

CONTROL TECHNOLOGY AND EXPOSURE ASSESSMENT FOR
ELECTRONIC RECYCLING OPERATIONS
ELKTON FEDERAL CORRECTIONAL INSTITUTION
ELKTON, OHIO

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EXECUTIVE SUMMARY

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted a study of the recycling of electronic components at the Federal Prison Industries facilities (aka, Unicor) in Elkton, Ohio, to assess workers' exposures to metals and other occupational hazards, including noise, associated with these operations. An in-depth evaluation was conducted from February 26 to March 2, 2007, and a follow-up survey was conducted from December 11 to 13, 2007, to evaluate changes made in selected activities as a result of initial recommendations.

The electronics recycling operations at Elkton can be organized into four production processes: a) receiving and sorting, b) disassembly, c) glass breaking operations, and d) packaging and shipping. A fifth operation, cleaning and maintenance, was also addressed but is not considered a production process per se. It is known that lead (Pb), cadmium (Cd), and other metals are used in the manufacturing of electronic components and pose a risk to workers involved in recycling of electronic components if the processes are not adequately controlled or the workers are not properly trained and provided appropriate personal protective clothing and equipment.

Methods used to assess worker exposures to metals during this evaluation included: personal breathing zone and area sampling for airborne metals; particle size sampling; surface wipe sampling to assess surface contamination; and bulk material samples to determine the composition of settled dust. Samples were analyzed for up to 31 metals with five selected elements (barium, beryllium, cadmium, lead and nickel) given emphasis. Noise exposures were determined using personal dosimeters.

The results of air sampling conducted during the February / March visit indicated that the highest exposures occurred to workers during the filter change-out maintenance operation. Airborne concentrations of Cd and Pb measured during filter change-out showed an 8-hour time weighted average of about 150 times the OSHA Permissible Exposure Limit (PEL) for Cd and 15 times the OSHA PEL for Pb for one of the two workers. Air samples collected on a second worker showed airborne concentrations of 30 times the PEL for Cd and 4 times the PEL for Pb. In both cases the results showed that the Cd concentrations exceeded the assigned protection factor for the powered air-purifying respirator being used by the workers. An over-exposure to Cd was also found during the weekly clean-up operation.

Although beryllium is used in consumer electronics and computer components, such as disk drive arms (beryllium-aluminum), electrical contacts, switches, and connector plugs (copper-beryllium) and printed wiring boards [Willis and Florig 2002, Schmidt 2002], most beryllium "in consumer products is used in ways that are not likely to create beryllium exposures during use and maintenance" [Willis and Florig 2002]. This may account for the fact that beryllium in this study was measured in only two samples at levels above the detection limit of the analytical method. The removal and sorting of components seen here is typical of a maintenance activity (components are removed from the cases and sorted, rather than removed and replaced). Other e-recycling activities that include further processing, such as shredding of

the components, may produce higher exposures to beryllium but these processes are not done at this facility.

Samples collected during routine daily glass breaking operations were less than 20% of the OSHA PELs for both Cd and Pb. Samples collected on disassembly workers in the general factory area of all three buildings ranged from non-detectable to 10% of the OSHA PEL for Cd and ranged from non-detectable to 5% of the OSHA PEL for Pb. Unless specified, results of samples presented are for duration of sample and not calculated on an 8 hour time weighted average basis.

Lead, cadmium and other heavy metals were detected in the surface wipe and bulk dust samples. There are few established standards available for wipe samples with which to compare these data. Most of the surfaces tested for lead indicated levels exceeding the most stringent criteria. The wipe sample results can not be used to determine when the contamination occurred. They only represent the surface contamination present at the time the sample was collected.

Measurement of noise levels indicated several samples exceeding the REL and TLV of 85 dBA. One sample exceeded the PEL of 90 dBA and 3 other samples exceeded 50% of the allowable dose requiring that those employees be placed in a hearing conservation program.

As a result of the February/March 2007 survey, it was recommended that the filter change operation be modified and that improved dust suppression methods be used to reduce airborne concentrations. Specific recommendations (implemented prior to the second evaluation) include: 1) the use of water spray to suppress dust during the filter change-out operation; 2) the immediate bagging and disposal of used filters rather than attempting to clean and re-use them; and 3) the use of HEPA vacuums and wet mopping to remove dust from the floor and work surfaces. Measurements made during the follow-up survey in December 2007 indicated significant reductions in the levels of airborne contaminants during this modified operation although respiratory protection during the filter change operation continues to be necessary and other improvements are needed. These improvements are described in detail later in this report.

Recommendations resulting from this study include:

- The respiratory protection program for this facility should be evaluated for this operation in order to ensure that it complies with OSHA regulations.
- Attention should be focused on practices to prevent accidental ingestion of lead.
- Management should evaluate the feasibility of providing and laundering work clothing for all workers in the recycling facility.
- Change rooms should be equipped with separate storage facilities for work clothing and for street clothes to prevent cross-contamination.
- A hearing conservation program must be implemented for workers in the glass breaking operation.
- All Unicor operations should be evaluated from the perspective of health, safety and the environment in the near future.
- A comprehensive program is needed within the Bureau to assure both staff and inmates a safe and healthy workplace.

I. INTRODUCTION

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted a study of exposures to metals and other occupational hazards associated with the recycling of electronic components at the Federal Prison Industries (aka, Unicolor) in Elkton, Ohio.* The principal objectives of this study were:

1. To measure full-shift, personal breathing zone exposures to metals including barium, beryllium, cadmium, lead and nickel;
2. To evaluate contamination of surfaces in the work areas that could permit skin contact or allow re-suspension of metals into the air;
3. To identify and describe the control technology and work practices in use in operations associated with occupational exposures to metals, as well as to determine additional controls, work practices, substitute materials, or technology that can further reduce occupational exposures;
4. To evaluate the use of personal protective equipment in operations involved in the recycling of electronic components; and,
5. To determine the size distribution of airborne particles for purposes of toxicity and control.

Other objectives such as a preliminary evaluation of noise exposures and visual observations of undocumented hazards, were secondary to those listed above but are discussed as appropriate in this document.

An initial walk-through evaluation was conducted on November 29, 2006, to observe processes and conditions in order to prepare for subsequent testing. An in-depth evaluation was conducted from February 26 to March 2, 2007, during which two full shifts of environmental monitoring were conducted for the duration of normal plant operations. An additional two days of monitoring were conducted during cleaning and maintenance as described later in Section II (Process Description) and Section III (Sampling and Analytical Methods). A follow-up survey was conducted December 11 – 13, 2007, to evaluate changes made in the cleaning and maintenance activities as a result of the recommendations contained in Section VI (Conclusions and Recommendations).

Computers and their components contain a number of hazardous substances. Among these are “platinum in circuit boards, copper in transformers, nickel and cobalt in disk drives, barium and cadmium coatings on computer glass, and lead solder on circuit boards and video screens” [Chepesiuk 1999]. The Environmental Protection Agency (EPA) notes that “In addition to lead, electronics can contain chromium, cadmium, mercury, beryllium, nickel, zinc, and brominated flame retardants” [EPA 2008]. Schmidt [2002] linked these and other substances

* This report documents the study conducted at Elkton, Ohio. Other NIOSH field studies were conducted at Federal correctional facilities in Lewisburg, Pennsylvania and Marianna, Florida

to their use and location in the “typical” computer: lead used to join metals (solder) and for radiation protection, is present in the cathode ray tube (CRT) and printed wiring board (PWB). Aluminum, used in structural components and for its conductivity, is present in the housing, CRT, PWB, and connectors. Gallium is used in semiconductors; it is present in the PWB. Nickel is used in structural components and for its magnetivity; it is found in steel housing, CRT and PWB. Vanadium functions as a red-phosphor emitter; it is used in the CRT. Beryllium, used for its thermal conductivity, is found in the PWB and in connectors. Chromium, which has decorative and hardening properties, may be a component of steel used in the housing. Cadmium, used in Ni-Cad batteries and as a blue-green phosphor emitter, may be found in the housing, PWB and CRT. Cui and Forssberg [2003] note that cadmium is present in components like SMD chip resistors, semiconductors, and infrared detectors. Mercury may be present in batteries and switches, thermostats, sensors and relays [Schmidt 2002, Cui and Forssberg 2003], found in the housing and PWB. Arsenic, which is used in doping agents in transistors, may be found in the PWB [Schmidt 2002].

Lee et al. [2004] divided the personal computer into three components, the main machine, monitor, and keyboard. They further divided the CRT of a color monitor into the “(1) panel glass (faceplate), (2) shadow mask (aperture), (3) electronic gun (mount), (4) funnel glass and (5) deflection yoke. Lee et al. [2004] note that panel glass has a high barium concentration (up to 13%) for radiation protection and a low concentration of lead oxide. The funnel glass has a higher amount of lead oxide (up to 20%) and a lower barium concentration. They analyzed a 14-in Philips color monitor by electron dispersive spectroscopy and reported that the panel contained silicon, oxygen, potassium, barium and aluminum in concentrations greater than 5% by weight, and titanium, sodium, cerium, lead, zinc, yttrium, and sulfur in amounts less than 5% by weight. Analysis of the funnel glass revealed greater than 5% silicon, oxygen, iron and lead by weight, and less than 5% by weight potassium, sodium, barium, cerium, and carbon. Finally, Lee et al. [2004] noted that the four coating layers are applied to the inside of the panel glass, including a layer of three fluorescent colors (red, blue and green phosphors) that contain various metals, and a layer of aluminum film to enhance brightness.

German investigators [BIA 2001, Berges 2008a] broke 72 cathode-ray tubes using three techniques (pinching off the pump port, pitching the anode with a sharp item, and knocking off the cathode) in three experiments performed on a test bench designed to measure emissions from the process. Neither lead nor cadmium was detected in the total dust, with one exception, where lead was detected at a concentration of 0.05 mg/cathode ray tube during one experiment wherein the researchers released the vacuum out of 23 TVs by pinching off the pump port [BIA 2001, Berges 2008b]. They described this result as “sufficiently low that a violation of the German atmospheric limit value of 0.1 mg/m³ need not generally be anticipated” [BIA 2001]. The researchers noted that “the working conditions must be organized such that skin contact with and oral intake of the dust are excluded” [BIA 2001].

However, there are few articles documenting occupational exposures among electronics recycling workers. Sjödin et al. [2001] and Pettersson-Julander et al. [2004] have reported potential exposures of electronics recycling workers to flame retardants while they dismantled electronic products, although no retardants were used in this facility. Recycling operations in the Elkton facility are limited to disassembly and sorting tasks, with the exception of breaking

CRTs and stripping insulation from copper wiring. Disassembly and sorting probably poses less of a potential hazard to workers than tasks that disrupt the integrity of the components, such as shredding or desoldering PWBs.

The process of greatest concern was the glass breaking operation (described below) that releases visible emissions into the workroom atmosphere. Material safety data sheets and other information on components of CRTs broken in this operation listed several metals, including Pb, Cd, Be and Ni. In addition, FOH investigators expressed a particular interest in Ba.

II. PROCESS DESCRIPTION

The recycling of electronic components at the Elkton Federal Correctional Institution (FCI) is done in three separate buildings: 1) the main factory located within the FCI main compound; 2) the Federal Satellite Low (FSL); and 3) the warehouse. Diagrams of these work areas are shown in Figures I, II and III, respectively, with an enlargement of the glass breaking operation in Figure IV. These figures provide a general visual description of the layout of the work process, although workers often moved throughout the various areas in the performance of their tasks. Photographs from these areas are also included and identified below.

The electronics recycling operations can be organized into four production processes: a) receiving and sorting, b) disassembly, c) glass breaking operations, and d) packaging and shipping. A fifth operation; cleaning and maintenance, will also be addressed but is not considered a production process per se.

Incoming materials to be recycled are received at the warehouse (see Figure III) where they are examined and sorted. During this evaluation it appeared that the bulk of the materials received were computers, either desktop or notebooks, or related devices such as printers. Some items, notably notebook computers, could be upgraded and resold, and these items were sorted out for that task.

After electronic memory devices (e.g., hard drives, discs, etc.) were removed and degaussed or shredded, computer central processing units (CPUs), servers and similar devices were sent for disassembly; monitors and other devices (e.g., televisions) that contain CRTs were separated and sent for disassembly and removal of the CRT. Printers, copy machines and any device that could potentially contain toner, ink, or other expendables were segregated and inks and toners were removed prior to being sent to the disassembly area.

In the disassembly process (see Figures I and II), external cabinets, usually plastic, were removed from all devices and segregated. Valuable materials such as copper wiring and aluminum framing were removed and sorted by grade for further treatment if necessary. Components such as circuit boards or chips that may have value or may contain precious metals such as gold or silver were removed and sorted. With few exceptions each of the approximately 85 workers in the main factory will perform all tasks associated with the disassembly of a piece of equipment into the mentioned components with the use of powered and un-powered hand tools (primarily screwdrivers and wrenches), with a few workers collecting the various parts and placing them into the proper collection bin. Work tasks

including removing screws and other fasteners from cabinets, unplugging or clipping electrical cables, removing circuit boards, and using whatever other methods necessary to break these devices into their component parts. Essentially all components currently are sold for some type of recycling.

The third production process to be evaluated was the glass breaking operation where CRTs from computer monitors and TVs were sent for processing. This was an area of primary interest in this evaluation due to concern from staff, review of process operations and materials involved, and observations during an initial walk-through. This was the only process where local exhaust ventilation was utilized or where respiratory protection was in universal use. Workers in other locations would wear eye protection and occasionally would voluntarily wear a disposable respirator. The local exhaust ventilation system consisted of a large walk-in hood, approximately 8 ft high and 16 ft wide and 6 ft deep, with 2 or 3 workers positioned toward the front. Air was pulled from behind the workers, past the work area where contaminant was released, and through a filtration system. The filtration system consisted of a blanket filter, a bank of pocket filters, and a high efficiency particulate air (HEPA) filter to remove progressively smaller particles from the air before exhausting into a storage area behind the hood.

Workers in the glass breaking operation wore powered air-purifying respirators (PAPRs), (MB14-72 PAPR w/ Super Top Hood, Woodsboro, MD, Global Secure Safety). Respirators, work boots, gloves and coveralls were donned and doffed in the changing area of the glass breaking room (see Figure IV) where street shoes were stored during the work day and the PPE was stored during off time. CRTs that had been removed from their cases were brought to this process area where they were placed on a metal grid for breaking. First the electron gun was removed by tapping with a hammer to break it free from the tube. Then a series of hammer blows was used to break the funnel glass and allow it to fall through the metal grid into large Gaylord boxes (cardboard boxes approximately 3 feet tall designed to fit on a standard pallet) positioned below the grid. Finally, any internal metal framing or lattice was removed before the panel glass was broken with a hammer and also allowed to fall into a Gaylord box. During the days of sampling the glass breaking operation was in “normal production” with regard to the number of CRTs broken. (Various sources stated that “normal” ranged from 250 to almost 800.) The count was not recorded for the March study, but during the December visit 442 and 265 monitors were broken on the two days of sampling. No count was made by the survey team regarding the number of color vs monochrome monitors broken.

The final production process, packing and shipping, returned the various materials segregated during the disassembly and glass breaking processes to the warehouse to be sent to contracted purchasers of those individual materials. To facilitate shipment some bulky components such as plastic cabinets or metal frames were placed in a hydraulic bailer to be compacted for easier shipping. Other materials were boxed or containerized and removed for subsequent sale to a recycling operation.

In addition to monitoring routine daily activities in the four production processes described above, environmental monitoring was conducted to evaluate exposures during a weekly cleaning operation in the glass breaking operation and during the replacement of filters in the

local exhaust ventilation system used for the glass breaking operation. The weekly cleaning involves all six workers in this area to perform routine cleaning operations such as sweeping and vacuuming. This task, done only in the glass breaking operation and taking approximately a half day, requires that all equipment in the area is either vacuumed with a HEPA vacuum or wiped with a wet mop. This same procedure is used for all walls, work surfaces (including the exposed surfaces of the blanket filter), and floors. Any areas where dust might accumulate are cleaned with one of these techniques. During the initial study dry sweeping was used to clean floors, but it was recommended that this practice be replaced with the vacuuming or mopping and during the second study that change was in place. Workers wore their normal work clothing during this procedure and the local exhaust ventilation system was in operation.

The filter change operation is normally performed by two workers (three were involved during the time of the second study because one was in training) who wear disposable Tyvek coveralls, gloves and PAPRs while they remove all three sets of filters, clean the system, and replace the filters. The filter change is a maintenance operation that occurs at approximately monthly intervals during which the ventilation system is shut down and all three sets of filters are removed and replaced (see Figure IV). Initially the blanket filter is vacuumed then removed. Then the pocket filters that are located behind the blanket filter are removed and the containment structure for both is vacuumed. Finally the HEPA filters, which are in a separate structure downstream from the fan, are removed and this area is vacuumed. During the initial sampling visit all filters were cleaned by vacuuming and/or by shaking to remove dust, and re-installed. The practice of replacing all filters as part of this operation was implemented prior to the second sampling visit and the entire process was wetted with a water spray prior to filter removal. This operation was of particular interest because of concern expressed by management and workers and anticipation of elevated exposures.

Subsequent to the initial monitoring of airborne particulate during the filter change operation, modifications were made to the procedure used for this process. The recommended changes included: 1) the immediate bagging and disposal of used filters rather than attempting to clean and re-use them; 2) the use of a water spray to suppress dust during the filter change operation; and 3) the use of HEPA vacuums and wet mopping to remove dust from the floor and work surfaces. The procedure was modified by the addition of a “spray down” step in which all filters were wetted with a water mist prior to removal, and the filters were then immediately bagged in plastic for disposal rather than being cleaned for re-use.

III. SAMPLING AND ANALYTICAL METHODS

Methods used to assess worker exposures in this workplace evaluation included: personal breathing zone and area sampling for airborne metals; particle size sampling; surface wipe sampling to assess surface contamination; and bulk material samples to determine the composition of settled dust. Material safety data sheets and background information on CRTs and other processes in this operation listed several metals, including Pb, Cd, Be and Ni. Additionally, Federal Occupational Health (FOH) personnel expressed specific interest in Ba.

Personal breathing zone and general area airborne particulate samples were collected and analyzed for metals and during the follow-up visit for airborne particulate. Samples were

collected for as much of the work shift as possible, at a flow rate of 3 liters/minute (L/min) using a calibrated battery-powered sampling pump (Model 224, SKC Inc., Eighty Four, PA) connected via flexible tubing to a 37-mm diameter filter (0.8 µm pore-size mixed cellulose ester filter) in a 3-piece, clear plastic cassette sealed with a cellulose shrink band. These samples were subsequently analyzed for metals using inductively coupled plasma spectroscopy (ICP) according to NIOSH Method 7300 [NIOSH 1994] with modifications. It is possible to determine both airborne particulate as well as metals on the same sample by using a pre-weighed filter (for both respirable and total particulate samples) and then post-weighing that filter to determine weight gain before digesting for metals analysis. This analytical technique produces a measure for dust and a measure of 31 elements, including the five of particular interest mentioned above, and that information is appended to this report. Because Method 7300 is an elemental analysis, the laboratory report describes the amount of the element present in each sample (µg/sample) as the element, regardless of the compound in which the element was present in the sample.

During the follow-up visit, sampling was conducted for respirable particulates. The respirable portion of a representative subset of samples was separated for collection using 37 mm aluminum cyclones (Cat. 225-01-02, SKC Inc., Eighty Four, PA) at a flow rate of 2.5 L/min, and analysis by weight, as specified in NIOSH method 0600 [NIOSH 1994]. This was done to determine the fraction of airborne contaminant in the respirable size range. Those samples were analyzed using NIOSH Method 7300 [NIOSH 1994] like those above.

Because there is evidence that the presence of an ultrafine component increases the toxicity for chronic beryllium disease and possibly other toxic effects, information on the aerosol size distribution was collected to assist in evaluation of the potential exposure [McCawley et al. 2001]. Personal breathing zone and general area aerosol size distributions were determined using four-stage Sioutas Cascade Impactors (SKC, Inc., Eighty Four, PA), having nominal 50% cut points of 0.25, 0.5, 1, and 2.5 µm aerodynamic diameter. The sampling flow rate for these impactors was 9 L/min, provided by a calibrated Leland Legacy™ sampling pump (SKC, Inc., Eighty Four, PA) [Misra et al. 2002]. A 25-mm diameter, 0.8 µm pore size PVC filter was used on each stage of the impactor to collect particles. A 37-mm diameter, 5 µm pore size PVC filter was used as a backup to collect all particles that were not impacted on the previous four stages. The impactor filters were analyzed by ICP in accordance with NIOSH Method 7300 modified for microwave digestion [NIOSH 1994]. During the follow-up study cyclones were used rather than impactors to provide a measure of respirable fraction for metals and total dust.

Bulk material samples were collected by gathering a few grams of settled dust or material of interest and transferring this to a glass collection bottle for storage and shipment. These samples were analyzed for metals using NIOSH Method 7300 [NIOSH 1994] modified for bulk digestion.

Surface wipe samples were collected using Ghost™ Wipes for metals (Environmental Express, Mt. Pleasant, SC) and Palintest® Dust Wipes for Be (Gateshead, United Kingdom) to evaluate surface contamination. These wipe samples were collected in accordance with ASTM Method D 6966-03 [ASTM 2002], with a disposable paper template with a 10-cm by 10-cm square

opening. The templates were held in place by hand or taped in place, to prevent movement during sampling. Wipes were placed in sealable test tube containers for storage until analysis. Ghost Wipes™ were sent to the laboratory to be analyzed for metals according to NIOSH Method 7303 [NIOSH 1994]. Palintest wipes were analyzed for beryllium using the Quantech Fluorometer (Model FM109515, Barnstead International, Dubuque, Iowa) for spectrofluorometric analysis by NIOSH Method 9110 [NIOSH 1994].

