CONTROL TECHNOLOGY AND EXPOSURE ASSESSMENT FOR ELECTRONIC RECYCLING OPERATIONS, UNICOR MARIANNA FEDERAL CORRECTIONAL INSTITUTION MARIANNA, FLORIDA

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TABLE OF CONTENTS

Page

Tables, Appendices and Figures

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, Inc. (FPI) facilities (aka, UNICOR) in Marianna, Florida, in August, 2007 to assess worker exposures to metals and other occupational hazards, including heat, associated with these operations.

The electronics recycling operations at Marianna 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, cadmium, 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 sampling for airborne metals and particulate; surface wipe sampling to assess surface contamination; and bulk material samples to determine the composition of settled dust. Samples were analyzed for 31 metals with five selected elements (barium, beryllium, cadmium, lead and nickel) given emphasis. Heat exposures were determined using wet bulb globe temperature monitors.

The results of air sampling conducted during the August visit indicated no overexposures of workers to metals above the most stringent occupational exposure limits during the routine and non-routine operations evaluated during that site visit. The highest exposures to metals (as determined by both arithmetic and geometric means) occurred to workers in the Federal Prison Camp (FPC) glass breaking operation while changing filters, while workers in the Federal Prison Camp (FPC) UNICOR factory had the highest exposure to airborne particulate during routine production operations. The results of two of those samples were affected by unanticipated events. In one instance, a worker touched the inlet of the cassette with her glove and some lint was sucked onto the filter. In the other, a worker unloading a truck reported that toner spilled onto her from surplus equipment she was unloading. When those two samples (which did not exceed allowable limits) are not considered, the particulate concentrations are well below levels of concern. When those two samples are not included in the analyses, the FPC glass breakers had the highest particulate exposures. These occurred during the filter change operation.

Exposures to airborne metals during the filter change-out maintenance operation were higher than exposures during other operations in the FPC but were below the most stringent occupational exposure limits. Total airborne particulate levels were higher during this operation than elsewhere, when the two samples described above are disregarded. Total particulate concentrations during routine glass-breaking operations ranged from <71 $\mu g/m^3$ (140 minute sample) for a breaker to 891 $\mu g/m^3$ (147 minute sample) for a feeder. During the filter change operation, they ranged from 4,912 $\mu g/m^3$ (57 minute sample) for a worker working inside the glass-breaking booth to 274 $\mu g/m^3$ (45 minute sample) for a worker outside the booth. All airborne particulate measurements representing potential exposures during routine and non-routine operations were, however, below applicable occupational exposure limits (e.g., the OSHA PEL of 15 mg/m^3 (15000 $\mu g/m^3$), 8-hr TWA for total particulate).

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], beryllium in this study was not detected at levels above the detection limit of the analytical method. Most of the recycling activities at this facility resemble typical maintenance activities on consumer products (e.g., personal computers), such as opening cases and removing components. Willis and Florig [2002] noted that most beryllium "in consumer products is used in ways that are not likely to create beryllium exposures during use and maintenance." This may account for the results seen at this facility. Other e-recycling activities that include further processing, such as shredding of the components, may produce higher exposures to beryllium but shredding does not occur at this facility.

Samples collected during routine daily glass breaking operations showed that the highest exposure was less than 10% of the OSHA PEL for lead of 50 µg/m^3 8 hr TWA (4.5 µg/m^3 8hr TWA for a 109 minute sample). The highest lead exposure measured during the filter change operation was 12.5 µg/m^3 8 hr TWA for a 57 minute sample. The highest cadmium result during routine glass breaking was 2.0 µg/m^3 8hr TWA for a 143 minute sample, less than half the OSHA PEL of 5 µg/m^3 8hr TWA. During the filter change operation, the highest cadmium concentration was 1.4 µg/m^3, 8hr TWA, for a 57 minute sample. Samples collected on disassembly workers in the FCI factory area and on workers in the FPC factory area were well below levels of concern for cadmium, lead and nickel. Unless specified, the results of the samples presented are for the 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. Some 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.

