until waste characterization samples could be collected and transportation for off-site disposal could be arranged. After completing the floor joint / soil excavation and removal, the contractor filled the excavation trenches with clean fill and repaired the floor with steel reinforced concrete.

Figure E-4 provides a photographic summary of the floor joint removal and soil excavation conducted in the Class C Area.

**Figure E - 4 – Floor Joint / Soil Removal**



## ***WASTEWATER VAULT REMEDIATION***

The decontamination of the Battery Area also included a small crawl-space area under the Office Area stairwell containing a wastewater collection tank system for the collection of sanitary wastewater from several sinks and restrooms located throughout the facility. The tank was equipped with a submersible pump and discharged to the municipal sewer system.

The area under the stairwell containing the collection system was an unfinished (i.e. dirt-floor) crawl-space with normal means of entrance was through a part of the facility not accessible to the owner. However during decontamination efforts, access was achieved by removing the stairway leading to the Office Area. Because the collection tank was of poor structural condition and a visual inspection indicated that the tank had overflowed at some point historically; taking a conservative approach, it was decided that the tank should be completely removed / replaced and the soil underneath remediated to eliminate any potential for mercury contamination to persist in this area after facility closure.

The decontamination of the wastewater system vault area was performed by the decontamination contractor. Prior to removing the sump tank, the cast iron piping runs which serviced the Class C maintenance area sink and the Battery Area bathrooms were removed, containerized and properly disposed. The piping from the facility bathrooms were temporarily disconnected from the sump tank and the tank was pumped out and removed from the vault area. The tank and bottom solids were containerized and disposed as hazardous waste.

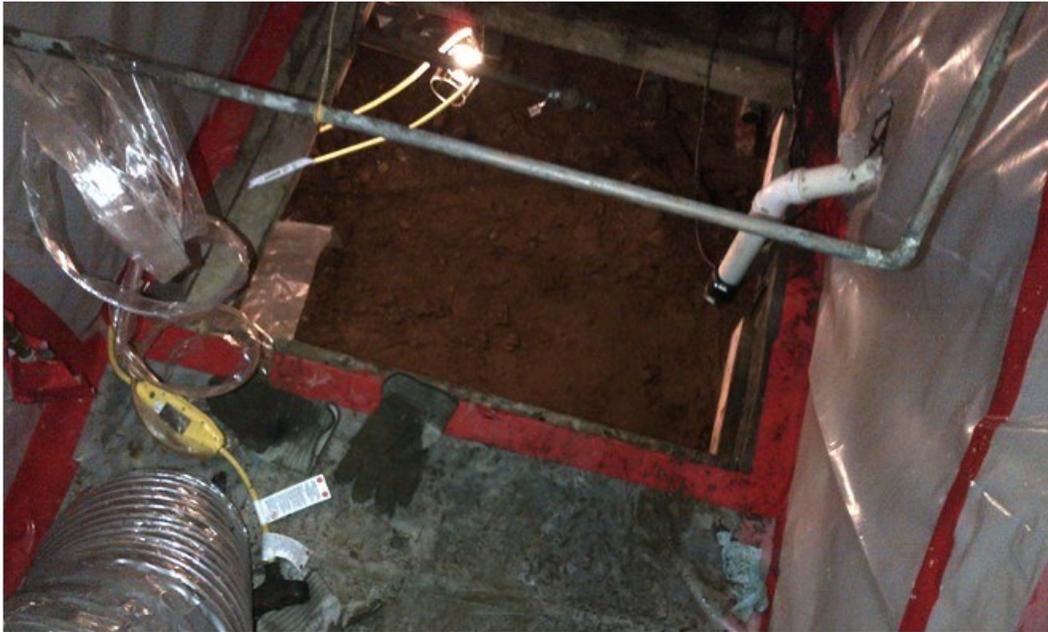
After the contractor completely removed the collection tank and top few inches of underlying soil, several rounds of direct-read mercury vapor surveys were

conducted the results of which were used to direct further remediation (Appendix D).

After it was determined that the soil in the wastewater vault area had been sufficiently remediated to not warrant further investigation, a new sump tank and associated pump/piping to service was installed.

Figure E-5 provides a photographic summary of the wastewater vault remediation efforts.

Figure E - 5 – Wastewater Vault Remediation



## ***GENERAL SURFACE DECONTAMINATION***

General surfaces in the facility were cleaned / decontaminated to meet the *No Visible Dust or Debris* standard. The *No Visible Dust or Debris* standard is essentially a “white-glove test”. Wetted, white, disposable cleaning cloths were used to wipe horizontal and vertical surfaces, and then were examined to determine whether or not dust was visible on the cloth. Areas that were wiped and did not generate significant dust discoloration of the cloth were considered to have achieved the *No Visible Dust or Debris* standard.

To achieve the *No Visible Dust or Debris* standard all exposed surfaces in the facility were cleaned / decontaminated using a “top-to-bottom” type approach; starting at the ceiling of each area in order ensure that lower surfaces were not re-contaminated by subsequent cleaning efforts on higher surfaces. This cleaning methodology assured that all settled dust was contained and removed while not being disturbed and entrained into the air. This approach was designed to limit migration of contamination (and dust) to other areas of the facility. Additionally, throughout the decontamination process the area being cleaned was fully enclosed with poly-sheet containment barriers and the area was placed negative (static pressure) with respect to all adjacent areas preventing migration of contamination into other areas of the facility.

All surfaces in all areas of the facility were thoroughly and aggressively vacuumed using HEPA equipped industrial-sized vacuums designed specifically for collecting mercury contamination. The importance of using specially designed vacuums for cleaning mercury cannot be overstated. Conventional vacuuming heats the mercury and can exhaust it into the air, spreading fine droplets and increasing

airborne concentrations. In addition, the conventional vacuum can become permanently contaminated and must be discarded.

Following vacuuming, all raised surfaces (i.e. ceiling and walls) were wet-cloth wipe cleaned by hand with a tri-sodium phosphate ("TSP") cleaning solution to remove any remaining dust or residual stains. After the TSP wet-wipe, select surfaces, which showed noticeable signs of corrosion (i.e. sprinkler lines, water mains, etc.), were cleaned with a dilute muriatic acid ("HCl") solution and carefully re-cleaned with TSP to remove residual acid. This acid cleaning technique was performed only on corroded surfaces to strip the outer layers of rust, which may have resisted initial TSP cleaning. All surfaces were wiped until the wet-cloth shows no sign of dust discoloration. Engineer personnel were on-site periodically to monitor various contractor cleaning activities to ensure the cleanliness expectations were being met.

Figure E-6 provides a photographic summary of the general surface cleaning being performed by the contractor.

Figure E - 6 – General Surface Decontamination



### ***AGGRESSIVE SURFACE REMEDIATION***

In the back corner of the Battery Area the interior wall of the area was a brick façade which was formerly the exterior wall of a boiler room and brick chimney. This location was the site of minor fire (date unknown) which burned the ceiling insulation and scorched the galvanized steel interior ceiling in the area surrounding the brick wall. In the time since the fire, the galvanized steel oxidized (rusted) considerably, and the brick façade had been painted several times. After the repeated decontamination efforts on the galvanized ceiling and on the brick surface failed to achieve sufficient decontamination goals (see Section 4.1.2.3, page 55 and Section 4.1.2.4, page 58), it was recommended that the painted brick surfaces be sandblasted to remove the top layers of paint on the brick wall and the galvanized ceiling in this area was removed and replaced by the contractor.

During this aggressive phase of decontamination, additional containment barriers were erected to enclose the brick wall area in order to prevent sandblasting material and demolition material from recontaminating the rest of the Battery Area.

Figure E-7 provides a photographic summary of before and after the aggressive surface remediation.

**Figure E - 7 – Aggressive Surface Remediation**



### ***CONCRETE FLOOR DECONTAMINATION***

A factor which was considered most important to fully decontaminate the facility, was to ensure that mercury could be adequately removed from the concrete floor (especially in the Class C Area). Mercury contamination has the ability to “seep” into porous building materials, such as concrete. Therefore, a number of different tests were devised to ensure that the prescribed decontamination techniques were adequate (see Section 3.1.2, page 29, and Section 3.1.3, page 31).

The entire concrete floor in the facility was cleaned using an industrial-sized floor buffer with a TSP detergent solution. After TSP application, the entire floor within each area was decontaminated with at least two (2) applications of Hg-X® mercury-sulfide converting agent with chelating and dispersion properties. Hg-X® reacts with elemental mercury to produce a stable non-vaporizing sulfide powder, which can be removed from the surface using general floor cleaning techniques. After removing the Hg-X® with a wet-vacuum, the floors were cleaned again with a final round of TSP solution.

Figure E-8 provides a photographic summary of floor decontamination being conducted.

Figure E - 8 – Concrete Floor Decontamination



## **APPENDIX F**

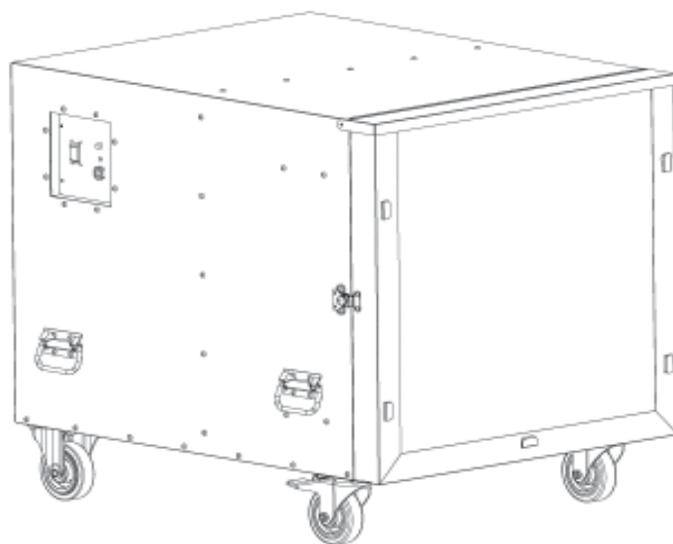
### **Equipment Specifications and Laboratory Sampling**

#### **Methods**



# HEPA-AIRE H2000L

## INSTRUCTION MANUAL



**Abatement Technologies, Inc./Asbestos Abatement Division**

**Abatement Technologies, Inc.**

**Georgia, USA**

**800-634-9091**

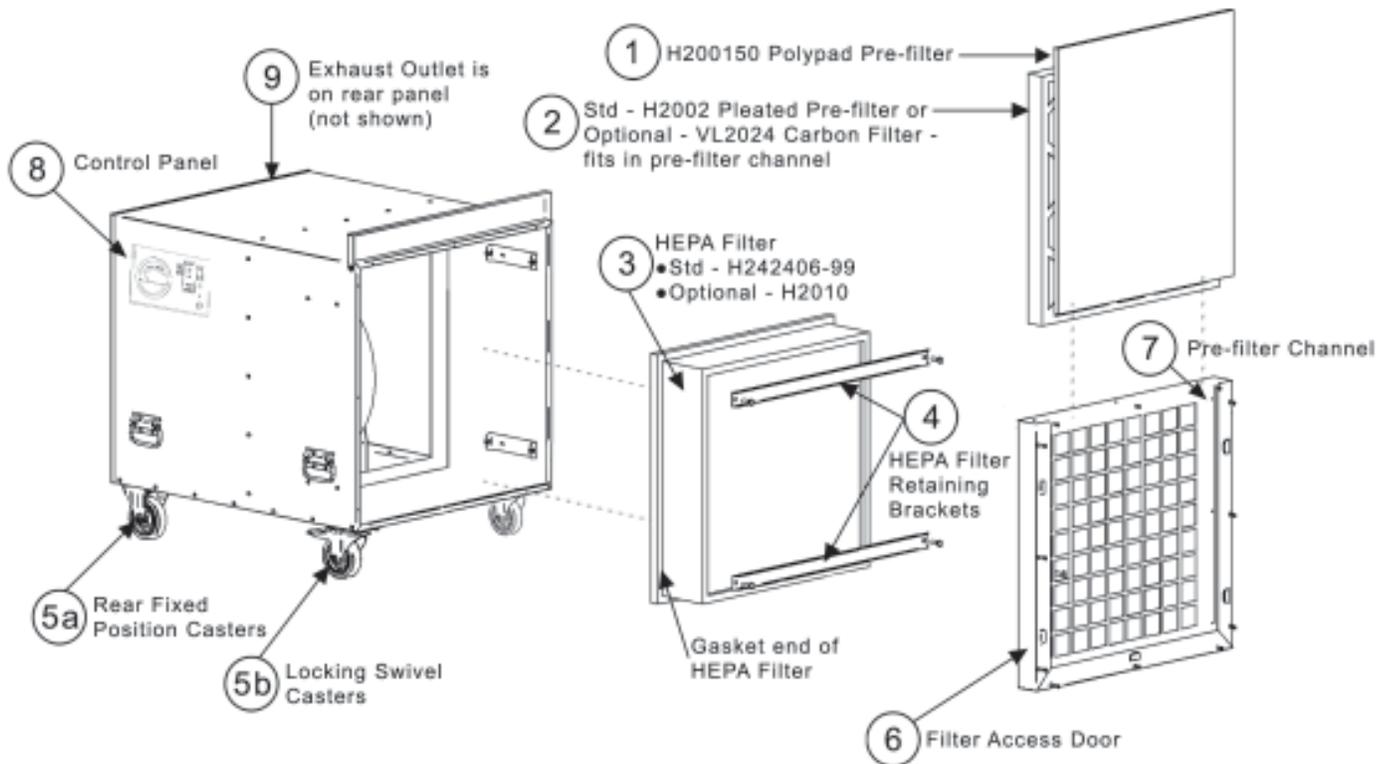
**Abatement Technologies, Ltd.**

**Ontario, Canada**

**905-871-4720**

**[www.abatement.com](http://www.abatement.com)**

# HEPA-AIRE Portable Air Filtration Unit Model: H2000L



1. First Stage:
  - Standard: 1" coarse particulate polypad pre-filter (P/N H200150)
2. Second Stage:
  - Standard: 2" pleated particulate pre-filter (H2002) or
  - Optional: 2" high capacity VAPOR-LOCK® carbon filter (P/N VL2024)
3. Final Stage:
  - Standard: 6" deep, 99.97% HEPA filter (P/N H242406-99)
  - Optional: 11 1/2" deep, 99.97% HEPA filter (P/N H2010)
4. HEPA filter retaining brackets
5. Casters:
  - a. 2 each 3.5" fixed position casters
  - b. 2 each 3.5" 360° swivel casters with locking feature
6. Filter access door
7. Pre-filter channel
8. Control panel
9. 12" exhaust outlet - on rear panel of unit

**HEPA-AIRE® Portable Air Filtration Unit**  
**Model: H2000L**  
**Instruction Manual**

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**READ AND SAVE THESE INSTRUCTIONS!**

- Note:** 1. **Read and understand all operating instructions before using the H2000L Portable Air Filtration Unit.**
2. **Save this manual for future reference.**

This instruction manual provides important information on the use of the HEPA-AIRE Portable Air Filtration Unit - model H2000L. These instructions must be carefully followed in order to operate the unit safely and correctly. If there are any questions regarding the use of the unit, please contact Abatement Technologies immediately at 800-634-9091 U.S. or 905-871-4720 Canada.

Abatement Technologies strongly urges users of air filtration unit and related accessories to follow the most recent guidelines and/or standards published by the Occupational Safety and Health Administration, Environmental Protection Agency, and all other federal, state, provincial and local regulations.

**Note:** The U.S. Environmental Protection Agency's publication "Guidance for Controlling Asbestos-Containing Materials in Buildings", EPA 560/5-85-024, includes helpful information on air filtration systems. Abatement Technologies strongly urges anyone performing asbestos abatement to read the most recent edition of this EPA publication before using any air filtration system.

**GENERAL INFORMATION**

The H2000L is a multi-use air filtration machine, equipped with pre-filters and a HEPA filter that are capable of filtering many airborne contaminants. An optional carbon pre-filter for capturing low concentrations of odors, vapors, gases, and volatile organic compounds, collectively known as OVG, is also available.

Types of contaminants captured by particulate pre-filters, HEPA filter, or carbon filters:

- |                |                           |  |
|----------------|---------------------------|--|
| • Dirt         | • Lung-damaging particles | • Low concentrations of OVG                              |
| • Dust         | • Metal fumes             | • Low concentrations of Volatile Organic Compounds (VOC) |
| • Drywall dust | • Smoke                   | • Unpleasant nuisance odors                              |
| • Saw dust     | • Mold and fungal spores  |  |

Note: To capture low concentrations of OVG, a Vapor-Lock® carbon filter must be used.

The H2000L is capable of providing particulate and odor, vapor, gas filtration with final stage filtration through a High Efficiency Particulate Air (HEPA) filter. The unit incorporates a series of particulate filters which successively remove larger size to smaller size particles from the air. In addition to providing HEPA filtration, the H2000L is primarily used in a negative pressure or recirculation mode. A negative pressure condition is created in order to confine contaminated airborne particles. This condition exists when the static pressure inside the room containing the unit is lower relative to the pressure of the environment outside the room. The static pressure differential is created and maintained by continuously exhausting air out of a given room at a faster rate than air enters the room from all other sources. In the recirculation mode, all of the filtered air is exhausted back into the room containing the unit.

## Standard Air Cleaning Stages (filters supplied with the unit)

The H2000L comes equipped with three progressively efficient particulate filters. The first and second stage filters mount in the pre-filter access door channel and the final stage HEPA filter is located inside the cabinet:

- First stage: 1" coarse particulate poly-pad (H200150) is designed to capture particles 100 microns or larger.
- Second stage: 2" deep, pleated pre-filter (H2002) is designed to capture up to 85% of particles 3-10 microns or larger.
- Final stage: HEPA filter (H242406-99) is tested and certified to capture at least 99.97% (9,997 out of 10,000) 0.3-micron particles.

## Optional Filters (must be purchased separately)

There are two optional filters that can be used in the H2000L:

- 2" deep, Vapor-Lock® pleated high-capacity carbon filter (VL2024) for capturing OVG and particles 10 microns or larger. The VL2024 mounts in the pre-filter channel.
- 11½" deep, fiberboard frame HEPA filter (H2010) is tested & certified to capture at least 99.97% of 0.3-micron particles.

The 2" deep Vapor-Lock® pleated high-capacity carbon filter can be used to reduce airborne OVG by chemically bonding the OVG molecules to the surface area of the carbon granules, via a process known as adsorption.

Effective carbon adsorption is dependent upon the amount of carbon & exposed carbon granule surfaces, and the dwell (contact) time the OVG molecules have with the carbon granules. Operating the unit at low speed to increase dwell time can therefore improve OVG adsorption, though it is highly unlikely that all of the OVG will be removed in one pass of air through the unit. Operating the unit in the recirculation mode can increase effectiveness, by exposing OVG particles to multiple passes through the Vapor-Lock® filter.

It is almost impossible to provide accurate estimates to two commonly asked questions: "how much time will it take to capture all of the OVG?", and "how do I know when a carbon filter should be replaced?" Unfortunately, unknown factors, such as concentration levels, fresh-air intake volume, temperature, and humidity prevent establishment of any more accurate 'rule of thumb' than one's sense of smell. Since off-gassing of adsorbed OVG can occur when the adsorption capacity of the filter is reached, replace the carbon filter as soon as odor breakthrough is sensed. More detailed information on carbon adsorption can be found in an article titled: "**Activated Carbon: How Is It Used? How Does It Work?**", which can be found on the Abatement Technologies website, [www.abatement.com](http://www.abatement.com).

## HOW TO DETERMINE THE REQUIRED NUMBER OF AIR FILTRATION DEVICES (AFD)

1. Calculate the total air volume (V) in cubic feet (ft<sup>3</sup>) within the enclosed containment area by multiplying the length (L) x the width (W) x the height (H), all in feet ( $V = L \times W \times H$ ).
2. Determine the minimum number of air changes per hour (ACH) specification. When no ACH number is specified, most users target at least 6 ACH for construction areas. Building in a safety factor to compensate for filter loading, duct losses, reduced voltage and other factors that can reduce actual installed airflow is a good practice. For example, if 6 ACH is the objective, you might design for 8 ACH.
3. Select an Abatement Technologies air filtration device (AFD) model and determine the peak airflow rating for that model in cubic feet per minute (CFM).

4. Determine the total number of AFD required using the following formula:  
Quantity =  $(V \times \text{Design ACH}) / (\text{AFD Rating} \times 60)$
5. Always round up to the next whole number. For example, if the total number of AFD required is 2.13, 3 units are recommended, not 2.

**Example:** How many air filtration devices (each with 600 CFM rated airflow) would be required to provide 8 ACH (including a safety factor) in a 40ft L x 24ft W x 10ft H containment area?

1.  $V = 40\text{ft} \times 24\text{ft} \times 10\text{ft} = 9,600\text{ft}^3$
2. Design ACH = 8
3. Quantity of AFD required =  $(9,600\text{ft}^3 \times 8 \text{ACH}) / (600 \text{CFM} \times 60) = 76,800/36,000 = 2.13 = 3 \text{ units}$

## H2000L TRANSPORT

**Note:** The H2000L should be transported in the horizontal position. If extremely poor road conditions exist or excessive shock and vibration are expected, take precautionary measures by padding the unit to provide impact absorption during transport.

**Caution:** Always use caution when moving the H2000L inside a building or home. The unit weighs 124 pounds with the H242406-99 HEPA filter and 151 pounds with the H2010 HEPA filter. Older structures with weakened floors or staircases may require special considerations for safe transport.