An initial assessment of noise levels during various tasks in all operations was made during the first in-depth study using a hand held sound level meter. This brief sound-level survey was used to determine where to target noise dosimetry during the follow-up study. During the follow-up study time weighted average noise exposures were determined using personal dosimeters (Quest Technologies model Q300, Oconomowoc, WI) capable of simultaneously logging sound pressure levels under three sets of parameters. For this evaluation data are reported using both the OSHA and NIOSH parameters as follows:

	<u>OSHA</u>	<u>NIOSH</u>
Criteria (dB)	90	85
Exchange rate	5	3
Threshold	80	0
Weight	A	A
Time constant	Slow	Slow

All dosimeters and sound level meters were calibrated on-site prior to use with a 110 dB source and data were downloaded to a laptop computer.

Observations regarding work practices and use of personal protective equipment were recorded. Information was obtained from conversations with the workers and management to determine if the sampling day was a typical workday to help place the sampling results in proper perspective.

A qualitative evaluation of the glass-breaking booth ventilation system was performed during the initial site visit. A smoke machine and smoke tubes were used to study the air flow patterns in the glass break area. The area was separated into four areas (A, B, C and D; see Figure IV) by transparent vinyl curtains hanging from ceiling to floor, and slit vertically at about 6 inch intervals to permit personnel and apparatus to pass through. The ventilation system was intended to capture any emissions of respirable dust, as well as larger airborne debris, generated during the CRT breaking process. No workers were present in the glass breaking operation at the time of this smoke study. Smoke was released in all four areas in order to visually observe air flow patterns.

IV. OCCUPATIONAL EXPOSURE LIMITS AND HEALTH EFFECTS

In evaluating the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended occupational exposure limits (OELs) for specific chemical, physical, and biological agents. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing

adverse health effects[†]. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, thus contributing to the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday[‡]. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values where there are health effects from higher exposures over the short-term. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time, even instantaneously.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. Some OELs are mandatory, legal limits; others are recommendations. The U.S. Department of Labor Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) [29 CFR 1910 (general industry); 29 CFR 1926 (construction industry); and 29 CFR 1915, 1917 and 1918 (maritime industry)] are legal limits that are enforceable in workplaces covered under the Occupational Safety and Health Act and in Federal workplaces under Executive Order 12196 [NARA 2008]. NIOSH Recommended Exposure Limits (RELs) are recommendations that are made based on a critical review of the scientific and technical information available on the prevalence of hazards, health effects data, and the adequacy of methods to identify and control the hazards. Recommendations made through 1992 are available in a single compendium [NIOSH 1992]; more recent recommendations are available on the NIOSH Web site (<http://www.cdc.gov/niosh>). NIOSH also recommends preventive measures (e.g., engineering controls, safe work practices, personal protective equipment, and environmental and medical monitoring) for reducing or eliminating the adverse health effects of these hazards. The NIOSH Recommendations have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs)[®] recommended by the American Conference of

[†] On March 20, 1991, the Supreme Court decided the case of International Union, United Automobile, Aerospace & Agricultural Implement Workers of America, UAW v. Johnson Controls, Inc., 111 S. Ct. 1196, 55 EPD 40,605. It held that Title VII forbids sex-specific fetal protection policies. Both men and women must be protected equally by the employer.

[‡] OSHA PELs, unless otherwise noted, are TWA concentrations that must not be exceeded during any 8-hour workshift of a 40-hour work-week [NIOSH 1997]. NIOSH RELs, unless otherwise noted, are TWA concentrations for up to a 10-hour workday during a 40-hour workweek [NIOSH 1997]. ACGIH[®] TLVs[®], unless otherwise noted, are TWA concentrations for a conventional 8-hour workday and 40-hour workweek [ACGIH 2008]

Governmental Industrial Hygienists (ACGIH)[®], a professional organization [ACGIH 2008]. ACGIH[®] TLVs[®] are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels (WEELs) are recommended OELs developed by AIHA, another professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA 2007].

Employers should understand that not all hazardous chemicals have specific OSHA PELs and for many agents, the legal and recommended limits mentioned above may not reflect the most current health-based information. However, an employer is still required by OSHA to protect their employees from hazards even in the absence of a specific OSHA PEL. In particular, OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Both the OSHA PELs and ACGIH[®] TLVs[®] address the issue of combined effects of airborne exposures to multiple substances [29 CFR 1910.1000(d)(1)(i), ACGIH 2008]. ACGIH[®] [2008] states:

When two or more hazardous substances have a similar toxicological effect on the same target organ or system, their combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, different substances should be considered as additive where the health effect and target organ or system is the same. That is, if the sum of

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n} \quad \text{Eqn. 1}$$

exceeds unity, the threshold limit of the mixture should be considered as being exceeded (where C_1 indicates the observed atmospheric concentration and T_1 is the corresponding threshold limit...).

A. Exposure Criteria for Occupational Exposure to Airborne Chemical Substances

The OELs for the five primary contaminants of interest, in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), are summarized and additional information related to those exposure limits is presented below.

Occupational Exposure Limits for Five Metals of Primary Interest ($\mu\text{g}/\text{m}^3$)

	Barium (Ba)	Beryllium (Be)	Cadmium (Cd)	Lead (Pb)	Nickel (Ni)
REL	500 TWA	0.5 TWA	Lowest Feasible Concentration	50 TWA	15 TWA
PEL	500 TWA	2 TWA 5 (30 minute ceiling) 25 (peak exposure never to be exceeded)	5 TWA	50 TWA	1000 TWA
TLV	500 TWA	2 TWA 10 (STEL)	10 (total) TWA 2 (respirable) TWA	50 TWA	1500 TWA (elemental) 100 TWA (soluble inorganic compounds) 200 TWA (insoluble inorganic compounds)

While this subset of five metals has been selected for consideration through the body of this report because their presence was noted on MSDSs or other information pertaining to CRTs and other processes at this facility (beryllium, cadmium, lead and nickel) or due to the interest expressed in barium exposures by FOH personnel, the occupational exposure limits of all 31 metals quantified in this work are listed in Appendix A. Note that these limits refer to the contaminant as the element (e.g., the TLVs[®], beryllium and compounds, as Be; cadmium and compounds, as Cd [ACGIH 2008]). Additionally, the OELs for dust and yttrium are presented here since these substances were found at high levels.

Occupational Exposure Criteria for Barium (Ba)

The current OSHA PEL, NIOSH REL, and ACGIH[®] TLV[®] is $0.5 \text{ mg}/\text{m}^3$ as a TWA for airborne barium exposures (barium and soluble compounds, except barium sulfate, as barium) [29 CFR 1910.1000, NIOSH 2005, ACGIH 2008]. There is no AIHA WEEL for barium [AIHA 2007]. Skin contact with barium, and many of its compounds, may cause local irritation to the eyes, nose, throat and skin, and may cause dryness and cracking of the skin and skin burns after prolonged contact [Nordberg 1998].

Occupational Exposure Criteria for Beryllium (Be)

The OSHA general industry standard sets a beryllium PEL of $2 \mu\text{g}/\text{m}^3$ for an 8-hour TWA, a ceiling concentration of $5 \mu\text{g}/\text{m}^3$, not to exceed 30 minutes and a maximum peak concentration of $25 \mu\text{g}/\text{m}^3$, not to be exceeded for any period of time [29 CFR 1910.1000]. The NIOSH REL for beryllium is $0.5 \mu\text{g}/\text{m}^3$ for up to a 10-hour work day, during a 40-hour workweek [NIOSH 2005]. The current TLV[®] is an 8-hr TWA of $2 \mu\text{g}/\text{m}^3$, and a STEL of $10 \mu\text{g}/\text{m}^3$ [ACGIH 2008]. The ACGIH[®] published a notice of intended changes for the beryllium TLV[®] to $0.05 \mu\text{g}/\text{m}^3$ TWA and $0.2 \mu\text{g}/\text{m}^3$ STEL based upon studies investigating both chronic beryllium

disease and beryllium sensitization [ACGIH 2008]. There is no AIHA WEEL for beryllium [AIHA 2007]. Beryllium has been designated a known human carcinogen by the International Agency for Research on Cancer [IARC 1993].

Occupational Exposure Criteria for Cadmium (Cd)

The OSHA PEL for cadmium is $5 \mu\text{g}/\text{m}^3$ as a TWA [29 CFR 1910.1027]. Exposure at or above half that value, the Action Level of $2.5 \mu\text{g}/\text{m}^3$ TWA, requires several actions of the employer. These include providing respiratory protection if requested [29 CFR 1910.1027(g)(1)(v)], medical surveillance if currently exposed more than 30 days per year [1910.1027(l)(1)(i)(A)], and medical surveillance if previously exposed unless potential aggregated cadmium exposure did not exceed 60 months [1910.1027(l)(1)(i)(b)]. Initial examinations include a medical questionnaire and biological monitoring of cadmium in blood (CdB), cadmium in urine (CdU), and Beta-2-microglobulin in urine (β 2-M) [29 CFR 1910.1027 Appendix A]. An employee whose biological testing results during both the initial and follow-up medical examination are elevated above the following trigger levels must be medically removed from exposure to cadmium at or above the action level: (1) CdU level: above $7 \mu\text{g}/\text{g}$ creatinine, or (2) CdB level: above $10 \mu\text{g}/\text{liter}$ of whole blood, or (3) β 2-M level: above $750 \mu\text{g}/\text{g}$ creatinine and (a) CdU exceeds $3 \mu\text{g}/\text{g}$ creatinine or (b) CdB exceeds $5 \mu\text{g}/\text{liter}$ of whole blood [OSHA 2004].

The ACGIH[®] TLV[®] for cadmium and compounds as cadmium is $10 \mu\text{g}/\text{m}^3$ as a TWA, and $2 \mu\text{g}/\text{m}^3$ TWA for the respirable fraction of airborne cadmium and compounds, as cadmium [ACGIH 2008]. The ACGIH[®] also published a Biological Exposure Index[®] that recommends that cadmium blood level be controlled at or below $5 \mu\text{g}/\text{L}$ and urine level to be below $5 \mu\text{g}/\text{g}$ creatinine [ACGIH 2008]. There is no AIHA WEEL for cadmium [AIHA 2007].

In 1976, NIOSH recommended that exposures to cadmium in any form should not exceed a concentration greater than $40 \mu\text{g}/\text{m}^3$ as a 10-hour TWA or a concentration greater than $200 \mu\text{g}/\text{m}^3$ for any 15-minute period, in order to protect workers against kidney damage and lung disease. In 1984, NIOSH issued a Current Intelligence Bulletin, which recommended that cadmium and its compounds be regarded as potential occupational carcinogens based upon evidence of lung cancer among a cohort of workers exposed in a smelter [NIOSH 1984]. NIOSH recommends that exposures be reduced to the lowest feasible concentration [NIOSH 2005]. This NIOSH REL was developed using a previous NIOSH policy for carcinogens (29 CFR 190.103). The current NIOSH policy for carcinogens was adopted in September 1995. Under the previous policy, NIOSH usually recommended that exposures to carcinogens be limited to the “lowest feasible concentration,” which was a nonquantitative value. Under the previous policy, most quantitative RELs for carcinogens were set at the limit of detection (LOD) achievable when the REL was originally established. From a practical standpoint, NIOSH testimony provided in 1990 on OSHA’s proposed rule on occupational exposure to cadmium noted that, “NIOSH research suggests that the use of innovative engineering and work practice controls in new facilities or operations can effectively contain cadmium to a level of $1 \mu\text{g}/\text{m}^3$. Also, most existing facilities or operations can be retrofitted to contain cadmium to a level of $5 \mu\text{g}/\text{m}^3$ through engineering and work practice controls” [NIOSH 1990].

Early symptoms of cadmium exposure may include mild irritation of the upper respiratory tract, a sensation of constriction of the throat, a metallic taste and/or cough. Short-term exposure effects of cadmium inhalation include cough, chest pain, sweating, chills, shortness of breath, and weakness. Short-term exposure effects of ingestion may include nausea, vomiting, diarrhea, and abdominal cramps [NIOSH 1989]. Long-term exposure effects of cadmium may include loss of the sense of smell, ulceration of the nose, emphysema, kidney damage, mild anemia, an increased risk of cancer of the lung, and possibly of the prostate [NIOSH 1989, Thun et al. 1991, Goyer 1991].

Occupational Exposure Criteria for Lead (Pb)

The OSHA PEL for lead is $50 \mu\text{g}/\text{m}^3$ (8-hour TWA), which is intended to maintain worker blood lead level (BLL) below $40 \mu\text{g}/\text{deciliter (dL)}$. Medical removal is required when an employee's BLL reaches $50 \mu\text{g}/\text{dL}$ [29 CFR 1910.1025]. The NIOSH REL for lead (8-hour TWA) is $0.050 \text{ mg}/\text{m}^3$; air concentrations should be maintained so that worker blood lead remains less than $0.060 \text{ mg Pb}/100 \text{ g}$ of whole blood [NIOSH 2005]. At BLLs below $40 \mu\text{g}/\text{dL}$, many of the health effects would not necessarily be evident by routine physical examinations but represent early stages in the development of disease. In recognition of this, voluntary standards and public health goals have established lower exposure limits to protect workers and their children. The ACGIH[®] TLV[®] for lead in air is $50 \mu\text{g}/\text{m}^3$ as an 8-hour TWA, with worker BLLs to be controlled to $\leq 30 \mu\text{g}/\text{dL}$. A national health goal is to eliminate all occupational exposures that result in BLLs $>25 \mu\text{g}/\text{dL}$ [DHHS 2000]. There is no AIHA WEEL for lead [AIHA 2007].

Occupational exposure to lead occurs via inhalation of lead-containing dust and fume and ingestion from contact with lead-contaminated surfaces. Symptoms of lead poisoning include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort (colic), fine tremors, and "wrist drop" [Saryan and Zenz 1994, Landrigan et al. 1985, Proctor et al. 1991a]. Overexposure to lead may also result in damage to the kidneys, anemia, high blood pressure, impotence, and infertility and reduced sex drive in both genders. In most cases, an individual's BLL is a good indication of recent exposure to and current absorption of lead [NIOSH 1978].

Occupational Exposure Criteria for Nickel (Ni)

The NIOSH REL for nickel metal and other compounds (as nickel) is $15 \mu\text{g}/\text{m}^3$ based on its designation as a potential occupational carcinogen [NIOSH 2005]. The ACGIH[®] TLV[®] for insoluble inorganic compounds of nickel is $200 \mu\text{g}/\text{m}^3$ (inhalable fraction). For soluble inorganic nickel compounds the TLV[®] is $100 \mu\text{g}/\text{m}^3$ (inhalable fraction). The TLV[®] for elemental nickel is $1,500 \mu\text{g}/\text{m}^3$ (inhalable fraction) [ACGIH 2008]. The OSHA PEL for nickel is $1,000 \mu\text{g}/\text{m}^3$ TWA [29 CFR 1910.1000]. Metallic nickel compounds cause allergic contact dermatitis [Proctor et al. 1991b]. NIOSH considers nickel a potential occupational carcinogen [NIOSH 2005]. There is no AIHA WEEL for nickel [AIHA 2007].

Occupational Exposure Criteria for Dust

The maximum allowable exposure to airborne particulate not otherwise regulated is established by OSHA at 15 mg/m³ for total and 5 mg/m³ for the respirable portion [29 CFR 1910.1000]. A more stringent recommendation of 10 mg/m³ inhalable and 3 mg/m³ respirable is presented by the ACGIH[®] which feels that “even biologically inert insoluble or poorly soluble particulate may have adverse health effects” [ACGIH 2008]. There is no AIHA WEEL for these substances [AIHA 2007].

Occupational Exposure Criteria for Yttrium (Y)

The NIOSH REL, OSHA PEL, and ACGIH[®] TLV[®] for yttrium and its compounds, as Y, are all 1,000 µg/m³ [NIOSH 2005, 29 CFR 1910.1000, ACGIH 2008]. Yttrium is used in color television phosphors when combined with rare earth elements [Proctor et al. 1991c]. Exposure occurs through inhalation [Proctor et al. 1991c]. While yttrium compounds irritate the lungs of animals, no effects have been noted among humans [Proctor et al. 1991c]. The ACGIH[®] TLV[®] is based upon value is intended to minimize the potential for respiratory fibrosis, reported in rats following intratracheal administration of a single, very large dose” [ACGIH 2001]. A study of occupational exposures to yttrium europium vanadate phosphor found no effects from exposure to the yttrium at a mean yttrium concentration of 1.4 mg/m³ [Tebrock and Machle 1968].

B. Surface Contamination Criteria

Occupational exposure criteria have been discussed above for airborne concentrations of several metals. Surface wipe samples can provide useful information in two circumstances; first, when settled dust on a surface can contaminate the hands and then be ingested when transferred from hand to mouth; and second, if the surface contaminant can be absorbed through the skin and the skin is in frequent contact with the surface [Caplan 1993]. Although some OSHA standards contain housekeeping provisions which address the issue of surface contamination by mandating that surfaces be maintained as free as practicable of accumulations of the regulated substances, there are currently no surface contamination criteria included in OSHA standards [OSHA 2008]. The health hazard from these regulated substances results principally from their inhalation and to a smaller extent from their ingestion; those substances are by and large “negligibly” absorbed through the skin [Caplan 1993]. NIOSH RELs do not address surface contamination either, nor do ACGIH TLVs or AIHA WEELs. Caplan [1993] stated that “There is no general quantitative relationship between surface contamination and air concentrations...” He also noted that, “Wipe samples can serve a purpose in determining if surfaces are as ‘clean as practicable’. Ordinary cleanliness would represent totally insignificant inhalation dose; criteria should be based on surface contamination remaining after ordinarily thorough cleaning appropriate for the contaminant and the surface.” With those caveats in mind, the following paragraphs present guidelines that help to place the results of the surface sampling conducted at this facility in perspective.

Surface Contamination Criteria for Five Metals of Primary Interest

Surface Contamination Criteria for Lead

Federal standards have not been adopted that identify an exposure limit for lead contamination of surfaces in the industrial workplace. However, in a letter dated January 13, 2003 [Fairfax 2003], OSHA's Directorate of Compliance Programs indicated that the requirements of OSHA's standard for lead in the construction workplace [29 CFR 1926.62(h)(1), 1926.62(i)(2)(i) and 1926(i)(4)(ii)] interpreted the level of lead-contaminated dust allowable on workplace surfaces as follows: a) All surfaces shall be maintained as 'free as practicable' of accumulations of lead, b) The employer shall provide clean change areas for employees whose airborne exposure to lead is above the permissible exposure limit, c) The employer shall assure that lunchroom facilities or eating areas are as free as practicable from lead contamination, d) The OSHA Compliance Directive for the Interim Standard for Lead in Construction, CPL 2-2.58 recommends the use of HUD's acceptable decontamination level of $200 \mu\text{g}/\text{ft}^2$ for floors in evaluating the cleanliness of change areas, storage facilities, and lunchrooms/eating areas, e) In situations where employees are in direct contact with lead-contaminated surfaces, such as, working surfaces or floors in change rooms, storage facilities, lunchroom and eating facilities, OSHA has stated that the Agency would not expect surfaces to be any cleaner than the $200 \mu\text{g}/\text{ft}^2$ level, and f) For other surfaces, OSHA has indicated that no specific level can be set to define how "clean is clean" nor what level of lead contamination meets the definition of "practicable." OSHA notes that "the term 'practicable' was used in the standard, as each workplace will have to address different challenges to ensure that lead-surface contamination is kept to a minimum. It is OSHA's view that a housekeeping program which is as rigorous as 'practicable' is necessary in many jobs to keep airborne lead levels below permissible exposure conditions at a particular site" [Fairfax 2003]. Specifically addressing contaminated surfaces on rafters, OSHA has indicated that they must be cleaned (or alternative methods used such as sealing the lead in place), as necessary to mitigate lead exposures. OSHA has indicated that the intent of this provision is to ensure that employers regularly clean and conduct housekeeping activities to prevent avoidable lead exposure, such as would potentially be caused by re-entrained lead dust. Overall, the intent of the "as-free-as-practicable" requirement is to ensure that accumulation of lead dust does not become a source of employee lead exposures. OSHA has stated that any method that achieves this end is acceptable.

In the United States, standards for final clearance following lead abatement were established for public housing and facilities related to children. However, no criteria have been recommended for other types of buildings, such as commercial facilities. One author has suggested criteria based upon lead-loading values. Lange [2001] proposed a clearance level of $1000 \mu\text{g}/\text{ft}^2$ for floors of non-lead free buildings and $1100 \mu\text{g}/\text{ft}^2$ for lead-free buildings, and states that "no increase in BLL should occur for adults associated or exposed within a commercial structure" at the latter level. These proposed clearance levels are based on calculations that make a number of intentionally conservative assumptions such as: a) Lead uptake following ingestion is 35% absorption of lead in the gastrointestinal system, b) Fingers have a total "touch" area of 10 cm^2 and 100% of the entire presumed lead content on all 10 fingers is taken up, c) The average 'normal' environmental lead dose (from 'uncontaminated food/water/air) is $20 \mu\text{g}$ per day, d) The weight of the exposed person is 70 kg, and e) Daily

lead excretion is limited to an average of 48 µg. Lange [2001] notes that “use of the proposed values would provide a standard for non-child-related premises (e.g. commercial, industrial, office)...” but cautions that, “Further investigation is warranted to evaluate exposure and subsequent dose to adults from surface lead.”