Environmental heat monitoring and estimates of work rate indicated that some workers in this facility were exposed to heat stress (e.g., above the ACGIH® TLV®) or at risk of heat stress (e.g., exceeding the ACGIH® Action Limit) during this survey period. The locations where heat stress was noted included the glass breaking operation (breakers, feeders, and outside workers) and the warehouse (truck crew), while a risk of heat stress was noted in the warehouse (other workers), FCI-disassembly and FCI-Refurbish.

Recommendations resulting from this study include:

- The implementation of a site specific health and safety program at Marianna that includes a heat stress program.
- The respiratory protection program for this facility should be evaluated to ensure that it complies with OSHA regulations.
- Attention should be focused on practices to prevent accidental ingestion of lead and other metals, such as housekeeping to reduce surface contamination and hand washing to prevent hand-to-mouth transfer of contaminants.
- 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.
- 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 of Prisons 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, UNICOR) in Marianna, Florida*. 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 create dermal exposures or allow re-entrainment of metals into the air.

3. To identify and describe the control technology and work practices used in operations associated with occupational exposures to beryllium, as well as to determine additional controls, work practices, substitute materials, or technology that can further reduce occupational exposures to beryllium and other metals.

4. To evaluate the use of personal protective equipment in operations involved in the recycling of electronic components.

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

An evaluation was conducted August 8 - 9, 2007, by NIOSH researchers from the Engineering and Physical Hazards Branch, Division of Applied Research and Technology, Cincinnati, Ohio. During this evaluation, two full shifts of environmental monitoring were conducted for the duration of routine plant operations, and monitoring was also conducted during non-routine operations, such as cleaning and maintenance as described in Section II (Process Description) and Section III (Sampling and Analytical Methods).

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 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

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

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.

The reports referenced in the two preceding paragraphs cite the potential hazards of electronic waste by listing the constituents of electronic components. However, they do not cite any data on emissions or occupational exposures that resulted from recycling work practices. 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. In contrast to the reports of potential hazards cited above, 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/m^3 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].

There are very few articles documenting actual 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. Recycling operations in the Marianna 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 (GBO, 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 lead, cadmium, beryllium and nickel. In addition, Federal Occupational Health (FOH) investigators expressed a particular interest in those metals and barium because of whistleblower allegations that inmate workers and civilian staff members were being exposed to toxic materials, including lead, cadmium, barium, and beryllium, at electronics recycling operations overseen by Federal Prison Industries (UNICOR) at a number of BOP facilities around the country.

Due to the location and time of the evaluation at this facility, the potential for heat stress was also evaluated at the Marianna recycling operation. This information was presented to the Bureau of Prisons and FOH in an earlier report dated September 26, 2007 and is included as part of this report.

II. PROCESS DESCRIPTION

The recycling of electronic components at the Marianna Federal Correctional Institution (FCI) is done in two separate buildings: 1) the main factory located within the FCI main compound; and 2) the Federal Prison Camp (FPC) located approximately a quarter mile to the south on the same property. Diagrams of these work areas are shown in Figures I and II, respectively, with an enlargement of the GBO in Figure III. These figures provide the layout of the work process, although workers often moved throughout the various areas in the performance of their tasks. The population of the UNICOR FCI facility was approximately 205 workers and of the FPC approximately 86 workers.

The recycling of electronic components at this facility 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 destined for recycling are received at a warehouse where they are examined and sorted. A truck crew loads and unloads semi-trailers at the loading dock in the warehouse area. They unloaded two trailers on August 8 and loaded two and unloaded two on August 9. 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 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 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 included 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 GBO 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. Workers in the GBO wore personal protective equipment (PPE) based upon their assigned work.