## ELECTRICAL REQUIREMENTS

1. The H2000L unit requires a minimum of 110 volts AC, 60 Hz to operate properly; however, maximum airflow performance requires 120 volts AC, 60 Hz.
2. Due to momentary start-up current surge, the unit requires a 15 amp circuit that is free of other loads.
3. If the unit is connected to a circuit that is protected by fuses, use time delay fuses.
4. Extension cords used for the H2000L must be UL-listed, heavy duty No. 12/3 AWG SJTW industrial grade 3-wire type. Use of larger numerical gauge (lower capacity wire) power cord(s) may result in electrical shock, fire hazards and/or damage to unit. The cord(s) must be in good condition and in continuous lengths (no splicing) and should not exceed a total of 50 feet in length. Make certain that any extension cords used do not reduce power to the unit to less than 110 volts. Use of a voltmeter to confirm adequate voltage is recommended.
5. Check to ensure that any circuit to which the unit is connected is protected by a 15 ampere circuit breaker.
6. The H2000L should be connected to a three-prong, properly grounded electrical outlet equipped with a Ground Fault Circuit Interrupt (GFCI) device. A GFCI is an electrical safety device that will trip the circuit and stop the flow of electricity if leakage of current is detected.  
**Important Note: The H2000L should be plugged into a GFCI receptacle at the power source to protect the power cord and the unit. This GFCI will trip the circuit if it detects leakage of current from the power cord or unit.**
7. To avoid personal injury, fire hazards and/or damage to the H2000L electrical system and power cord, do not connect or disconnect the power cord to an electrical outlet unless the motor is "OFF" (middle position of Motor Speed Switch).

## REQUIREMENTS FOR SAFE OPERATION

1. Never allow unauthorized individuals or children to operate the unit at any time.
2. Abatement Technologies urges anyone operating the H2000L to wear the proper personal protective equipment and follow safe work practices in accordance with federal, state, provincial and employer regulations.

3. Check the condition of power cord(s) before using them. Damaged cords can cause fatal electric shock and/or motor failure.
4. Power cord(s) should never be exposed to water, heat, sharp, or abrasive objects; in addition, they should never be kinked or crushed. Avoid tightly wrapping the cords to prevent kinking of the internal wires. Always replace damaged power cords immediately.
5. Never pull the unit by the power cord.
6. Avoid running over power cords with utility equipment and vehicles.

#### **Important Safety Instructions**

- a. **Do not operate any unit with a damaged cord or plug. Discard unit or return it to an authorized service facility for examination and/or repair.**
- b. **Do not run cord under carpeting. Do not cover cord with throw rugs, runners, or similar coverings. Do not route cord under furniture or appliances. Arrange cord away from traffic area and where it will not be tripped over.**

**Caution:** As with any piece of electrical equipment, always make sure that the unit is turned “OFF” prior to connecting the power cord to an electrical outlet or disconnecting it from an electrical outlet. Failure to do so will cause “arcing”, and could result in personal injury, fire hazards and/or damage to the unit. Do not disconnect the power cord from supply receptacle while the unit is operating.

**Warning:** To reduce risk of electrical shock, do not expose this unit to water or rain. Do not touch the electrical outlet or power cord(s) with wet hands or while standing on a wet or damp surface.

**Warning:** Risk of electrical shock! Can cause injury or death! Turn unit “OFF” and disconnect power cord from supply receptacle before replacing the HEPA filter and before cleaning or servicing the unit.

**Warning:** The H2000L is equipped with an automatic restart motor and blower assembly that will restart without warning after a temporary power interruption or recovery from a thermal overload (over-heating) condition. Keep clear of the motor and blower assembly at all times to reduce the risk of injury.

**Warning:** To reduce risk of fire or electrical shock, do not use the H2000L with any solid state speed control device. Do not use in a cooking area.

**Caution:** The H2000L is designed for indoor use only.

**CAUTION:** For General Ventilating Use Only. Do Not Use To Exhaust Hazardous Or Explosive Materials And Vapors.

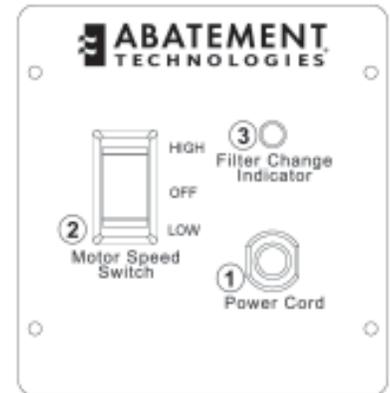
**Warning:** Abatement Technologies air filtration systems are not intrinsically safe for use in hazardous environments. Always consult a certified industrial hygienist before using them. Do NOT use this equipment in any atmosphere that is or may be immediately dangerous to life or health (IDLH), combustible, flammable, explosive, oxygen deficient, and/or contains odors, vapors, gases or particulates that exceed permissible exposure levels. Such atmospheres may require the use of intrinsically safe equipment, specific engineering controls, and personal protective equipment in accordance with Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), Canadian Standards Association (CSA), and other federal, state, provincial and local regulations.

**Warning:** This equipment is not classified as “intrinsically safe” and should not be used in the following hazardous locations as defined by the Underwriters Laboratories: Class I Division 1, Class I Division 2, Class I Zone 0, Class I Zone 1, Class I Zone 2, Class II Division 1, Class II Division 2, Class III Division 1, Class III Division 2. Refer to the UL web site: <http://www.ul.com/hazloc/define.htm>.

**Warning:** Do not use this unit near sparks, open flames or other possible sources of ignition.

## CONTROL PANEL COMPONENTS

1. **Power Cord** - Hardwired, 8 ft 18/3 AWG SJTW power cord for connection to electrical outlet.
2. **Motor Speed Switch** - Three position switch, “HIGH”, “OFF” (middle position of switch), and “LOW”, that controls the speed of the motor.
3. **Filter Change Indicator** - Amber light that indicates excessive restriction on intake or loading of the filter(s) and that filter change procedures should be followed. Check the Filter Loading Indicator when the unit is operating on “HIGH” speed.



## BEFORE OPERATING THE UNIT, NOTE THE FOLLOWING:

Assemble the 4 casters to the bottom of the H2000L cabinet. Refer to Figure A. The casters are packed inside a separate box.

Inspect and tighten any HEPA filter retaining bolts that may have loosened during transportation. Inspect the filters for any material or structural damage prior to use and replace any damaged filters before operating the unit. When removing any filters prior to operation, always put them back in place with airflow indicator on filter housing oriented in the proper direction (if applicable).

As with any air filtration system, external airflow losses not attributable to the air filtration unit will reduce the airflow of the system. The following recommendations can minimize airflow losses created by external static resistance.

1. Always use the minimum length of ducting possible with the fewest possible number of turns and bends.
2. Rigid metal ducting creates less turbulence and consequently less airflow loss than flexible ducting. Regardless of the type of ducting used, rigid, “sweep-type”, radiused connections should be used for all turns and bends.
3. If flexible ducting is used, it must be kept as taut as possible to avoid flattening.

## LOCATION OF THE UNIT AND MODES OF OPERATION

1. **Negative Pressure** - used to help ensure that airborne contaminants do not escape from a contained area, by maintaining negative (lower) air pressure within that area compared to adjacent areas. This is generally accomplished by placing the unit inside the containment area and exhausting filtered air from the unit out of the area. The filtered air must be exhausted outside of the containment area, either directly to the outdoors, or into another part of the building. To maintain negative pressure, the air exhaust must exceed the air supply by

the greater of: 10% or 100 CFM. To achieve this differential, the air supply volume to the area may have to be reduced. Negative pressure levels should be continuously monitored.

2. **Recirculation** - used to reduce concentrations of airborne contaminants in a room or area by continuously cleaning the air and exhausting it back into the same room or area.
3. **Positive Pressure** - used to help prevent airborne contaminants from entering a containment area, by keeping that area under positive pressure compared to adjacent spaces, so any air leakage will be an outflow of clean air, and not inflow of contaminated air. This pressure differential can be established by:
  - a. placing the unit inside the containment area, and using it to pull air into the area by attaching flex duct between the inlet collar and a location outside of the containment area.
  - b. placing the unit outside of containment area, and using it to push HEPA-filtered air into the area through flex duct attached between the outlet collar and a location inside the area.

To ensure that the proper pressure differential is maintained, the volume of HEPA-filtered air supplied to the area must be the greater: of 10% or 100 CFM higher than the volume of air exhausted from it by the HVAC system. Positive pressure levels should be monitored continuously.

**Important Note: Do not operate the unit unless the pre-filter and HEPA filter are installed and the filter access panel is in place.**

## TO START UNIT

1. Check to make sure that the Motor Speed switch is in the "OFF" (middle) position. Plug power cord into a 120 volt AC, 60 Hz, 15 amp supply circuit.
2. Set the Motor Speed switch to the "HIGH" or "LOW" position.  
Note: Refer to the chart in this instruction manual entitled "AIRFLOW RATINGS" that lists the airflows corresponding to the various speeds for the H2000L.

**Note: In the event of a power failure while the unit is running or loss of power due to any other cause, this unit's motor will re-start when power is restored.**

## FILTER CHANGE INDICATOR

Filter Change Indicator light "ON" indicates one or more of the following:

1. Loaded filter(s). Refer to filter change procedures.
2. Restrictions on air intake. Refer to Troubleshooting Guide.

## FILTER REPLACEMENT

**Note: Personnel responsible for changing filters, servicing unit or relocating unit within the facility are urged to wear the proper personal protective equipment and follow safe work practices in accordance with federal, state, provincial, and employer regulations.**

**Note: Filters being replaced must be disposed of in accordance with federal, state, provincial, local and facility regulations.**

System airflow reduction is generally the result of filter loading, blockage of the unit's inlet or use of excessive lengths of flex duct that is connected to the inlet.

The size and concentration of airborne contaminants, temperature and humidity conditions, and duration of use determine how often filters need replacement. If the Filter Change Indicator light turns "ON",

this indicates one or more of the following: (1) pre-filter(s) are loaded, (2) the inlet is obstructed, (3) the flex duct, if attached to inlet, is too long or has too many bends, and (4) the HEPA filter is loaded.

The method of determining when to replace the optional activated carbon filter is somewhat subjective. As the odor, vapor, and/or gas filtration capacity decreases, the user will begin to sense a slight odor or taste of the contaminant, indicating that the filter should be replaced.

**Note:** The filters are not reusable, therefore, do not attempt to clean and reuse them.

**Caution: Abatement Technologies H2000L Portable Air Filtration Unit is designed to meet or exceed standards for high efficiency air filtration equipment. Use only Abatement Technologies parts, including replacement filters. Use of non-Abatement Technologies parts and filters voids the product warranty and all performance claims.**

**Warning: To reduce the risk of fire, electrical shock or personal injury, always turn the unit "OFF" and disconnect the power cord from supply receptacle before replacing the HEPA filter and before cleaning or servicing the unit.**

## **FILTER CHANGE PROCEDURE**

### **To Change the First Stage Filter:**

1. With the unit operating, remove the first stage filter and replace it with a new one.
2. If the Filter Change Indicator light remains "ON" after changing the first stage filter, the second stage filter should be replaced.

### **To Change the Second Stage Filter:**

1. Remove the second stage filter (located behind the first stage polypad filter) and replace it with a new one.
2. Return the first stage filter into place in front of the new second stage filter.
3. If the Filter Change Indicator light remains "ON" after changing the second stage filter, the HEPA filter should be replaced.

**Note:** If an optional Vapor-Lock® filter is being used, be sure to remove it from its poly bag before installing it in the unit. Vapor-Lock® filters are packaged in poly bags to preserve the integrity of the carbon granules.

### **To Change the HEPA Filter (H242406-99 or optional H2010)**

1. Turn the unit "OFF" and disconnect the unit's power cord from the electrical outlet.
2. Unlatch and open the Filter Access Door.
3. Remove the bolts that secure the HEPA filter retaining brackets in place (remove the lower bracket first, then the top bracket), set the brackets aside, and remove the HEPA filter from the cabinet.
4. Carefully install a new HEPA filter (part# H242406-99 or H2010) inside the cabinet, gasketed end first. Ease the filter into the cabinet until it is flush against its sealing surface. For reference purposes, the top panel of the H242407-99 filter has various labels affixed to it and the rear of the filter is the gasketed end.
5. Re-attach the HEPA filter retaining brackets to secure the filter in its proper position. The top bracket should be re-attached first, then the bottom bracket. The bolts should be snug but not over-tightened.

Note: The HEPA filter is delicate and should be handled with care. When removing or re-attaching the HEPA filter retaining brackets, do not touch the filter media; otherwise, damage to the filter and leakage of contaminated air could result.

6. Close and securely latch the Filter Access Door.

**Warning: Use only Abatement Technologies pre-filters, HEPA filters, and replacement parts. Substitute parts void the warranty, jeopardize worker and environmental safety, and adversely effect engineered performance levels.**

## HEPA-AIRE H2000L SPECIFICATIONS

| FEATURE   | H2000L   |
|---|--|
| Net weight w/ filters:  | 124 lbs. with H242406-99 HEPA; 151 lbs. with H2010 HEPA.   |
| Shipping weight:  | 141 lbs. with H242406-99 HEPA; 168 lbs. with H2010 HEPA.   |
| Dimensions - LxWxH:   | 35 3/4"L x 26"W x 30 1/4"H.  |
| Power supply requirements:  | 115-120 volts AC, 60Hz, 15 amp circuit.  |
| Normal operating amps:  | 8 amps or less.  |
| Motor:  | 1 HP, 2 speed motor with thermal overload protection, auto re-set, 60 HZ, single phase.                            |
| Operational sound level:  | 70 dBA on high speed. Reading taken at a distance of 5 feet.   |
| Cabinet material:   | 20 gauge galvanized steel.   |
| Transportability:   | 2 each removable 3.5", 360° swivel casters with locking feature.<br>2 each removable 3.5", fixed position casters. |
| First stage filter:   | 1" coarse particulate polypad pre-filter (H200150).  |
| Second stage filter:  | 2" pleated particulate pre-filter (H2002)  |
| Optional second stage filter:                                     | 2" high capacity carbon filter (VL2024).   |
| HEPA filter:  | Tested and certified to an efficiency of 99.97% or higher against 0.3 micron size particles (H242406-99).          |
| Optional HEPA filter:   | Tested and certified to an efficiency of 99.97% or higher against 0.3 micron size particles (H2010).               |
| Air inlet (optional - not included with unit) and outlet collars: | Both collars are 12" in diameter.  |

Note: Specifications subject to change without notice.

### AIRFLOW RATINGS

|        | HIGH Speed | LOW Speed |
|--------|------------|-----------|
| H2000L | 1,950 CFM  | 1,300 CFM |

Note: Airflow ratings estimates are based on factory and independent testing @ 120 VAC with an air straightener and a traverse of readings taken with a computing vane-anemometer. Actual results may vary for various reasons, including motor and blower and HEPA filter tolerances. Factors such as filter loading, reduced voltage to the motor, and inlet and outlet ducting will reduce airflow. Use these ratings as a general guideline only.

## TROUBLESHOOTING GUIDE

| PROBLEM                                    | POSSIBLE CAUSE  | SOLUTION   |
|--|---|--|
| NO RESPONSE WHEN THE POWER IS TURNED "ON". | POWER CORD UNPLUGGED.<br><br>DEFECTIVE POWER CORD.<br><br>TRIPPED CIRCUIT BREAKER.<br><br>TRIPPED GROUND FAULT CIRCUIT INTERRUPTER.<br><br>THERMAL OVERLOAD ON THE MOTOR HAS TRIPPED. | PLUG POWER CORD FIRMLY INTO ELECTRICAL OUTLET IN WALL.<br><br>CHECK ALL CONNECTIONS AND CONDITION OF ALL CORDS. DO NOT OPERATE WITH DAMAGED POWER CORD(S).<br><br>RESET BREAKER FOR BUILDING.<br><br>RESET GFCI AT POWER SOURCE.<br><br>TURN UNIT "OFF", WAIT 30 MINUTES AND RESTART UNIT. |
| CIRCUIT BREAKER FOR BUILDING "TRIPS".      | OVERLOADED CIRCUIT.   | REMOVE OTHER LOADS FROM CIRCUIT. RESET CIRCUIT BREAKER.  |
| UNIT RUMBLES WHEN ATTEMPTING TO START.     | LOW VOLTAGE OR LIMITED AMPERAGE IS SUPPLIED.<br><br>EXTENSION CORD IS TOO LONG OR OF TOO HIGH A GAUGE.<br><br>OTHER MACHINES OR LOADS ON SAME CORD OR CIRCUIT.                        | CHECK POWER SUPPLY. FOR MAXIMUM PERFORMANCE, THE UNIT REQUIRES A 115 - 120 VOLT 15 AMP CIRCUIT THAT IS LOAD FREE.<br><br>EXTENSION CORD(S) SHOULD NOT EXCEED A TOTAL OF 50 FT IN LENGTH. USE GROUNDED 3-WIRE 12 GAUGE CORD(S).<br><br>REMOVE OTHER LOADS FROM SAME CIRCUIT.                |
| FILTER CHANGE INDICATOR "ON".              | LOADED FILTERS.<br><br>EXCESSIVE RESTRICTIONS ON INTAKE.<br><br>CARBON FILTER HAS NOT BEEN REMOVED FROM POLYBAG.  | CHANGE IN ACCORDANCE WITH OPERATING INSTRUCTIONS.<br><br>REDUCE BENDS, LENGTH OF FLEX DUCT OR ELIMINATE RESTRICTIONS.<br><br>REMOVE CARBON FILTER FROM POLYBAG.  |

Note: If unit does not start or malfunctions after carefully following the Troubleshooting Guide, call Abatement Technologies service department at 800-634-9091 (U.S.) or 905-871-4720 (Canada) for assistance.

### COMPONENT REPLACEMENT AND CARE OF THE UNIT

**Warning: To reduce the risk of fire, electrical shock or personal injury, always turn the unit "OFF" and disconnect power cord from supply receptacle before removing the control panel, replacing the HEPA filter and before cleaning or servicing the unit. The H2000L is equipped with an automatic restart motor and blower assembly that will restart without warning after a temporary power interruption or recovery from a thermal overload (over-heating) condition. Keep clear of the motor and blower assembly at all times to reduce the risk of injury.**

Occasionally a defective component will cause the unit to operate improperly or not at all. Any electrical component can fail. Refer to the Wiring Diagram and Wiring Schematic to diagnose the failure of any component. Diagnostics should only be performed by a technician qualified to service electrical equipment.

The unit should be cleaned with a damp cloth or a water-based cleaner/sanitizer. Do not use harsh chemicals, solvents or detergents to clean the unit.

**Warning: Keep electrical components dry as their exposure to liquids poses a safety hazard and can damage components.**

## **CERTIFICATION OF ROOM AIR FILTRATION UNITS**

The Abatement Technologies room air filtration units have been tested by Intertek Testing Services (ITS) and are ETL and ETLIC (Canada) listed for electrical safety.

ITS is accredited by the U.S. Occupational Safety and Health Administration (OSHA) as a Nationally Recognized Testing Laboratory (NRTL).

## **LIMITED WARRANTY**

Abatement Technologies, Inc (ATI) warrants that goods sold to the original user shall be free from defects in material and workmanship for a period of 1 year, except such as are commercially acceptable. This warranty does not include useful filter life. **ATI does not warrant that the goods sold are merchantable or fit for any particular purpose. ATI makes no warranties other than as stated in this paragraph. All other warranties, guaranties, or representations, express or implied, by operation of law or otherwise, are expressly disclaimed.** Goods found by ATI to be defective or not to conform to specification shall upon return be replaced or repaired by ATI without any additional charges, or, at ATI's option, ATI may refund the purchase price of such goods. ATI will pay return transportation charges on returned goods not exceeding the transportation charges applicable to shipment from original destination unless the returned goods are free from defect and conform to specifications. Returned goods which are found by ATI to be free from defect and to conform to specifications shall be held for Purchaser's shipping instructions, which instructions Purchaser shall furnish promptly upon request. **ATI's liability shall in no event extend beyond replacement, repair or refund of the purchase price and ATI shall not be liable under any circumstances for special, contingent or consequential damages, nor for loss, damages, or expenses directly or indirectly arising from the use of the goods, including without limitation, warehousing, labor, handling and service charges, die, equipment, or machine breakage, nor for costs, lost profits or loss of good will. The use of substitute, non-ATI parts and/or filters, in any ATI product, voids all warranties and performance claims. The remedies set forth herein are exclusive.**

For warranty information and assistance contact Abatement Technologies' Customer Service Department at 800-634-9091 (U.S.) or 905-871-4720 (Canada.)