Surface Contamination Criteria for Beryllium

A useful guideline is provided by the U.S. Department of Energy, where DOE and its contractors are required to conduct routine surface sampling to determine housekeeping conditions wherever beryllium is present in operational areas of DOE/NNSA facilities. Those facilities must maintain removable surface contamination levels that do not exceed 3 µg/100 cm² during non-operational periods. The DOE also has release criteria that must be met before beryllium-contaminated equipment or other items can be released to the general public or released for use in a non-beryllium area of a DOE facility. These criteria state that the removable contamination level of equipment or item surfaces does not exceed the higher of 0.2 µg/100 cm² or the level of beryllium in the soil in the area of release. Removable contamination is defined as “beryllium contamination that can be removed from surfaces by nondestructive means, such as casual contact, wiping, brushing, or washing.”

Surface Contamination Criteria for Cadmium

Like lead and beryllium, cadmium poses serious health risks from exposure. Cadmium is a known carcinogen, is very toxic to the kidneys, and can also cause depression. However, OSHA, NIOSH, AIHA and ACGIH[®] have not recommended criteria for use in evaluating wipe samples. The OSHA Cadmium standard [29 CFR 1910.1027] mandates that “All surfaces shall be maintained as free as practicable of accumulations of cadmium,” that, “all spills and sudden releases of material containing cadmium shall be cleaned up as soon as possible,” and that, “surfaces contaminated with cadmium shall, wherever possible, be cleaned by vacuuming or other methods that minimize the likelihood of cadmium becoming airborne.”

Surface Contamination Criteria for Nickel

NIOSH, OSHA, AIHA and ACGIH[®] have not established occupational exposure limits for nickel on surfaces.

Surface Contamination Criteria for Barium

NIOSH, OSHA, AIHA and ACGIH[®] have not established occupational exposure limits for barium on surfaces.

C. Noise Exposure Criteria

The OSHA standard for occupational exposure to noise [29 CFR 1910.95] specifies a maximum PEL of 90 dB(A) for a duration of 8 hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dB(A) for no more than 4 hours, to 100 dB(A) for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dB(A) is allowed by this exchange rate. NIOSH, in its Criteria for a Recommended Standard, proposed an REL of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard [NIOSH 1972]. The NIOSH 1972 criteria document also used a 5 dB time/intensity trading relationship in calculating exposure limits. However,

the 1998 revised criteria recommends a 3 dB exchange rate, noting that it is more firmly supported by scientific evidence [NIOSH 1998]. The ACGIH[®] also changed its TLV[®] in 1994 to a more protective 85 dB(A) for an 8-hour exposure, with the stipulation that a 3 dB exchange rate be used to calculate time-varying noise exposures. Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to no more than 88 dB(A) for 4 hours or 91 dB(A) for 2 hours.

In 1983, a hearing conservation amendment to the OSHA noise standard took effect [29 CFR 1910.95(c)] that requires employers to “administer a continuing, effective hearing conservation program” whenever employee noise exposures equal or exceed an 8-hour TWA of 85 dBA or, equivalently, a dose of fifty percent. The requirements include noise monitoring, audiometric testing, providing hearing protectors, training workers, and recordkeeping.

V. RESULTS AND DISCUSSION

The initial work described here was conducted in early 2007 at the Elkton FCI, Unicor Recycling Factory, Federal Satellite Low (FSL) and Warehouse electronic components recycling operations. Follow-up testing was done at the FCI Unicor Recycling Factory only in December 2007, to evaluate the effectiveness of improvements made in response to that initial work. During this testing, air, surface wipe, bulk dust and noise samples were collected in locations where the various electronics recycling operations were taking place or had taken place in the past. The primary purposes of this evaluation were to estimate the potential exposures of inmates and/or staff to toxic substances generated during the recycling of electronic components; and to recommend remedial measures to reduce exposures if necessary.

A statistical summary of air sampling results is presented in Table 1 and results of personal breathing zone and area air sampling are shown in Tables 2 and 3, with the former being total and the latter being size-selective (impactor) data; surface wipe sample results are contained in Table 4; bulk material sample results are presented in Table 5; and noise measurements in Table 6. As mentioned in Section III above, all samples were analyzed for 31 metals due to the parameters of the analytical method. While the data in these tables present the results of just the five metals of primary interest in this evaluation; results of all analyses are contained in the appendices. These data indicate levels well below the occupational exposure limits of those other metals, even when results for combined exposures as calculated by Equation 1 are considered.

A. Bulk Material Sample Results

Three bulk material samples of dust from the floor of the glass breaking operation were collected in February 2007 during the filter change operation. These samples were analyzed for metals, and the composition of all three samples was similar. The results are presented in the Table 5 for the metals of primary interest. Beyond those 5 metals, the only metal present in these samples in significant concentration was zinc, which was approximately 1% of all three. The entire data set (all 31 metals) is presented in Appendix B.

B. Surface Wipe Sample Results

The surface wipe sample results collected during both sampling visits in the electronic recycling operations at the Elkton FCI are summarized below and in Table 4, and the entire surface wipe sample data set is contained in Appendix C. Results of spectrofluorometric analysis for Be confirmed ICP measurements. Wipe samples were also collected by FOH industrial hygienists, but from different locations and for different purposes, and those data are not included in this report.

Recycling Factory

Wipe samples collected during the February / March study indicated no beryllium (Be) detectable in the recycling factory; the limit of detection was 0.03 $\mu\text{g}/\text{sq ft}$. Most (10 of 14) of the surfaces tested for lead (Pb) indicated levels exceeding the OSHA recommended 200 $\mu\text{g}/\text{sq ft}$, with five above 1,000, and one above 10,000 $\mu\text{g}/\text{sq ft}$. The highest concentration of barium detected in a wipe sample was 150 $\mu\text{g}/\text{sq ft}$. Several of the Cd measurements were between 40 and 250 $\mu\text{g}/\text{sq ft}$. Nickel surface contamination was less than 250 $\mu\text{g}/\text{sq ft}$ in 10 of 11 samples. Housekeeping practices that reduce surface dust levels and engineering controls that reduce particulate release into the air should reduce these levels in the future.

Wipe sample data collected during the second visit did not appear to be different than that discussed above. The analytical limit of detection for Be was 0.1 $\mu\text{g}/\text{sq ft}$ which did produce detectable Be on most of the wipe samples during this study. (Analytical instrumentation had been adjusted to improve sensitivity for 24 elements at the cost of eliminating measurements for Al, Sb, Ca, Li, Mg, K and Ti.) Modifications in the procedures for changing filters in the GBO were not expected to produce lower surface contamination, and no reduction was seen.

FSL Building

Wipe samples collected in the FSL also did not indicate metals on work surfaces at levels of concern. No Be was detected here. All Pb samples were below the OSHA recommended level. Surface measurements of Cd and Ni were below levels of immediate concern. No samples were collected in the FSL during the December study.

Warehouse

Surface wipe samples were not collected in the warehouse as part of this work.

C. Air Sample Results

Air measurements were collected during both normal and non-routine operations in the areas identified, including the glass breaking operation. Data presented here and in Table 2 are for the duration of the samples rather than for an 8-hour time weighted average since the concentrations of contaminants are so low. Measurements made during non-routine operations showed significant exposures and are discussed below and presented at the bottom of Table 2. The full data set of all 31 metals is presented in Appendix D.

Recycling Factory

Twenty-five samples were collected in the Unicor recycling factory for airborne metals during the February study and an additional twenty in December, including measurements made in the

glass breaking operation during normal production operations. These data can be identified by date in Table 2, but the magnitudes of the exposures were not generally different by date. Measurements in the GBO during other operations are discussed below. Measurements during routine operations revealed that barium concentrations ranged between 0.1 and 4.3 $\mu\text{g}/\text{m}^3$ and were unremarkable. Beryllium levels also were very low, with one of 25 samples being above the LOD of 0.07 $\mu\text{g}/\text{m}^3$, and that sample was 0.08 $\mu\text{g}/\text{m}^3$. Cd and Ni, likewise, were found at low levels ranging up to 1 and 0.6 $\mu\text{g}/\text{m}^3$, respectively. Lead was the metal found in highest quantity, with concentrations ranging up to 18 $\mu\text{g}/\text{m}^3$, but only 5 samples were $>5 \mu\text{g}/\text{m}^3$ (10% of the occupational exposure limits).

FSL Building

Airborne metal concentrations in the FSL were generally lower than those in the factory. In the 12 samples collected in this location, Ba ranged up to 1 $\mu\text{g}/\text{m}^3$, all Be concentrations were below 0.07 $\mu\text{g}/\text{m}^3$, Cd ranged from 0.1 to 0.5 $\mu\text{g}/\text{m}^3$, and all Ni measurements were $<1 \mu\text{g}/\text{m}^3$. Even the lead samples were all below 1 $\mu\text{g}/\text{m}^3$ except one which the NIOSH investigator suspected was compromised based on visual observations and analytical results. No samples were collected in the FSL during the December study.

Warehouse

Six air samples were collected in the warehouse to measure airborne metal levels, and again, results were unremarkable. Ba ranged from 0.1 to 0.3 $\mu\text{g}/\text{m}^3$, all Be samples were below the LOD, Cd ranged from <0.1 to 0.4 $\mu\text{g}/\text{m}^3$, and all Pb and Ni measurements were at or below the LOD. No samples were collected in the warehouse during the December study.

Glass Breaking Operation- Filter Cleaning and Maintenance Operation

One non-routine operation evaluated was the weekly cleaning of the glass breaking operation. During the first in-depth study one of four samples collected during this procedure indicated an exposure to 23 $\mu\text{g}/\text{m}^3$ for Cd for a 79-minute sample. Assuming no additional exposure to Cd during the shift (based on visual observations of work tasks during that time) results in an 8-hour TWA exposure of 3.8 $\mu\text{g}/\text{m}^3$ which is above the Action Level of 2.5 $\mu\text{g}/\text{m}^3$, but below the PEL of 5 $\mu\text{g}/\text{m}^3$.

The filter change operation in the glass breaking operation, discussed in the Process Description (Section II), was the task of most concern regarding exposures of workers to toxic metals. Visual observations indicated, and measurements confirmed, very high levels of airborne dust and metals during this operation (see Figure VIII). Airborne concentrations of Cd and Pb in excess of their respective occupational criteria were documented; the amount of Cd detected exceeded the assigned protection factor of the powered air purifying respirators (PAPRs) being used by the workers (see further discussion below). Task-based airborne Ba concentrations ranged from 1 to 460 $\mu\text{g}/\text{m}^3$. No Be was measured (LOD = 0.02 $\mu\text{g}/\text{m}^3$) in any samples. One 128-minute sample for Ni measured 25 $\mu\text{g}/\text{m}^3$, resulting in an 8-hr TWA exposure of 6.7 $\mu\text{g}/\text{m}^3$ (assuming no further exposure), less than the applicable OELs. Other Ni measurements ranged from a 113 minute area sample to a 114 minute personal sample of 0.3 to 7 $\mu\text{g}/\text{m}^3$ Ni, respectively, resulting in 8-hr TWAs of 0.07 $\mu\text{g}/\text{m}^3$ to 1.7 $\mu\text{g}/\text{m}^3$, below relevant OELs.

Lead measurements ranged up to 2,700 $\mu\text{g}/\text{m}^3$ and Cd measurements ranged up to 2,400 $\mu\text{g}/\text{m}^3$, but when TWA exposures were calculated for these workers those exposures became 860 and 760 $\mu\text{g}/\text{m}^3$ Pb and Cd (samples ECMFF 03A&B) and 220 and 170 $\mu\text{g}/\text{m}^3$ Pb and Cd (samples ECMFF 04A&B). These 8-hr TWA measurements indicate exposures above the REL, TLV and PEL of 50 $\mu\text{g}/\text{m}^3$ for lead and the PEL of 5 $\mu\text{g}/\text{m}^3$ for cadmium. Both workers' 8-hr TWA exposures to cadmium exceeded the maximum use concentration assumed for the PAPRs used by these workers (the assigned protection factor of 25 multiplied by the OSHA PEL of 5 $\mu\text{g}/\text{m}^3$). The respirators provided adequate protection against the measured exposures to lead.

Subsequent to the initial monitoring of airborne particulate during the filter change operation, modifications (describes in Section II) were made to the procedure used for this process. The results of these changes would appear to be a dramatic reduction in airborne particulate. The last six measurements in Table 2 indicate levels of Ba, Be, Pb and Ni well below those respective exposure limits. Eight-hour TWAs based on two task-based Cd measurements of 7.8 and 12.9 $\mu\text{g}/\text{m}^3$ were 3.5 and 6.1 $\mu\text{g}/\text{m}^3$, respectively. The former exceeds the OSHA Action level for cadmium of 2.5 $\mu\text{g}/\text{m}^3$, while the latter exceeds the PEL of 5 $\mu\text{g}/\text{m}^3$. Measurements of respirable Cd were below the TLV of 2 $\mu\text{g}/\text{m}^3$ for that entity. Comparing the geometric means of the 8-hour TWA personal breathing zone cadmium exposures shows the reduction achieved by the change in work practices. The geometric mean of the two 8-hour cadmium TWAs from the March sampling date was 357 $\mu\text{g}/\text{m}^3$. The geometric mean of the four 8-hour cadmium TWAs from the December sampling was 0.375 $\mu\text{g}/\text{m}^3$. This indicates a reduction of 99.9%.

D. Particulate Size Sampling Results (Impactor Data)

Figures IX and X show the relative concentrations of metals in eleven sets of impactor data, excluding the filter change operation, as a function of particle size. The first figure displays all five particle-size cuts measured using these samples, showing the sum of the metals measured for each size range for each sample. The significant information here is that the mass of metals on the backup filters was, in most instances, greater than the sum of the metals on all stages. The second figure is an enlargement showing just the mid-three cut points and confirming that the mass of metals is similar regardless of particle size. Given that the mass of a particle is proportional to the square of that particle's radius, these data would indicate a very large portion of particles are in the small size ranges.

Impactor sampling data tend to confirm that seen with other air samples. The first two sets of impactor data in Table 3 (ECMFF 5 & 6) were taken during the filter change operation in the glass breaking exhaust system and correspond to the samples for total metals taken during that procedure. These indicate airborne levels of Cd and Pb above the occupational exposure limits with little Ba, Be, and Ni. Samples ECMFF 5(a – e) combined also indicated a total of 4,500 $\mu\text{g}/\text{m}^3$ of Y (occupational exposure limit is 1,000 $\mu\text{g}/\text{m}^3$ per Appendix A) during a five-hour period and 19,000 $\mu\text{g}/\text{m}^3$ for metals in the air (data not shown in attached tables). Time weighted average exposures for both Y and dust would be exceeded for this sample.

The third and fourth impactors (ECMHF 5 and 6), taken during the weekly cleaning of the glass breaking operation, indicate generally higher levels of metals than during normal

operations but are in general an order of magnitude lower than the samples collected during the filter change operation.

Impactor samples collected during the two days of normal production in February, in the glass breaking operation and elsewhere, again tend to confirm the samples for total metals in that there were generally measurable levels of Ba, Cd, Pb and Ni (Be was below the limit of detection in most samples) but at levels much below the occupational exposure limits.

During the follow-up study cyclones were used rather than impactors to provide a measure of respirable fraction for metals and total dust. These data indicate levels below all occupational exposure limits, including respirable Cd.

E. Sound level measurements

Spot measurements of noise made with a hand-held sound pressure meter in February 2007, suggested the need for a more comprehensive noise study. That was done during the December visit and is described here.

The data collected with noise dosimeters is presented in Table 6 for the 9 sets of data collected. Five personal and 2 area samples were collected in the GBO and 2 area samples were collected in the disassembly area where the February measurements had indicated a lower potential for overexposure. On each day of sampling, each sample is described, and the start and stop times are presented along with the sample duration (run time). Following that, the mean sound pressure level for the duration of the run (TEST AVERAGE DB) and the time weighted average sound pressure level for an eight hour day (TWA DB) is shown. Sound pressure levels are in dB, A weighted, slow response and presented for both the OSHA and NIOSH criteria. Time weighted calculations assume no exposure during the un-sampled time. For the first day of sampling, two sets of samples are shown because the dosimeters were stopped during lunch and restarted after lunch. This resulted in two separate samples. During the second and third days the dosimeters were not stopped during the lunch break. The technique was modified for the second day for the workers' convenience. Several of the noise samples exceeded the REL and TLV of 85 dBA.

The OSHA noise standard [29 CFR 1910.95] instructs the employer to calculate the allowable noise dose from more than one sample as follows:

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: $C(1)/T(1) + C(2)/T(2) + \dots + C(n)/T(n)$ exceeds unity, then, the mixed exposure should be considered to exceed the limit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level.

This means that, using the OSHA exchange values, one of the three samples collected on December 11, 2007 exceeded the allowable dose to document an overexposure to the PEL of 90 dBA. Using the allowable doses in Appendix B to the OSHA noise standard, and rounding,

sample E2CST-2 resulted in a dose of 1.37 (137% of the allowable dose).[§] The other two samples collected that day exceeded 50% of their allowable dose, requiring the employees represented by that sample to be placed in a hearing conservation program.^{**}

Noise doses on the second and third days were less than 50% of the allowable dose, except for sample E2CSW-2. That sample was collected on a worker breaking glass. That individual was exposed at a level of 90.6 dBA for 345 minutes of an allowable dose at 91 dB of 420 minutes, or 82% of the allowable dose.

F. Air Flow Observations

Smoke was released from the smoke machine in all four areas of the glass breaking operation (see Figure IV). In area A, the staging area, all smoke released traveled through the curtain *s* and was captured by the ventilation hood. Some of the smoke released close to area B moved first through curtain *t* and room B before passing through curtain *s* and being captured. There were two major recirculation zones in area A, as indicated by the circular patterns in the diagram adjacent to the entrance jet (4 straight arrows).

In area B (changing room), all smoke released traveled through curtain *s* and was captured by the ventilation system. The air flow was subjectively described as weak by visual observation in the back of area B (nearest the door), but strong and direct near curtain *s*. A slight tendency of the air near curtain *t* to flow in to area A first was noted in the back half of area B.

No smoke released in area C flowed back behind curtain *s*, even when the jet of smoke was directed at the curtain from C back towards area A. The hood in this area was a walk-in type, with three glass breaking stations. Visible airborne emissions from glass breaking were removed quickly from the point of release by the air flow, and were apparently captured by the booth ventilation.

Area D was normally occupied by workers only during ventilation system maintenance. No smoke released in area D migrated to any other area, but was captured efficiently by the ventilation system.

Smoke released in the booth confirmed the apparent capture effectiveness of the exhaust hood in two of the three glass breaking stations. The station on the right side of the booth, however, exhibited some back flow within the booth when smoke was released at the level of the grille. Smoke released at this point traveled first toward the ventilation inlet at the back of the booth, but subsequently, a small portion of the smoke was seen to travel back along the ceiling and the right side wall toward and beyond the front of the booth. Workers would be present along this path, both beside the breaking station (the normal work position for the glass breakers), and in front of the booth, where coordinators handled full and empty Gaylord boxes.

[§] 71 minutes at 92.5 dBA/318 minutes allowed at 93 dBA + 179 minutes at 97.7 dBA/156 minutes allowed at 98 dBA = 1.37, or 137% of the allowable dose.

^{**} 67 min at 90.5dbA/420 minutes allowed at 91 dBA + 181 minutes at 93.4 dBA/318 minutes allowed at 93 dBA = 0.73, or 73% of allowable dose; and 102 minutes at 91.6 dBA/306 minutes allowed at 92 dBA + 177 minutes at 91 dBA/420 minutes allowed at 91 dBA = 0.75, or 75% of the allowable dose.

Only this qualitative assessment of air flow was conducted, no quantitative air flow measurements were made.

VI. CONCLUSIONS AND RECOMMENDATIONS

The primary purpose of sampling is to determine the extent of employee exposures and the adequacy of protection. Sampling also permits the employer to evaluate the effectiveness of engineering and work practice controls and informs the employer whether additional controls need to be installed. Values that exceed OELs indicate that additional controls are necessary. This evaluation focused on the evaluation of airborne exposures, with additional data collected on surface contamination and noise exposures. The results of air sampling during the February/March 2007 Elkton survey found that lead, cadmium, and other metals, such as barium and zinc are generated and released during the recycling operations at this facility. Exposures were found that exceeded the OSHA Action Level for cadmium during the weekly clean-up in the glass-breaking area. In addition, 8-hr TWA measurements indicate exposures above the REL, TLV and PEL of $50 \mu\text{g}/\text{m}^3$ for lead and the PEL of $5 \mu\text{g}/\text{m}^3$ for cadmium for two workers during the filter change operation. Both workers' 8-hr TWA exposures to cadmium exceeded the maximum use concentration assumed for the PAPRs used by these workers (the assigned protection factor of 25 multiplied by the OSHA PEL of $5 \mu\text{g}/\text{m}^3$). The respirators provided adequate protection against the measured exposures to lead. Additional testing in December 2007 indicated marked improvements in control and reductions in excess of 99% in airborne exposures to metals during the filter change operations in the GBO. However, air sampling revealed exposures that exceeded the OSHA Action Level and PEL for cadmium during the filter change operation, even after that process was modified to improve control.

The results of air sampling clearly indicate that the highest exposures occurred among workers involved in the glass breaking operations. These operations involve three distinct processes: the filter change-out maintenance operation which occurs about once a month; a weekly cleaning process, and routine glass breaking which occurs on a daily basis. The highest potential exposures were measured among the workers involved in the filter change-out maintenance operation. The second highest exposed group is those same workers during the routine daily glass breaking operations. Samples collected for the routine operation showed detectable concentrations were less than 20% of the OSHA PELs for both Cd and Pb.

Smoke tests indicated the ventilation system appears to capture dust before worker exposure can occur, except possibly at the right hand breaking station. Air sampling tends to confirm these observations. No corrective measures were attempted during this study, but it appears that extending the overhead push jet to the right so that this jet is continuous across the front face of the hood may correct the backflow condition. It appeared that dust could migrate from the glass breaking booth to adjacent work areas and in particular to the area where workers changed to and from protective clothing and respirators. Workers in the glass breaking operation were also overexposed to noise.