Two outside workers moved inventory for feeders and breakers. One wore a tee-shirt, work pants and cloth gloves; the other wore a short-sleeve work shirt, work pants and cloth gloves. Two feeders removed CRTs from large (Gaylord) boxes and placed them on a roller conveyor for the breakers. Feeders wore spun-bonded olefin coveralls over tee-shirts and work pants, shoe covers, Kevlar® sleeve guards, and cloth work gloves with rubberized palms and fingers. Two breakers broke the funnel and panel glass. The breakers wore loose-fitting hood-type powered air-purifying respirators (PAPRs), (MB14-72 PAPR w/ Super Top Hood, Woodsboro, MD, Global Secure Safety), spun-bonded olefin coveralls over work pants and tee-shirts, shoe covers over work boots, cloth work gloves over rubber gloves, and Kevlar® sleeve guards. The PPE is kept in lockers against a wall in the GBO, opposite the glass-breaking booth. When the breakers are finished breaking glass, they clean the floor, first with brooms and then with a high-efficiency particulate air (HEPA) vacuum cleaner. The breakers leave the booth in their coveralls and PAPR, use another HEPA vacuum cleaner on their coveralls before removing them, then remove and dispose of their coveralls, remove their PAPRs and leave the work area. Shoes are HEPA-vacuumed before exiting the GBO (visitors are offered shoe covers). Battery chargers for the PAPRs are located on a bookcase against the wall adjacent to the glass-breaking booth in the staging area.

CRTs that had been removed from their cases were trucked to this process area in large boxes. These are staged by the outside workers using a pallet jack. The CRTs are lifted by hand from Gaylord boxes by the feeders and placed on a roller conveyor through an opening on the side of the glass breaking enclosure. The breakers roll the CRTs onto an angle-iron grate for breaking (see Figure IV). Each breaker stands on an elevated platform facing the grate, which is positioned in front of the local-exhaust ventilation unit described by the manufacturer as a reverse flow horizontal filter module (HFM). As the CRT moved from left to right in the booth 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 grate into large Gaylord boxes (cardboard boxes approximately 3 feet tall designed to fit on a standard pallet) positioned below the grate. This was done at the first (left) station in Figure V. The CRT was moved to the second (right) station where 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 two days of sampling 293 and 258 CRTs were broken. Various sources on-site stated that "normal production" was approximately 300 CRTs per day. The work shift in the GBO was abbreviated due to the environmental heat on both days, and was further shortened on August 9 to allow time for the filter change procedure. Given the shortened work schedule, the production rate (number of CRTs broken) on the days of sampling was not thought to be lower than expected for a typical day. No count was made by the survey team regarding the number of color vs. monochrome monitors broken.

The HFMs were designed and manufactured by Atmos-Tech Industries (model HFM24-ST/RF/SP, Ocean City, NJ). Each unit is equipped with a bank of 35% efficient pleated pre-filters and a HEPA filter, a direct-drive 1200 cfm fan with a ½ horsepower motor, and a control panel with a minihelic pressure gauge and variable speed control. Air enters through the pre-filters in the front of the unit, passes through the HEPA filter, and is discharged into the room through a grille at the back of the unit. A frame attached to the front of each unit supports 24-in long plastic strip curtains on the front and sides. The top is enclosed with a sheet of ¼-inch clear polycarbonate plastic. The prefilters are held in place by a metal grille. Glass breaking is performed on top of an angle-iron grate inside the area enclosed by the strip curtains. Figure V shows the left-hand HFM, number 1.

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 the replacement of filters in the local exhaust ventilation system used for the GBO. This is a maintenance operation that occurs at approximately monthly intervals during which the two sets of filters in this ventilation system are removed and replaced. This operation was of particular interest because of concern expressed by management and workers and also because of elevated exposures documented in previous similar operations. Two workers in spun-bonded olefin coveralls, gloves and PAPRs remove both sets of filters, clean the system, and replace the filters. They are assisted by two additional workers who wear spun-bonded olefin coveralls and gloves while working outside the glass breaking enclosure. The filter change is a maintenance operation that occurs at approximately monthly intervals during which the ventilation system is shut down and all filters are removed and replaced. Initially the exhaust system components, including the accessible surfaces of the filters, are vacuumed with a HEPA vacuum. Then the filters are removed and bagged for disposal, and the area inside the filter housing is vacuumed. New filters are inserted to replace the old ones, the LEV system is reassembled, and any residual dust is HEPA vacuumed.