Abatement Technologies' H2000L high-efficiency air filtration units are originally equipped with true HEPA (High Efficiency Particulate Air) filters designed to maximize the performance of the equipment, and to meet the following industry standards:

### **Institute of Environment Sciences and Technology**

IEST-RP-CC001.4 (Type A HEPA and ULPA Filters)

IEST-RP-CC021.2 (Testing HEPA and ULPA Filter Media)

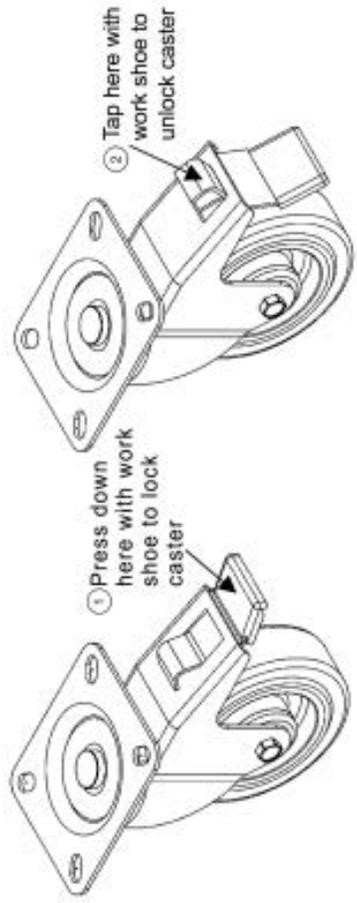
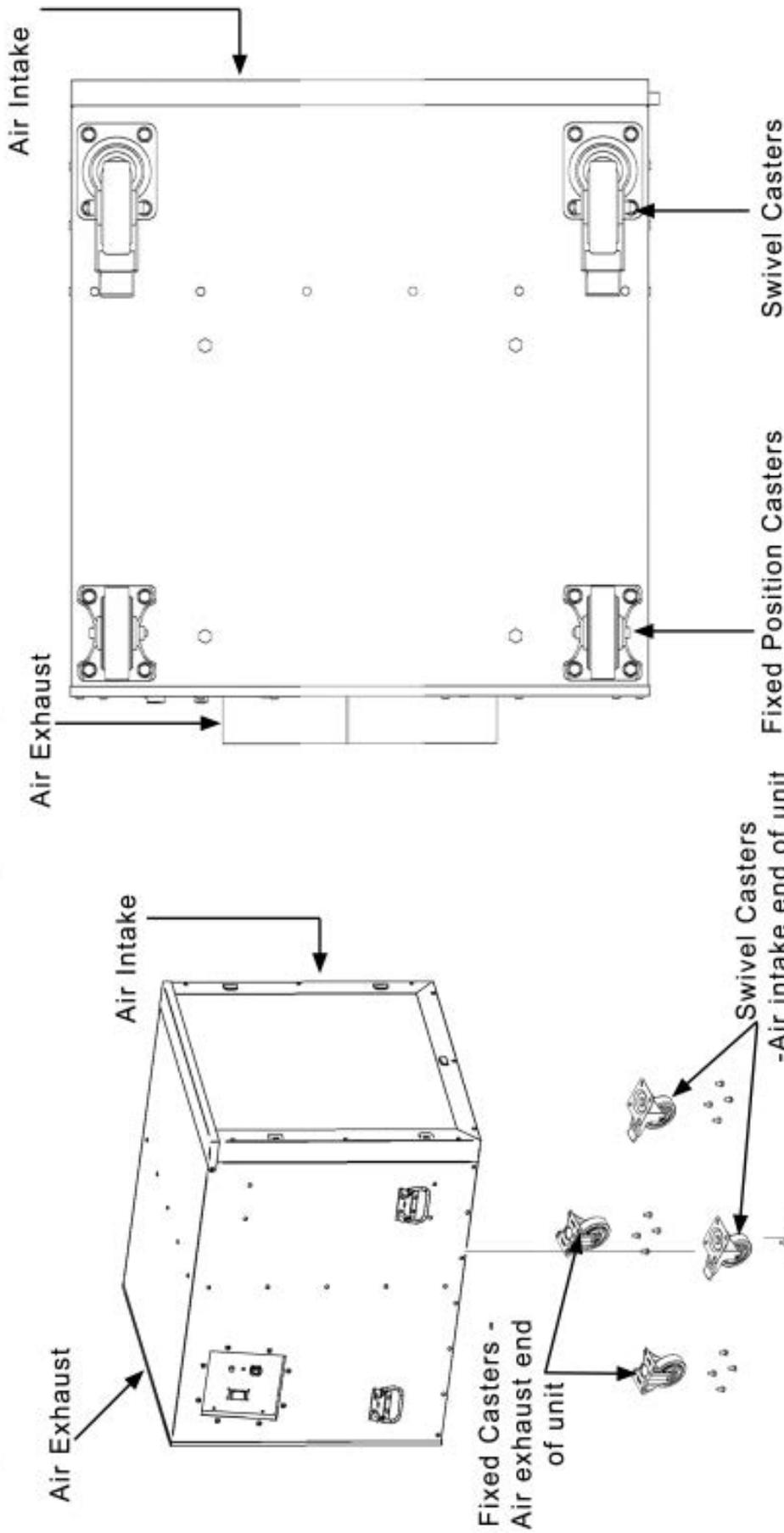
### **Underwriters Laboratories**

UL900, Class II (Flammability Specifications)

### **100% Efficiency Tested**

Abatement Technologies HEPA filters are individually tested and certified to ensure that the completed filter provides an overall minimum efficiency of 99.97% when challenged by a thermally generated test aerosol, 0.3-microns in size, in accordance with IEST-RP-CC034.2.

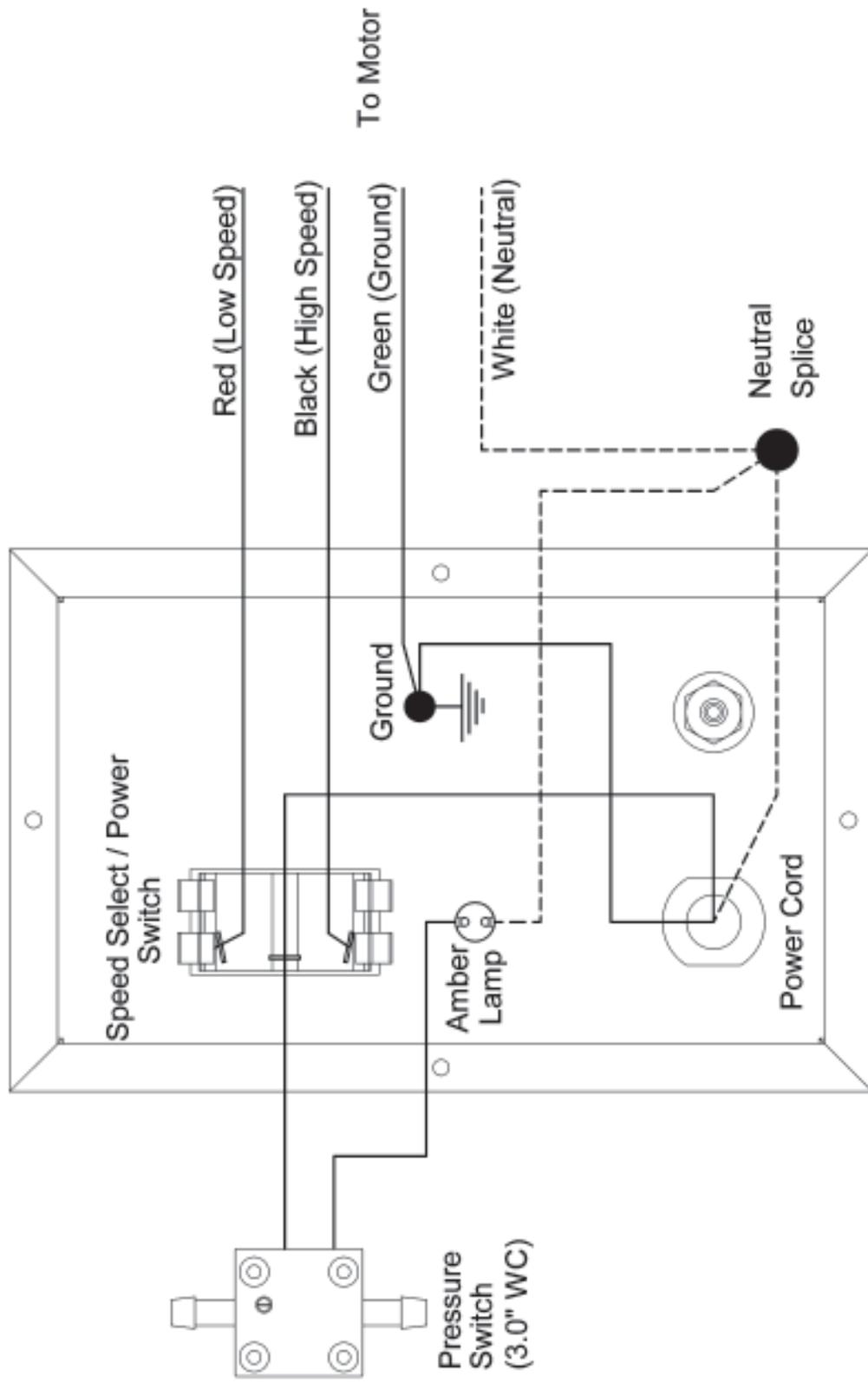
Figure A: H2000L Caster Assembly and Operation



1. Press down on caster flange with work shoe until flange locks in downward position. Once locked, the caster will not roll or swivel.
2. Tap with work shoe to release caster from locked position.

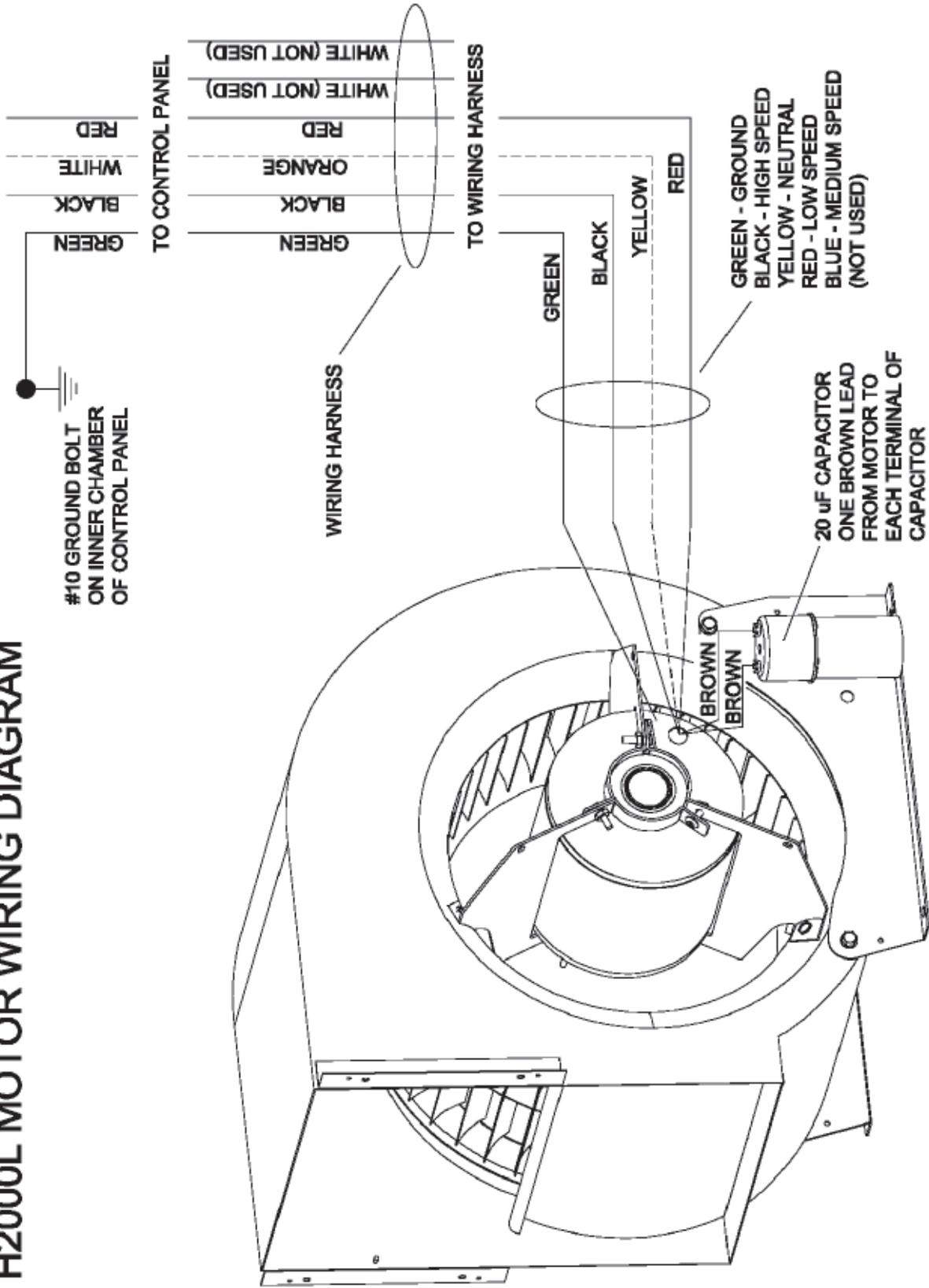
**Warning: Pinch Hazard!** Do not use hands or fingers to lock or unlock this swivel caster or personal injuries such as severe pinching or cuts could result. Use work shoe to lock and unlock caster.

# H2000L Control Panel Wiring Diagram

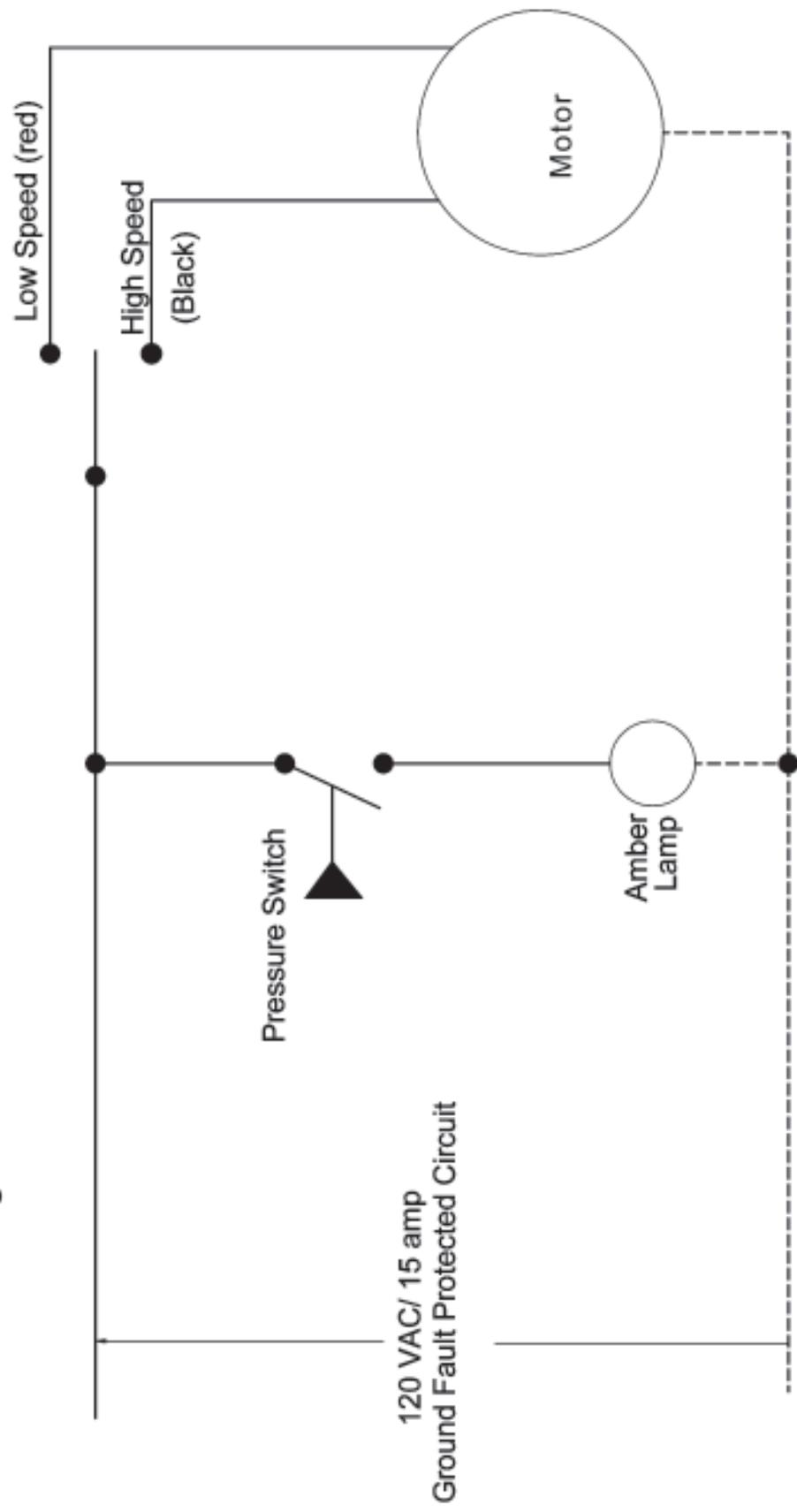


Revision D

# H2000L MOTOR WIRING DIAGRAM



# H2000L Wiring Schematic



# HGR<sup>®</sup> for Mercury Removal

## Granular Activated Carbon



### Description

Calgon Carbon HGR<sup>®</sup> granular activated carbon is a sulfur impregnated carbon. The base carbon is made from select grades of bituminous coal and suitable binders to create the unique pore structure and superior hardness necessary for the intended service. Activation is controlled to impart a pore structure that will both accept substantial quantities of impregnant and maintain access for the gas being treated to the complex pore structure. After activation, the sulfur is distributed in a thin layer over the extensive internal surface area of the carbon. This provides it with the unique properties required for the removal of elemental and organic mercury from natural gas, air, and by-product hydrogen streams.

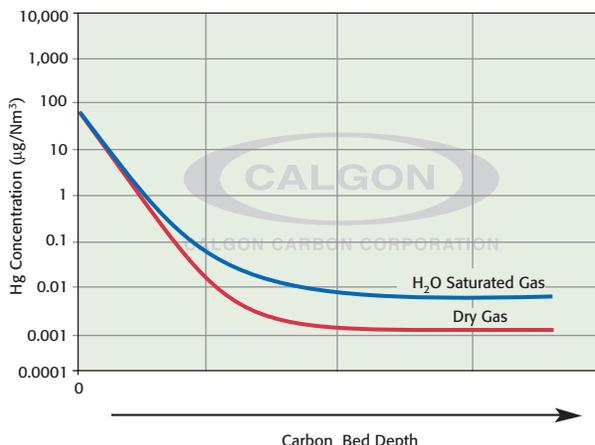
### The Mercury Removal Process

Mercury removal with HGR<sup>®</sup> activated carbon is an established process for removal of mercury from natural gas and by-product hydrogen streams. The mercury is removed from natural gas feedstocks to LNG and LPG plants to protect aluminum heat exchangers from corrosion. The exhaust air from mercury cell chlorine plants or metallurgical processing equipment can be treated to provide an environmentally safe atmosphere for employees and delicate instruments. Type HGR<sup>®</sup> is also used in mercury cell chloralkali plants to remove mercury from by-product hydrogen streams.

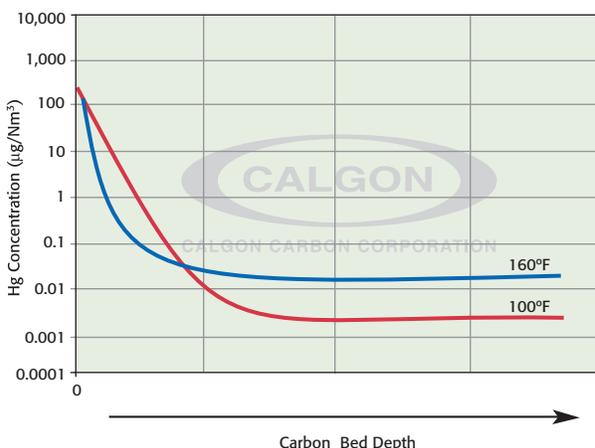
The mercury removal process employs a single or dual vessel adsorption system designed to reduce concentrations to  $<0.01 \mu\text{g}/\text{Nm}^3$  in the treated gas. During the adsorption process, mercury is attracted to the activated carbon surface where a chemical reaction converts the mercury to mercuric sulfide. The sulfide product is then retained in the pores of the carbon granule. Mercury capacity of Type HGR<sup>®</sup> activated carbon can be as high as 20% by weight.

In a properly designed HGR<sup>®</sup> carbon system, the maximum attainable mercury concentration in treated gas is not affected by changing the pressure or inlet mercury concentration of the gas. However, lowering the gas temperature or moisture content of the inlet gas will improve the process and further reduce the mercury concentration in the treated gas. For instance, a gas stream at 150°F saturated with moisture will result in a treated gas containing  $0.1 \mu\text{g}/\text{Nm}^3$  of mercury. The mercury level in the treated gas can be further reduced to  $<0.01 \mu\text{g}/\text{Nm}^3$  by reducing the temperature to 70°F and the moisture to trace levels.

### Impact of Moisture



### Impact of Temperature



### Specifications

|  |                                  |
|--|----------------------------------|
| Apparent Density                         | 37 lb./ft <sup>3</sup> (approx.) |
| Sulfur Content by weight                 | 10% (min)                        |
| Screen Size by weight, U.S. Sieve Series |                                  |
| On 4 mesh                                | 5.0% (max)                       |
| Through 10 mesh                          | 5.0% (max)                       |

# HGR<sup>®</sup> for Mercury Removal Granular Activated Carbon



## Packaging

225 lb. (55 gal.) steel drum, net wt.

## Safety Message

Wet activated carbon preferentially removes oxygen from air. In closed or partially closed containers and vessels, oxygen depletion may reach hazardous levels. If workers are to enter a vessel containing carbon, appropriate sampling and work procedures for potentially low oxygen spaces should be followed, including all applicable Federal and State requirements.

## Limitations of Liability

The Supplier's liability and the Purchaser's exclusive remedy for any cause of action arising out of this transaction, including, but not limited to, breach of warranty, negligence and/or indemnification, is expressly limited to a maximum of the purchase price of spare parts or equipment sold hereunder. All claims of whatsoever nature shall be deemed waived unless made in writing within forty-five (45) days of the occurrence giving rise to the claim. In no event shall the Supplier, for any reason or pursuant to any provision of the warranty, be liable for incidental or consequential damages or damages in excess of the purchase price, nor shall the Supplier be liable for loss of profits or fines imposed by governmental agencies.