Disassembly workers as a group, including those in the FSL, had lower potential exposures during routine day-to-day operations as do workers in the warehouse. Samples collected on

disassembly workers in the general factory area of all three buildings ranged from non-detectable to 10% of the OSHA PEL for Cd and ranged from non-detectable to 5% of the OSHA PEL for Pb.

The data collected during the filter change maintenance operation showed that airborne concentrations during this once per month maintenance operation exceeded the OSHA PELs for cadmium and lead. Although the two workers performing the filter change-out operation wore respiratory protection, the Cd concentrations detected exceeded the assigned protection factor of the powered air purifying respirator (PAPR) being used. Modifications to the process resulted in a reduction in exposures that exceeded 99%. There were not enough samples to test for statistical significance.

While overexposures were documented in the filter change operation only, modifications can be made to improve operations in general. Based on the data presented above, the following recommendations are made. These recommendations are divided into 3 categories, described as programmatic issues, procedural issues, and housekeeping issues.

Programmatic issues:

1. The respiratory protection program for this facility should be evaluated for this operation in order to ensure that it complies with OSHA regulation 1910.134.
2. Based upon the air sampling results during filter changing and weekly clean-up, a regulatory assessment should be performed with respect to OSHA regulations found at 29 CFR 1910.1025 (Lead) and 29 CFR 1910.1027 (Cadmium).
3. Because of the noise levels found in the glass breaking operation, engineering controls should be designed or selected using noise reduction as a criterion.
4. Until noise in the glass breaking operation can be reduced through engineering controls, a hearing conservation program including noise monitoring, audiometric testing, providing hearing protectors, training workers, and recordkeeping must be implemented for workers in the glass breaking operation.
5. Training of workers should be scheduled and documented in the use of techniques for dust suppression, the proper use of local ventilation, personal protection equipment (e.g., coveralls, respirators, gloves) and hazard communication.
6. Frequently while conducting the on-site work, NIOSH researchers observed tasks being conducted in a manner which appeared to be biomechanically taxing. Tasks should be evaluated to determine there are excesses in repetitive stress trauma and if modifications in procedures or equipment would provide benefit to this workplace.
7. Heat stress should be evaluated during hot weather (e.g., the summer months). Heat exposures above recommended limits were measured at a similar BOP facility during the summer, and it is recommended that appropriate measurements be taken at Elkton to prevent this problem.
8. All Unicor operations, including but not limited to recycling should be evaluated from the perspective of health, safety and the environment in the near future.
9. A program should be established within the Bureau of Prisons to assure that these issues are adequately addressed by competent trained and certified individuals. While a written program to address these issues is necessary at each facility, adequate staffing with safety and health professionals is required to ensure its implementation. One

indication of adequate staffing is provided by the United States Navy, which states “Regions/Activities with more than 400 employees shall assign, at a minimum, a full time safety manager and adequate clerical support” [USN 2005]. That document also provides recommended hazard-based staffing levels for calculating the “number of professional personnel needed to perform minimum functions in the safety organization.”

10. A comprehensive program is needed within the Bureau which provides sufficient resources, including professional assistance, to assure each facility the assets needed to assure both staff and inmates a safe and healthy workplace.
11. This facility is a Federal prison, and the workers are Federal prisoners. The Belmont Report [HEW 1979] notes that, “...under prison conditions they [prisoners] may be subtly coerced or unduly influenced to engage in research activities for which they would not otherwise volunteer.” Although we did not observe this, Elkton managers should ensure that prisoners are not unduly influenced to perform work which is considered unsafe or unhealthy.

Procedural issues:

12. The modifications to the filter change-out practice should be adopted as standard operating procedure for this process, including: 1) the immediate bagging and disposal of used filters rather than attempting to clean and re-use them; 2) the use of a water spray to suppress dust during the filter change operation; and 3) the use of HEPA filtered vacuums and wet mopping to remove dust from the floor and work surfaces. When using wet methods to help control dust, care needs to be taken to assure that the wet methods do not introduce any potential electrical or other safety hazard.
13. The use of an alternative method (e.g., static pressure drop) should be investigated to determine frequency of filter change. The manufacturer of this system may have guidelines in this regard.
14. Workers performing the filter change operation must continue to utilize respiratory protection as part of a comprehensive respiratory protection program. The PAPRs used provide adequate protection for the modified filter change operation.
15. Because the facility already provides uniforms to its workers, management should evaluate the feasibility of providing and laundering work clothing for all workers in the recycling facility, instead of the current practice of providing disposable clothing for glass breaking workers only. Contaminated work clothing must be segregated from other clothes and laundered in accordance with applicable regulations.
16. Change rooms should be modified to provide separate storage facilities for protective work clothing and equipment and for street clothes that prevent cross-contamination.
17. The use of alternative methods to break cathode-ray tubes should be investigated by Elkton management. Lee et al. [2004] present different methods to separate panel glass from funnel glass in CRT recycling (sec 2.1) and for removing the coatings from the glass (sec 2.2). The hot wire and vacuum suction methods (supplemented with local exhaust ventilation) described by Lee et al. may produce fewer airborne particulates than breaking the glass with a hammer. The authors [Lee et al. 2004] describe a commercially-available method in which an electrically-heated wire is either manually or automatically wound around the junction of the panel and funnel glass, heating the glass. After heating the glass for the necessary time, cool (e.g., room temperature) air is directed at the surface, fracturing the glass-to-glass junction using thermal shock.

The separated panel and funnel glass can then be sorted by hand. They also describe a method wherein a vacuum-suction device is moved over the inner surface of the panel glass to remove the loose fluorescent coating [Lee et al. 2004]. The vacuum used must be equipped with HEPA filtration. Industrial central vacuum systems are available; they may cost less in the long run than portable HEPA vacuum cleaners. These modifications may also reduce the noise exposure to glass breakers.

18. German authorities [BG/BIA 2001] have issued a set of best-practices for dismantling CRTs. Their recommendations include the use of a closed cleaning cabinet that incorporates 300 air changes per hour to control emissions.

Housekeeping:

19. Due to the levels of surface contamination of lead measured in the recycling facility, special attention should be focused on hygiene practices to prevent accidental ingestion of lead. Workers should wash their hands before eating, drinking, or smoking.
20. Given the concentrations of lead and cadmium detected in the bulk dust samples surface wipe samples and air measurements, periodic industrial hygiene evaluations and facility inspections are recommended to confirm that exposures are maintained below applicable occupational exposure limits.
21. Daily and weekly cleaning of work areas by HEPA-vacuuuming and wet mopping should be continued. The BG/BIA guidelines [2001] recommend daily cleaning of tables and floors with a type-H vacuum cleaner. Type H is the European equivalent of a HEPA vacuum, where the H class requires that the filter achieve 99.995% efficiency, where 90% of the test particles are smaller than 1.0 um and pass the assembled appliance test, 99.995% efficiency where 10% of the particles are smaller than 1.0 um, 22% below 2.0 um, and 75% below 5.0 um. While some surface contamination was measured in work areas, this would be much greater if it were not for the good housekeeping practices in effect in all locations observed. Other practices not observed during the time of this evaluation, but which have been observed at other facilities should be discouraged; these include the use of compressed air to clean parts or working surfaces, and the consumption of food, beverage or tobacco in the workplace.

References

ACGIH [2001]. Yttrium. In: *Documentation of the threshold limit values*. 7th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH [2008]. Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AIHA [2007]. Workplace environmental exposure levels. Fairfax, VA: American Industrial Hygiene Association.

ASTM [2002]. Standard practice for collection of settled dust samples using wipe sampling methods for subsequent determination of metals. West Conshohocken, PA: ASTM International.

Berges M (Markus.Berges@dguv.de)[2008a]. WG: Project-Nr. BIA3058: Dust emission during release of vacuum from cathode-ray tubes. Private e-mail message to Alan Echt (AEcht@cdc.gov), June 16.

Berges M (Markus.Berges@dguv.de)[2008b]. AW: BG.BIA-Empfehlungen zur Überwachung translated. Private e-mail message to Alan Echt (AEcht@cdc.gov), June 27.

BG/BIA [2001]. Recommendations for monitoring work areas – manual disassembly of monitors and other electrical equipment.

BIA [2001]. Project-Nr. BIA 3058 Dust emission during release of vacuum from cathode-ray tubes. Berufsgenossenschaftliches Institut für Arbeitssicherheit –BIA, Berufsgenossenschaft der Feinmechanik und Elektrtechnik. Available on-line at <http://www.hvbg.de/e/bia/pro/pro1/pr3058.html>. Accessed June 13, 2008.

Caplan KJ [1993]. The significance of wipe samples. *Am Ind Hyg Assoc J* 53:70–75.

CFR. Code of Federal regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Chepesiuk R [1999]. Where the chips fall: environmental health in the semiconductor industry. *Environ Health Perspect.* 107:A452–A457.

Cui J, Forssberg E [2003]. Mechanical recycling of waste electric and electronic equipment: a review. *J Hazard Mater.* 99:243–263.

DHHS [2000]. *Healthy people 2010: Understanding and Improving Health. 2nd ed.* Washington, DC: U.S. Department of Health and Human Services. Available on the internet at: www.health.gov/healthypeople/Document/default.htm

EPA [2008]. eCycling. Available on-line at <http://www.epa.gov/ecycling/>. Accessed June 3, 2008.

Fairfax RE [2003]. Letter of January 13, 2003 from RE Fairfax, Director, Directorate of Compliance Programs, OSHA, to Frank White, Vice President, Organization Resource Counselors, Inc. Available at http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=25617. Accessed May 12, 200

Goyer RA [1991]. Toxic effects of metals. In: Amdur ML, Doull J, Klaassen CD (eds.) *Casarett and Doull's Toxicology*, pp. 623–680.

HEW [1979]. *The Belmont report: ethical principles and guidelines for the protection of human subjects of research.* Washington DC: Department of Health, Education and Welfare, Office of the Secretary, The National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. Available on-line at

<http://www.hhs.gov/ohrp/humansubjects/guidance/belmont.htm>. Accessed June 11, 2008.

IARC [1993]. IARC monographs on the evaluation of carcinogenic risks to humans: beryllium, cadmium, mercury, and exposures in the glass manufacturing industry. Vol. 58. Lyon, France: World Health Organization, International Agency for Research on Cancer.

ICF [1999]. General background document on cathode ray tube glass-to-glass recycling. Fairfax VA: ICF Incorporated. Office of Solid Waste, US Environmental Protection Agency. May 25, 1999 draft. Available on-line at [yosemite.epa.gov/ee/epa/riafile.nsf/vwAN/S99-23.pdf/\\$File/S99-23.pdf](http://yosemite.epa.gov/ee/epa/riafile.nsf/vwAN/S99-23.pdf/$File/S99-23.pdf). Accessed July 2, 2008.

Landrigan PJ, Froines JR, Mahaffey KR [1985]. Body lead burden: summary of epidemiological data on its relation to environmental sources and toxic effects. In: Dietary and environmental lead: human health effects. Amsterdam: Elsevier Science Publishers.

Lange JH [2001]. A suggested lead surface concentration standard for final clearance of floors in commercial and industrial buildings. *Indoor and Built Environment* 10:48–51.

Lee C-H, Chang C-T, Fan K-S, Chang T-C [2004]. An overview of recycling and treatment of scrap computers. *J Hazard Mater.* 114:93–100.

McCawley MA, Kent MS, Berakis MT [2001]. Ultrafine beryllium number concentration as a possible metric for chronic beryllium disease risk. *Appl Occup Environ Hyg.* 16:631–638.

Misra C, Singh M, Shen S, Sioutas C, Hall PM [2002]. Development and evaluation of a personal cascade impactor sampler (PCIS). *Aerosol Science* 33:1027–1047.

NARA [2008]. Executive Order 12196--Occupational safety and health programs for Federal employees. College Park, MD:U.S. National Archives and Records Administration. Available on-line at: <http://www.archives.gov/federal-register/codification/executive-order/12196.html>. Accessed June 6, 2008.

NIOSH [1978]. Criteria for a recommended standard: occupational exposure to inorganic lead. Revised criteria – 1978. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-158.

NIOSH [1984]. Current intelligence bulletin #42: Cadmium. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 84-116.

NIOSH [1989]. Occupational health guidelines for chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH)/DOL (OSHA) Publication No. 81-123 and supplements 88-118, 89-104

NIOSH [1990]. NIOSH testimony on the Occupational Safety and Health Administration's proposed rule on occupational exposure to cadmium, July 17, 1990, OSHA Docket No. H-057A. NIOSH policy statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health. p.16.

NIOSH [1992]. NIOSH recommendations for occupational safety and health, compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. DHHS(NIOSH) Publication No. 92-100.

NIOSH [1994]. NIOSH Manual of Analytical Methods (NMAM®), 4th ed. Schlecht, P.C. & O'Connor, P.F. eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 94-113 (August, 1994), 1st Supplement Publication 96-135, 2nd Supplement Publication 98-119, 3rd Supplement 2003-154.

NIOSH [1998]. NIOSH criteria for a recommended standard: occupational noise exposure. Revised criteria 1998. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS(NIOSH) Publication No. 98-126.

NIOSH [2005]. NIOSH pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005-149. Available on-line at <http://www.cdc.gov/niosh/npg/>. Accessed June 6, 2008.

Nordberg G, ed. [1998]. Barium. In: Metals: chemical properties and toxicity. Chapter 63. In: Stellman, JM, ed. Encyclopedia of occupational health and safety. 4th ed. Vol. 2. Geneva: International Labor Office. Pp. 63.8-63.9.

OSHA [2004]. Cadmium. Washington, DC: U.S. Department of Labor Occupational Safety and Health Administration OSHA 3136-06R. Available on-line at: <http://www.osha.gov/Publications/osha3136.pdf>. Accessed June 4, 2008.

Pettersson-Julander A, van Bavel B, Engwall M, Westberg H [2004]. Personal air sampling and analysis of polybrominated diphenyl ethers and other bromine containing compounds at an electronic recycling facility in Sweden. J Environ Monit. 6:874-880. Epub 2004 Oct 21.

Proctor NH, Hughes JP, Fischman ML [1991a]. Lead. In: *Chemical hazards of the workplace. 3rd ed.* Philadelphia, PA: J.B. Lippincott Company, Philadelphia, pp 353-357.

Proctor NH, Hughes JP, Fischman ML [1991b]. Nickel and inorganic compounds. In: *Chemical hazards of the workplace. 3rd ed.* Philadelphia, PA: J.B. Lippincott Company, Philadelphia, pp 422-424.

Proctor NH, Hughes JP, Fischman ML [1991c]. Yttrium. In: *Chemical hazards of the workplace. 3rd ed.* Philadelphia, PA: J.B. Lippincott Company, Philadelphia, pp 591.

Saryan LA, Zenz C [1994]. Lead and its compounds. In: *Occupational medicine. 3rd ed.* Chicago, IL: Mosby-Year Book, Inc.

Schmidt CW [2002]. e-Junk explosion. *Environ Health Perspect.* 110:A188–A194.

Sjödin A, Carlsson H, Thuresson K, Sjölin S, Bergman A, Ostman C [2001]. Flame retardants in indoor air at an electronics recycling plant and at other work environments. *Environ Sci Technol.* 35:448–454.

Tebrock H E, Machle W [1968] Exposure to europium-activated yttrium orthovanadate: a cathodoluminescent phosphor. *J. Occup. Med.* 10:692–696.

Thun MJ, Elinder CG, Friberg L [1991]. Scientific basis for an occupational standard for cadmium. *Am J Ind Med.* 20:629-42.

USN [2005] Navy safety and occupational health (soh) program manual, chapter 3. organization and staffing. Washington, DC: Department of the Navy, Office of the Chief Of Naval Operations OPNAVINST 5100.23G. 30 DEC 2005. Available online at http://safetycenter.navy.mil/instructions/osh/510023/5100_23G_Cover_Ch10.pdf Accessed May 12, 2008.

Willis HH, Florig HK [2002]. Potential exposures and risks from beryllium-containing products. *Risk Anal.* 22:1019–1033.

Table 1
Summary Statistics for Airborne Metal Measurements*

	Ba $\mu\text{g}/\text{m}^3$	Be $\mu\text{g}/\text{m}^3$	Cd $\mu\text{g}/\text{m}^3$	Pb $\mu\text{g}/\text{m}^3$	Ni $\mu\text{g}/\text{m}^3$
25 samples taken in the FCI Unicorn factory					
Ar. Mean	0.54	0.02	0.18	2.73	0.18
Ar. St Dev	0.90	0.02	0.19	4.13	0.15
Geo Mean	0.29	0.02	0.12	1.24	0.12
GSD	2.70	2.11	2.42	3.65	2.78
12 samples taken in the Federal Satellite Low					
Ar. Mean	0.41	0.02	0.20	1.53	0.54
Ar. St Dev	0.23	0.02	0.13	3.50	0.15
Geo Mean	0.36	0.01	0.16	0.59	0.52
GSD	1.62	1.76	1.90	3.14	1.37
3 samples taken in the Warehouse					
Ar. Mean	0.23	0.19	0.41	1.17	0.45
Ar. St Dev	0.06	0.55	0.54	1.20	0.39
Geo Mean	0.23	0.02	0.27	0.71	0.32
GSD	1.26	1.00	2.08	2.00	1.49
4 samples taken in the GBO during the weekly cleaning procedure; LEV was operating;					
Ar. Mean	1.00	0.05	8.05	3.11	0.50
Ar. St Dev	0.58	0.00	10.37	2.06	0.00
Geo Mean	0.88	0.05	2.59	2.55	0.50
GSD	1.75	1.00	10.06	2.13	1.00
7 samples taken in the GBO during filter change operation; LEV not operating;					
Ar. Mean	120.57	0.01	941.75	1177.50	10.50
Ar. St Dev	162.82	0.00	1018.46	1039.76	9.85
Geo Mean	33.65	0.01	412.89	900.47	7.79
GSD	8.79	1.00	11.42	8.93	4.72

The following samples were taken during the second site visit

	Ba μg/m ³	Be μg/m ³	Cd μg/m ³	Pb μg/m ³	Ni μg/m ³	Particulate μg/m ³
10 samples taken during normal operations						
Ar. Mean	0.61	0.01	0.29	1.33	0.12	415.37
Ar. St Dev	0.57	0.00	0.36	2.59	0.05	216.01
Geo Mean	0.30	0.01	0.10	0.40	0.11	344.83
GSD	4.30	1.22	5.33	4.11	1.70	2.10
10 samples taken during normal operation, respirable fractions						
Ar. Mean	0.08	0.01	0.02	0.15	0.04	66.49
Ar. St Dev	0.08	0.00	0.00	0.10	0.02	31.76
Geo Mean	0.04	0.01	0.02	0.13	0.03	58.59
GSD	4.54	1.30	1.30	1.89	1.92	1.79
3 samples taken during filter change operations						
Ar. Mean	1.97	0.01	7.04	0.31	0.17	188.27
Ar. St Dev	1.57	0.00	6.32	0.00	0.12	44.82
Geo Mean	1.32	0.01	3.35	0.31	0.14	184.81
GSD	3.59	1.26	6.84	1.00	2.00	1.26
3 samples taken during filter change operations, respirable fractions						
Ar. Mean	0.38	0.01	0.07	0.31	0.05	173.50
Ar. St Dev	0.14	0.00	0.05	0.00	0.03	77.35
Geo Mean	0.37	0.01	0.06	0.31	0.04	161.49
GSD	1.46	1.49	2.48	1.00	1.92	1.61

*Ar. Mean = arithmetic mean

Ar. St Dev = arithmetic standard deviation

Geo Mean = geometric mean

GSD = geometric standard deviation

All “non-detected” samples were set at half the limit of detection for statistical calculations.