III. SAMPLING AND ANALYTICAL METHODS

Air sampling techniques

Methods used to assess worker exposures in this workplace evaluation included: personal breathing zone sampling for airborne metals and total particulate; 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 lead, cadmium, beryllium and nickel. Additionally, FOH personnel expressed specific interest in barium due to whistleblower allegations that inmate workers and civilian staff members were being exposed to toxic materials, including lead, cadmium, barium, and beryllium, at electronics recycling operations overseen by Federal Prison Industries (UNICOR) at a number of BOP facilities around the country.

Personal breathing zone and general area airborne particulate samples were collected and analyzed for metals and 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 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. The method does not distinguish among the compounds which may have contained the element in the sample.

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]. An aerodynamic particle sizer (APS model 3321, TSI Instruments, Shoreview, MN) was used to collect this information on a real time basis with data transfer directly to a laptop computer. The number concentration [number of particles/cubic centimeter (cm^3)] of particles of various sizes was counted over the range from 0.5 to 20 µm a using time-of-flight technique. The sampler was placed inside of the glass-breaking enclosure.

Bulk sampling and analysis

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 contamination technique

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].

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.

Heat Exposure Measurements

Measurements to determine heat exposure were made with a QUESTemp° 34 datalogging thermal environment monitor (Quest Technologies, Oconomowoc, WI). This device was capable of measuring wet-bulb, dry-bulb and globe temperatures and calculating the Wet Bulb Globe Temperature Index $(WBGT)_{out}$ (for solar load, not used for this evaluation), $WBGT_{in}$ (for no solar load), and humidity. The $WBGT_{in}$ (indoors or outdoors with no solar load) is the sum of 0.7 times the Natural Wet-Bulb (NWB) Temperature and 0.3 times the Globe Temperature (GT), expressed by the equation:

$$WBGT_{in} = 0.7\ NWB + 0.3\ GT$$

Where NWB is measured using a natural (static) wet-bulb thermometer and GT is measured using a black globe thermometer. Measurements were stored electronically in the instrument and downloaded to a computer at the end of the work day.

Local Exhaust Ventilation Characterization Methods
Several methods were used to evaluate the local exhaust ventilation system. These methods included measuring air velocity at the face of each of the HFMs inside the glass-breaking area, and measuring air velocities at the plastic curtains enclosing the glass-breaking grate in front of each HFM. In addition, a smoke tracer was used to confirm the direction of the airflow and effect of secondary airflows on hood performance. A Velocicalc Plus Model 8388 thermal anemometer (TSI Incorporated, St. Paul, MN) was used to measure air speeds at the face of each HFM and just inside the enclosing plastic strip curtain. A Wizard Stick smoke device (Zero Toys, Inc., Concord, MA) was used to visualize air flow.

The face velocity tests were performed by dividing the face of the HFM into 12 rectangles of equal area and measuring the velocity at the center of each. Face velocities were taken at each center point averaged over a period of 30 seconds, using a 5-second time averaging setting on the instrument. The metal grid in front of the pre-filters was used to support the edge of the probe and the researcher stood to one side to avoid obstructing air flow. To measure the velocities achieved by the control at each center point, the anemometer probe was held perpendicular to the air flow direction at those points. The same measurements were repeated at the front edge of the plastic strip curtains enclosing the area immediately in front of each HFM to determine the capture velocity at that point.

Smoke was released around the periphery of the hood and in the interior of the hood to qualitatively evaluate the capture and determine areas of concern. By releasing smoke at points in and around the hood, the path of the smoke, and thus any airborne material potentially released at that point, could be qualitatively determined.

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.

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[*] 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.

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 Governmental Industrial Hygienists (ACGIH)®, a professional organization [ACGIH 2008]. ACGIH® TLV®s 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 the American Industrial Hygiene Association (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

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[†] 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]

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® TLV®s 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

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

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 (μg/m^3), are summarized in Table 1 and additional information related to those exposure limits is presented below.

Table 1: Occupational Exposure Limits for Five Metals of Primary Interest (μg/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

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 due to whistleblower allegations that inmate workers and civilian staff members were being exposed to toxic materials, including lead, cadmium, barium, and beryllium, at electronics recycling operations overseen by Federal Prison Industries (UNICOR) at a number of BOP facilities around the country.