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## Your local representative

# VM-3000 Mercury Vapor Monitor

Continuous mercury measurement  
in air and other gases



- Direct reading mercury vapor meter
- Portable, integrated battery for 6 hours operation
- Proven reliable detection method: UV absorption
- Easy operation
- Automatic zero adjustment
- Measuring ranges 0-100 / 0-1000 / 0-2000 µg/m<sup>3</sup>
- High resolution 0.0001 mg/m<sup>3</sup>
- Data logger integrated

## Fields of application

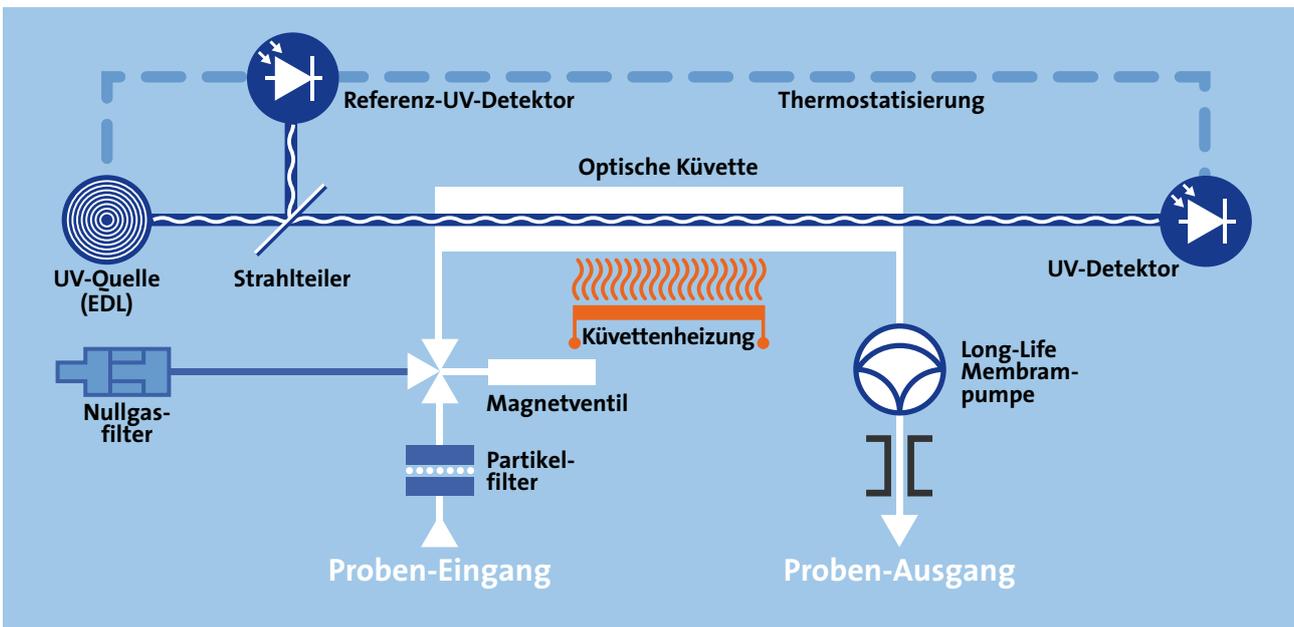
The VM-3000 Mercury Tracker serves for continuous measurement of the mercury concentration in air and other gases in laboratory as well as in industry and mobile applications.

It has a wide variety of applications:

- work place monitoring (threshold limit value)
- exhaust air monitoring in mercury recovery plants
- emission monitoring in the chemical industry
- ground air screening of contaminated soil
- quality control of hydrogen and natural gas
- detector for laboratory applications

## Measuring principle

The mercury concentration is measured in an optical cell made of fused silica. A maintenance-free membrane pump continuously feeds the sample gas to the optical cell where light absorption measurement takes place at a wavelength of 253.7 nm. This so-called “cold vapor atomic absorption spectroscopy (CVAAS)” measuring method is extremely sensitive for mercury determination and has been used successfully for many years. In contrast to the occasionally propagated atomic fluorescence spectroscopy (AFS) method it is low in interference and requires neither an amalgamation step nor expensive noble gases as carriers.



VM-3000 flow chart

## Analytical Performance

The VM-3000 uses a high-frequency driven electrodeless Hg low pressure (EDL) lamp as UV source. It generates emission lines of an extremely narrow bandwidth which are congruent with the absorption lines of the Hg atoms. Cross-sensitivities are thus minimized. The extremely high stability of the UV source in the VM 3000 is a result of the reference beam feedback control method. Total background noise is less than 0.1 µg/m<sup>3</sup>. To prevent temperature drift both the lamp unit and the detectors are temperature-stabilized. Because the optical cell is heated the VM-3000 is insensitive to water vapor.



Easy to operate:  
LabAnalyzer 254, the preferred system for many laboratories world-wide

## Special Features

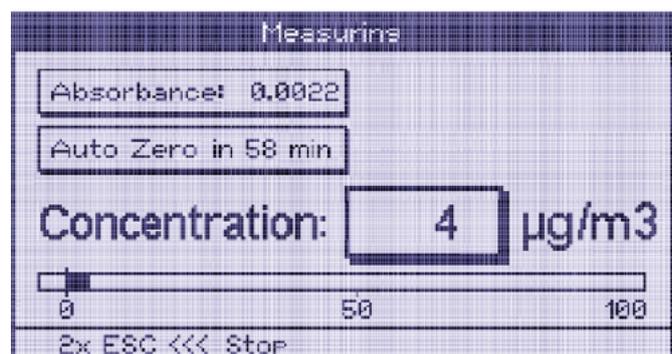
- Metal housing with sturdy handle
- Option: Rack version with mounting brackets for 19" racks
- Membrane pump with long service life
- Input filter with teflon membrane
- Stable optical bench
- Factory-calibrated

## Easy to operate

The user controls the VM-3000 by menu-guided inputs via a waterproof membrane keypad. After switch-on the light source is stabilized (approx. 1 - 15 minutes). When the measurement mode is started, a zero adjustment is first carried out automatically. Then the analyzer switches to measurement and continuously indicates the measured mercury concentration of the gas as a numerical value and a graphic bar. The following settings are possible in the "parameters" menu: duration and repeat interval of the zero adjustment, selection of the concentration unit ( $\mu\text{g}/\text{m}^3$  or ppb), measuring range (0.1-100, 0-1000, 0-2000  $\mu\text{g}/\text{m}^3$ ), input of three different alarm levels, calculation of a mean value over three freely selectable time intervals, printer activation, and, if required, a sample dilution factor.

## Display and Output of Measurements

The result of the measurement is displayed on an LCD in real time, both numerically and graphically and is output as an electrical signal of 4-20 mA. The device has outputs for alarm, status and measurement values for full integration in plant control systems. The device also has a serial interface (RS 232) for data collection on a PC.



Graphical and numerical display of results in realtime

## Extensions

The VM-3000 Mercury Vapor Monitor is the basic model of our modular system for mercury analytics. An optional reaction unit and activation of the relevant software turn it into a laboratory unit for liquid samples. A gold trap installed upstream allows measurements in the extreme trace range.

## Multiplexer operation

A multiplexer unit can be connected for automatic monitoring of several measurement points. See information in special brochure.



## Self Diagnosis System

If an important component of the VM-3000 malfunctions the user is warned via the display (blinking messages: clean cell, lamp, low battery, alarm) and via output signals.

## Battery Operation

For operation independent from mains power the VM-3000 is also available with a built-in rechargeable battery and a charger unit. This option allows mobile battery-powered applications of up to approx. 5 hours.

## Data Logger Function

A data logger function can be integrated into the VM-3000 as an option. Up to 30000 readings can be stored in the data memory. The logging interval can be set from 1 - 16 seconds revealing a total recording capacity of 4-60 hours. The stored data can be read out with a PC using the serial interface of the VM-3000 according RS232 standard.

# VM-3000 Mercury Vapor Monitor

## Technical Specifications

|                            |   |
|----------------------------|---|
| Measuring principle:       | UV-Absorption   |
| Wavelength:                | 253,7 nm  |
| UV source:                 | Electrodeless low-pressure mercury lamp   |
| Stabilization:             | reference beam and thermal  |
| Optical cell:              | fused silica (Suprasil), 23 cm long   |
| Optical cell heating:      | approx. 70° C   |
| Measuring range:           | 1...100µg/m <sup>3</sup> ; 1...1000µg/m <sup>3</sup> ; 1 - 2000µg/m <sup>3</sup>                  |
| Sensitivity:               | 0.1 µg/m <sup>3</sup>   |
| Response time:             | 1 sec   |
| Computation of mean value: | autom. via three freely selectable time intervals   |
| Alarm:                     | when concentration is exceeded, 3 levels are programmable   |
| Status alarms:             | measuring cell soiled, battery state, UV source   |
| Control pad:               | waterproof membrane keypad  |
| Measurement display:       | Graphic display with background lighting  |
| Signal outputs:            | 4...20 mA for recorder;<br>RS 232 bidirectional for PC, data logger etc.,<br>parallel for printer |
| Pump:                      | membrane pump, approx. 2 L / min.<br>optional Flow meter with alarm message                       |
| Filter:                    | PTFE, 1 µ, 47-50 mm diameter  |
| Power supply:              | 110 ... 240 V/(50/60 Hz)  |
| Battery operation:         | optional, 12 V batteries integrated, 6 h capacity<br>or external DC Source                        |
| Data logger-function:      | Up to 30000 readings capacity   |
| Power consumption:         | 40 W  |
| Dimensions:                | 45 x 15 x 35 cm (W x H x D)   |
| Weight:                    | approx. 7 kg  |



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# PORTABLE ZEEMAN MERCURY ANALYZER



RA-915<sup>+</sup> analyzer; RP-91 and RP-91C attachments



## METHOD AND APPLICATIONS

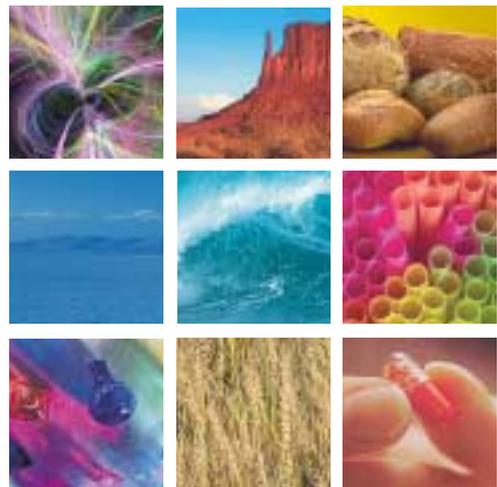
A portable spectrometer designed for interference free analysis/monitoring of mercury content in ambient air; water; soil, natural and stack gases, chlorine alkali manufacturing, spill response, hazardous waste, foodstuff, biological materials.

## PRINCIPLE OF OPERATION

Atomic absorption spectrometer with a 10-meter multipath optical cell and Zeeman background correction. This combination eliminates interferences and provides the highest sensitivity.

## FEATURES AND BENEFITS

- direct detection of mercury without its preliminary accumulation on a gold trap
- ultralow mercury detection limit in air (2 ng/m<sup>3</sup>) in real-time operation mode
- wide dynamic quantification measuring range (0.00001 – 0.1 mg/m<sup>3</sup>)
- mercury determination in complex samples without sample pretreatment
- field operation from a built-in battery for measurements of atmospheric air and industrial gases measurements
- built-in test cell for field performance verification



LUMEX

## APPLICATION SAMPLES

| Samples                 | Detection limit           | Sample volume or weight | Atomization technique | Number of analyses per hour |
|-------------------------|---------------------------|-------------------------|-----------------------|-----------------------------|
| Ambient air             | 2 ng/m <sup>3</sup>       | 20 l/min                | without atomization   | *                           |
| Natural and other gases | 2 – 500 ng/m <sup>3</sup> | 5 – 20 l/min            | without atomization   | *                           |
| Water                   | 0.5 ng/l                  | 20 ml                   | cold vapor            | 15                          |
| Oil and condensate      | 50 µg/kg                  | 10 mg                   | pyrolysis             | 15                          |
| Soil and sediments      | 0.5 µg/kg                 | 200 mg                  | pyrolysis             | 15                          |
| Urine                   | 5 ng/l                    | 1 ml                    | cold vapor            | 15                          |
| Tissues                 | 5 µg/kg                   | 10 mg                   | pyrolysis             | 15                          |
| Hair                    | 20 µg/kg                  | 10 mg                   | pyrolysis             | 15                          |
| Blood                   | 0.5 µg/l                  | 0.2 ml                  | cold vapor            | 15                          |
| Plants                  | 2 µg/kg                   | 50 mg                   | pyrolysis             | 15                          |
| Foodstuff               | 2 – 10 µg/kg              | 5 – 50 mg               | pyrolysis             | 15                          |

\* Real-time assaying with a response time of 1 sec

## EQUIPMENT AND OPTIONS

- RA-915+ portable Zeeman mercury analyzer
- MS Windows® software
- RP-91 attachment (for liquid samples)
- RP-91C attachment (for complex samples)

For software installation a PC is necessary. Minimal system requirements: Windows®-95/98, Pentium® 120 MHz, 20 Mb RAM, free serial port.



RA-915+ with RP-91C



RA-915+ with RP-91

## SPECIFICATIONS

|   | Size           | Weight | Power supply                        | Power consumption | Rate of analyses per hour |
|---|----------------|--------|-------------------------------------|-------------------|---------------------------|
| RA-915+ (air)                             | 460x210x110 mm | 7.5 kg | ~220/110 V, 50/60 Hz;<br>dc 10/14 V | 15 W              | *                         |
| RP-91 attachment ("cold vapor" technique) | 340x240x120 mm | 4 kg   | ~220/110 V, 50/60 Hz;<br>dc 6 V     | 15 W              | 12 – 15                   |
| RP-91C attachment (pyrolysis technique)   | 340x240x120 mm | 5.5 kg | ~220/110 V, 50/60 Hz                | 250 W             | 6 – 8                     |

\* Real-time analysis with a response time of 1 sec

## WARRANTY

The unit is so portable and light that we offer a 48-hour replacement policy on the instrument returned to our service site for repairs. A yearly calibration and service contract are available. Experienced Technical support will answer questions and work through problems.

Windows® and Pentium® are registered trademarks of Microsoft Corp. and Intel Corp., respectively. The information and specifications in this publication are subject to change without notice.



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<http://www.OhioLumex.com>



# LEAD in Surface Wipe Samples

9100

Pb

MW: 207.19

CAS: 7439-92-1

RTECS: OF7525000

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**METHOD:** 9100, Issue 1  
1994

**EVALUATION:** PARTIAL

**ISSUE 1:** 15 August

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**PURPOSE:** Determination of surface contamination by lead and its compounds.

**LIMIT OF DETECTION:** **2 µg Pb** per sample ( $0.02 \mu\text{g}/\text{cm}^2$  for  $100\text{-cm}^2$  area) by **flame AAS** or **ICP**;  
**0.1 µg Pb** per sample ( $0.001 \mu\text{g}/\text{cm}^2$  for  $100\text{-cm}^2$  area) by **graphite furnace AAS**.

**FIELD EQUIPMENT:**

1. Bags, plastic, sealable (e.g., with attached wire, tape or "zip"-type seal).
2. Sample pads, 2" x 2", sterile cotton gauze (Curity™, Johnson & Johnson™, or equivalent), or ashless quantitative filter paper.  
NOTE: Wash'n Dri™ wipes may also be used. Other wipes may not ash properly, or may have a significant lead blank value.
3. Gloves, latex, disposable.
4. Template, plastic, 10 cm x 10 cm, or other standard size.
5. Water, distilled, in plastic squeeze bottle.

**SAMPLING:**

1. Using a new pair of gloves, remove a gauze pad from its protective package. Moisten the gauze pad with approximately 1 to 2 mL of distilled water.  
NOTE 1: Apply no more distilled water than that necessary to moisten approximately the central 80% of the area of the gauze pad. Excess distilled water may cause sample loss due to dripping from the gauze pad.  
NOTE 2: If using the premoistened Wash'n Dri™, omit the distilled water.
2. Place the template over the area to be sampled. Wipe the surface to be sampled with firm pressure, using 3 to 4 vertical S-strokes. Fold the exposed side of the pad in and wipe the area with 3 to 4 horizontal S-strokes. Fold the pad once more and wipe the area with 3 to 4 vertical S-strokes.
3. Fold the pad, exposed side in, and place it in a new plastic bag. Seal and label the bag clearly. Discard the gloves.
4. Clean the template in preparation for the next wipe sample .
5. Include two blank pads (moistened and placed in bags) with each sample set.

**SAMPLE PREP:** Use the procedure of NIOSH Method 7105, including final sample dilution to 10 mL.  
NOTE: Additional portions of nitric acid may be needed for complete digestion of the sample, including the pad. Include appropriate media and reagent blanks.

**MEASUREMENT:** Screening of all samples by flame AAS or ICP, followed by graphite furnace AAS for those samples giving "Not Detected" is an efficient scheme. Use the procedures of NIOSH Methods 7082 (Lead by flame AAS), 7300 (Elements by ICP), 7105 (Lead by graphite furnace AAS), or other appropriate methods.

**METHOD WRITTEN**

**WRITTEN BY:** Peter M. Eller, Ph.D., QASA/DPSE

[<< Back to Sampling and Analytical Methods](#)

*For problems with accessibility in using figures and illustrations in this method, please contact the SLTC at (801) 233-4900. These procedures were designed and tested for internal use by OSHA personnel. Mention of any company name or commercial product does not constitute endorsement by OSHA.*

## PARTICULATE MERCURY IN WORKPLACE ATMOSPHERES

|  |   |
|--|---|
| Method no.:  | ID-145  |
| Matrix:  | Air*, Wipe, or Bulk   |
| OSHA Permissible Exposure Limits<br>Aryl and Inorganic Compounds of<br>Mercury (Final Rule Limit): | 0.1 mg/m <sup>3</sup> as mercury (Ceiling)<br><br>Also Skin Designation   |
| Mercury<br>(Transitional Limit):   | 0.1 mg/m <sup>3</sup> as mercury (Time Weighted Average)  |
| Sampling (Air Samples)   | Mixed-cellulose ester (MCE) filters and a calibrated personal sampling pump are used.   |
| Collection Device:   | 2.0 L/min   |
| Recommended Sampling Rate:   | 10 L  |
| Recommended Air Volume:  | The collection medium is digested using nitric and sulfuric acids. Potassium permanganate and hydroxylamine hydrochloride are then added. The mercury in the sample is reduced using stannous chloride and analyzed using a cold vapor-atomic absorption spectrophotometer. |
| Analytical Procedure:  |   |
| Detection Limit:   |   |
| Qualitative:   | 0.001 mg/m <sup>3</sup> for a 10 L air sample   |
| Quantitative:  | 0.002 mg/m <sup>3</sup> for a 10 L air sample   |
| Precision and Accuracy (from samples prepared with phenyl mercuric acetate)                        |   |
| CV <sub>1</sub>  | 0.086   |
| Bias   | +0.033  |
| Method Classification:   | Validated Method  |
| Date (Date Revised):   | 1987 (December, 1989)   |

\* If mercury vapor is also suspected to be present, OSHA Method No. ID-140 should also be consulted.

Commercial manufacturers and products mentioned in this method are for descriptive use only and do not constitute endorsements by USDOL-OSHA. Similar products from other sources can be substituted.

Methods Development Team  
Industrial Hygiene Chemistry Division  
OSHA Salt Lake Technical Center  
Sandy UT 84070-6406

## 1. Introduction

This method describes the collection of airborne particulate mercury on 0.8- $\mu\text{m}$  mixed-cellulose ester membrane (MCE) filters and the subsequent analysis using a cold vapor-atomic absorption spectrophotometer (CV-AAS). Wipe and bulk samples can also be collected and analyzed for mercury content using this method.

### 1.1. History

This method is an adaptation of an analytical technique proposed by Hatch and Ott (8.1.). Particulate mercury contained in air samples, as well as wipe and bulk samples have always been analyzed at the OSHA Salt Lake Technical Center (OSHA-SLTC) using CV-AAS. Elemental mercury vapor is sampled and analyzed using techniques described in reference 8.2.

### 1.2. Principle

Airborne and non-airborne particulate mercury compounds and mercury-containing dust are collected, respectively, on 0.8- $\mu\text{m}$  MCE and wipe filters. Bulk material is collected by grab sampling. Air filter, wipe, and bulk samples are initially dissolved using concentrated nitric and sulfuric acids. A potassium permanganate solution is added to help dissolve the sample matrix. A hydroxylamine hydrochloride solution is then added to reduce the excess potassium permanganate. Finally, stannous chloride is added to an aliquot of the sample to reduce the mercury to the vapor state. This vapor is then driven into an absorption cell of a flameless atomic absorption spectrophotometer for analysis.

### 1.3. Advantages and Disadvantages

1.3.1. The air sampling device is small and portable.

1.3.2. This method has adequate sensitivity for measuring workplace exposure to mercury-containing dust and particulate mercury compounds.

1.3.3. Sample preparation for analysis involves simple procedures.

1.3.4. Particulate organo-mercury compounds may also be collected using 0.8  $\mu\text{m}$  MCE filters.

1.3.5. Elemental mercury vapor cannot be collected on the 0.8  $\mu\text{m}$  MCE filters. If elemental mercury vapor is suspected to be present, a sample using Hydrar<sup>R</sup> or hopcalite solid sorbent as the collection medium should be separately taken (8.2.).