Table 2 –Airborne Metal Measurements

Sample ID	Building	Date	Area /		Sample Duration Minutes	Ba μg/M ³	Be g/M ³	Cd g/M ³	Pb g/M ³	Ni g/M ³
			Personal	Sample Description						
The following 25 samples were taken in the FCI Unicolor factory										
ECMTFT1	FCI	2/27/2007	A	Worker stripping copper	393	0.1	<0.03	<0.6	<0.4	<0.08
ECMTFT2	FCI	2/27/2007	P	Worker stripping copper	291	0.2	<0.05	<0.1	0.6	0.1
ECMTFT3	FCI	2/27/2007	A	Monitor tear-down between 4th & 5th work station from back Material disassembly, front	379	0.2	<0.04	<0.1	0.8	0.3
ECMTFT4	FCI	2/27/2007	A	1/2	20	<0.5	<0.07	<1	<8	<1
ECMTFT5	FCI	2/27/2007	P	Orderly Material disassembly, 3rd table from back Material disassembly, Table 7 from back Material disassembly, Table 6 from front	281	0.3	<0.05	<0.1	1.3	0.2
ECMTFT6	FCI	2/27/2007	P	Orderly Material disassembly, 3rd table from back Material disassembly, Table 7 from back Material disassembly, Table 6 from front	255	0.2	<0.05	<0.1	0.8	0.2
ECMTFT7	FCI	2/27/2007	P	Orderly Material disassembly, 3rd table from back Material disassembly, Table 7 from back Material disassembly, Table 6 from front	256	0.3	<0.05	0.1	1.8	0.3
ECMTFT8	FCI	2/27/2007	P	6 from front	164	0.2	0.08	<0.1	1.5	0.3
ECMTFT11	FCI	2/27/2007	P	Coordinator	423	0.4	<0.01	0.2	2.7	0.1
ECMTFT12	FCI	2/27/2007	A	Glass breaking	420	0.2	<0.01	<0.1	1	<0.02
ECMTFT13	FCI	2/27/2007	P	Intake	238	<0.1	<0.01	<0.1	<0.1	<0.03
ECMWFT1	FCI	2/28/2007	A	Glass breaker	208	1.4	<0.06	0.2	9.5	<0.1
ECMWFT2	FCI	2/28/2007	P	Glass breaker	305	1.7	<0.01	0.6	8.9	0.1
ECMWFT3	FCI	2/28/2007	P	Glass breaking, feeder	258	1.4	<0.01	0.3	7.5	0.2
ECMWFT4	FCI	2/28/2007	P	Glass breaking, coordinator	412	4.3	<0.01	0.8	18	0.4
ECMWFT5	FCI	2/28/2007	A	Monitor disassembly, 4th	395	0.3	<0.03	0.2	1.1	0.2

				bench from back						
ECMWFT6	FCI	2/28/2007	A	Monitor disassembly, 8th bench from back	400	0.2	<0.03	0.1	0.8	<0.1
ECMWFT7	FCI	2/28/2007	P	Intake area, forklift driver	332	0.2	<0.03	0.1	0.5	0.1
ECMWFT8	FCI	2/28/2007	A	Intake area, near weigh station	408	0.2	<0.03	0.1	0.7	0.1
ECMWFT9	FCI	2/28/2007	A	Copper stripping area	390	0.1	<0.03	<0.1	0.4	<0.1
ECMWFT10	FCI	2/28/2007	P	Worker stripping copper	300	0.1	<0.04	<0.1	<0.6	<0.1
ECMWFT11	FCI	2/28/2007	P	Monitor disassembly, 8th bench from back	289	0.2	<0.05	0.1	1.2	0.2
ECMWFT12	FCI	2/28/2007	P	Monitor disassembly, 2nd bench from back	283	0.2	<0.05	0.1	1.1	0.1
ECMWFT13	FCI	2/28/2007	P	Monitor disassembly, 4th bench from back	280	0.5	<0.05	0.3	2.3	0.6
ECMWFT14	FCI	2/28/2007	P	Monitor disassembly, material handler	251	0.3	<0.05	0.1	1.2	0.2

The following 12 samples were taken in the Federal Satellite Low

ELMTF-P1	FSL	2/27/2007	P	Disassembly worker	207	<0.5	<0.02	0.1	0.7	0.7
ELMTF-P2	FSL	2/27/2007	P	Disassembly worker	203	<0.5	<0.02	0.1	<0.4	0.5
ELMTF-P3	FSL	2/27/2007	P	Disassembly worker	198	<0.5	<0.03	<0.1	0.9	0.6
ELMTF-T1	FSL	2/27/2007	A	Area sample north	369	<0.5	<0.02	0.1	<0.3	0.3
ELMWF-A11	FSL	2/28/2007	A	North FSL area	392	0.3	<0.04	0.2	<0.5	0.5
ELMWF-A12	FSL	2/28/2007	A	Area - Central FSL	395	0.6	<0.03	0.2	0.7	0.7
ELMWF-A13	FSL	2/28/2007	A	Area south FSL (suspect tampering)	398	1	<0.03	0.3	12.6	0.6

Table 2 –Airborne Metal Measurements (continued)

Sample ID	Building	Date	Area / Personal	Sample Description						
						Be μg/M ³	Cd g/M ³	Pb g/M ³	Ni g/M ³	Ni g/M ³
ELMWF-P11	FSL	2/28/2007	P	Bailer (metal)	187	0.5	0.07	0.3 μ	<0.5 μ	0.7 μ
ELMWF-P12	FSL	2/28/2007	P	Bailer (plastic cardboard)	286	0.5	<0.02	0.1	0.5	0.4
ELMWF-P13	FSL	2/28/2007	P	Worker on line 1 (north)	Ba 284	0.2	<0.02	0.2	0.7	0.5
ELMWF-P14	FSL	2/28/2007	P	Worker on central line		287	0.5	<0.02	0.5	0.9
ELMWF-P15	FSL	2/28/2007	P	Orderly	280	0.3	<0.02	0.2	0.5	0.3

The following 6 samples were taken in the warehouse

EWMWF1	WHSE	2/27/2007	P	Orderly	253	0.2	<0.1	<0.1	<2	<1
EWMWF2	WHSE	2/27/2007	P	General worker	247	0.13	<0.1	<0.1	<2	<1
EWMWF03	WHSE	2/28/2007	P	Clean-up, sweeping	307	0.2	<0.02	0.4	0.3	0.1
EWMWF04	WHSE	2/28/2007	P	De-gaussing, grinding	202	0.2	<0.02	0.4	<0.3	0.2
EWMWF05	WHSE	2/28/2007	P	Work on floor	338	0.3	<0.02	0.3	0.5	0.1
EWMWF06	WHSE	2/28/2007	A	Area sample, middle of warehouse	381	0.2	<0.02	0.1	<0.3	0.1

The following 4 samples were taken in the GBO during the weekly cleaning procedure; LEV was operating;

ECMHF1	FCI / GBO	3/1/2007	P	GBO worker doing weekly cleaning	79	1.8	<0.1	23.3	5.7	<1
ECMHF2	FCI / GBO	3/1/2007	P	GBO worker doing weekly cleaning	72	0.66	<0.1	4.7	2.02	<1
ECMHF3	FCI / GBO	3/1/2007	A	In change area during weekly cleaning	67	<1	<0.1	0.1	<2	<1
ECMHF4	FCI / GBO	3/1/2007	A	In breaking area during weekly cleaning	64	1.02	<0.1	4.1	3.7	<1

The following 7 samples were taken in the GBO during the filter change maintenance operation; LEV not operating;

ECMFF04B	FCI / GBO	3/2/2007	P	Worker doing filter change	91	5	<0.02	18	25	3
ECMFF07	FCI / GBO	3/2/2007	A	On computer monitor at desk of clerk,	113	1	<0.02	3	6	0.3
ECMFF01	FCI / GBO	3/2/2007	A	BZ level, near HEPA filter	318	15	<0.02	31	71	0.5
ECMFF02	FCI / GBO	3/2/2007	A	BZ level in right GBO station	322	63	<0.02	27	360	3
ECMFF03A	FCI / GBO	3/2/2007	P	Worker doing filter change	128	460	<0.02	2,400	2700	25
ECMFF03B	FCI / GBO	3/2/2007	P	Worker doing filter change	90	150	<0.02	650	760	7
ECMFF04A	FCI / GBO	3/2/2007	P	Worker doing filter change about 20 ft from GBO	114	150	<0.02	690	890	7

The following samples were taken during the second site visit and include measurements for airborne particulate;

Sample ID	Building	Date	Area / Personal	Sample Description		Ba	Be	Cd	Pb	Ni	Particulate
											*
E2CMTR-01	FCI	12/11/2007	P	Feeding monitors	281	0.15	<0.02	<0.03	0.31	0.02	85.6 R
E2CMTR-02	FCI	12/11/2007	P	Glass breaking	286	0.22	<0.02	<0.03	0.29	<0.08	59.0 R
E2CMTT-01	FCI	12/11/2007	P	Glass breaking	267	1.02	<0.03	0.65	3.26	0.13	490
E2CHTT-02	FCI	12/11/2007	P	Feeding monitors	283	1.66	<0.02	0.98	8.17	0.17	722
E2CMTM-01	FCI	12/11/2007	P	Moving product	285		<0.07				
E2CMTT-03	FCI	12/11/2007	P	Moving product	284	0.08	<0.02	<0.05	<0.23	0.15	223
E2CMWT-01	FCI	12/12/2007	P	Moving product	237	0.08	<0.03	<0.06	<0.28	0.11	199
E2CMWT-02	FCI	12/12/2007	P	Moving product	224	0.99	<0.03	<0.06	0.31	0.15	467
E2CMWT-03	FCI	12/12/2007	P	Feeding monitors	240	1.03	<0.03	0.64	0.31	0.21	654
E2CMWT-04	FCI	12/12/2007	P	Copper stripping	239	0.04	<0.03	<0.06	<0.28	<0.14	70.3
E2CMWT-05	FCI	12/12/2007	P	Glass breaking	233	0.82	<0.03	0.45	0.31	<0.14	519
E2CMWR-01	FCI	12/12/2007	P	Feeding monitors	233	0.05	<0.02	<0.04	<0.21	<0.10	73.0 R
E2CHWR-02	FCI	12/12/2007	P	Feeding monitors	239	0.11	<0.02	<0.04	<0.20	<0.10	81.5 R
E2CMWR-03	FCI	12/12/2007	P	Moving product	231	0.04	<0.02	<0.04	<0.21	<0.10	113 R
E2CMWR-04	FCI	12/12/2007	P	Disassembly	240	<0.02	<0.02	<0.04	<0.20	<0.10	30.1 R

E2CMWR-05	FCI	12/12/2007	P	Disassembly	229	<0.02	<0.02	<0.04	<0.21	0.06	52.2 R
E2CMWM-01	FCI	12/12/2007	P	Feeding monitors	235		<0.09				
E2CMWM-03	FCI	12/12/2007	A	Disassembly area	162		<0.12				
E2CMWT-06	FCI	12/12/2007	P	Disassembly	244	0.35	<0.03	<0.05	0.31	0.15	394
E2CMWR-06	FCI	12/12/2007	P	Disassembly	105	<0.01	<0.01	<0.02	<0.12	0.01	23.2 R

The following 6 samples were taken during filter change operations

E2CMHT-01	FCI	12/13/2007	A	On top of HEPA filters	304	0.31	<0.02	0.37	0.31	0.12	179
E2CMHT-02	FCI	12/13/2007	P	Filter change	215	2.19	<0.02	7.83	0.31	0.08	148.8
E2CMHT-03	FCI	12/13/2007	P	Filter change	225	3.42	<0.03	12.93	0.31	0.31	237.8
E2CMHR-02	FCI	12/13/2007	A	Center exhaust hood face, 6.5 Ft. high	307	0.25	<0.01	0.08	0.31	0.02	169 R
E2CMHR-03	FCI	12/13/2007	P	Filter change	220	0.37	<0.02	<0.04	0.31	<0.11	98.5 R
E2CMHR-04	FCI	12/13/2007	P	Filter change	229	0.53	<0.02	0.11	0.31	0.07	253 R

*R indicates respirable fraction

Table 3 –Impactor Samples

Sample ID	Description	Location	Date	Particle Size Cut point (μm)	Ba $\mu\text{g}/\text{m}^3$	Be g/m^3	Cd g/m^3	Pb g/m^3	Ni g/m^3	TOTAL METALS g/m^3
ECMFF 5A	Five hour personal sample on worker doing filter change in GBO	FCI	3/2/07	2.5	83	<0.03	388	560	3.7	7,100
ECMFF 5B				1.0	75	<0.03	330	359	2.9	6,500
ECMFF 5C				0.50	6	<0.03	13	19	<0.1	410
ECMFF 5D				0.25	42	<0.03	131	96	0.8	2,900
ECMFF 5E				Filter	4	<0.03	4	2	0.1	2,200
	Total metal per sample				210	<0.03	866	1037	7.6	19,000
ECMFF 6A	Two hour personal sample on worker doing filter change in GBO	FCI	3/2/07	2.5	22	<0.01	50	114	0.7	1,900
ECMFF 6B				1.0	2	<0.01	1	7	<0.04	82
ECMFF 6C				0.50	0.3	<0.01	0.03	2	<0.04	13
ECMFF 6D				0.25	0.1	<0.01	0.02	0	<0.04	8
ECMFF 6E				Filter	0.1	<0.01	0.01	<0.1	0.01	540
	Total metal per sample				24	<0.01	51	123	0.8	2,500
ECMHF 5A	Two hour personal sample on worker doing clean-up in glass breaking area/room	FCI	3/1/07	2.5	0.5	<0.02	3	5	0.1	62
ECMHF 5B				1.0	<0.04	<0.02	0.1	4	<0.1	16
ECMHF 5C				0.50	<0.02	<0.02	<0.02	<0.02	5	<0.1
ECMHF 5D				0.25	<0.02	<0.02	<0.02	3	<0.1	13
ECMHF 5E				Filter	<0.4	<0.02	<0.02	<0.3	<0.1	1,600
	Total metal per sample				0	<0.02	3	16	0.1	1,700
ECMHF 6A	Two hour personal sample on worker doing clean-up in glass breaking area/room	FCI	3/1/07	2.5	0.1	<0.06	<0.1	<0.8	<0.1	31
ECMHF 6B				1.0	0.1	<0.06	0.3	24	<0.1	59
ECMHF 6C				0.50	<0.05	<0.06	<0.1	7	<0.1	
ECMHF 6D				0.25	<0.05	<0.06	<0.1	12	<0.1	35
ECMHF 6E				Filter	1	<0.06	<0.1	<0.5	0.1	2,500
	Total metal per sample				1	<0.06	0.3	43	0.1	2,700
ECMTFS 2A	On table 1, front half	FCI	2/27/07	2.5	0.3	<0.03	0.05	6	0.4	70
ECMTFS 2B				1.0	0.0	<0.03	<0.05	11	<0.06	27
ECMTFS 2C				0.50	<0.02	<0.03	<0.05	4	<0.06	17
ECMTFS 2D				0.25	<0.02	<0.03	<0.05	3	<0.06	13
ECMTFS 2E				Filter	0.3	<0.03	<0.05	<0.2	0.1	1,000
	Total metal per sample				1	<0.03	0.05	23	0.4	1,200

Table 3 –Impactor Samples (continued)

SampleID	Description	Location	Date	Particle Size Cut point (μm)	Ba $\mu\text{g}/\text{m}^3$	Be g/m^3	Cd g/m^3	Pb g/m^3	Ni g/m^3	TOTAL METALS g/m^3
ECMTFS 3A	3rd funnel breaker	FCI	2/27/07	2.5	2 μ	<0.02 μ	1	25 μ	0.2 μ	260
ECMTFS 3B				1.0	1	<0.02 μ	0.2 μ	6	<0.06	50
ECMTFS 3C				0.50	1	<0.02	0.1	5	<0.06	31
ECMTFS 3D				0.25	0.1	<0.02	<0.04	1	<0.06	11
ECMTFS 3E				Filter	1	<0.02	0.1	0.3	<0.06	840
	Total metal per sample				5	<0.02	2	37	0.2	1,200
ECMTFS 4A	Panel breaker	FCI	2/27/07	2.5	8	<0.01	10	44	0.7	750
ECMTFS 4B				1.0	1	<0.01	0.1	3	<0.03	25
ECMTFS 4C				0.50	0.1	<0.01	<0.01	5	<0.03	11
ECMTFS 4D				0.25	0.1	<0.01	<0.01	4	<0.03	9
ECMTFS 4E				Filter	<0.02	<0.01	0.01	<0.1	<0.03	500
	Total metal per sample				9	<0.01	10	56	0.7	1,300
ECMTFS 6A	Intake area	FCI	2/27/07	2.5	0.1	0.01	<0.03	1	0.1	19
ECMTFS 6B				1.0	0.01	0.01	<0.03	1	0.03	8
ECMTFS 6C				0.50	0.01	0.01	<0.03	1	0.03	6
ECMTFS 6D				0.25	0.01	0.01	<0.03	3	0.03	9
ECMTFS 6E				Filter	0.1	0.01	0.01	0	0.01	630
	Total metal per sample				0.2	0.07	0.01	6	0.2	670
ECMWFS 7A	Area sample, glass breaking booth	FCI	2/28/07	2.5	2.1	0.005	0.4	19	0.2	180
ECMWFS 7B				1.0	0.2	0.005	<0.001	1	0.02	12
ECMWFS 7C				0.50	0.1	0.005	0.01	0	0.02	8
ECMWFS 7D				0.25	0.03	0.005	<0.001	0	0.02	4
ECMWFS 7E				Filter	0.1	0.005	0.01	<0.1	0.01	350
	Total metal per sample				2.5	0.02	0.4	21	0.3	550
ECMWFS 8A	Glass breaker	FCI	2/28/07	2.5	2.3	0.01	0.5	13	0.1	200
ECMWFS 8B				1.0	1.5	0.01	0.2	8	0.1	110
ECMWFS 8C				0.50	0.4	0.01	0.03	1	0.03	20
ECMWFS 8D				0.25	0.2	0.01	<0.01	1	0.03	8
ECMWFS 8E				Filter	0.5	0.01	0.05	0.4	0.01	460
	Total metal per sample				4.9	0.03	1	24	0.2	800

Table 3 –Impactor Samples (continued)

Sample ID	Description	Location	Date	Particle Size Cut point (μm)	Ba $\mu\text{g}/\text{m}^3$	Be g/m^3	Cd g/m^3	Pb g/m^3	Ni g/m^3	TOTAL METALS g/m^3
ECMWFS 9A	Glass breaking feeder	FCI	2/28/07	2.5	1.2 μ	0.01 μ	0.2 μ	10 μ	0.1 μ	97
ECMWFS 9B				1.0	0.3	0.01	0.04	3	<0.03	24
ECMWFS 9C				0.50	0.1	0.01	<0.01	1	<0.03	8
ECMWFS 9D				0.25	0.1	0.01	<0.01	1	<0.03	6
ECMWFS 9E				Filter	0.2	0.01	0.01	<0.1	0.01	560
	Total metal per sample				1.7	0.03	0.3	15	0.2	700
EWMTF 3A	Area sample, warehouse, location 2 (see diagram)	W	2/27/07	2.5	0.2	0.01	<0.01	5	<0.03	60
EWMTF 3B				1.0	0.02	0.01	<0.01	5	<0.03	16
EWMTF 3C				0.50	0.01	0.01	<0.01	3	<0.03	9
EWMTF 3D				0.25	0.01	0.01	<0.01	0.3	<0.03	6
EWMTF 3E				Filter	0.1	0.01	<0.01	<0.1	<0.03	490
	Total metal per sample				0.4	0.06	<0.01	14	<0.03	590
EWMTF 4A	Area sample, warehouse, location 1 (see diagram)	W	2/27/07	2.5	0.1	0.01	<0.01	1	<0.03	28
EWMTF 4B				1.0	0.1	0.01	<0.01	1	<0.03	10
EWMTF 4C				0.50	0.01	0.01	<0.01	1	<0.03	7
EWMTF 4D				0.25	0.01	0.01	<0.01	1	<0.03	7
EWMTF 4E				Filter	0.1	0.01	<0.01	<0.1	<0.03	560
	Total metal per sample				0.3	0.06	<0.01	4	<0.03	610

*Total metals per sample, and total metals per stage are sums of all 31 metals quantified rather than the five metals listed in this table

Table 4 –Wipe Sample Results

Sample ID	Location	Date	Sample description	Results in ug/sq ft				
				Ba	Be	Cd	Pb	Ni
The following samples were taken in the FCI Unicorn Factory								
ECMTW1	FCI	2/28/2007	On steel work bench, copper stripping	44	<0.3	25	360	43
ECMTW2	FCI	2/28/2007	On work bench, smooth rubber, far end	56	<0.3	13	3,000	110
ECMTW3	FCI	2/28/2007	On work bench, cardboard cover, far end	17	<0.3	2	150	21
ECMTW4	FCI	2/28/2007	On work bench, rough rubber, near end	120	<0.3	56	660	260
ECMTW5	FCI	2/28/2007	On work bench, smooth rubber near end	150	<0.3	33	670	240
ECMTW6	FCI	2/28/2007	On gray desk top in weigh station	3	<0.3	2	24	<4
ECMTW7	FCI	3/1/2007	Charger bench in change room	72	<0.3	70	1,200	6
ECMTW8	FCI	3/1/2007	Outside of locker door in change room	<0.7	<0.3	<0.7	4	<4
ECMTW9	FCI	3/1/2007	Back of aluminum bench in change room	<0.7	<0.3	1	11	<4
ECMTW10	FCI	3/1/2007	Front of aluminum bench in change room	90	<0.3	9	1,400	7
ECMTW11	FCI	3/1/2007	Right side of I-beam in breaking room	100	<0.3	350	580	7
ECMTW12	FCI	3/1/2007	Back of inlet jet at top front of hood, right side, breaking room	35	<0.3	44	330	<4
ECMTW13	FCI	3/1/2007	Floor in breaking room adjacent to change room	590	<0.3	30	10,200	66
ECMTW14	FCI	3/1/2007	Floor, middle of entry room to glass breaking	190	<0.3	11	2,100	15
The following samples were taken in the Federal Satellite Low								
ELMTF-W1	FSL	2/28/2007	End of shift, on Table 1 north	12	<0.3	4	21	4
ELMTF-W2	FSL	2/28/2007	End of shift, on Table 1 central	28	<0.3	8	77	93
ELMTF-W3	FSL	2/28/2007	End of shift, table 3 south	27	<0.3	13	36	45
ELMTF-W4	FSL	2/28/2007	Bailer 1	130	<0.3	17	120	160
ELMTF-W5	FSL	2/28/2007	Bailer 2	55	<0.3	5	100	290
ELMWF-W11	FSL	3/1/2007	Bailer (metal)	66	<0.3	10	57	110
ELMWF-W12	FSL	3/1/2007	Bailer (plastic)	37	<0.3	4	72	40
ELMWF-W13	FSL	3/1/2007	Table 1, north	25	<0.3	8	190	200
ELMWF-W14	FSL	3/1/2007	Table 1 south	20	<0.3	4	180	240
ELMWF-W15	FSL	3/1/2007	Table 3, central	26	<0.3	167	86	120

Table 4 –Wipe Sample Results (Continued)

The following samples were taken in the FCI Unicorn Factory during the second site visit

Sample ID	Date	Description	Ba	Be	Cd	Pb	Ni
E2CMTW-01	12/11/2007	ADP north end on computer desk top near doors to recycle operations	<0.2	<0.1	<0.9	<4	<3
E2CMTW-02	12/11/2007	ADP south end on computer desk top near doors to recycle operations	0.2	0.1	<0.9	3.6	<3
E2CMTW-03	2/11/2007	Recycle room south end work bench top near doors to ADP	202.5	0.1	24.2	170.9	55.7
E2CMTW-04	12/11/2007	Recycle room north end work bench top near doors to ADP	63.2	0.2	22.3	310.3	102.2
E2CMTW-05	12/11/2007	Recycle room north end work bench top middle of disassembly area	249.0	0.1	63.2	505.4	260.1
E2CMTW-06	12/11/2007	Recycle room south end work bench top middle of disassembly area	4.6	0.1	3.2	22.3	15.8
E2CMTW-07	12/11/2007	Recycle room outside double door to glass breaking room on top of order desk	8.0	0.1	4.6	36.2	4.5
E2CMTW-08	12/11/2007	Recycle CLERK station near glass breaking room	3.3	0.1	1.8	8.4	7.7
E2CMTW-09	12/12/2007	Filter room on top of HEPA filter	193.2	<0.1	371.6	1202.1	10.2
E2CMTW-10	12/12/2007	Glass breaking table	249.0	<0.1	399.5	1202.1	13.0
E2CMTW-11	12/12/2007	Change room on top of lockers	26.0	0.2	32.5	133.8	12.1

Table 5
Composition of Bulk Dust Samples from the Glass Breaking Operation
February 2007

Sample	Ba	Be	Cd	Pb	Ni
ECMFB01	670	<0.1	240	14000	60
ECMFB02	650	<0.1	240	14000	40
ECMFB03	860	<0.1	350	9100	79

The data are presented in milligram of metal per kg of dust (mg/kg).