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 TLV®s, beryllium and compounds, as Be; cadmium and compounds, as Cd [ACGIH 2008]). Additionally, the OEL for dust is presented here to place those air sampling results in perspective.

Occupational Exposure Criteria for Barium (Ba)
The current OSHA PEL, NIOSH REL, and ACGIH® TLV® is 0.5 mg/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 µg/m^3 for an 8-hour TWA, a ceiling concentration of 5 µg/m^3, not to exceed 30 minutes and a maximum peak concentration of 25 µg/m^3, not to be exceeded for any period of time [29 CFR 1910.1000]. The NIOSH REL for beryllium is 0.5 µg/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 µg/m^3, and a STEL of 10 µg/m^3 [ACGIH 2008]. The ACGIH® published a notice of intended changes for the beryllium TLV® to 0.05 µg/m^3 TWA and 0.2 µg/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 µg/m^3 as a TWA [29 CFR 1910.1027]. Exposure at or above half that value, the Action Level of 2.5 µg/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 (β2-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 µg/g creatinine, or (2) CdB level: above 10 µg/liter of whole blood, or (3) β2-M level: above 750 µg/g creatinine and (a) CdU exceeds 3 µg/g creatinine or (b) CdB exceeds 5 µg/liter of whole blood [OSHA 2004].

The ACGIH® TLV® for cadmium and compounds as cadmium is 10 µg/m^3 as a TWA, and 2 µg/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 µg/L and urine level to be below 5 µg/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 µg/m^3 as a 10-hour TWA or a concentration greater than 200 µg/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 1990.103). 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 µg/m^3. Also, most existing facilities or operations can be retrofitted to contain cadmium to a level of 5 µg/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 µg/m^3 (8-hour TWA), which is intended to maintain worker blood lead level (BLL) below 40 µg/deciliter (dL). Medical removal is required when an employee's BLL reaches 50 µg/dL [29 CFR 1910.1025]. The NIOSH REL for lead (8-hour TWA) is 0.050 mg/m^3; air concentrations should be maintained so that worker blood lead remains less than 0.060 mg Pb/100 g of whole blood [NIOSH 2005]. At BLLs below 40 µg/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 µg/m^3 as an 8-hour TWA, with worker BLLs to be controlled to ≤ 30 µg/dL. A national health goal is to eliminate all occupational exposures that result in BLLs >25 µg/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 µg/m^3 based on its designation as a potential occupational carcinogen [NIOSH 2005]. The ACGIH® TLV® for insoluble inorganic compounds of nickel is 200 µg/m^3 (inhalable fraction). For soluble inorganic nickel compounds the TLV® is 100 µg/m^3 (inhalable fraction). The TLV® for elemental nickel is 1,500 µg/m^3 (inhalable fraction) [ACGIH 2008]. The OSHA PEL for nickel is 1,000 µg/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/m^3 for total and 5 mg/m^3 for the respirable portion [29 CFR 1910.1000]. A more stringent recommendation of 10 mg/m^3 inhalable and 3 mg/m^3 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].

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® TLV®s 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 21.5 μg/100 cm^2 (200 μg/square foot [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 21.5 μg/100 cm^2 (200 μg/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

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[‡] OSHA has referenced a Department of Housing and Urban Development (HUD) lead criteria in documents related to its enforcement of the lead standard [Fairfax 2003].

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 108 μg/100 cm^2 (1000 μg/ft^2) for floors of non-lead free buildings and 118 μg/100 cm^2 (1100 μg/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 μg 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 cm^2 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 cm^2 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. Heat Stress Evaluation Criteria

Section 19 of the Occupational Safety and Health Act of 1970 (the Act) identifies federal agency safety program and responsibilities and, through its implementing regulations, requires agency heads to furnish federal employees places and conditions of employment "that are free from recognized hazards that are causing or are likely to cause death or serious physical harm" [29 CFR 1960.8]. In addition, Executive Order 12196 expands on the responsibilities originating from the Act and requires agency heads to "[a]ssure prompt abatement of unsafe or unhealthy working conditions." In circumstances where such conditions cannot be abated, the agency must develop a plan that identifies a timetable for abatement and a summary of interim steps to protect employees. Employees exposed to the conditions also must be informed of the provisions of the plan.