### 1.4. Workplace Exposure

Occupations with potential exposure to mercury and its compounds are listed (8.3.):

---

|                               |                              |
|-------------------------------|------------------------------|
| amalgam makers                | fur processors               |
| bactericide makers            | gold extractors              |
| barometer makers              | histology technicians        |
| battery makers, mercury       | ink makers                   |
| boiler makers                 | insecticide makers           |
| bronzers                      | investment casting workers   |
| calibration instrument makers | jewelers                     |
| cap loaders , percussion      | laboratory workers, chemical |
| carbon brush makers           | lampmakers, fluorescent      |
| caustic soda makers           | manometer makers             |
| ceramic workers               | mercury workers              |
| chlorine makers               | miners, mercury              |
| dental amalgam makers         | neon light makers            |
| dentists                      | paint makers                 |
| direct current meter workers  | paper makers                 |
| disinfectant makers           | percussion cap makers        |
| disinfectors                  | pesticide workers            |
| drug makers                   | photographers                |
| dye makers                    | pressure gage makers         |
| electric apparatus makers     | refiners, mercury            |
| electroplates                 | seed handlers                |
| embalmers                     | silver extractors            |
| explosive makers              | switch makers, mercury       |
| farmers                       | tannery workers              |
| fingerprint detectors         | taxidermists                 |
| fireworks makers              | textile printers             |
| fungicide makers              | thermometer makers           |
| fur preservers                | wood preservative workers    |

---

### 1.5. Toxic Effects

Note: Information listed within this section is a synopsis of current knowledge of the physiological effects of mercury and is not intended to be used as a basis for OSHA policy.

Exposure to elemental mercury vapor can occur via the respiratory tract and skin. Possible symptoms from an acute exposure include severe nausea, vomiting, abdominal pain, bloody diarrhea, kidney damage, and death. These symptoms usually present themselves within 10 days of exposure. Potential symptoms from a chronic exposure include inflammation of the mouth and gums, excessive salivation, loosening of the teeth, kidney damage, muscle tremors, jerky gait, spasms of the extremities, personality changes, depression, irritability, and nervousness (8.3., 8.4.).

### 1.6. Properties (8.3.-8.5.)

Elemental mercury (CAS No. 7439-97-6) is a silver-white, heavy, mobile, liquid metal at room temperature. Some physical properties and data for mercury are:

---

|               |        |
|---------------|--------|
| Atomic Number | 80     |
| Atomic Symbol | Hg     |
| Atomic Weight | 200.61 |

|                |                          |
|----------------|--------------------------|
| Freezing Point | -38.87 °C                |
| Boiling Point  | 356.90 °C                |
| Density        | 13.546 g/mL (20 °C)      |
| Synonyms       | Quicksilver, Hydrargyrum |

Many different inorganic and aryl compounds of mercury exist. One of the more common aryl compounds is phenyl mercuric acetate ( $C_6H_5HgOCOCH_3$ ) which is used as a fungicide:

|               |   |
|---------------|---|
| CAS no.       | 62-38-4   |
| Atomic Weight | 336.75  |
| Melting Point | 149 °C  |
| Volatility    | slightly volatile at room temp.   |
| Solubility    | soluble in alcohol, benzene, and glacial acetic acid, slightly soluble in water |

## 2. Range

### 2.1. Detection Limits

The qualitative and quantitative detection limits for the analytical procedure are 0.01 µg and 0.02 µg mercury, respectively (8.6.).

### 2.2. Working Range

The range of the analytical procedure has been determined to be 0.1 to 2 µg mercury. Using the analytical conditions specified, a nonlinear response was noted above 2 µg.

## 3. Method Performance

3.1. The average recovery of 88 quality control samples containing mercury spiked on MCE filters in the approximate range of 1 to 2 times the OSHA PEL (assuming a 20-L air volume) was 90.8% with a coefficient of variation ( $CV_1$ ) of 0.149 (8.7.). The variability and slight decrease in recovery for these samples, which were prepared from 1984 to 1986, was attributed to instability during storage. These samples had been spiked with dilute nitric acid solutions containing mercury and some samples were analyzed months after preparation.

3.2. An additional test to determine method performance was conducted using spikes of phenyl mercuric acetate (PMA) on 24 MCE filters (8.8.). The filters were spiked with PMA solutions containing 50 to 200 µg total mercury. The recovery for 18 of the samples was 103.3% and a coefficient of variation of 0.086. The remaining six samples were subjected to a retention efficiency test where air was drawn through the spiked filters for 3 h. The filters were then analyzed. Results indicated the filters sufficiently retained the PMA.

## 4. Interferences

Organic-free deionized water should be used during sample and standard preparation. Any compound with the same absorbance wavelength as mercury (253.7 nm) can be a positive interference. Some volatile organic compounds (i.e. benzene, toluene, acetone, carbon tetrachloride) absorb at this wavelength and are considered analytical interferences. They occur as contaminants in the reagents used during sample preparation. These compounds are not expected to be retained on an MCE filter during sample collection. Analytical interferences are rendered insignificant by using organic-free deionized water and at least reagent grade chemicals or by blank subtraction.

Increasing the concentration of nitric acid in the samples or standards appears to produce an elevated background signal. The nitric acid concentration in the samples and standards should not be greater than 10%.

## 5. Sampling - Particulate Mercury

For the sampling and analysis of mercury vapor, consult reference 8.2.

### 5.1. Equipment - Air Filters

5.1.1. Filters: Mixed-cellulose ester (MCE) filters (0.8-µm pore size), cellulose backup pads, and cassettes, 37-mm diameter (part no. MAWP 037 A0, Millipore Corp., Bedford, MA).

5.1.2. Gel bands (Omega Specialty Instrument Co., Chelmsford, MA) for sealing cassettes.

5.1.3. Sampling pumps capable of sampling at 2 liters per minute (L/min).

5.1.4. Assorted flexible tubing.

5.1.5. Stopwatch and bubble tube or meter for pump calibration.

### 5.2. Equipment - Wipe Samples

Smear tabs (part no. 225-24, SKC Inc., Eighty Four, PA), or wipe filters (Whatman no. 41 or no. 42 filters, Whatman LabSales Inc., Hillsboro, OR).

### 5.3. Equipment - Bulk Samples

Scintillation vials, 20-mL (part no. 74515 or 58515, Kimble, Div. of Owens-Illinois Inc., Toledo, OH) with polypropylene or Teflon cap liners. If possible, submit bulk or wipe samples in these vials. Tin or other metal cap liners should not be used since amalgamation can occur between the metal and mercury.

### 5.4. Sampling Procedure - Air Samples

5.4.1. Place a MCE filter and a cellulose backup pad in each two- or three-piece cassette. Seal each cassette with a gel band.

5.4.2. Calibrate each personal sampling pump with a prepared cassette in-line to approximately 2 L/min.

5.4.3. Attach prepared cassettes to calibrated sampling pumps (the backup pad should face the pump) and place in appropriate positions on the employee or workplace area.

5.4.4. Collect the samples for at least 5 min.

5.4.5. Place plastic end caps on each cassette after sampling. Attach an OSHA-21 seal around each cassette in such a way as to secure the end caps.

#### 5.5. Sampling Procedure - Wipe Samples

A skin designation has been assigned to these mercury-containing compounds.

5.5.1. Wear clean, impervious, disposable gloves when taking each wipe sample.

5.5.2. Moisten the wipe filters with deionized water prior to use.

5.5.3. If possible, wipe a surface area covering 100 cm<sup>2</sup>.

5.5.4. Fold the wipe sample with the exposed side in.

5.5.5. Transfer the wipe sample into a 20-mL scintillation vial and seal with vinyl or electrical tape. Securely wrap an OSHA-21 seal length-wise from vial top to bottom.

#### 5.6. Sampling Procedure - Bulk Samples

In order of laboratory preference, bulk samples may be one of the following:

- 1) a high-volume filter sample,
- 2) a representative settled dust (rafter) sample,
- 3) a sample of the bulk material in the workplace.

5.6.1. Transfer the bulk material into a 20-mL scintillation vial and seal with vinyl or electrical tape. Securely wrap an OSHA-21 seal length-wise from vial top to bottom.

5.6.2. The type of bulk sample should be stated on the OSHA 91 and cross-referenced to the appropriate air sample(s).

#### 5.7. Shipment

5.7.1. Submit at least one blank sample with each set of air or wipe samples. Blank filter samples should be handled in the same manner as other samples, except that an air or wipe sample is not taken.

5.7.2. Send the samples to the laboratory as soon as possible with the OSHA 91A paperwork requesting particulate mercury analysis.

5.7.3. Bulk samples should be shipped separately from air samples. They should be accompanied by Material Safety Data Sheets if available. Check current shipping restrictions and ship to the laboratory by the appropriate method.

## 6. Analysis

### 6.1. Safety Precautions

6.1.1. Wear safety glasses, labcoat, and gloves at all times.

6.1.2. Handle acid solutions with care. Avoid direct contact of acids with work area surfaces, eyes, skin, and clothes. Flush acid solutions which contact the skin or eyes with copious amounts of cold water.

6.1.3. Prepare solutions containing hydrochloric acid in an exhaust hood and store in narrow-mouthed bottles.

6.1.4. Keep B.O.D. bottles containing stannous chloride/hydrochloric acid solutions capped when not in use to prevent inhalation of noxious vapors.

6.1.5. Exercise care when using laboratory glassware. Do not use chipped pipets, volumetric flasks, beakers or any glassware with sharp edges exposed.

6.1.6. Never pipet by mouth.

6.1.7. Always purge the mercury from the CV-AAS into an exhaust vent.

6.1.8. Occasionally monitor the CV-AAS for mercury vapor leaks using an appropriate direct-reading instrument.

### 6.2. Equipment - Cold Vapor Analysis

(Note: Specific equipment is listed for illustration only)

6.2.1. Atomic absorption spectrophotometer (model 503, Perkin-Elmer, Norwalk, CT).

6.2.2. Mercury hollow cathode lamp or electrodeless discharge lamp and power supply.

6.2.3. Biological Oxygen Demand (B.O.D.) bottles, borosilicate glass, 300 mL.

6.2.4. Peristaltic pump, 1.6 to 200 mL range, and controller, 1-100 rpm range (Masterflex model 7553-30 with model 7015 head, Cole-Parmer, Chicago, IL).

6.2.5. Quartz absorption cell, 22 mm (7/8 in) o.d. X 152 mm (6 in) long (part no. 303-3101, Perkin-Elmer).

6.2.6. Heating tape.

6.2.7. Variable transformer 50-60 Hz, single phase, 10 A, 120 V input, 0-140 V output, 1.4 kW (Superior Electric, Bristol, CT).

6.2.8. Tygon peristaltic pump tubing (part no. N06409-15, Cole-Parmer), and glass tubing.

6.2.9. Aerator (part no. 0303-3102, Perkin-Elmer).

6.2.10. Chart recorder.

- 6.2.11. Desiccant (Drierite, W.A. Hammond Drierite Co., Xenia, OH).
- 6.2.12. Volumetric flasks, volumetric pipets, beakers, and other laboratory glassware.
- 6.2.13. Automatic pipets, adjustable, 0.1 to 5.0 mL range (models P-1000 and P-5000, Rainin Instruments Co., Woburn, MA).
- 6.2.14. Exhaust vent.
- 6.2.15. Automatic pipets, glass or Teflon, unlubricated (cat. no. 050-03-908-1, Brinkmann Dispensette, Brinkmann Instruments, Westbury, NY).
- 6.2.16. Phillips beakers, 250 mL.
- 6.2.17. Hot plate (used only for cleaning glassware, not for sample digestions).
- 6.2.18. Analytical balance (0.01 mg).

### 6.3. Reagents - All reagents should be at least reagent grade.

Potassium permanganate (KMnO<sub>4</sub>)

Hydroxylamine hydrochloride (NH<sub>2</sub>OH·HCl)

Stannous chloride (SnCl<sub>2</sub>)

- 6.3.1. Deionized water (DI H<sub>2</sub>O), organic-free.
- 6.3.2. Hydrochloric acid (HCl), concentrated (36.5 to 38%), with a mercury concentration less than 0.005 ppm.
- 6.3.3. Hydroxylamine hydrochloride (NH<sub>2</sub>OH·HCl) solution, 20%: Dissolve 200 g NH<sub>2</sub>OH·HCl in DI H<sub>2</sub>O and dilute to 1 L. A glass automatic pipet is useful in dispensing this reagent. Rinse the automatic pipet dispenser with DI H<sub>2</sub>O after the analysis is completed.
- 6.3.4. Mercury standard stock solution, 1,000 µg/mL: Use a commercially available certified standard or, alternatively, dissolve 1.0798 g of dry mercuric oxide (HgO) in 50 mL of 1:1 hydrochloric acid and then dilute to 1 L with DI H<sub>2</sub>O. Store this reagent in a dark environment, preferably in an amber colored container.
- 6.3.5. Nitric acid (HNO<sub>3</sub>), concentrated (69 to 71%), with a mercury concentration less than 0.005 ppm.
- 6.3.6. Nitric acid, 1:1: Carefully add equal portions of concentrated HNO<sub>3</sub> and DI H<sub>2</sub>O.
- 6.3.7. Nitric acid, 10%: Carefully add 100 mL of concentrated HNO<sub>3</sub> to 900 mL of DI H<sub>2</sub>O.
- 6.3.8. Potassium permanganate (KMnO<sub>4</sub>) solution, 5%: Dissolve 50 g KMnO<sub>4</sub> in 1 L DI H<sub>2</sub>O. This concentration is near saturation and the crystals will dissolve slowly. Stirring with a magnetic stirring bar/stirrer is recommended. An unlubricated glass automatic pipet is useful in dispensing the reagent during the analysis. After the analysis is completed, rinse and clean the automatic pipet dispenser to prevent seizing. Remove any dark deposits produced by permanganate reduction products with a 20% hydroxylamine hydrochloride solution.
- 6.3.9. Stannous chloride (SnCl<sub>2</sub>) solution, 10%: Dissolve 20 g SnCl<sub>2</sub> in 100 mL concentrated HCl. Slowly and carefully pour this solution into 100 mL DI H<sub>2</sub>O and then mix well. Transfer and store the final solution in a capped B.O.D. bottle to prevent oxidation. Prepare this solution before each new analysis.
- 6.3.10. Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), concentrated (95 to 98%), with a mercury concentration less than 0.005 ppm.
- 6.3.11. Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), 5 M: Cautiously add 278 mL concentrated H<sub>2</sub>SO<sub>4</sub> to approximately 600 mL DI H<sub>2</sub>O. Allow the solution to cool to room temperature and then dilute slowly to 1 L.

### 6.4. Glassware Preparation

- 6.4.1. Clean the 250-mL Phillips beakers by refluxing with 1:1 HNO<sub>3</sub> on a hot plate in an exhaust hood. Thoroughly rinse with DI H<sub>2</sub>O and allow to dry.
- 6.4.2. Clean the B.O.D. bottles and stoppers with 1:1 HNO<sub>3</sub> and thoroughly rinse with DI H<sub>2</sub>O prior to use.
- 6.4.3. Rinse all other glassware with 10% HNO<sub>3</sub> and then with DI H<sub>2</sub>O prior to use.

### 6.5. Standard Preparation

- 6.5.1. Prepare a 1 µg/mL mercury standard by making appropriate ten-fold serial dilutions of the 1,000 µg/mL mercury standard stock solution with 10% HNO<sub>3</sub>.
- 6.5.2. Prepare working mercury standards (ranging from 0.1 to 2.0 µg) and reagent blanks *immediately prior to use*. A few standards at each concentration should be prepared. Add an appropriate aliquot of the 1 µg/mL standard to a clean B.O.D. bottle containing enough 10% HNO<sub>3</sub> to bring the total volume to 100 mL. A suggested dilution scheme is given:

| Standard (µg) | Aliquot (mL)* | Final Volume (mL) |
|---------------|---------------|-------------------|
| Reagent Blank | 0             | 100               |
| 0.1           | 0.1           | 100               |
| 0.2           | 0.2           | 100               |
| 0.5           | 0.5           | 100               |
| 1.0           | 1.0           | 100               |
| 1.5           | 1.5           | 100               |
| 2.0           | 2.0           | 100               |

\* Aliquot taken from 1 µg/mL standard prepared in Section 6.5.1.

## 6.6. Sample Preparation

Sample digestion is performed at room temperature under oxidizing conditions to avoid loss of mercury.

6.6.1. Perform the transfer and digestion of samples in an exhaust hood. Transfer air and wipe samples, and previously weighed aliquots of bulk samples to separate labeled 250 mL Phillips beakers.

6.6.2. Add 5 mL conc. HNO<sub>3</sub> (per 100 mL final volume) to each Phillips beaker and allow to stand for a few min. Subsequently add 15 mL of 5 M H<sub>2</sub>SO<sub>4</sub> (per 100 mL final volume) followed by the appropriate amount of 5% KMnO<sub>4</sub> to each sample to completely oxidize any additional organic material:

|  |   |
|--|---|
| Bulk samples                           | 40 mL of 5% KMnO <sub>4</sub> (per 100 mL final volume) |
| Large (> 4 cm diameter) wipe samples   | 40 mL of 5% KMnO <sub>4</sub> (per 100 mL final volume) |
| Air, small wipe, and smear tab samples | 20 mL of 5% KMnO <sub>4</sub> (per 50 mL final volume)  |

Swirl the samples frequently to break up the collection media and allow the samples to digest at least 1 h at room temperature.

6.6.3. Add the appropriate amount of 20% NH<sub>2</sub>OH-HCl to each Phillips beaker:

|  |                                 |
|--|---------------------------------|
| Bulk samples (per 100 mL final volume) | 10 mL (per 100 mL final volume) |
| Large (> 4 cm diameter) wipe samples   | 10 mL                           |
| Air, small wipe, and smear tab samples | 5 mL (per 50 mL final volume)   |

The solution and suspended matter in each Phillips beaker should lose the dark-brown or purple color resulting from the KMnO<sub>4</sub> treatment and become clear. If it does not, add NH<sub>2</sub>OH-HCl crystals directly to the beaker until clear.

6.6.4. Quantitatively transfer the sample solution from each Phillips beaker to an appropriate volumetric flask and dilute to volume. This is a good place to stop if the analysis cannot be completed the same day.

## 6.7. Analysis - Instrument Parameters

6.7.1. Set up the CV-AAS as illustrated in Figure 1.

6.7.2. Wrap the heating tape around the quartz cell and then turn on the variable transformer. The heat setting on the tape should be sufficient to prevent water vapor condensation in the absorption cell.

6.7.3. Place the aerator in a B.O.D. bottle which contains approximately ½ to 1 inch of desiccant. Operate the peristaltic pump for approximately 30 min at full speed to remove any water vapor from the system.

6.7.4. Operate the hollow cathode or electrodeless discharge mercury lamp at the manufacturer's recommended current or power rating.

6.7.5. Use the following settings (Note: The mentioned instrument settings are for specific models used at the OSHA-SLTC. If instrumentation other than what is specified in Section 6.2. is used, please consult the instrument manufacturer's recommendations.):

### *Atomic Absorption Spectrophotometer:*

|            |             |
|------------|-------------|
| Slit       | 0.7 nm      |
| Signal     | Repeat Mode |
| Function   | ABS         |
| Mode       | ABS         |
| Range      | UV          |
| Wavelength | 253.7 nm    |
| Filter     | Out         |
| EM Chopper | Off         |
| Phase      | Normal      |

### *Strip Chart Recorder:*

|             |          |
|-------------|----------|
| Chart Speed | 5 mm/min |
| Chart Range | 10 mV    |

6.7.6. Optimize the ENERGY meter reading at 253.7 nm.

6.7.7. Align the beam of the mercury lamp so it passes directly through the center of the quartz cell windows. This can be accomplished by adjusting the burner height, depth, and angle knobs to give a minimum ABSORBANCE reading.

6.7.8. Operate the peristaltic pump at full speed. Rinse the aerator with DI H<sub>2</sub>O and insert it into a holder in the exhaust vent.

6.7.9. Perform the following steps to obtain a baseline signal near an absorbance of zero:

- 1) start the chart recorder,
- 2) set the spectrophotometer absorbance reading to zero,
- 3) wait until the baseline stops drifting,
- 4) set the reading to zero again.

## 6.8. Analytical Procedure

6.8.1. Samples: *Immediately before analyzing*, transfer an appropriate aliquot (It is recommended to use 10 mL of each wipe and bulk and 25 to 50 mL of each air filter sample. Aliquot amounts from air filter sample solutions can be determined from the air volume taken. A general rule is to take an aliquot which will allow a detection limit of at least 0.1 times the PEL) of the sample solution to a clean B.O.D. bottle containing enough 10% HNO<sub>3</sub> solution to bring the total volume to 100 mL. The transfer must be done with a volumetric pipet.

6.8.2. Standards: *Immediately before analyzing*, prepare standards according to instructions listed in Section 6.5.2.

6.8.3. Deliver 5 mL of the 10% SnCl<sub>2</sub> solution with an automatic pipet to a B.O.D. bottle containing a standard, reagent blank, or sample to be analyzed. Immediately place the aerator into the solution with the peristaltic pump operating at full speed.

6.8.4. Record the maximum absorbance reading and label the signal produced on the strip chart.

6.8.5. Stop the pump, remove the B.O.D. bottle from the CV-AAS and stopper it. Rinse the aerator with DI H<sub>2</sub>O and insert it into a holder in the exhaust vent. Turn the pump on at full speed until the CV-AAS system is purged of mercury and the baseline returns to zero.

6.8.6. If the absorbance reading of a sample is greater than the highest standard *at any time* during analysis, *immediately* remove the B.O.D. bottle from the CV-AAS. Purge the system following the procedure listed in Section 6.8.5. Take a smaller aliquot or dilute the high concentration sample and re-analyze. Make any necessary sample dilutions with 10% HNO<sub>3</sub> and use the appropriate dilution factor when calculating results.

6.8.7. Repeat Sections 6.8.3. through 6.8.5. for each prepared standard, reagent blank, or sample.

## 6.9. Analytical Recommendations

6.9.1. It is recommended to analyze the reagent blank, lowest, and highest standard two or three times each to check for contamination, reproducibility, and sensitivity before starting the sample analysis. A 2.0-μg mercury standard should give a three-quarter to full-scale deflection on the chart recorder and an absorbance unit reading of about 0.850 when using the equipment and conditions specified. The lowest and highest standard should provide a linear response and the lowest standard should be at least two to three times the blank signal.