**Table 6
Noise Exposure Measurements**

Date:	12/11/07					
Sample I D:	E2CST - 2		E2CST - 3		E2CST - 1	
Description:	Glass breaking		Glass breaking		Sweeper in GBO	
Dosimeter serial no.	QC9040064		QC9050002		QC9040070	
<u>Test Started</u>	9:53:19AM		8:59:02AM		9:27:35AM	
<u>Test Stopped</u>	11:04:47AM		10:06:51AM		11:10:15AM	
<u>Test Run Time</u>			1:07		1:42	
		NIOSH	OSHA	NIOSH	OSHA	NIOSH
TEST AVG (DB)	92.5	95.6	90.5	93.1	91.6	93.2
TWA (DB) 1:11	78.8	87.3	76.4	84.6	80.4	86.5

Date:	12/11/07					
Sample I D:	E2CST - 2		E2CST - 3		E2CST - 1	
Description:	Glass breaking		Glass breaking		Sweeper in GBO	
Dosimeter serial no.	QC9040064		QC9050002		QC9040070	
<u>Test Started</u>	12:53:38PM		11:57:06AM		1:01:48PM	
<u>Test Stopped</u>	3:52:59PM		2:58:05PM		3:59:16PM	
<u>Test Run Time</u>			3:01		2:57	
		NIOSH	OSHA	NIOSH	OSHA	NIOSH
TEST AVG (DB)	97.7	99.4	93.4	96.0	91.0	92.1
TWA (DB) 2:59	90.6	95.1	86.3	91.8	83.9	87.8
Date:	12/12/07					

Sample I D:	E2CSW - 2	E2CSW - 3			E2CSW - 1		E2CSW- 4		
Description:	Glass breaking	Area sample - CRT disassembly			Cleaner - GBO		Area sample - CRT disassembly		
Dosimeter serial no.	QC9040064	QC9050002			QC9040070		QC9040061		
<u>Test Started</u>	8:44:41AM	8:09:14AM			8:47:10AM		9:17:50AM		
<u>Test Stopped</u>	2:30:29PM	1:47:18PM			2:35:28PM		2:42:33PM		
<u>Test Run Time</u>		5:38			5:48		5:24		
		NIOSH	OSHA	NIOSH	OSHA	NIOSH	OSHA	NIOSH	
TEST AVG (DB)	90.6	94.1	75.8	86.9	85.9	88.8	61.5	76.8	
TWA (DB) 5:45	88.3	92.6	73.3	85.4	83.6	87.4	58.7	75.1	

Date:	12/13/07								
Sample I D:	E2CSW - 9	E2CSW - 10							
OSHA Description:	Area - in GBO near feed window	Area - in GBO, left side of hood							
Dosimeter serial no.	QC9040064	QC9040070							
<u>Test Started</u>	8:43:23AM	8:49:38AM							
<u>Test Stopped</u>	1:56:41PM	2:03:22PM							
<u>Test Run Time</u>		5:14							
		NIOSH	OSHA	NIOSH					
TEST AVG (DB)	67.4	79.2	68.2	77.5					
TWA (DB) 5:13	64.4	77.3	65.1	75.7					

Appendix A Occupational Exposure Criteria for Metal/Elements

ELEMENTS (ICP): METHOD 7300, Issue 3, dated 15 March 2003 - Page 6 of 8

TABLE 2. EXPOSURE LIMITS, CAS #, RTECS

Element (Symbol)	CAS #	RTECS	Exposure Limits, mg/m ³ (Ca = carcinogen)		
			OSHA	NIOSH	ACGIH
Silver (Ag)	7440-22-4	VW3500000	0.01 (dust, fume, metal)	0.01 (metal, soluble)	0.1 (metal) 0.01 (soluble)
Aluminum (Al)	7429-90-5	BD0330000	15 (total dust) 5 (respirable)	10 (total dust) 5 (respirable fume) 2 (salts, alkyls)	10 (dust) 5 (powders, fume) 2 (salts, alkyls)
Arsenic (As)	7440-38-2	CG0525000	varies	C 0.002, Ca	0.01, Ca
Barium (Ba)	7440-39-3	CQ8370000	0.5	0.5	0.5
Beryllium (Be)	7440-41-7	DS1750000	0.002, C 0.005	0.0005, Ca	0.002, Ca
Calcium (Ca)	7440-70-2	—	varies	varies	varies
Cadmium (Cd)	7440-43-9	EU9800000	0.005	lowest feasible, Ca	0.01 (total), Ca 0.002 (respir.), Ca
Cobalt (Co)	7440-48-4	GF8750000	0.1	0.05 (dust, fume)	0.02 (dust, fume)
Chromium (Cr)	7440-47-3	GB4200000	0.5	0.5	0.5
Copper (Cu)	7440-50-8	GL5325000	1 (dust, mists) 0.1 (fume)	1 (dust) 0.1 (fume)	1 (dust, mists) 0.2 (fume)
Iron (Fe)	7439-89-6	NO4565500	10 (dust, fume)	5 (dust, fume)	5 (fume)
Potassium (K)	7440-09-7	TS6460000	—	—	—
Lanthanum	7439-91-0	—	—	—	—
Lithium (Li)	7439-93-2	—	—	—	—
Magnesium (Mg)	7439-95-4	OM2100000	15 (dust) as oxide 5 (respirable)	10 (fume) as oxide	10 (fume) as oxide
Manganese (Mn)	7439-96-5	OO9275000	C 5	1; STEL 3	5 (dust) 1; STEL 3 (fume)
Molybdenum (Mo)	7439-98-7	QA4680000	5 (soluble) 15 (total insoluble)	5 (soluble) 10 (insoluble)	5 (soluble) 10 (insoluble)
Nickel (Ni)	7440-02-0	QR5950000	1	0.015, Ca	0.1 (soluble) 1 (insoluble, metal)
Phosphorus (P)	7723-14-0	TH3500000	0.1	0.1	0.1
Lead (Pb)	7439-92-1	OF7525000	0.05	0.05	0.05
Antimony (Sb)	7440-36-0	CC4025000	0.5	0.5	0.5
Selenium (Se)	7782-49-2	VS7700000	0.2	0.2	0.2
Tin (Sn)	7440-31-5	XP7320000	2	2	2
Strontium (Sr)	7440-24-6	—	—	—	—
Tellurium (Te)	13494-80-9	WY2625000	0.1	0.1	0.1
Titanium (Ti)	7440-32-6	XR1700000	—	—	—
Thallium (Tl)	7440-28-0	XG3425000	0.1 (skin) (soluble)	0.1 (skin) (soluble)	0.1 (skin)
Vanadium (V)	7440-62-2	YW2400000	—	C 0.05	—
Tungsten	7440-33-7	—	5	5 10 (STEL)	5 10 (STEL)
Yttrium (Y)	7440-65-5	ZG2980000	1	N/A	1
Zinc (Zn)	7440-66-6	ZG8600000	—	—	—
Zirconium (Zr)	7440-67-7	ZH7070000	5	5, STEL 10	5, STEL 10

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Appendix B

Metallic Composition of Bulk Dust Samples from the Glass Breaking Operation Concentrations are in mg/kg (ppm by weight)

Sample #:	ECMFB01	ECMFB02	ECMFB03
Al	480	480	1100
Sb	8.8	5.4	21
As	<6	<6	<6
Ba	670	650	860
Be	<0.1	<0.1	<0.1
Cd	240	240	350
Ca	1100	910	1700
Cr	13	14	24
Co	<0.5	<0.5	0.9
Cu	15	15	29
Fe	2000	2000	2500
La	12	16	13
Pb	14000	14000	9100
Li	0.5	0.5	1.4
Mg	150	150	300
Mn	43	43	41
Mo	<2	<2	<2
Ni	60	40	79
P	57	68	82
K	460	450	690
Se	<10	16	<10
Ag	<0.2	<0.2	<0.2
Sr	190	180	240
Te	4	<4	15
Tl	<4	8.6	<4
Sn	26	15	18
Ti	10	10	13
V	<0.3	<0.3	<0.3
Y	6500	5700	3500
Zn	15000	14000	9000
Zr	<7	7.4	0

Appendix C
Metallic Composition of Wipe Samples

Concentrations are in ug/sq foot

Sample ID	ECMTW1	ECMTW10	ECMTW11	ECMTW12	ECMTW13	ECMTW14	ECMTW2	ECMTW3	ECMTW4	ECMTW5	ECMTW6	ECMTW7	ECMTW8	ECMTW9	EWMTW05	EWMTW06	EWMTW07	EWMTW08	EWMTW09	EWMTW10
Al	320	350	33	11	440	430	250	270	340	270	240	190	240	4.8	1300	260	180	290	200	270
Sb	8.4	<u>2</u>	-	-	4.2	2.1	19	12	12	35	<u>2</u>	-	-	-	21	3.9	<u>2</u>	8.4	<u>2</u>	-
As	<u>5</u>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ba	4.7	9.7 ²	11 ²	3.8	63	20	6	1.8	13	48	0.33 ²	7.7 ²	<u>0.08</u> ²	<u>0.08</u>	89	3.2	1.5	51	1.7 ²	0.41
Be	<u>0.03</u> ⁵																			
Cd	2.7	0.94	38	4.7	3.2	1.2	1.4	0.24	6	3.5	0.17	7.5	<u>0.07</u>	0.11	6	0.18	0.09	0.33	<u>0.07</u>	<u>0.07</u>
Ca	520	280	230	220	1100	810	520	270	600	620	290	<u>100</u>	<u>100</u>	300	14000	<u>100</u>	<u>100</u>	1700	<u>100</u>	<u>100</u>
Cr	2.5	0.78	0.61	<u>0.02</u>	2.5	0.6	2.7	0.74	3.3	10	<u>0.02</u>	1.9	<u>0.02</u>	<u>0.02</u>	18	0.53	0.18	3.6	0.67	0.2
Co	0.27	<u>0.06</u>	<u>0.06</u>	<u>0.06</u>	0.1	<u>0.06</u>	0.35	<u>0.06</u>	0.22	0.58	<u>0.06</u>	<u>0.06</u>	<u>0.06</u>	<u>0.06</u>	2	<u>0.06</u>	<u>0.06</u>	0.19	<u>0.06</u>	<u>0.06</u>
Cu	69	2.2	1.1	0.49	11	4.3	33	8.9	45	170	1.2	1.7	0.3	<u>0.03</u>	110	2.7	1.1	170	1.7	1.9
Fe	490	110	53	24	720	300	1100	83	590	440	47	140	3.6	<u>0.9</u>	5800	90	50	560	60	36
La	<u>0.3</u>	<u>0.3</u>	0.38	<u>0.3</u>	0.73	<u>0.3</u>	0.86	<u>0.3</u>	0.54	0.46	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	3.2	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>
Pb	39	150	62	35	1100	230	320	16	71	72	2.6	130	0.47	1.2	110	3.8	1	8.7	1.6	0.96
Li	0.29	0.12	0.11	0.05	0.35	0.31	0.83	0.17	1.3	1.4	0.16	0.08	0.04	0.04	2.6	0.12	0.06	1.7	0.12	0.08
Mg	60	29	13	8.4	81	56	120	43	100	87	46	14	44	<u>7</u>	2200	38	13	500	29	32
Mn	8	2.3	1.3	0.52	12	5.6	290	8.1	92	35	2	2.1	0.68	<u>0.04</u>	160	2.6	1.1	11	1.1	1.2
Mo	0.39	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	0.32	<u>0.3</u>	0.54	0.57	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	<u>0.3</u>	3.8	<u>0.3</u>	<u>0.3</u>	0.62	<u>0.3</u>	<u>0.3</u>
Ni	4.6	0.76	0.78	<u>0.4</u>	7.1	1.6	12	2.3	28	26	<u>0.4</u>	0.65	<u>0.4</u>	<u>0.4</u>	31	1.1	<u>0.4</u>	7.6	<u>0.4</u>	<u>0.4</u>
P	30	4.9	6.5	5.3	17	17	12	3.4	16	<u>1</u>	4.7	3.3	<u>1</u>	-	190	7.6	12	7.3	9.3	3.1
K	76	59	13	11	160	100	120	34	110	140	58	18	15	18	1900	120	140	240	160	61
Se	<u>2</u>	-	2.4	<u>2</u>	-	-	-	-	-	-	-	-	- ¹	-	-	-	-	-	-	-
Ag	0.17	0.04	<u>0.02</u>	<u>0.02</u>	0.1	0.11	1.7	0.47	1.1	0.83	0.03	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	2.6	0.15	0.03	2.3	0.07	0.05
Sr	2 ²	5.1	4.3	1.6 ²	30 ²	13 ²	2.6 ²	0.69 ²	11 ²	3.1 ²	0.26 ²	2.2 ²	<u>0.1</u> ²	0.61 ²	35 ²	0.19 ²	<u>0.1</u> ²	3.4 ²	0.41 ²	<u>0.1</u>

Te	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	0.6	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	1.4	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>	<u>0.5</u>
Tl	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>
Sn	7.6	<u>2</u>	-	-	3	<u>2</u>	470	27	92	100	<u>2</u>	-	-	-	21	6	<u>2</u>	8.5	<u>2</u>	-
Ti	2	1.3	0.81	0.35	6.2	3.9	2.5	1.4	9.2	17	0.74	0.98	0.38	0.07	40	1.3	0.53	9.5	0.94	0.72
V	0.03	0.03 ²	0.02 ²	<u>0.02</u>	0.15	0.1	0.29	0.05	0.15	0.17	<u>0.02</u> ²	0.02 ²	<u>0.02</u> ²	<u>0.02</u>	2.2	0.04	<u>0.02</u>	0.26	0.03 ²	0.03
Y	3.5	5.3	260	35	32	7.8	5.1	0.29	4.6	2.8	0.41	46	0.2	0.81	14	0.56	0.09	0.23	0.11	0.06
Zn	94	22	620	98	200	47	950	72	630	1200	32	140	<u>9</u>	-	910	26	<u>9</u>	320	<u>9</u>	-
Zr	<u>0.6</u>	<u>0.6</u>	<u>0.6</u>	<u>0.6</u>	1.1	1.2	0.61	<u>0.6</u>	1	1.2	<u>0.6</u>	<u>0.6</u>	<u>0.6</u>	<u>0.6</u>	3.1	<u>0.6</u>	<u>0.6</u>	1.1	<u>0.6</u>	<u>0.6</u>

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Underline = <LOD (Limit of detection)

Appendix C (Continued)
Metallic Composition of Wipe Samples

Concentrations are in ug/sq foot

These samples were collected during the second site visit

Sample ID	E2CMTW-01	E2CMTW-02	E2CMTW-03	E2CMTW-04	E2CMTW-05	E2CMTW-06	E2CMTW-07	E2CMTW-08	E2CMTW-09	E2CMTW-10	E2CMTW-11
As	<9	13.0	<9	<9	<9	<9	<9	11.1	15.7	13.9	<9
Ba	<0.2	0.2	201.9	63.0	248.2	4.5	8.3	3.3	192.6	248.2	25.9
Be	<0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	<0.1	<0.1	0.2
Cd	<0.9	<0.9	24.1	22.2	63.0	3.1	4.6	1.8	370.4	398.2	32.4
Cr	0.3	0.6	14.3	43.9	69.8	8.1	3.1	2.2	23.5	21.7	6.0
Co	<0.6	<0.6	9.1	4.6	11.1	1.8	<0.6	<0.6	2.0	1.1	2.7
Cu	<0.5	<0.5	82.4	1203.8	879.7	16.7	16.7	6.0	<0.5	21.3	10.2
Fe	<60	9.3	2778.0	4352.2	10093.4	537.1	398.2	92.6	453.7	2963.2	518.6
La	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	6.2	<0.5	0.9
Pb	<4	3.6	170.4	309.3	503.7	22.2	36.1	8.3	1198.2	1198.2	133.3
Mn	<2	7.1	73.2	148.2	583.4	18.5	12.0	4.7	13.0	28.7	16.7
Mo	<2	<2	<2	11.1	10.2	<2	<2	<2	<2	<2	<2
Ni	<3	<3	55.6	101.9	259.3	15.7	4.4	7.7	10.2	13.0	12.0
P	<200	<200	<200	259.3	1944.6	<200	213.0	185.2	250.0	416.7	379.7

Se	<10	<10	14.8	<10	<10	<10	<10	<10	<10	<10	<10
Ag	<0.2	0.2	3.0	6.5	10.2	0.8	0.4	<0.2	<0.2	0.3	0.5
Sr	<0.3	<0.3	19.4	19.4	51.9	1.9	4.5	0.3	128.7	212.1	14.8
Te	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tl	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Sn	<20	<20	157.4	379.7	407.4	<20	<20	<20	<20	18.5	<20
V	<0.2	<0.2	0.4	1.4	1.2	0.6	0.3	<0.2	<0.2	<0.2	0.2
Y	0.3	0.5	5.7	12.0	41.7	2.3	4.1	1.2	1203.8	1111.2	86.1
Zn	<100	287.1	2092.8	2926.2	10982.4	175.9	120.4	<100	5333.8	10982.4	83.3
Zr	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20

Appendix D
Metallic Composition of Filter Samples
Concentrations are in $\mu\text{g}/\text{m}^3$

<LOD Underline

Sample ID	ECMTFT1	ECMTFT11	ECMTFT12	ECMTFT13	ECMTFT2	ECMTFT3	ECMTFT4	ECMTFT5	ECMTFT6	ECMTFT7	ECMTFT8
Al	0.93	1.50	<u>0.35</u>	<u>0.26</u>	1.52	1.71	<u>14.59</u>	3.67	1.23	4.58	3.51
Sb	<u>0.42</u>	<u>0.12</u>	<u>0.12</u>	<u>0.14</u>	<u>0.58</u>	<u>0.45</u>	<u>8.10</u>	<u>0.59</u>	<u>0.67</u>	<u>0.65</u>	<u>1.03</u>
As	<u>0.59</u>	<u>0.17</u>	<u>0.16</u>	<u>0.20</u>	<u>0.82</u>	<u>0.63</u>	<u>11.35</u>	<u>0.83</u>	<u>0.94</u>	<u>0.92</u>	<u>1.44</u>
Ba	0.08	0.40	0.15	0.02	0.20	0.18	<u>0.49</u>	0.27	0.16	0.31	0.25
Be	<u>0.03</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.05</u>	<u>0.04</u>	<u>0.65</u>	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.08</u>
Cd	<u>0.59</u>	0.18	0.05	<u>0.02</u>	<u>0.08</u>	<u>0.06</u>	<u>1.13</u>	<u>0.08</u>	<u>0.09</u>	0.09	<u>0.14</u>
Ca	11.85	10.73	4.20	2.37	16.36	20.64	53.48	35.47	18.77	44.49	30.95
Cr	<u>0.08</u>	<u>0.02</u>	<u>0.02</u>	<u>0.03</u>	<u>0.11</u>	<u>0.08</u>	<u>1.46</u>	<u>0.11</u>	<u>0.12</u>	<u>0.12</u>	<u>0.19</u>
Co	<u>0.05</u>	<u>0.01</u>	<u>0.01</u>	<u>0.02</u>	<u>0.07</u>	<u>0.05</u>	<u>0.97</u>	<u>0.07</u>	<u>0.08</u>	<u>0.08</u>	<u>0.12</u>
Cu	<u>0.08</u>	<u>0.02</u>	<u>0.02</u>	<u>0.03</u>	<u>0.12</u>	<u>0.09</u>	<u>1.62</u>	<u>0.12</u>	<u>0.13</u>	0.42	<u>0.21</u>
Fe	4.49	4.74	1.59	1.36	6.78	7.90	11.35	15.37	8.18	15.70	16.71
La	<u>0.03</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.04</u>	<u>0.03</u>	<u>0.49</u>	<u>0.04</u>	<u>0.04</u>	<u>0.04</u>	<u>0.06</u>
Pb	<u>0.42</u>	2.75	1.00	<u>0.14</u>	0.61	0.76	<u>8.10</u>	1.30	0.75	1.83	1.47
Li	<u>0.85</u>	<u>0.25</u>	<u>0.23</u>	<u>0.29</u>	<u>1.17</u>	<u>0.90</u>	<u>16.21</u>	<u>1.18</u>	<u>1.34</u>	<u>1.31</u>	<u>2.06</u>
Mg	0.69	0.72	0.21	0.13	0.91	1.35	<u>6.48</u>	2.60	1.23	3.01	1.96
Mn	0.20	0.12	0.04	0.03	0.20	0.25	<u>1.13</u>	0.46	0.28	0.51	0.68
Mo	<u>0.25</u>	<u>0.07</u>	<u>0.07</u>	<u>0.09</u>	<u>0.35</u>	<u>0.27</u>	<u>4.86</u>	<u>0.35</u>	<u>0.40</u>	<u>0.39</u>	<u>0.62</u>
Ni	<u>0.08</u>	0.08	<u>0.02</u>	<u>0.03</u>	<u>0.11</u>	0.27	<u>1.46</u>	0.25	0.16	0.27	0.29
P	<u>2.54</u>	<u>0.75</u>	<u>0.70</u>	<u>0.87</u>	<u>3.51</u>	<u>2.69</u>	<u>48.62</u>	<u>3.55</u>	<u>4.02</u>	<u>3.93</u>	<u>6.19</u>
K	<u>0.85</u>	0.85	0.30	<u>0.29</u>	<u>1.17</u>	0.99	<u>16.21</u>	1.77	<u>1.34</u>	2.62	<u>2.06</u>
Se	<u>1.69</u>	<u>0.50</u>	<u>0.47</u>	<u>0.58</u>	<u>2.34</u>	2.15	<u>32.41</u>	<u>2.36</u>	<u>2.68</u>	<u>2.62</u>	<u>4.13</u>

Ag	<u>0.03</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.05</u>	<u>0.04</u>	<u>0.65</u>	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.08</u>
Sr	0.03	0.14	0.06	0.01	0.06	0.07	<u>0.32</u>	0.15	0.07	0.16	0.10
Te	<u>0.42</u>	<u>0.12</u>	<u>0.12</u>	<u>0.14</u>	<u>0.58</u>	<u>0.45</u>	<u>8.10</u>	<u>0.59</u>	<u>0.67</u>	<u>0.65</u>	<u>1.03</u>
Tl	<u>0.68</u>	<u>0.20</u>	<u>0.19</u>	<u>0.23</u>	<u>0.94</u>	<u>0.72</u>	<u>12.97</u>	<u>0.95</u>	<u>1.07</u>	<u>1.05</u>	<u>1.65</u>
Sn	<u>0.76</u>	<u>0.22</u>	<u>0.21</u>	<u>0.26</u>	<u>1.05</u>	<u>0.81</u>	<u>14.59</u>	<u>1.06</u>	<u>1.21</u>	<u>1.18</u>	<u>1.86</u>
Ti	0.08	0.08	0.03	0.01	0.14	0.13	0.16	0.24	0.11	0.25	0.25
V	<u>0.03</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.04</u>	<u>0.03</u>	<u>0.49</u>	<u>0.04</u>	<u>0.04</u>	<u>0.04</u>	<u>0.06</u>
Y	0.06	5.74	1.61	0.01	0.14	0.11	<u>0.32</u>	0.52	0.12	0.18	0.78
Zn	1.35	10.73	3.50	0.40	2.10	2.60	7.94	5.79	5.50	7.72	8.25
Zr	<u>0.34</u>	<u>0.10</u>	<u>0.09</u>	<u>0.12</u>	<u>0.47</u>	<u>0.36</u>	<u>6.48</u>	<u>0.47</u>	<u>0.54</u>	<u>0.52</u>	<u>0.83</u>

Sample ID	ECMWFT12	ECMWFT13	ECMWFT14	ECMWFT2	ECMWFT3	ECMWFT4	ECMWFT5	ECMWFT6	ECMWFT7	ECMWFT8	ECMWFT9	EC
Al	3.29	8.78	2.92	4.78	5.92	10.91	3.46	2.24	2.27	1.41	0.86	
Sb	<u>0.61</u>	<u>0.59</u>	<u>0.66</u>	<u>0.49</u>	<u>0.57</u>	<u>0.65</u>	<u>0.42</u>	<u>0.41</u>	<u>0.42</u>	<u>0.41</u>	<u>0.43</u>	
As	<u>0.85</u>	<u>0.83</u>	<u>0.93</u>	<u>0.68</u>	<u>0.80</u>	<u>0.91</u>	<u>0.59</u>	<u>0.58</u>	<u>0.59</u>	<u>0.58</u>	<u>0.60</u>	
Ba	0.24	0.50	0.25	1.66	1.37	4.29	0.31	0.21	0.19	0.16	0.09	
Be	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.04</u>	<u>0.05</u>	<u>0.05</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	
Cd	0.15	0.30	0.09	0.58	0.32	0.82	0.15	0.09	0.06	0.07	0.06	
Ca	26.81	54.58	31.87	22.46	46.66	54.57	32.91	17.38	18.48	18.26	10.36	
Cr	<u>0.11</u>	<u>0.11</u>	<u>0.12</u>	<u>0.09</u>	<u>0.10</u>	<u>0.12</u>	<u>0.08</u>	<u>0.07</u>	<u>0.08</u>	<u>0.07</u>	<u>0.08</u>	
Co	<u>0.07</u>	<u>0.07</u>	<u>0.08</u>	0.07	<u>0.07</u>	0.08	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	
Cu	0.28	0.94	<u>0.13</u>	<u>0.10</u>	<u>0.11</u>	0.16	0.17	<u>0.08</u>	<u>0.08</u>	<u>0.08</u>	<u>0.09</u>	
Fe	13.40	55.77	13.28	9.76	18.21	31.18	15.19	11.59	13.44	7.80	6.22	
La	<u>0.04</u>	0.06	<u>0.04</u>	<u>0.03</u>	<u>0.03</u>	<u>0.04</u>	<u>0.03</u>	<u>0.02</u>	<u>0.03</u>	<u>0.02</u>	<u>0.03</u>	
Pb	1.12	2.25	1.22	8.88	7.51	18.19	1.10	0.79	0.50	0.67	<u>0.43</u>	
Li	<u>1.22</u>	<u>1.19</u>	<u>1.33</u>	<u>0.98</u>	<u>1.14</u>	<u>1.30</u>	<u>0.84</u>	<u>0.83</u>	<u>0.84</u>	<u>0.83</u>	<u>0.86</u>	
Mg	1.46	4.51	1.73	1.37	2.85	3.51	2.03	1.16	1.76	1.16	0.48	
Mn	0.44	1.54	0.42	0.21	0.44	0.84	0.50	0.41	0.40	0.23	0.24	
Mo	<u>0.37</u>	<u>0.36</u>	<u>0.40</u>	<u>0.29</u>	<u>0.34</u>	<u>0.39</u>	<u>0.25</u>	<u>0.25</u>	<u>0.25</u>	<u>0.25</u>	<u>0.26</u>	

Ni	<i>0.11</i>	0.63	<i>0.19</i>	<i>0.11</i>	<i>0.16</i>	<i>0.36</i>	<i>0.22</i>	<u>0.07</u>	<i>0.08</i>	<i>0.13</i>	<u>0.08</u>
P	<u>3.66</u>	<u>3.56</u>	<u>3.98</u>	<u>2.93</u>	<u>3.41</u>	<u>3.90</u>	<u>2.53</u>	<u>2.48</u>	<u>2.52</u>	<u>2.49</u>	<u>2.59</u>
K	<i>1.58</i>	<i>3.80</i>	<i>1.59</i>	<i>2.54</i>	<i>2.73</i>	4.81	<i>1.94</i>	<i>1.32</i>	<i>1.34</i>	<i>1.24</i>	<i>0.95</i>
Se	<u>2.44</u>	<u>2.37</u>	<u>2.66</u>	<u>1.95</u>	<u>2.28</u>	<u>2.60</u>	<u>1.69</u>	<u>1.66</u>	<u>1.68</u>	<u>1.66</u>	<u>1.73</u>
Ag	<u>0.05</u>	<u>0.05</u>	<u>0.05</u>	<u>0.04</u>	<u>0.05</u>	<u>0.05</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>
Sr	<i>0.11</i>	0.26	<i>0.12</i>	0.59	0.50	1.05	0.16	0.11	<i>0.08</i>	<i>0.07</i>	<i>0.04</i>
Te	<u>0.61</u>	<u>0.59</u>	<u>0.66</u>	<u>0.49</u>	<u>0.57</u>	<u>0.65</u>	<u>0.42</u>	<u>0.41</u>	<u>0.42</u>	<u>0.41</u>	<u>0.43</u>
Tl	<u>0.97</u>	<u>0.95</u>	<u>1.06</u>	<u>0.78</u>	<u>0.91</u>	<u>1.04</u>	<u>0.68</u>	<u>0.66</u>	<u>0.67</u>	<u>0.66</u>	<u>0.69</u>
Sn	<u>1.10</u>	<i>1.90</i>	<u>1.20</u>	<u>0.88</u>	<u>1.02</u>	<u>1.17</u>	<u>0.76</u>	<u>0.75</u>	<u>0.76</u>	<u>0.75</u>	<u>0.78</u>
Ti	0.19	0.38	0.23	0.18	0.31	0.42	0.24	0.15	0.15	0.14	0.09
V	<u>0.04</u>	<u>0.04</u>	<u>0.04</u>	<u>0.03</u>	<u>0.03</u>	<u>0.04</u>	<u>0.03</u>	<u>0.02</u>	<u>0.03</u>	<u>0.02</u>	<u>0.03</u>
Y	0.19	0.28	0.17	47.84	13.66	66.26	0.17	0.12	0.13	0.12	0.08
Zn	10.97	18.98	4.91	86.90	29.59	119.53	5.15	3.56	2.69	2.57	1.55
Zr	<u>0.49</u>	<u>0.47</u>	<u>0.53</u>	<u>0.39</u>	<u>0.46</u>	<u>0.52</u>	<u>0.34</u>	<u>0.33</u>	<u>0.34</u>	<u>0.33</u>	<u>0.35</u>

Sample ID	ECMTFS 4E	ELMTF-P1	ELMTF-P2	ELMTF-P3	ELMTF-T1	ELMTF-T2	ELMTF-T3	ELMWF- A11	ELMWF- A12	ELMWF- A13	ELMWF- P11	ELMWF- P12	ELMWF- P13	ELMWF- P14	ELMWF- P15
Al	1.68	3.97	4.10	4.25	2.53	3.79	3.07	4.60	7.06	10.71	4.76	3.82	5.04	5.26	3.60
Sb	<u>0.10</u>	<u>0.36</u>	<u>0.37</u>	<u>0.39</u>	<u>0.27</u>	<u>0.27</u>	<u>0.27</u>	<u>0.53</u>	<u>0.52</u>	<u>0.50</u>	<u>0.53</u>	<u>0.35</u>	<u>0.35</u>	<u>0.36</u>	<u>0.36</u>
As	<u>0.34</u>	<u>1.20</u>	<u>1.24</u>	6.44	<u>0.90</u>	<u>0.90</u>	<u>0.90</u>	<u>1.77</u>	<u>1.72</u>	<u>1.67</u>	<u>1.76</u>	<u>1.16</u>	<u>1.17</u>	<u>1.20</u>	<u>1.20</u>
Ba	<u>0.15</u>	<u>0.29</u>	<u>0.32</u>	<u>0.89</u>	<u>0.26</u>	<u>0.36</u>	<u>0.21</u>	0.34	0.59	0.95	0.51	0.45	0.25	0.45	0.35
Be	<u>0.01</u>	<u>0.02</u>	<u>0.02</u>	<u>0.03</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	<u>0.04</u>	<u>0.03</u>	<u>0.03</u>	<i>0.07</i>	<i>0.02</i>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>
Cd	<i>0.01</i>	0.11	<i>0.06</i>	<i>0.04</i>	0.06	0.08	0.08	0.19	0.24	0.27	0.26	0.09	0.18	0.50	0.16
Ca	318.17	32.49	29.85	29.60	18.07	30.71	21.68	24.75	46.48	85.37	26.43	27.76	26.94	38.27	22.80

Cr	0.10	0.94	0.62	0.71	0.39	0.54	0.45	0.72	0.90	0.84	0.95	0.64	0.66	0.61	0.47
Co	<u>0.01</u>	<u>0.04</u>	<u>0.04</u>	<u>0.04</u>	<u>0.03</u>	0.04	<u>0.03</u>	0.05	0.05	<u>0.05</u>	<u>0.14</u>	<u>0.03</u>	<u>0.04</u>	<u>0.04</u>	0.04
Cu	0.17	0.52	0.72	0.68	0.33	0.67	0.23	0.58	1.48	1.84	0.65	0.60	0.59	1.20	0.59
Fe	<u>0.68</u>	19.25	38.56	28.31	21.68	36.13	14.45	33.59	68.86	61.94	31.71	30.07	42.17	49.04	49.20
La	<u>0.00</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.02</u>	<u>0.02</u>	<u>0.02</u>	0.05	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>
Pb	<u>0.10</u>	0.66	<u>0.37</u>	0.93	<u>0.27</u>	0.49	0.41	<u>0.53</u>	0.71	12.55	<u>0.53</u>	0.50	0.67	0.87	0.48
Li	<u>0.34</u>	1.20	<u>1.24</u>	<u>1.29</u>	<u>0.90</u>	<u>0.90</u>	<u>0.90</u>	<u>1.77</u>	<u>1.72</u>	<u>1.67</u>	<u>1.76</u>	<u>1.16</u>	<u>1.17</u>	<u>1.20</u>	<u>1.20</u>
Mg	1.68	2.29	2.24	2.45	1.36	2.62	1.54	<u>1.77</u>	3.79	7.03	2.11	2.66	2.34	3.35	2.04
Mn	<u>0.01</u>	0.43	0.51	0.53	0.34	0.61	0.32	0.57	1.22	1.09	0.72	0.61	0.52	0.84	0.86
Mo	<u>0.07</u>	<u>0.24</u>	<u>0.25</u>	<u>0.26</u>	<u>0.18</u>	<u>0.18</u>	<u>0.18</u>	<u>0.35</u>	<u>0.34</u>	<u>0.33</u>	<u>0.35</u>	<u>0.23</u>	<u>0.23</u>	<u>0.24</u>	<u>0.24</u>
Ni	<u>0.01</u>	0.66	0.49	0.58	0.30	0.48	0.14	0.46	0.65	0.62	0.65	0.38	0.47	0.73	0.28
P	171.06	3.25	<u>2.49</u>	<u>2.57</u>	<u>1.81</u>	3.07	<u>1.81</u>	<u>3.54</u>	<u>3.44</u>	4.18	<u>3.52</u>	<u>2.43</u>	2.34	2.75	<u>2.40</u>
K	0.19	3.13	2.86	2.70	1.81	4.52	2.08	3.18	4.99	12.22	3.70	3.24	2.69	4.66	2.76
Se	<u>0.24</u>	<u>0.84</u>	3.23	2.83	<u>0.63</u>	2.26	<u>0.63</u>	<u>1.24</u>	1.29	2.68	1.66	<u>0.81</u>	<u>0.82</u>	<u>0.84</u>	1.15
Ag	<u>0.01</u>	<u>0.02</u>	0.04	0.09	0.05	0.05	0.03	0.07	0.07	0.13	0.07	0.06	0.04	0.10	0.07
Sr	0.19	0.26	0.35	0.40	0.31	0.56	0.26	0.51	1.31	0.80	0.39	0.38	0.36	0.73	1.32
Te	<u>0.17</u>	<u>0.60</u>	<u>0.62</u>	<u>0.64</u>	<u>0.45</u>	<u>0.45</u>	<u>0.45</u>	<u>0.88</u>	<u>0.86</u>	<u>0.84</u>	<u>0.88</u>	<u>0.58</u>	<u>0.59</u>	<u>0.60</u>	<u>0.60</u>
Tl	<u>0.24</u>	<u>0.84</u>	<u>0.87</u>	<u>0.90</u>	<u>0.63</u>	<u>0.63</u>	<u>0.63</u>	<u>1.24</u>	<u>1.21</u>	<u>1.17</u>	<u>1.23</u>	<u>0.81</u>	<u>0.82</u>	<u>0.84</u>	<u>0.84</u>
Sn	<u>0.34</u>	1.20	<u>1.24</u>	<u>1.29</u>	<u>0.90</u>	<u>0.90</u>	<u>0.90</u>	<u>1.77</u>	<u>1.72</u>	21.76	<u>1.76</u>	<u>1.16</u>	<u>1.17</u>	<u>1.20</u>	<u>1.20</u>
Ti	0.03	0.24	0.30	0.49	0.25	0.42	0.22	0.41	0.93	0.75	0.41	0.37	0.41	0.55	0.83
V	<u>0.01</u>	<u>0.04</u>	<u>0.04</u>	<u>0.04</u>	<u>0.03</u>	<u>0.03</u>	<u>0.03</u>	0.05	<u>0.05</u>	<u>0.05</u>	0.07	<u>0.03</u>	<u>0.04</u>	<u>0.04</u>	0.04
Y	0.00	0.01	0.01	0.03	0.03	0.03	0.02	0.07	0.07	0.40	0.11	0.05	0.02	0.04	0.05
Zn	<u>0.07</u>	4.81	7.09	11.33	3.70	5.33	2.35	6.54	8.61	10.88	11.10	8.67	8.67	10.05	4.08
Zr	<u>0.14</u>	<u>0.48</u>	<u>0.50</u>	<u>0.51</u>	<u>0.36</u>	<u>0.36</u>	<u>0.36</u>	<u>0.71</u>	<u>0.69</u>	0.74	1.76	<u>0.46</u>	<u>0.47</u>	<u>0.48</u>	<u>0.48</u>

Appendix D
Metallic Composition of Filter Samples
Concentrations are in $\mu\text{g}/\text{m}^3$

Sample ID	E2CMTR-01	E2CMTR-02	E2CMTT-01	E2CHTT-02	E2CMTT-03	E2CMWT-01	E2CMWT-02	E2CMWT-03	E2CMWT-04	E2CMWT-05	E2CMWR-01	E2CHWR-02
Date	12/11/07	12/11/07	12/11/07	12/11/07	12/11/07	12/12/07	12/12/07	12/12/07	12/12/07	12/12/07	12/12/07	12/12/07
Al	<0.86	<0.84	<1.26	<1.18	<1.17	<1.42	<1.51	<1.39	<1.41	<1.44	<1.04	<1.02
Sb	<0.34	<0.34	<0.50	<0.47	<0.47	<0.57	<0.60	<0.56	<0.56	<0.58	<0.42	<0.41
As	<0.60	<0.59	<0.88	<0.83	<0.82	<0.99	<1.05	<0.97	<0.98	<1.01	<0.73	<0.71
Ba	0.15	0.22	1.02	1.66	0.08	0.08	0.99	1.03	0.04	0.82	0.05	0.11
Be	<0.02	<0.02	<0.03	<0.02	<0.02	<0.03	<0.03	<0.03	<0.03	<0.03	<0.02	<0.02
Cd	<0.03	<0.03	0.65	0.98	<0.05	<0.06	<0.06	0.64	<0.06	0.45	<0.04	<0.04
Ca	5.13	3.29	10.67	14.21	15.27	14.06	16.57	23.67	5.34	18.74	3.23	4.58
Cr	<0.17	<0.17	0.34	<0.24	<0.23	<0.28	<0.30	<0.28	<0.28	<0.29	<0.21	<0.20
Co	<0.04	<0.04	<0.06	<0.06	<0.06	<0.07	<0.08	<0.07	<0.07	<0.07	<0.05	<0.05
Cu	0.04	0.08	0.19	0.20	0.11	0.18	0.18	0.35	0.11	0.19	<0.03	0.05
Fe	<1.71	<1.68	6.53	11.84	4.93	10.79	18.07	16.71	2.95	6.92	<2.09	<2.04
La	<0.009	<0.008	<0.013	<0.012	<0.012	<0.014	<0.015	<0.014	<0.014	<0.014	<0.010	<0.010
Pb	0.31	0.29	3.26	8.17	<0.23	<0.28	0.31	0.31	<0.28	0.31	<0.21	<0.20
Li	<0.009	<0.008	<0.013	<0.012	<0.012	<0.014	<0.015	<0.014	<0.014	<0.014	<0.010	<0.010
Mg	0.28	0.16	0.67	1.11	0.80	0.50	0.66	1.39	0.31	0.88	<0.10	<0.10
Mn	<0.04	0.05	0.09	0.40	0.11	0.12	0.18	0.24	<0.07	0.14	<0.05	<0.05
Mo	<0.26	<0.25	<0.38	<0.36	<0.35	<0.43	<0.45	<0.42	<0.42	<0.43	<0.31	<0.31
Ni	0.02	<0.08	0.13	0.17	0.15	0.11	0.15	0.21	<0.14	<0.14	<0.10	<0.10
P	<0.86	<0.84	<1.26	<1.18	<1.17	<1.42	<1.51	<1.39	<1.41	<1.44	<1.04	<1.02
K	0.27	0.26	1.23	2.01	0.56	<0.43	1.01	2.09	<0.42	1.44	<0.31	<0.31
Se	<2.57	<2.53	<3.77	<3.55	<3.52	<4.26	<4.52	<4.18	<4.22	<4.32	<3.13	<3.06
Ag	<0.009	<0.008	<0.013	<0.012	<0.012	<0.014	<0.015	<0.014	<0.014	<0.014	<0.010	<0.010
Sr	0.06	0.07	0.41	0.50	0.04	0.31	0.30	0.56	0.34	0.58	0.01	0.05
Te	<0.34	<0.34	<0.50	<0.47	0.05	<0.57	<0.60	<0.56	0.47	0.83	<0.42	<0.41
Tl	<0.43	<0.42	<0.63	<0.59	<0.59	<0.71	<0.75	<0.70	<0.70	<0.72	<0.52	<0.51