6.9.2. It is also recommended to analyze an entire series of standards (including the reagent blank) at the beginning and end of the sample analysis to ensure standard readings are reproducible. As a general guideline, standard readings should be within ±10% throughout the analysis.

6.9.3. A standard near the concentration range of the samples should be analyzed after every four to five samples.

6.9.4. Quality control (QC) samples should be prepared and analyzed using the same matrix and analytical conditions as the samples. If possible, the QC samples should be generated from an independent source.

6.9.5. Approximately 10% of the samples should be reanalyzed.

## 7. Calculations

7.1. Use a least squares regression program to plot a concentration-response curve of peak absorbance versus the amount (μg) of mercury in each standard.

7.2. Determine the amount (μg) of mercury, A, corresponding to the peak absorbance in each analyzed sample aliquot from this curve.

7.3. Calculate the total amount (μg) of mercury, W, in each sample:

$$W = \frac{(A) (\text{sample volume, mL}) (DF)}{(\text{aliquot, mL})}$$

Where:

DF = Dilution Factor (if none, DF = 1)

7.4. Calculate the total concentration of mercury in each sample using the appropriate equation:

$$\text{Mercury mg/m}^3 = \frac{W - W_B}{\text{air volume, L}} \quad (\text{Air Samples})$$

$$\text{Total Mercury} = W - W_b \quad (\text{Wipe Samples})$$

$$\text{Mercury \% (w/w)} = \frac{(W) (100\%)}{(\text{sample wt, mg}) (1,000 \text{ } \mu\text{g/mg})} \quad (\text{Bulk Samples})$$

Where:

W<sub>b</sub> = total μg of mercury in the blank sample.  
Sample wt = aliquot of bulk taken in Section 6.6.1.

## 7.5. Reporting Results

7.5.1. Air sample results are reported as mg/m<sup>3</sup> mercury.

7.5.2. Wipe sample concentrations are reported as total micrograms or milligrams mercury.

7.5.3. Bulk sample results are reported as approximate percent by weight mercury. Due to differences in sample matrices between bulks

and standards, bulk results are approximate.

## 8. References

- 8.1. **Hatch, W.R. and W.L Ott:** Determination of Submicrogram Quantities of Mercury by Atomic Absorption Spectrophotometry. *Anal. Chem.*, 1968, 40, 2085-87.
- 8.2. **Occupational Safety and Health Administration Technical Center:** *Mercury Vapor in Workplace Atmospheres* (OSHA-SLTC Method No. ID-140). Salt Lake City, UT. Revised 1991.
- 8.3. **National Institute for Occupational Safety and Health:** *Criteria for a Recommended Standard -- Occupational Exposure to Inorganic Mercury* (DHEW/NIOSH Pub. No. HSM-73-11024). Cincinnati, OH: National Institute for Occupational Safety and Health, 1973.
- 8.4. **Windholz, M., ed.:** *The Merck Index*. 10th ed. Rahway, NJ: Merck & Co. Inc., 1983.
- 8.5. **Sax, N.I. and R.J. Lewis Sr., ed.:** *Hawley's Condensed Chemical Dictionary*, 11th ed.; New York: Van Nostrand Reinhold Co., 1987.
- 8.6. **Occupational Safety and Health Administration Analytical Laboratory:** *Detection Limit Study for Mercury Cold Vapor Analysis* by C. Merrell. Salt Lake City, UT. 1987 (unpublished).
- 8.7. **Occupational Safety and Health Administration Analytical Laboratory:** *Quality Control Data - Mercury-Spiked Filter Cold Vapor Analysis* by B. Babcock. Salt Lake City, UT. 1987 (unpublished).
- 8.8. **Occupational Safety and Health Administration Analytical Laboratory:** *Phenyl Mercuric Acetate (PMA) Procedure* by S. Edwards. Salt Lake City, UT. 1981 (unpublished).

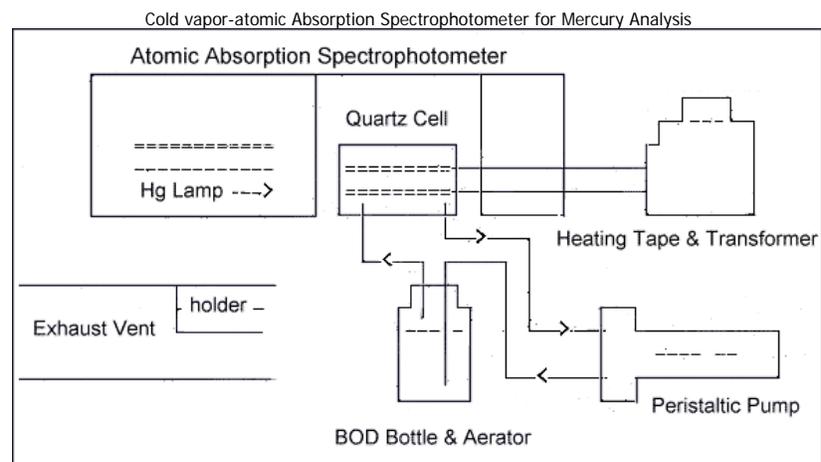


Figure 1

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# Operating Instructions

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## Passive Sampler for Inorganic Mercury Catalog No. 520 Series

### Introduction

The 520 Series Passive Sampler for Inorganic Mercury is a lightweight, reusable personal sampler designed to be worn in the breathing zone of individuals who are potentially exposed to inorganic mercury vapor.

The sampler is comprised of a reusable housing and a replaceable sorbent capsule. The sample enters the sampler by positive controlled diffusion. The sorbent is analyzed by flameless atomic absorption. The sampler housing can be cleaned and reused with a new sorbent capsule. Validation of the SKC 520 Series Passive Sampler for Inorganic Mercury is based on OSHA ID-140.

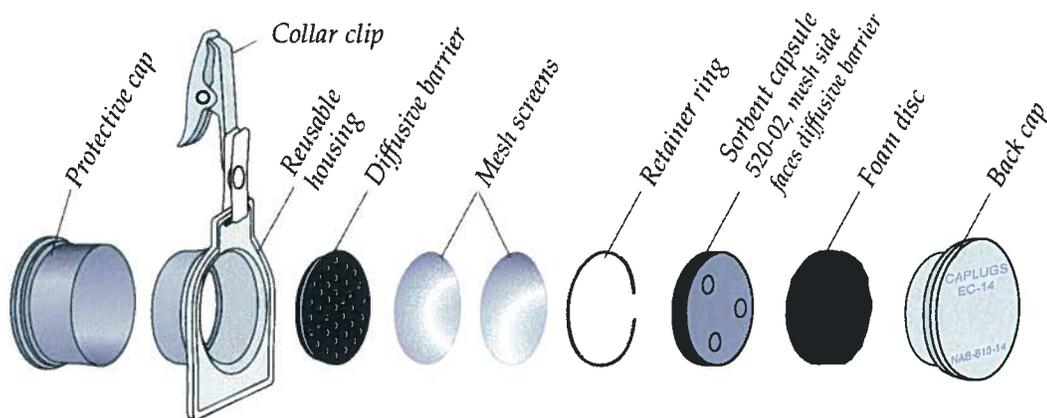


Figure 1. Complete Assembly of Passive Sampler for Inorganic Mercury

### Specifications\*

|                                    |  |
|------------------------------------|--|
| Sorbent:                           | Anasorb® C300 (SKC proprietary sorbent; equivalent to Hydrar® and Carulite®) |
| Background:                        | 0.02 µg/200 mg section   |
| Limit of Detection:                | 0.01 µg†   |
| Limit of Quantitation:             | 0.04 µg†   |
| Capacity:                          | > 30 µg mercury per capsule  |
| Breakthrough Volume:               | > 1500 liters of air   |
| Overall Co-efficient of Variation: | 6.1%   |

\* Specifications are based on a study conducted by the Health and Safety Executive (HSE) in the U.K. as an update to Method MDHS 16.

† Limits may vary with analysis and instrumentation.

Note: For sampling low levels of mercury, use a sorbent tube.

## Preparing the Sampler

### For Sampling

1. Remove the back cap from the housing with a screwdriver or a coin.
2. Remove a sorbent capsule from the plastic vial, and place it in the housing with the mesh side facing the diffusive barrier.

 *Keep the plastic vial with remaining sorbent capsules in a safe place free from mercury contamination.*

3. Ensure the back cap contains a foam disk. Press the back cap onto the housing.
4. Record I.D., date, and start time on a provided I.D. label (included with replacement sorbent capsules), and place it on the sampler's back cap. Note any other pertinent sampling information.
5. Using the clip, attach to clothing of individual near breathing zone or place in desired location for area sampling.
6. To begin sampling, remove protective cap. Retain the cap in a safe place free from contamination. Recommended sampling time is four to eight hours.
7. When sampling period is complete, replace protective cap and record finish time on I.D. label. Note any other pertinent sampling information.

 **Avoid excessive agitation of the sampler.**

### For Analysis

1. As soon as possible after sampling, take the sampler to a clean area. Remove sorbent capsule by pulling off the back cap. Remove foam disk from back cap and dispose properly.
2. Place the sorbent capsule in the provided ziploc bag. Remove the I.D. label from the sampler's back cap and adhere to the ziploc bag.
3. Mail or transport the sorbent capsule and at least one field blank to a qualified laboratory for analysis. The sorbent should be analyzed within 30 days of sampling.

 **Store sample away from sources of contamination.**

### For Cleaning

1. Unsnap and remove the collar clip. Clean with soap or detergent and water.
2. Disassemble the sampler and place all parts (except foam disk, sorbent capsule, and collar clip) in a container. Wash in a dilute solution of nitric acid (approximately 15%) in distilled water.
3. Rinse parts three times in separate rinses of distilled water.
4. Dry as quickly as possible.
5. Re-assemble sampler housing for storage, without the sorbent capsule or foam disk (*see Figure 1*).
6. Store in a clean area where the sampler will not become contaminated with mercury until ready to use again.

-  • *Always use a sorbent capsule within a few days of removing it from the plastic vial and placing it in the housing; the protective cap does not provide a hermetic seal.*
- *When inserting a replacement sorbent capsule, ensure that the two mesh disks are in place within the housing. These disks must be kept in place at all times to ensure reproducible sampling rates under all environmental conditions.*
  - *Do not store any parts of the sampler in areas where they may become contaminated with mercury.*
  - *Store the exposed sorbent capsule in the provided ziploc bag after the sampling period.*
  - *Always clean the housing before reusing to guard against accidental carry-over from previous sampling.*

- Always replace the used foam disk in the back cap with a clean disk after cleaning the housing.
- This sampler only samples elemental mercury (Hg) in the vapor phase and does not sample organic mercury compounds or particulate matter.
- Take precautions when sampling for mercuric chloride. It can collect on the face of the badge and interfere with sampling.

## Interferences During Sampling

### Ambient Temperature

The sampling rate will vary with ambient temperature changes which affect the diffusion co-efficient. This effect is small but may be significant if sampling at unusually high or low temperatures. The diffusion coefficient (D) is a function of the absolute temperature (T) by the relation  $D \propto T^{1.5}$ . This factor is taken into account in the calculation used in the OSHA method (see page 4).

### Wind Velocity

The sampling rate will remain substantially constant over a range of wind velocity from 25 to 750 ft/min. In very still air conditions (below 25 ft/min), the sampling rate will drop by up to 30%. If very high wind velocities (in excess of 750 ft/min) are expected, passive samplers should not be used.

### Ambient Pressure Changes

The sampling rate varies with ambient pressure changes which affect the diffusion co-efficient. The diffusion coefficient is inversely proportional to the ambient pressure. This factor is taken into account in the calculation used in the OSHA method (see page 4).

### Presence of Other Gases

The sampling of mercury on the sorbent has been shown to be unaffected by the presence of other gases, including chlorine. Note, however, that complex interactions in the atmosphere may reduce the total free elemental mercury present to be sampled.

## Analysis

**Consult OSHA Method ID 140 and MDHS 16 for detailed analytical procedures.**

### Preparation of Samples

Open the sorbent capsule and carefully pour the sorbent into a 50-ml volumetric flask. Add 5 ml of concentrated nitric acid followed by 5 ml of concentrated hydrochloric acid. Allow to stand for approximately 30 minutes or until the sorbent is fully dissolved. Stir gently if necessary. Add approximately 15 ml of distilled water to bring total liquid quantity up to 25 ml.

**⚠ When Anasorb C300 is dissolved, a milky suspension results. This is an insoluble residue and must be removed by filtration or centrifugation before analysis.**

Take aliquots from this solution and analyze at 253.7 nm by cold vapor atomic absorption.

Prepare several "blanks" by dissolving fresh, unexposed capsules of the same lot number as the test specimen. These "blank" values represent the background level of mercury in the sorbent and should be subtracted from all readings.

### Mercury Desorption

The basic mechanism of desorption consists of adding an excess of stannous chloride to the aliquot of sample solution. This causes the mercury to be released as elemental mercury which is swept into the analyzer by an air or nitrogen stream.

## Calibration

The complete analytical system can be calibrated by injecting aliquots from standard solutions (either from liquid or sorbent solution standards or both). It is recommended that three different concentrations be checked to insure linearity of the equipment over the likely range.

It is further recommended that standards and blank values be interspersed between samples to check for any variations in response. Take particular care to avoid buildup of mercury on the internal surfaces of the equipment; this will cause an increase in readings. A buildup of mercury can be detected by a gradual apparent increase in the blank values during use. If this occurs, run several aliquots of mercury-free solutions through the equipment until the analyzer indication drops to zero. Retest the "blank" solution as an additional precaution before proceeding.

Report all results as nanograms or micrograms of mercury on the capsule by direct comparison with the known standards. Relate the aliquot size to the total 25 ml of liquid solution.

**Consult OSHA Method ID 140 and MDHS 16 for detailed analytical procedures.**

## Interpretation of Results

The lab result will indicate the total mass of mercury which was collected on the sorbent capsule in either nanograms ( $10^{-9}$  gram) or micrograms ( $10^{-6}$  gram). The airborne concentration of mercury is determined as follows:

1. Convert reported mass of mercury into micrograms ( $10^{-6}$  gram).
2. Convert sampling period into minutes.
3. Sample Volume (L) =  
$$\frac{\text{Sampling Period (mins)} \times \text{Sampling Rate (L/min)} \times \text{Temperature/Pressure Correction Factor}}{1}$$

### Where:

Sampling rate = 0.020 L/min at 20 C and 760 torr

Temperature/Pressure Correction Factor =  $(T_1/T_2)^{1.5} \times (P_2/P_1)$

$T_1$  = Sampling Site Temperature (K)

$T_2$  = 293 K

$P_1$  = Sampling Site Pressure (torr)

$P_2$  = 760 torr

4. Mercury  $\text{mg/m}^3$  =  $\frac{\text{Mercury Mass } (\mu\text{g}) - \text{Mercury Blank } (\mu\text{g})}{\text{Sample Volume (L)}}$

*Note: This is the calculation of mercury concentration as given in OSHA Method ID-140 (Revised June 1991), page 16.*

## Ordering Information

**Replacement Sorbent Capsules** contain Anasorb C300\* and include replacement foams and resealable bags ..... Cat. No. 520-02A/10

Cat. No. 520-02C/30

**Reusable Capsule Holder** ..... Cat. No. 520-03

\* Anasorb C300 is equivalent to Hydrar and Carulite

## SKC Limited Warranty and Return Policy

SKC products are subject to the SKC Limited Warranty and Return Policy, which provides SKC's sole liability and the buyer's exclusive remedy. To view the complete SKC Limited Warranty and Return Policy, go to <http://www.skcinc.com/warranty.asp>.

MERCURY VAPOR IN WORKPLACE ATMOSPHERES




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|  |   |
|--|---|
| Method Number:                                     | ID-140  |
| Matrix:  | Air   |
| OSHA PEL:  | 0.1 mg/m <sup>3</sup> as total mercury (TWA)  |
| Collection Device:                                 | A passive or an active sampling device are available. Both devices use Hydrar or hopcalite as the solid sorbent.  |
| Recommended Sampling Rate<br>Passive Dosimeter:    | 0.020 L/min (@ 20 °C and 101 kPa)   |
| Active Sampler:                                    | 0.20 L/min  |
| Recommended Air Volume Range<br>Passive Dosimeter: | 9.6 L   |
| Active Sampler:                                    | 3 to 100 L  |
| Analytical Procedure:                              | The sorbent is digested using nitric acid and hydrochloric acid. The mercury in the sample is reduced to elemental mercury using stannous chloride and analyzed using a cold vapor-atomic absorption spectrophotometer. |
| Detection Limit<br>Qualitative                     |   |
| Passive Dosimeter:                                 | 0.002 mg/m <sup>3</sup> for a 240-min (4.8 L) sample  |
| Active Sampler:                                    | 0.00067 mg/m <sup>3</sup> for a 75-min (15 L) sample  |
| Quantitative                                       |   |
| Passive Dosimeter:                                 | 0.004 mg/m <sup>3</sup> for a 240-min (4.8 L) sample  |
| Active Sampler:                                    | 0.0013 mg/m <sup>3</sup> for a 75-min (15 L) sample   |
| Precision and Accuracy                             |   |
| Passive Dosimeter<br>Validation Range:             | 0.061 to 0.20 mg/m <sup>3</sup>   |
| CV <sub>T</sub> (pooled)                           | 0.039   |
| Bias   | +0.008  |
| Overall Error                                      | ±8.6%   |
| Method Classification:                             | Validated Method  |
| Date (Date Revised):                               | 1987 (June, 1991)   |

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Commercial manufacturers and products mentioned in this method are for descriptive use only and do not constitute endorsements by USDOL-OSHA. Similar products from other sources can be substituted.

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Division of Physical Measurements and Inorganic Analyses  
 OSHA Technical Center  
 Salt Lake City, Utah

## 1. Introduction

This method describes the collection of airborne elemental mercury in a passive dosimeter or active sampling device and subsequent analysis using a cold vapor-atomic absorption spectrophotometer (CV-AAS).

### 1.1 Principle

The mercury dosimeter samples the workplace atmosphere by controlled diffusion into the badge while the active sampler uses a calibrated sampling pump. The mercury vapor entering either passive or active device is collected on a solid sorbent (Hydrar or hopcalite) which has an irreversible affinity for mercury (8.1, 8.2). After sample collection the sorbent is initially dissolved with concentrated nitric acid and then hydrochloric acid. Stannous chloride is added to an aliquot of the sample to generate mercury vapor. This vapor is then driven into an absorption cell of a flameless atomic absorption spectrophotometer for analysis.

### 1.2 History

Previously, mercury samples were collected on iodine-impregnated charcoal contained in glass tubes. The treated charcoal was analyzed for mercury by placing it in a tantalum sampling boat and then heating to drive the mercury vapor into the beam of an atomic absorption spectrophotometer (8.3). The amount of mercury was determined by absorbance at 253.7 nm. The detection limit was approximately 0.1 µg. Drawbacks with this method were:

- a) The mercury vapor and hence the entire sample was immediately lost into the surrounding atmosphere
- b) The method was imprecise at lower sample loadings (8.4)
- c) The analytical technique was somewhat tedious Hopcalite solid sorbent (8.5) was substituted in place of the iodine-impregnated charcoal for mercury vapor sampling. Previously, hopcalite had been used in respirator cartridges for carbon monoxide and consisted of oxides of copper, manganese, cobalt, and silver (8.6). Analysis of recent batches of hopcalite used for mercury collection indicate the composition was mainly oxides of manganese and copper. Hydrar has been used as a substitute for collecting mercury vapor and is very similar in composition to hopcalite. A ceramic material, insoluble in nitric and hydrochloric acid, is present in the Hydrar but not in the hopcalite.

### 1.3 Advantages and Disadvantages

- 1.3.1 These sampling and analytical techniques have adequate sensitivity for measuring workplace atmospheric concentrations of elemental mercury.
- 1.3.2 The passive dosimeter used for collection of mercury vapor is small, lightweight, and requires no sampling pumps. Also, the dosimeter housing is reusable; therefore, cost per measurement is kept to a minimum.
- 1.3.3 The collected mercury sample is stable for at least 30 days.
- 1.3.4 Sample preparation for analysis involves simple procedures.
- 1.3.5 Either sampling device can be analyzed in any laboratory equipped with a CV-AAS.
- 1.3.6 A disadvantage with the passive dosimeter is particulate compounds cannot be collected with the device. A separate sampling pump and collection media should be used for particulate collection.
- 1.3.7 Another disadvantage with the dosimeter is sample rate dependence on face velocity. The dosimeter should not be used in areas where the air velocity is greater than 229 m/min (750 ft/min) since erratic increases in sampling rate may occur.
- 1.3.8 A disadvantage with the active device is the dependence on a calibrated pump to take the sample.

1.4 Toxic Effects (This section is for information only and should not be taken as a basis for OSHA policy.)

Exposure to elemental mercury vapor can occur via the respiratory tract and skin. Possible symptoms from an acute exposure include severe nausea, vomiting, abdominal pain, bloody diarrhea, kidney damage, and death. These symptoms usually present themselves within 10 days of exposure. Potential symptoms from a chronic exposure include inflammation of the mouth and gums, excessive salivation, loosening of the teeth, kidney damage, muscle tremors, jerky gait, spasms of the extremities, personality changes, depression, irritability, and nervousness (8.7, 8.8).