Sn	<0.60	<0.59	<0.88	<0.83	<0.82	<0.99	1.08	<0.97	<0.98	<1.01	<0.73	<0.71
Ti	0.02	<0.01	0.05	0.08	0.07	0.18	0.11	0.18	0.18	0.12	<0.01	<0.01
V	<0.02	<0.02	<0.03	<0.02	<0.02	<0.03	<0.03	<0.03	<0.03	<0.03	<0.02	<0.02
Y	0.33	0.75	40.18	59.22	0.27	0.33	28.62	20.89	<0.03	25.94	0.16	0.35
Zn	1.0	1.8	63.9	65.0	1.4	2.0	39.0	38.8	0.8	43.1	0.4	1.1
Zr	<0.09	<0.08	<0.13	<0.12	<0.12	<0.14	<0.15	<0.14	<0.14	<0.14	<0.10	<0.10

Appendix D (Continued)

Sample ID	E2CMWR-03	E2CMWR-04	E2CMWR-05	E2CMWT-06	E2CMWR-06	E2CMHT-01	E2CMHT-02	E2CMHT-03	E2CMHR-02	E2CMHR-03	E2CMHR-04
Date	12/12/07	12/12/07	12/12/07	12/12/07	12/12/07	12/13/07	12/13/07	12/13/07	12/13/07	12/13/07	12/13/07
Al	<1.03	<1.01	<1.04	<1.36	<0.58	<0.78	2.98	5.80	<0.54	<1.09	<1.06
Sb	<0.41	<0.40	<0.42	<0.54	<0.23	<0.31	<0.63	<0.59	<0.22	<0.44	<0.42
As	<0.72	<0.70	<0.73	<0.95	<0.41	<0.54	<1.10	<1.04	<0.38	<0.77	<0.74
Ba	0.04	<0.02	<0.02	0.35	<0.01	0.31	2.19	3.42	0.25	0.37	0.53
Be	<0.02	<0.02	<0.02	<0.03	<0.01	<0.02	<0.02	<0.03	<0.01	<0.02	<0.02
Cd	<0.04	<0.04	<0.04	<0.05	<0.02	0.37	7.83	12.93	0.08	<0.04	0.11
Ca	3.40	2.71	3.13	62.45	0.64	4.51	25.07	38.63	3.81	4.81	6.22
Cr	<0.21	<0.20	<0.21	<0.27	<0.12	<0.16	0.38	0.43	<0.11	<0.22	<0.21
Co	<0.05	<0.05	<0.05	<0.07	<0.03	<0.04	<0.08	<0.07	<0.03	<0.05	<0.05
Cu	0.10	0.43	0.20	1.29	0.06	0.06	0.33	0.48	0.13	0.11	0.19
Fe	<2.06	<2.01	<2.09	10.05	<1.16	2.18	12.85	26.75	1.63	<2.19	<2.11
La	<0.010	<0.010	<0.010	<0.014	<0.006	<0.008	<0.016	0.030	<0.005	<0.011	<0.011
Pb	<0.21	<0.20	<0.21	0.31	<0.12	0.31	0.31	0.31	0.31	0.31	0.31
Li	<0.010	<0.010	<0.010	<0.014	<0.006	<0.008	<0.016	<0.015	<0.005	<0.011	<0.011
Mg	<0.10	<0.10	<0.10	1.63	<0.06	0.18	1.44	2.38	0.27	0.13	0.27
Mn	<0.05	0.71	0.20	0.26	<0.03	<0.04	0.33	0.56	0.14	<0.05	<0.05
Mo	<0.31	<0.30	<0.31	<0.41	<0.17	<0.23	<0.47	<0.45	<0.16	<0.33	<0.32
Ni	<0.10	<0.10	0.06	0.15	0.01	0.12	0.08	0.31	0.02	<0.11	0.07
P	<1.03	<1.00	<1.04	<1.36	<0.58	<0.78	<1.57	49.04	<0.54	<1.09	4.64

K	<0.31	<0.30	<0.31	1.00	<0.17	0.64	4.70	5.50	0.87	0.51	1.16
Se	<3.09	<3.01	<3.13	<4.07	<1.74	<2.33	<4.70	<4.46	<1.63	<3.28	<3.17
Ag	<0.010	<0.010	<0.010	<0.014	<0.006	<0.008	<0.016	<0.015	<0.005	<0.011	<0.011
Sr	0.08	<0.01	1.25	0.90	0.70	0.16	1.02	1.63	1.03	0.12	0.24
Te	<0.41	<0.40	1.31	<0.54	<0.23	<0.31	<0.63	<0.59	<0.22	<0.44	<0.42
Tl	<0.52	<0.50	<0.52	<0.68	<0.29	<0.39	<0.78	<0.74	<0.27	<0.55	<0.53
Sn	<0.72	<0.70	<0.73	<0.95	<0.41	<0.54	<1.10	<1.04	<0.38	<0.77	<0.74
Ti	0.05	<0.01	0.56	0.50	<0.01	0.03	0.15	0.28	0.50	<0.01	0.02
V	<0.02	<0.02	<0.02	<0.03	<0.01	<0.02	<0.03	<0.03	<0.01	<0.02	<0.02
Y	0.39	<0.02	<0.02	0.09	<0.01	7.70	104.96	178.31	2.34	1.86	3.27
Zn	1.0	0.1	0.4	4.1	0.0	17.8	234.8	386.2	6.5	5.4	9.0
Zr	<0.10	<0.10	<0.10	<0.14	<0.06	<0.08	<0.16	<0.15	<0.05	<0.11	<0.11

Figure I

Diagram of the Unicorn factory located within the FCI main compound
(See Figure IV for more detail of Glass Breaking Operation)

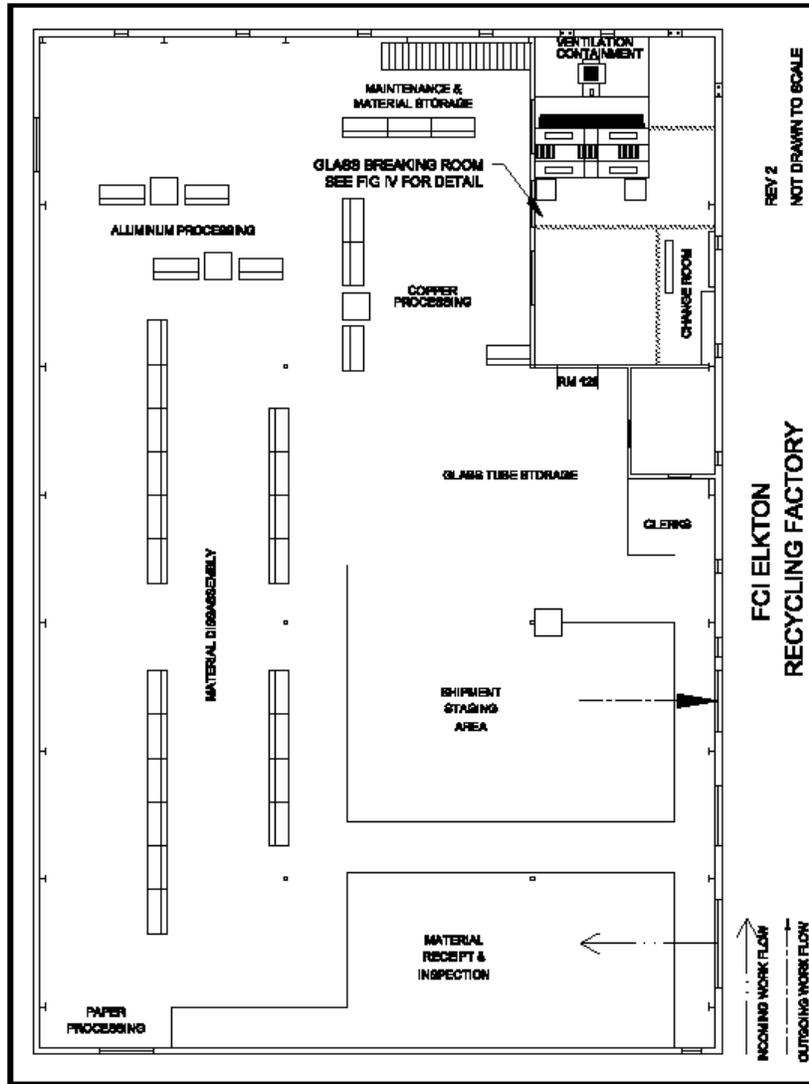


Figure II Diagram of the Unicorn facility in the Federal Satellite Low (FSL)

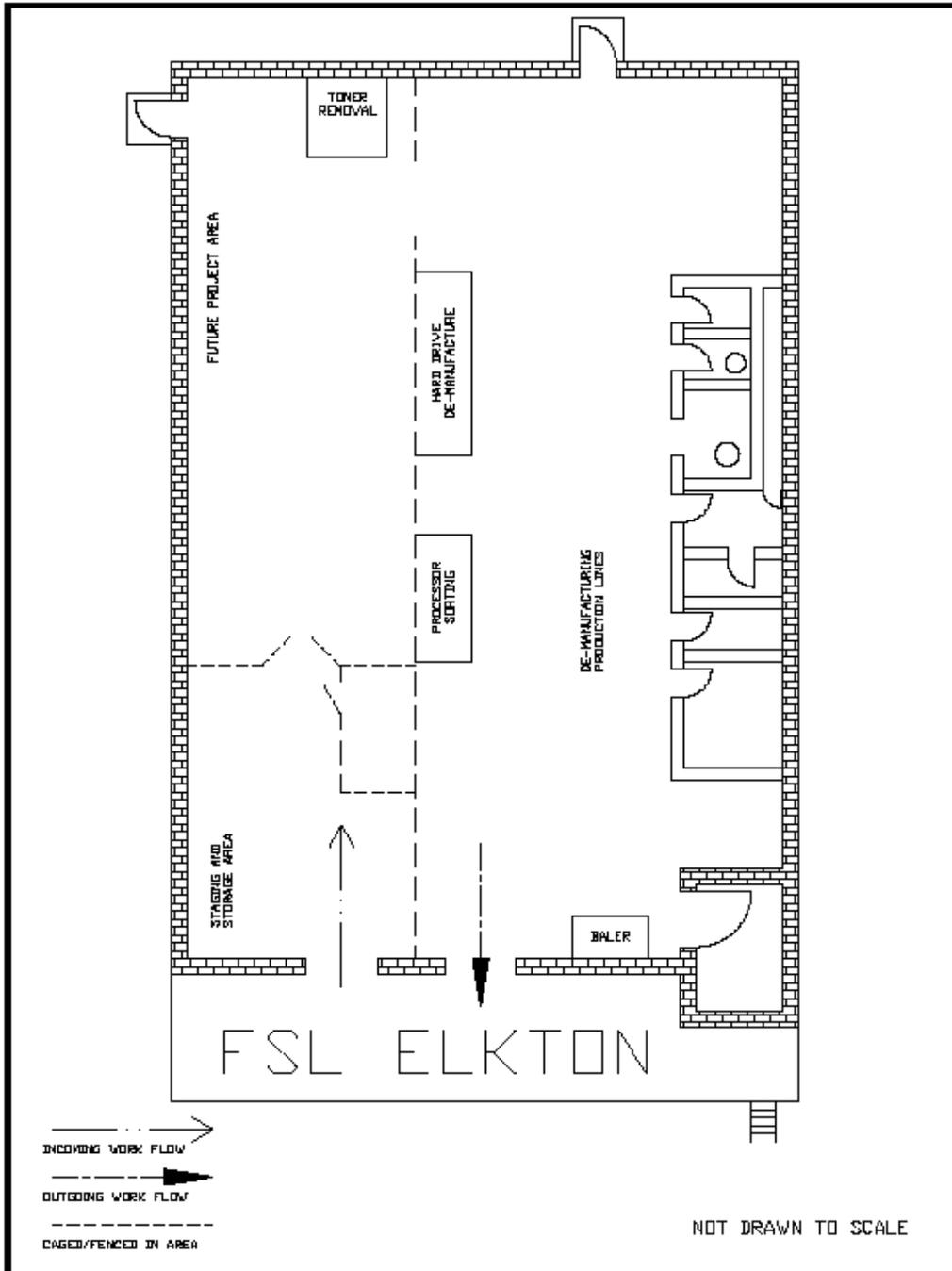


Figure III Diagram of the warehouse handling electronics recycling operations

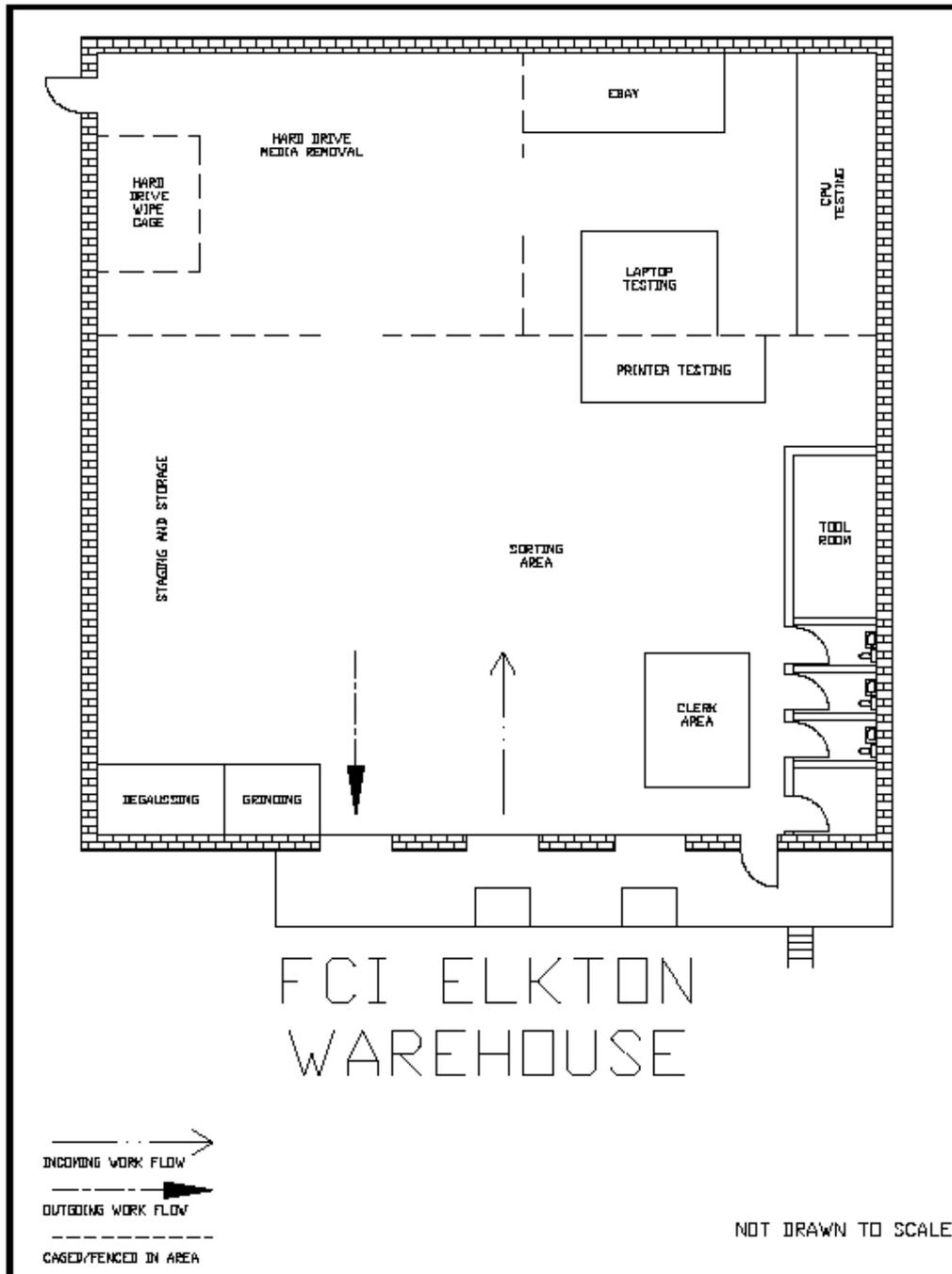


Figure IV Diagram of the glass breaking area within the FCI

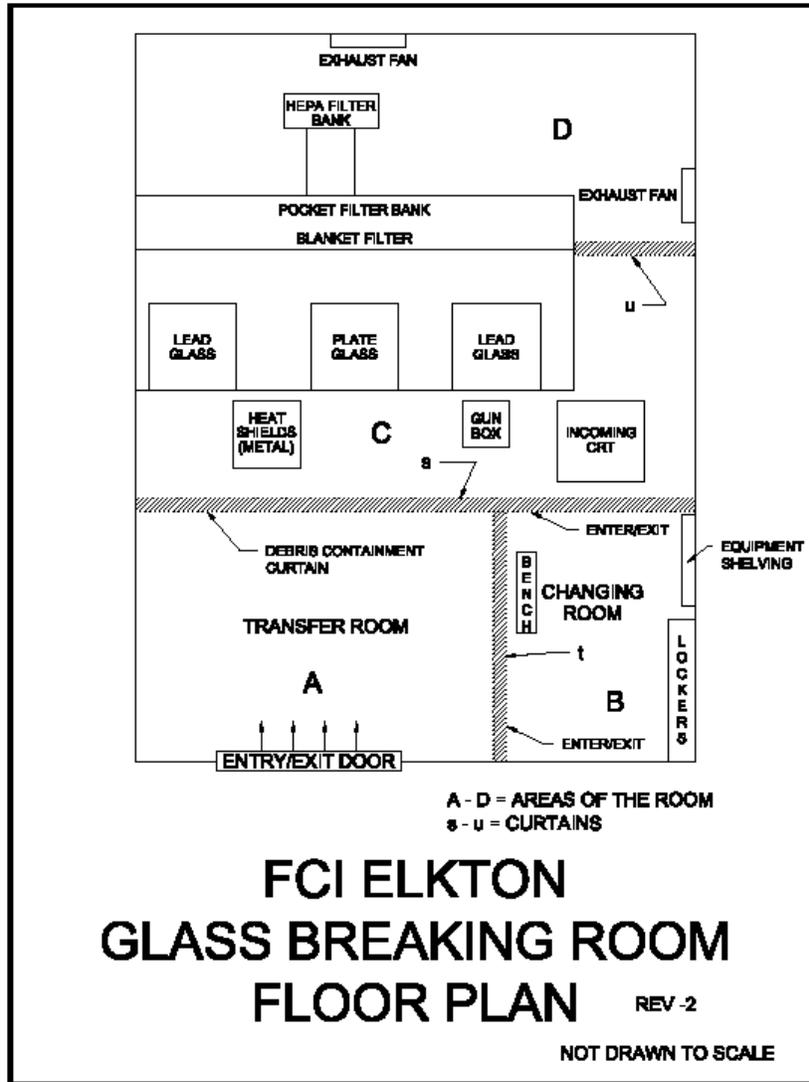


Figure V – Elkton Warehouse Showing Storage Areas with Boxes of Items to be Recycled



Figure VI – Overview of Elkton Recycling Factory Disassembly Area



Figure VII – Electron Gun Removal in Glass Breaking Operation



Figure VIII – Filter Change Operation in Glass Breaking Area
Showing Large Amount of Visible Dust



Figure IX – Five cut particle size distribution from impactor data

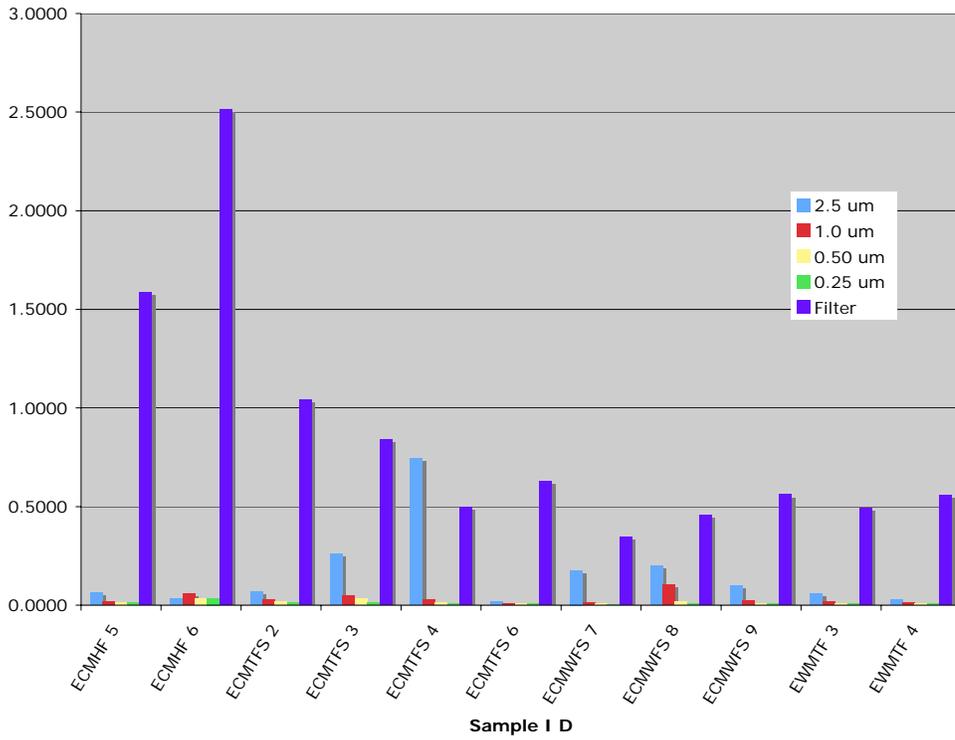


Figure X – Three cut particle size distribution from impactor data