1.5 Workplace Exposure

Occupations with potential exposure to mercury and its compounds are listed (8.8):

|                               |                              |
|-------------------------------|------------------------------|
| amalgam makers                | fur processors               |
| bactericide makers            | gold extractors              |
| barometer makers              | histology technicians        |
| battery makers, mercury       | ink makers                   |
| boiler makers                 | insecticide makers           |
| bronzers                      | investment casting workers   |
| calibration instrument makers | jewelers                     |
| cap loaders, percussion       | laboratory workers, chemical |
| carbon brush makers           | lampmakers, fluorescent      |
| caustic soda makers           | manometer makers             |
| ceramic workers               | mercury workers              |
| chlorine makers               | miners, mercury              |
| dental amalgam makers         | neon light makers            |
| dentists                      | paint makers                 |
| direct current meter workers  | paper makers                 |
| disinfectant makers           | percussion cap makers        |
| disinfectors                  | pesticide workers            |
| drug makers                   | photographers                |
| dye makers                    | pressure gage makers         |
| electric apparatus makers     | refiners, mercury            |
| electroplaters                | seed handlers                |
| embalmers                     | silver extractors            |
| explosive makers              | switch makers, mercury       |
| farmers                       | tannery workers              |
| fingerprint detectors         | taxidermists                 |
| fireworks makers              | textile printers             |
| fungicide makers              | thermometer makers           |
| fur preservers                | wood preservative workers    |

1.6 Properties (8.7, 8.8)

Elemental mercury (CAS No. 7439-97-6) is a silver-white, heavy, mobile, liquid metal at room temperature. Some physical properties and data for mercury are:

|                |                          |
|----------------|--------------------------|
| Atomic Number  | 80                       |
| Atomic Symbol  | Hg                       |
| Atomic Weight  | 200.61                   |
| Freezing Point | -38.87 °C                |
| Boiling Point  | 356.90 °C                |
| Density        | 13.546 g/mL (20 °C)      |
| Synonyms       | Quicksilver, Hydrargyrum |

The high vapor pressure of mercury at normal temperatures combined with the potential toxicity makes good control measures necessary to avoid exposure. Also, the concentration of mercury vapor in the air rapidly increases as the temperature increases. To illustrate, listed below are vapor pressures of mercury, and mercury concentrations of air after saturation with mercury vapor at different temperatures:

Vapor Pressure-Saturation Concentration of Mercury at Various Temperatures

| Temperature |       | Vapor Pressure | Mercury Concentration |
|-------------|-------|----------------|-----------------------|
| °C          | °F    | (torr)         | (µg/m <sup>3</sup> )  |
| 0           | 32.0  | 0.000185       | 2,180                 |
| 10          | 50.0  | 0.000490       | 5,880                 |
| 20          | 68.0  | 0.001201       | 13,200                |
| 24          | 75.2  | 0.001691       | 18,300                |
| 28          | 82.4  | 0.002359       | 25,200                |
| 30          | 86.0  | 0.002777       | 29,500                |
| 32          | 89.6  | 0.003261       | 34,400                |
| 36          | 96.8  | 0.004471       | 46,600                |
| 40          | 104.0 | 0.006079       | 62,600                |

## 2. Range

2.1 The qualitative and quantitative detection limits for the analytical procedure are 0.01 µg and 0.02 µg mercury, respectively (8.9).

### 2.2 Working Range

The range of the analytical procedure has been determined to be 0.1 to 2 µg mercury. Using the analytical conditions specified, a nonlinear response was noted above 2 µg.

## 3. Method Performance

3.1 The SKC Hydrar gas monitoring dosimeter badge for mercury (SKC Inc., Eighty Four, PA) was evaluated at 80% RH and 25 °C over the range of 0.061 to 0.203 mg/m<sup>3</sup> using a dynamic generation system (8.2). The pooled coefficient of variation (CV<sub>T</sub>) for badge samples taken in this concentration range was 0.039. The average recovery was 100.8% and the overall error was ±8.6%.

In a separate study, active samplers were spiked with mercury in the range of 1 to 2.5 µg. The mean recovery of these 125 quality control samples was 96.9% with a CV<sub>1</sub> of 0.106 (8.10).

3.2 In storage stability studies, the mean recoveries of Hydrar<sup>R</sup> samples analyzed 5, 14, and 30 days after collection were within ±10% of the known generated concentration (8.2).

3.3 The Hydrar active sampling device was compared using linear regression statistics to the dosimeter in a field study (8.11). The dosimeter results agreed well with the active sampler and are summarized below (Note: A correlation coefficient and slope = 1 would indicate ideal agreement):

|                                 |      |   |                               |
|---------------------------------|------|---|-------------------------------|
| Number of paired samples        | (N)  | = | 26                            |
| Concentration Range             |      | = | 0.01 to 0.7 mg/m <sup>3</sup> |
| Correlation coefficient         | (r)  | = | 0.985                         |
| Intercept                       | (a)  | = | 0.017                         |
| Slope                           | (b)  | = | 0.960                         |
| Standard deviation of the slope | (Sb) | = | 0.038                         |

## 4. Interferences

### 4.1 Sampling:

Particulate mercury compounds are a positive interference; however, the badge does not sample particulates and the glass wool of the active sampler prevents particulate from entering the sorbent. Chlorine in the sampled air does not interfere when using Hydrar or hopcalite sorbent. The chlorine does react with available mercury vapor in the air to presumably form mercuric chloride (8.12). Workplaces containing both chlorine and mercury should be sampled for both mercury vapor and particulate.

### 4.2 Analysis:

Organic-free deionized water should be used during sample and standard preparation. Any compound with the same absorbance wavelength as mercury (253.7 nm) can be a positive interference. Some volatile organic compounds (i.e., benzene, toluene, acetone, carbon

tetrachloride) absorb at this wavelength and are considered analytical interferences. They occur as contaminants in the reagents used during sample preparation. These compounds are not expected to be retained on Hydrar or hopcalite during sample collection. Analytical interferences are rendered insignificant by using organic-free deionized water and at least reagent grade chemicals or by blank subtraction.

Increasing the concentration of nitric acid in the samples or standards appears to produce an elevated background signal. The nitric acid concentration in the samples and standards should not be greater than 10%.

## 5. Sampling

[Note: A prefilter assembly, consisting of a mixed-cellulose ester filter in a polystyrene cassette, can be used with the active samplers. Although a significant loss of mercury vapor, presumably due to the prefilter assembly, has been noted when using this type of sampling train (8.12), these results were not duplicated in a series of recent experiments (8.13).]

### 5.1 Equipment

Either tubes or dosimeters can be used to collect mercury vapor. The dosimeter should not be used when:

- 1) The air velocity of the sampling site is greater than 229 m/min (750 ft/min)
- 2) The operation being sampled is characterized by extremely poor hygienic practices and splashing of mercury on the badge may occur
- 3) Determination of total mercury is necessary and mercury particulate appears to be present in the workplace atmosphere

The tube can be used to determine **total mercury (vapor + particulate)**. The badge can only collect mercury vapor. For short-term exposures to particulate mercury, or for wipe and bulk sampling and analysis consult reference 8.14 for further information.

#### 5.1.1 PASSIVE DOSIMETER:

Gas monitoring dosimeter badge and pouch containing a Hydrar<sup>®</sup> capsule [badge - cat. no. 520-03, pouch - cat. no. 520-02 (SKC Inc., Eighty Four, PA)]. The capsule contains 800 mg of sorbent.

#### 5.1.2 ACTIVE SAMPLER:

Hydrar<sup>®</sup> or hopcalite sampling tubes (cat. no. 226-17-1 or 226-17-1A, SKC, Inc., Eighty Four, PA). These are 6-mm o.d. x 70-mm long glass tubes which contain 200 mg of sorbent.

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Note: Before use, the active sampling tubes must be examined for movement of the solid sorbent into the glass wool. See Section 5.3.1 for further details.

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5.1.3 Sampling pumps capable of sampling at 0.2 liters per minute (L/min).

5.1.4 Assorted flexible tubing.

5.1.5 Stopwatch and bubble tube or meter for pump calibration.

### 5.2 Sampling Procedure - PASSIVE DOSIMETER

5.2.1 Assemble the components of the mercury monitoring badge according to manufacturer instructions (8.1).

Note: A foam insert must be placed in the Model 520-03 dosimeter to hold the capsule in place (8.13).

5.2.2 Record the sampling start time, sampling site temperature, and atmospheric pressure. Remove the protective cap and then place the dosimeter in the breathing zone of the employee. The suggested sampling time for the dosimeter is 8 h.

- 5.2.3 Immediately after sampling, carefully remove the sorbent capsule from the dosimeter and place it in the sorbent pouch. Fold the pouch top twice and press it flat to seal the capsule inside the pouch. Record the sampling stop time, final temperature, and atmospheric pressure. Calculate and record the total sampling time, average temperature, and pressure.

### 5.3 Sampling Procedure - ACTIVE SAMPLER

- 5.3.1 Calibrate each personal sampling pump with an active sampler in-line using a flow rate of about 0.2 L/min.

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Note: A prefilter assembly consisting of a mixed-cellulose ester filter, polystyrene cassette, and a **minimum** amount of Tygon tubing can be used if:

- a) particulate mercury compounds may present a problem during sampling  
or
- b) the hopcalite or Hydrar contained in the active sampling tube has migrated to the glass wool plug.

Before use, the active sampling tubes must be examined for movement of the solid sorbent into the glass wool. Certain lots of Hydrar or hopcalite have been noted as being very friable or having a sorbent particle-size range small enough as to allow migration. This movement can easily be noted - the glass wool in the sampling tube appears somewhat discolored (darkened) from the small sorbent particles. If sorbent migration has occurred, a prefilter assembly is recommended. The recommended sampling flow rate is also 0.2 L/min with the prefilter-sampling tube-pump assembly.

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- 5.3.2 Connect a sampling tube (or sampling assembly) to a calibrated pump using flexible tubing. If a prefilter is used, connect it to the sampling tube with a minimum amount of Tygon tubing. Connect the other end of the sampling tube to the pump. Place the sampling tube (or assembly) in the breathing zone and the pump in an appropriate position on the employee.

- 5.3.3 Use an air volume in the range of 3 to 100 L to collect the mercury in the workplace air. Record the total volume.

- 5.3.4 Replace the plastic end caps on the active sampler after sampling is completed.

### 5.4 Sample Shipment

- 5.4.1 Securely wrap each sorbent pouch or active sampling tube end-to-end with an OSHA Form 21 sample seal. Also seal and prepare cassettes if a prefilter assembly was used.

- 5.4.2 Submit at least one blank sample with each set of samples. The blank sample should be handled in the same manner as the other samples except that an air sample is not taken.

- 5.4.3 Request the laboratory to analyze the samples for mercury. Submit any pertinent sampling information to the lab. Record if a prefilter assembly was used.

- 5.4.4 Ship the sealed pouches and used dosimeter housings, or active sampling tubes to the laboratory in appropriate containers as soon as possible. The filter/cassette assembly can also be submitted for mercury particulate analysis; however, sampling periods may be longer than reflected in exposure regulations.

## 6. Analysis

### 6.1 Safety Precautions

- 6.1.1 Wear safety glasses, labcoat, and gloves at all times.

- 6.1.2 Handle acid solutions with care. Avoid direct contact of acids with work area surfaces, eyes, skin, and clothes. Flush acid solutions which contact the skin or eyes with copious amounts of cold water.

- 6.1.3 Prepare solutions containing hydrochloric acid in an exhaust hood and store in narrow-mouthed bottles.
  - 6.1.4 Keep B.O.D. bottles containing stannous chloride/hydrochloric acid solutions capped when not in use to prevent inhalation of noxious vapors.
  - 6.1.5 Exercise care when using laboratory glassware. Do not use chipped pipets, volumetric flasks, beakers or any glassware with sharp edges exposed.
  - 6.1.6 Never pipet by mouth.
  - 6.1.7 When scoring the glass of active samplers to remove the sorbent before analysis, score with care. Apply only enough pressure to scratch a clean mark on the glass. Use a paper towel or cloth to support the opposite side while scoring. Moisten the mark with DI H<sub>2</sub>O and wrap the tube in cloth before breaking. If the tube does not break easily, re-score. Dispose of glass in a waste receptacle specifically designed and designated for broken-glass.
  - 6.1.8 Always purge the mercury from the CV-AAS into an exhaust vent.
  - 6.1.9 Occasionally monitor the CV-AAS for mercury vapor leaks using an appropriate direct reading instrument.
- 6.2 Equipment - Cold Vapor Analysis
- (Note: Specific equipment is listed for illustration only)
- 6.2.1 Atomic absorption spectrophotometer (model 503, Perkin-Elmer, Norwalk, CT).
  - 6.2.2 Mercury hollow cathode lamp or electrodeless discharge lamp and power supply.
  - 6.2.3 Biological Oxygen Demand (B.O.D.) bottles, borosilicate glass, 300 mL.
  - 6.2.4 Peristaltic pump, 1.6 to 200 mL range, and controller, 1-100 rpm range (Masterflex model 7553-30 with model 7015 head, Cole-Parmer, Chicago, IL).
  - 6.2.5 Quartz absorption cell, 22-mm (7/8 in) o.d. × 152-mm (6 in) long (part no. 303-3101, Perkin-Elmer).
  - 6.2.6 Heating tape.
  - 6.2.7 Variable transformer 50-60 Hz, 10 A, 120 V input, 0-140 V output, 1.4 kW (Superior Electric, Bristol, CT).
  - 6.2.8 Tygon peristaltic pump tubing (part no. N06409-15, Cole-Parmer) and glass tubing.
  - 6.2.9 Aerator (part no. 0303-3102, Perkin-Elmer).
  - 6.2.10 Chart recorder.
  - 6.2.11 Desiccant (Drierite, W.A. Hammond Drierite Co., Xenia, OH).
  - 6.2.12 Volumetric flasks, volumetric pipets, beakers, and other laboratory glassware.
  - 6.2.13 Automatic pipets, adjustable, 0.1 to 5.0 mL range (models P-1000 and P-5000, Rainin Instruments Co., Woburn, MA).
  - 6.2.14 Glass tube scorer, or needle, 21 to 25 gauge - for removing metal screens in dosimeters or glass wool from tubes. A piece of bent wire can also be used.
  - 6.2.15 Exhaust vent.
- 6.3 Reagents - All reagents should be at least reagent grade.
- Stannous chloride, (SnCl<sub>2</sub>)
- 6.3.1 Deionized water (DI H<sub>2</sub>O), organic-free.

- 6.3.2 Hydrochloric acid (HCl), concentrated (36.5 to 38%), with a mercury concentration less than 0.005 ppm.
- 6.3.3 Mercury standard stock solution, 1,000 µg/mL: Use a commercially available certified standard or, alternatively, dissolve 1.0798 g of dry mercuric oxide (HgO) in 50 mL of 1:1 hydrochloric acid and then dilute to 1 L with DI H<sub>2</sub>O. Store this reagent in a dark environment, preferably in an amber colored container.
- 6.3.4 Nitric acid (HNO<sub>3</sub>), concentrated (69 to 71%), with a mercury concentration less than 0.005 ppm.
- 6.3.5 Nitric acid, 1:1: Carefully add equal portions of concentrated HNO<sub>3</sub> and DI H<sub>2</sub>O.
- 6.3.6 Nitric acid, 10%: Carefully add 100 mL concentrated HNO<sub>3</sub> to 900 mL DI H<sub>2</sub>O.
- 6.3.7 Stannous chloride (SnCl<sub>2</sub>) solution, 10%: Dissolve 20 g SnCl<sub>2</sub> in 100 mL concentrated HCl. Slowly and carefully pour this solution into 100 mL DI H<sub>2</sub>O and then mix well. Transfer and store the final solution in a capped B.O.D. bottle to prevent oxidation. Prepare this solution before each new analysis.

#### 6.4 Glassware Preparation

- 6.4.1 Clean the B.O.D. bottles and stoppers with 1:1 HNO<sub>3</sub> and thoroughly rinse with DI H<sub>2</sub>O prior to use.
- 6.4.2 Rinse all other glassware with 10% nitric acid and then with DI H<sub>2</sub>O prior to use. Air dry all 50-mL volumetric flasks to be used in sample preparation.

#### 6.5 Standard Preparation

- 6.5.1 Prepare a 1 µg/mL mercury standard by making appropriate ten-fold serial dilutions of the 1,000 µg/mL mercury standard stock solution with 10% HNO<sub>3</sub>.
- 6.5.2 Prepare working mercury standards (ranging from 0.1 to 2.0 µg) and reagent blanks immediately prior to use. A few standards at each concentration should be made. Add an appropriate aliquot of the 1 µg/mL standard to a clean B.O.D. bottle containing enough 10% HNO<sub>3</sub> to bring the total volume to 100 mL. A suggested dilution scheme is given:

| Mercury Standard (µg) | Aliquot (mL)* | Final Volume (mL) |
|-----------------------|---------------|-------------------|
| Reagent Blank         | 0             | 100               |
| 0                     | 0.1           | 100               |
| 0.2                   | 0.2           | 100               |
| 0.5                   | 0.5           | 100               |
| 1.0                   | 1.0           | 100               |
| 1.5                   | 1.5           | 100               |
| 2.0                   | 2.0           | 100               |

\* Aliquot taken from 1 µg/mL standard prepared in Section 6.5.1

- 6.6 Sample Preparation [Note: A hooked needle or piece of fine wire is useful to remove the dosimeter screen or glass wool (active sampler) and the sorbent particles.]

##### 6.6.1 DOSIMETER

Open each sample pouch and remove the sorbent capsule. Carefully remove the screen from the top of the capsule without losing any sorbent. Carefully pour the sorbent into a clean, dry 50-mL flask without spilling any. Discard the screen and empty capsule.

### 6.6.2 ACTIVE SAMPLER

Score the tube with a glass tube cutter (also see Section 6.1.7) and then break open the front section of the tube above the glass wool. An alternative approach to scoring and breaking is to carefully remove the glass wool with a bent wire or needle.

- a) If a prefilter was not used during sampling, place the glass wool and sorbent into separate 50-mL volumetric flasks.
- b) If a prefilter was used and the glass wool appears to contain hopcalite or Hydrar, the glass wool can be analyzed along with the sorbent. Carefully transfer the glass wool and sorbent to a 50-mL volumetric flask without losing any of the particles.

### 6.6.3 Prefilter

Prepare and analyze any prefilters according to reference 8.14.

6.6.4 Add 2.5 mL of concentrated HNO<sub>3</sub> followed by 2.5 mL concentrated HCl to each volumetric flask [Note: To minimize any loss of mercury through a change in oxidation state, the HNO<sub>3</sub> is added before the HCl (8.5)].

6.6.5 Gently swirl the sample occasionally for approximately 1 h. If Hydrar was used to collect the sample, the dark brown solution will also contain some undissolved clear to white-tan colored ceramic material.

6.6.6 Carefully dilute to a 50-mL total volume with DI H<sub>2</sub>O. The final sorbent sample solution will be light blue or blue-green. This is a good place to stop if the analysis cannot be completed the same day.

## 6.7 Analysis - Instrument Parameters

6.7.1 Set up the CV-AAS as illustrated in Figure 1.

6.7.2 Wrap the heating tape around the quartz cell and then turn on the variable transformer. The heat setting on the tape should be sufficient to prevent water vapor condensation in the absorption cell.

6.7.3 Place the aerator in a B.O.D. bottle which contains approximately ½ to 1 inch of desiccant. Operate the peristaltic pump for approximately 30 min at full speed to remove any water vapor from the system.

6.7.4 Operate the hollow cathode or electrodeless discharge mercury lamp at the manufacturer's recommended current or power rating.

6.7.5 Use the following settings (Note: The mentioned instrument settings are for specific models used at the OSHA-SLCAL. If instrumentation other than what is specified in Section 6.2 is used, please consult the instrument manufacturer's recommendations.):

#### Atomic Absorption Spectrophotometer:

|            |             |
|------------|-------------|
| Slit       | 0.7 nm      |
| Signal     | Repeat Mode |
| Function   | ABS         |
| Mode       | ABS         |
| Range      | UV          |
| Wavelength | 253.7 nm    |
| Filter     | Out         |
| EM Chopper | Off         |
| Phase      | Normal      |

#### Strip Chart Recorder:

|             |          |
|-------------|----------|
| Chart Speed | 5 mm/min |
| Chart Range | 10 mV    |

6.7.6 Optimize the ENERGY meter reading at 253.7 nm.

- 6.7.7 Align the beam of the mercury lamp so it passes directly through the center of the quartz cell windows. This can be accomplished by adjusting the burner height, depth, and angle knobs to give a minimum ABSORBANCE reading.
- 6.7.8 Operate the peristaltic pump at full speed. Rinse the aerator with DI H<sub>2</sub>O and insert it into a holder in the exhaust vent.
- 6.7.9 Perform the following steps to obtain a baseline signal near an absorbance of zero:
- 1) start the chart recorder,
  - 2) set the spectrophotometer absorbance reading to zero,
  - 3) wait until the baseline stops drifting,
  - 4) set the reading to zero again.

## 6.8 Analysis

- 6.8.1 Samples: Immediately before analyzing, transfer an appropriate aliquot of the sample solution to a clean B.O.D. bottle containing enough 10% HNO<sub>3</sub> solution to bring the total volume to 100 mL. The transfer must be done with a volumetric pipet.
- 6.8.2 Standards: Immediately before analyzing, prepare standards according to instructions listed in Section 6.5.2.
- 6.8.3 Deliver 5 mL of the 10% SnCl<sub>2</sub> solution with an automatic pipet to a B.O.D. bottle containing a standard, reagent blank, or sample to be analyzed. Immediately place the aerator into the solution with the peristaltic pump operating at full speed.
- 6.8.4 Record the maximum absorbance reading and label the signal produced on the strip chart.
- 6.8.5 Stop the pump, remove the B.O.D. bottle from the CV-AAS and stopper it. Rinse the aerator with DI H<sub>2</sub>O and insert it into a holder in the exhaust vent. Turn the pump on at full speed until the CV-AAS system is purged of mercury and the baseline returns to zero.
- 6.8.6 If the absorbance reading of a sample is greater than the highest standard at any time during analysis, immediately remove the B.O.D. bottle from the CV-AAS. Purge the system following the procedure listed in Section 6.8.5. Take a smaller aliquot or dilute the high concentration sample and re-analyze. Make any necessary sample dilutions with 10% HNO<sub>3</sub> and use the appropriate dilution factor when calculating results.
- 6.8.7 Repeat Sections 6.8.3 through 6.8.5 for each prepared standard, reagent blank, or sample.

## 6.9 Analytical Recommendations

- 6.9.1 It is recommended to analyze the reagent blank, lowest, and highest standard two or three times each to check for contamination, reproducibility, and sensitivity before starting the sample analysis. A 2.0- $\mu$ g mercury standard should give a three-quarter to full-scale deflection on the chart recorder and an absorbance unit reading of about 0.850 when using the equipment and conditions specified. The lowest and highest standard should provide a linear response and the lowest standard should be at least two to three times the blank signal.
- 6.9.2 It is also recommended to analyze an entire series of standards (including the reagent blank) at the beginning and end of the sample analysis to ensure standard readings are reproducible. As a general guideline, standard readings should be within  $\pm 10\%$  throughout the analysis.
- 6.9.3 A standard near the concentration range of the samples should be analyzed after every four to five samples.
- 6.9.4 Quality control (QC) samples should be prepared and analyzed using the same matrix and analytical conditions as the samples. If possible, the QC samples should be generated from an independent source.
- 6.9.5 Approximately 10% of the samples should be reanalyzed.

## 7. Calculations

- 7.1 Use a least squares regression program to plot a concentration-response curve of peak absorbance versus the amount ( $\mu\text{g}$ ) of mercury in each standard.
- 7.2 Determine the amount ( $\mu\text{g}$ ) of mercury, A, corresponding to the peak absorbance in each analyzed sample aliquot from this curve.
- 7.3 Calculate the total amount ( $\mu\text{g}$ ) of mercury, W, in each sorbent or glass wool sample:

$$W = \frac{(A)(\text{Sample vol, mL})(DF)}{\text{Aliquot, mL}}$$

DF = Dilution Factor (if none, DF = 1)

- 7.4 A blank correction is made for each sample (Note: When using the reagents and conditions specified, previous blank results have been less than 1  $\mu\text{g}$ ). Calculate the concentration of mercury in each sorbent or glass wool sample:

$$\text{Mercury mg/m}^3 = \frac{W - W_b}{\text{Air vol, L}}$$

Where:

W<sub>b</sub> = Total  $\mu\text{g}$  of mercury in the blank sample.

Air vol = Sampling time x flow rate (for ACTIVE SAMPLERS)

(Note: For PASSIVE DOSIMETERS, the sampling rate is affected by temperature and pressure. To correct for this, use:

$$\text{Air vol} = ST \times 0.020 \times \left(\frac{T_1}{T_2}\right)^{1.5} \times \frac{P_2}{P_1}$$

Where:

ST = Sampling time (min)

0.020 = Sampling rate (L/min) at 20 °C and 760 torr

T<sub>1</sub> = Sampling site temperature (K)

T<sub>2</sub> = 293 K

P<sub>1</sub> = Sampling site pressure (torr)

P<sub>2</sub> = 760 torr

- 7.5 Reporting Results to the Industrial Hygienist

For PASSIVE DOSIMETER samples, report results to the industrial hygienist as  $\text{mg/m}^3$  mercury vapor.

For ACTIVE SAMPLERS, report results as:

- a)  $\text{mg/m}^3$  mercury vapor
- b)  $\text{mg/m}^3$  total mercury

For mercury vapor result a): If a prefilter was used and the glass wool and sorbent were combined:

mercury vapor = glass wool + sorbent

The prefilter (if used) was present during sampling to assure that mercury particulate was not trapped in the glass wool.

For total mercury result (b): The sum of the mercury found in the sorbent (vapor), glass wool, and prefilter (if used) for each active sampler is considered. This result is used to determine total mercury.

Any mercury particulate anticipated on the prefilter can be analyzed for mercury. See Reference 8.14 for further details.

If sampling information has not been provided by field personnel, results are reported in total micrograms.

## 8. References

- 8.1 SKC Inc.: Gas Monitoring Dosimeter Badge for Mercury (Operating Instructions). Eighty Four, PA: SKC Inc., no publication date given.
- 8.2 Occupational Safety and Health Administration Technical Center: Evaluation of Mercury Solid Sorbent Passive Dosimeter by J. Ku (OSHA-SLTC Backup Report for Method No. ID-140). Salt Lake City, UT, Revised 1989.
- 8.3 Moffitt, A.E., Jr. and R.E. Kupel: A Rapid Method Employing Impregnated Charcoal and Atomic Absorption Spectroscopy for the Determination of Mercury. Am. Ind. Hyg. Assoc. J. **32**: 614 (1971).
- 8.4 McCammon, C.S., Jr., S.L. Edwards, R.D. Hull, and W.J. Woodfin: A Comparison of Four Personal Sampling Methods for the Determination of Mercury Vapor. Am. Ind. Hyg. Assoc. J. **41**: 528-531 (1980).
- 8.5 Rathje, A.O. and D.H. Marcero: Improved Hopcalite Procedure for the Determination of Mercury Vapor in Air by Flameless Atomic Absorption. Am. Ind. Hyg. Assoc. J. **37**: 331 (1976).
- 8.6 Sax, N.I. and R.J. Lewis Sr., ed.: Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987.
- 8.7 Vindholz, M., ed.: The Merck Index. 10th ed. Rahway, NJ: Merck & Co. Inc., 1983.
- 8.8 National Institute for Occupational Safety and Health: Criteria for a Recommended Standard -- Occupational Exposure to Inorganic Mercury (DHEW/NIOSH Pub. No. HSM-73-11024). Cincinnati, OH: National Institute for Occupational Safety and Health, 1973.
- 8.9 Occupational Safety and Health Administration Analytical Laboratory: Detection Limit Study for Mercury Cold Vapor Analysis by C. Merrell. Salt Lake City, UT. 1987 (unpublished).
- 8.10 Occupational Safety and Health Administration Analytical Laboratory: Quality Control Data - Mercury Cold Vapor Analysis by B. Babcock. Salt Lake City, UT. 1987 (unpublished).
- 8.11 Occupational Safety and Health Administration Analytical Laboratory: An Evaluation of Mercury Vapor Sampling Devices by R. Cee, J. Ku, E. Zimowski, S. Edwards, and J. Septon (OSHA-SLTCAL Product Evaluation No. PE-6). Salt Lake City, UT. 1987
- 8.12 Menke, R. and G. Wallis: Detection of Mercury in Air in the Presence of Chlorine and Water Vapor. Am. Ind. Hyg. Assoc. J. **41**: 120-124 (1980).
- 8.13 Occupational Safety and Health Administration Technical Center: An Evaluation of Hopcalite Sampling Methods for Mercury by J. Septon. Salt Lake City, UT. In progress (unpublished).
- 8.14 Occupational Safety and Health Administrations Technical Center: Mercury Particulate in Workplace Atmospheres (OSHA-SLTC Method No. ID-145). Salt Lake City, UT. 1989

Cold Vapor-Atomic Absorption Spectrophotometer for Mercury Analysis

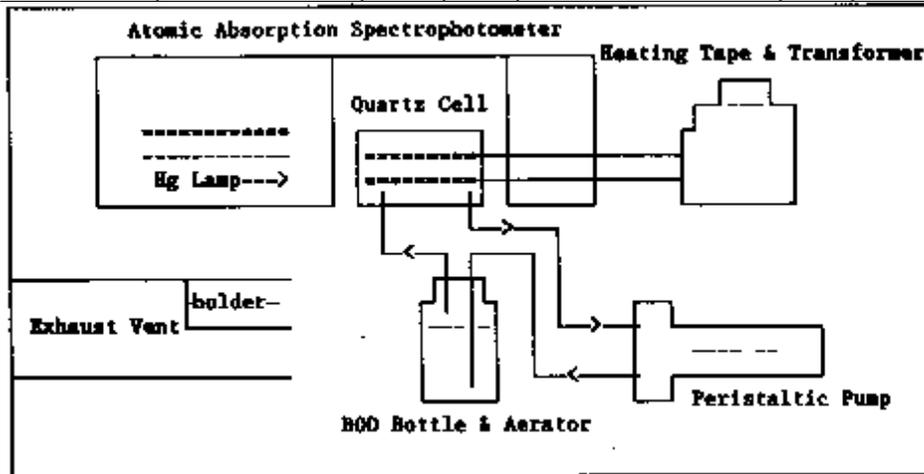


Figure 1

# MERCURY

6009

Hg

MW: 200.59

CAS: 7439-97-6

RTECS: OV4550000

METHOD: 6009, Issue 2

EVALUATION: PARTIAL

Issue 1: 15 May 1989  
Issue 2: 15 August 1994

OSHA : C 0.1 mg/m<sup>3</sup> (skin)  
NIOSH: 0.05 mg/m<sup>3</sup> (skin)  
ACGIH: 0.025 mg/m<sup>3</sup> (skin)

PROPERTIES: liquid; d 13.55 g/mL @ 20 °C; BP 356 °C;  
HP -39 °C; VP 0.16 Pa (0.0012 mm Hg;  
13.2 mg/m<sup>3</sup>) @ 20 °C; Vapor Density  
(air=1) 7.0

SYNONYMS: quicksilver

| SAMPLING  |   | MEASUREMENT                                |   |
|---|---|--|---|
| <b>SAMPLER:</b>                                       | SOLID SORBENT TUBE<br>(Hopcalite in single section, 200 mg) | <b>TECHNIQUE:</b>                          | ATOMIC ABSORPTION, COLD VAPOR                                 |
| <b>FLOW RATE:</b>                                     | 0.15 to 0.25 L/min  | <b>ANALYTE:</b>                            | elemental mercury   |
| <b>VOL-MIN:</b>                                       | 2 L @ 0.5 mg/m <sup>3</sup>                                 | <b>DESORPTION:</b>                         | conc. HNO <sub>3</sub> /HCl @ 25 °C,<br>dilute to 50 mL       |
| <b>-MAX:</b>  | 100 L   | <b>WAVELENGTH:</b>                         | 253.7 nm  |
| <b>SHIPMENT:</b>                                      | routine   | <b>CALIBRATION:</b>                        | standard solutions of Hg <sup>2+</sup> in 1% HNO <sub>3</sub> |
| <b>SAMPLE STABILITY:</b>                              | 30 days @ 25 °C [1]   | <b>RANGE:</b>                              | 0.1 to 1.2 µg per sample                                      |
| <b>FIELD BLANKS:</b>                                  | 2 to 10 field blanks per set                                | <b>ESTIMATED LOD:</b>                      | 0.03 µg per sample  |
| <b>MEDIA BLANKS:</b>                                  | at least 3 per set  | <b>PRECISION (<math>\hat{S}_r</math>):</b> | 0.042 @ 0.9 to 3 µg per sample [4]                            |
| ACCURACY  |   |  |   |
| <b>RANGE STUDIED:</b>                                 | 0.002 to 0.8 mg/m <sup>3</sup> [2]<br>(10-L samples)        |  |   |
| <b>BIAS:</b>  | not significant   |  |   |
| <b>OVERALL PRECISION (<math>\hat{S}_{rT}</math>):</b> | not determined  |  |   |
| <b>ACCURACY:</b>                                      | not determined  |  |   |

**APPLICABILITY:** The working range us 0.01 to 0.5 mg/m<sup>3</sup> for a 10-L air sample. The sorbent material irreversibly collects elemental mercury. A prefilter can be used to exclude particulate mercury species from the sample. The prefilter can be analyzed by similar methodology. The method has been used in numerous field surveys [3].

**INTERFERENCES:** Inorganic and organic mercury compounds may cause a positive interference. Oxidizing gases, including chlorine, do not interfere.

**OTHER METHODS:** This replaces method 6000 and its predecessors, which required a specialized desorption apparatus [4,5,6]. This method is based on the method of Rathje and Marcero [7] and is similar to the OSHA method ID 145H [2].

**REAGENTS:**

1. Water, organics-free, deionized.
2. Hydrochloric acid (HCl), conc.
3. Nitric acid (HNO<sub>3</sub>), conc.
4. Mercuric oxide, reagent grade, dry.
5. Calibration stock solution, Hg<sup>2+</sup>, 1000 µg/mL. Commercially available or dissolve 1.0798 g of dry mercuric oxide (HgO) in 50 mL of 1:1 hydrochloric acid, then dilute to 1 L with deionized water.
6. Intermediate mercury standard, 1 µg/mL. Place 0.1 mL 1000 µg/mL stock into a 100 mL volumetric containing 10 mL deionized water and 1 mL hydrochloric acid. Dilute to volume with deionized water. Prepare fresh daily.
7. Stannous chloride, reagent grade, 10% in 1:1 HCl. Dissolve 20 g stannous chloride in 100 mL conc. HCl. Slowly add this solution to 100 mL deionized water and mix well. Prepare fresh daily.
8. Nitric acid, 1% (w/v). Dilute 14 mL conc. HNO<sub>3</sub> to 1 L with deionized water.

**EQUIPMENT:**

1. Sampler: glass tube, 7 cm long, 6-mm OD, 4-mm ID, flame sealed ends with plastic caps, containing one section of 200 mg Hopcalite held in place by glass wool plugs (SKC, Inc., Cat. #226-17-1A, or equivalent).  
NOTE: A 37-mm, cellulose ester membrane filter in a cassette preceding the sorbent may be used if particulate mercury is to be determined separately.
2. Personal sampling pump, 0.15 to 0.25 L/min, with flexible connecting tubing.
3. Atomic absorption spectrophotometer with cold vapor generation system (see Appendix) or cold vapor mercury analysis system.\*
4. Strip chart recorder, or integrator.
5. Flasks, volumetric, 50-mL, and 100-mL.
6. Pipet, 5-mL, 20-mL, others as needed.
7. Micropipet, 10- to 1000-µL.
8. Bottles, biological oxygen demand (BOD), 300-mL.

\* See SPECIAL PRECAUTIONS

**SPECIAL PRECAUTIONS:** Mercury is readily absorbed by inhalation and contact with the skin. Operate the mercury system in a hood, or bubble vented mercury through a mercury scrubber.

**SAMPLING:**

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Break ends of sampler immediately prior to sampling. Attach sampler to pump with flexible tubing.
3. Sample at an accurately known rate of 0.15 to 0.25 L/min for a total sample size between 2 and 100 L.  
NOTE: Include a minimum of three unopened sampling tubes from the same lot as the samples for use as media blanks.
4. Cap sampler and pack securely for shipment.

**SAMPLE PREPARATION:**

5. Place the Hopcalite sorbent and the front glass wool plug from each sampler in separate 50-mL volumetric flasks.
6. Add 2.5 mL conc. HNO<sub>3</sub> followed by 2.5 mL conc. HCl.  
NOTE: The mercury must be in the oxidized state to avoid loss. For this reason, the nitric acid must be added first.
7. Allow the sample to stand for 1 h or until the black Hopcalite sorbent is dissolved. The solution will turn dark brown and may contain undissolved material.
8. Carefully dilute to 50 mL with deionized water. (Final solution is blue to blue-green).
9. Using a volumetric pipet, transfer 20 mL of the sample to a BOD bottle containing 80 mL of deionized water. If the amount of mercury in the sample is expected to exceed the standards, a smaller aliquot may be taken, and the volume of acid adjusted accordingly. The final volume in

the BOD bottle must be 100 mL. To prevent possible loss of mercury during transfer, place the pipet tip below the surface of the liquid in the BOD bottle.

#### CALIBRATION AND QUALITY CONTROL:

10. Prepare a minimum of two series (six levels each) of working standards covering the range 0.01 to 0.5 µg Hg per aliquot by adding known amounts of the intermediate standard to BOD bottles containing enough 1% nitric acid to bring the final volume to 100 mL.
11. Analyze the working standards together with the samples and blanks (steps 13 through 16). Analyze full set of standards at the beginning of the run, and a second set at the end of the run. Additional standards may be run intermediately during the analysis to confirm instrument response.
12. Prepare calibration graph (peak height vs. solution concentration, µg/sample).

#### MEASUREMENT:

13. Zero the spectrophotometer by removing the bubbler from the BOD bottle, allowing the baseline on the recorder to stabilize.
14. Place the bubbler in a BOD bottle containing 0.5 µg mercury in 100 mL 1% nitric acid. Adjust the spectrophotometer so that it will give a 75% to full-scale deflection of the recorder.
15. Vent the mercury vapor from the system.
16. Analyze standards, samples and blanks (including media blanks).
  - a. Remove the bubbler from the BOD bottle.
  - b. Rinse the bubbler with deionized water.
  - c. Allow the recorder tracing to establish a stable baseline.
  - d. Remove the stopper from the BOD bottle containing the next sample to be analyzed. Gently swirl the BOD bottle.
  - e. Quickly add 5 mL 10% stannous chloride solution.
  - f. Quickly place the bubbler into the BOD bottle.
  - g. Allow the spectrophotometer to attain maximum absorbance.
  - h. Vent the mercury vapor from the system.
  - i. Place the bubbler into an empty BOD bottle. Continue venting the mercury until a stable baseline is obtained.
  - j. Close the mercury vent.

#### CALCULATIONS:

17. Calculate the amount of mercury in the sample aliquot (W, µg) from the calibration graph.
18. Calculate the concentration C (mg/m<sup>3</sup>), of mercury in the air volume sampled, V (L):

$$C = \frac{W \cdot \frac{V_s}{V_a} - B}{V}$$

Where: Vs = original sample volume (step 8; normally 50 mL)

Va = aliquot volume (step 9; normally 20 mL)

B = average amount of mercury present in the media blanks

**EVALUATION OF METHOD:**

Rathje and Marcero originally used Hopcalite (MSA, Inc.) as the sorbent material [7]. Later, Hopcalite was shown superior to other methods for the determination of mercury vapor [8]. Atmospheres of mercury vapor for the study were dynamically generated in the range 0.05 to 0.2 mg/m<sup>3</sup> and an adsorbent tube loading of 1 to 7 µg was used. The Hydrar material sometimes used is similar to Hopcalite. No significant difference in the laboratory analysis of mercury collected on the two sorbent materials was observed [9]. OSHA also validated a method for mercury using Hydrar [2]. An average 99% recovery, with  $\bar{S}_r = 0.042$ , was seen for 18 samples with known amounts (0.9 to 3 µg) of mercury added (as Hg(NO<sub>3</sub>)<sub>2</sub>) [10]. No change in recovery was seen for samples stored up to 3 weeks at room temperature or up to 3 months at -15 °C; longer storage times were not investigated [10].

**REFERENCES:**

- [1] Evaluation of Mercury Solid Sorbent Passive Dosimeter, Backup Data Report. Inorganic Section, OSHA Analytical Laboratory, Salt Lake City, Utah, 1985.
- [2] Mercury in Workplace Atmospheres (Hydrar Tubes). Method ID 145H, Inorganic Section, OSHA Analytical Laboratory, Salt Lake City, UT, 1987.
- [3] NIOSH/MRSB. Reports for analytical Sequence Nos. 5854, 5900, 6219, and 6311, NIOSH (Unpublished, 1987-1988).
- [4] NIOSH Manual of Analytical Methods, 3rd. ed., Method 6000. (1984).
- [5] NIOSH Manual of Analytical Methods. 2nd. ed., V. 4, S199, U.S. Dept. of Health, Education, and Welfare Publ. (NIOSH) 79-141 (1979).
- [6] Ibid., V. 5, P&CAM 175, Publ. (NIOSH) 79-141 (1979).
- [7] Rathje, A.O., Marcero, D.H. Improved hopcalite procedure for the determination of mercury in air by flameless atomic absorption, Am. Ind. Hyg. Assoc. J. **37**, 311-314 (1976).
- [8] McCammon, C.S., Edwards, S.L., Hull, R.D., Woodfin, W.J., A comparison of four personal sampling methods for the determination of mercury vapor, Am. Ind. Hyg. Assoc. J., **41**, 528-531 (1980).
- [9] Internal Methods Development Research, DataChem Laboratories, Inc., Salt Lake City, UT (1982).
- [10] Eller, P.M., NIOSH, unpublished data (1987-88).

**METHOD WRITTEN BY:**

Keith R. Nicholson and Michael R. Steele, DataChem Laboratories, Inc., Salt Lake City, Utah, under NIOSH contract No. 200-87-2533.

**APPENDIX: COLD VAPOR MERCURY ANALYSIS SYSTEM**

1. The valve should direct the vented vapors to a hood or to a mercury scrubber system.
2. When the valve is opened to "Vent" the peristaltic pump should draw room air. Place a Hopcalite tube in the air intake to eliminate any mercury that may be present.
3. Adjust the peristaltic pump to a flow that will create a steady stream of bubbles in the BOD bottle, but not so great that solution droplets enter the tubing to the quartz cell.
4. If water vapor condenses in the quartz cell, heat the cell slightly above room temperature by wrapping it with a heating coil and attaching a variable transformer.
5. The bubbler consists of a glass tube with a bulb at the bottom, slightly above the bottom of the BOD bottle. The bulb contains several perforations to allow air to escape into the solution (in a stream of small bubbles). A second tube is provided to allow the exit of the vapor. The open end of the second tube is well above the surface of the liquid in the bottle. The two tubes are fixed into a stoppering device (preferably ground glass) which fits into the top of the bottle. A coarse glass frit can be used in place of the bulb on the first tube. However, it is more difficult to prevent contamination when a frit is used.
6. Replace the flexible tubing (Tygon or equivalent) used to connect the bubbler, cell, and pump periodically to prevent contamination from adsorbed mercury.