The criteria OSHA uses to determine overexposures to heat stress were developed by the NIOSH and the ACGIH®. Factors taken into consideration in evaluating heat stress include environmental and metabolic heat (judged as the work rate) of the worker; the clothing and personal protective equipment worn; and the cycle of work and recovery. The assumptions made for the purposes of this report are that all workers have been acclimatized under heat-stress conditions similar to those anticipated for a minimum of 2 weeks and that there is adequate water and salt intake.

As described in the ACGIH® Documentation of Threshold Limit Values [ACGIH 2007], Light work is illustrated as, "Sitting with light manual work with hands or hands and arms and driving. Standing with some light arm work and occasional walking." The Moderate work category, considered to be the predominant rate observed at Marianna, is defined by the ACGIH® TLV® as, "Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and trunk work, or light pushing and pulling. Normal walking." The example of Heavy work given in the ACGIH® TLV® as, "Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace." Very Heavy work is exemplified by, "Very intense activity at fast to maximum pace."

Because the evaporation of sweat from the skin is the predominant heat removal mechanism for workers, any clothing or PPE that impedes that evaporation needs to be considered in an evaluation of heat stress. Accepted clothing for heat stress evaluation using the TLV® WBGT criteria is traditional long sleeve work shirt and pants. This is essentially the level of clothing worn by all workers at the Marianna facility. Therefore an adjustment for clothing beyond such a summer work uniform; a Clothing Adjustment Factor – [CAF]), should be made for workers in the GBO, due primarily to their use of spun-bonded olefin coveralls [ACGIH 2007, Bernard 2005].

NIOSH Recommended Exposure Limits
The NIOSH RELs for Heat Stress for acclimatized workers are shown in Figure VI [NIOSH 1986]. NIOSH recommends controlling total heat exposures so that unprotected, healthy acclimatized workers are not exposed to combinations of metabolic and environmental heat that exceed the applicable RELs. The recommended limits are for healthy workers who are physically and medically fit for the level of activity required by their work and are wearing the traditional one layer work clothing of not more than long-sleeved work shirts and pants (or equivalent). The limits may not provide adequate protection to workers wearing clothing with lower air or vapor permeability or insulation values that exceed those of

traditional work clothing. NIOSH recommends that no worker be exposed to combinations of metabolic and environmental heat exceeding the applicable ceiling limit unless provided with and properly using adequate heat-protective clothing.

NIOSH [1986] recommends reducing the REL and RAL by 2 °C (3.8 °F) when the worker is wearing a two-layer clothing system, and lowering the REL and RAL by 4 °C (7.2 °F) when a "partially air and/or vapor impermeable ensemble or heat reflective or protective leggings, gauntlets, etc. are worn." However, the NIOSH document notes that those suggested corrections are scientific judgments that were not substantiated by controlled experimental studies or prolonged experience in industrial settings.

Threshold Limit Value and Action Level

The above work rate and clothing factors can be used, in combination with the hourly work / rest regimen of exposed workers, to find the permissible maximum WBGT heat exposure limit (expressed in °C) from the table of TLV®s.

Table 2: Heat Stress TLV®s and Action Limit WBGT Values [ACGIH 2007]

Allocation of Work in a Cycle of Work and Recovery	TLV® (WBGT values in °C)				Action Limit (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75% to 100%	31.0	28.0	—	—	28.0	25.0	—	—
50% to 75%	31.0	29.0	27.5	—	28.5	26.0	24.0	—
25% to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0% to 25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0

Assessment of exposures in relation to the stress and strain TLV®s is a step-by-step process, once exposures and working conditions have been assessed. The first step is to ascertain whether or not a CAF is available. There is a CAF for polyolefin coveralls of 1.0 °C (1.8 °F) WBGT. The TLV®s note that "the recommended adjustment factors are based on a worker wearing a single layer coverall over modesty clothing" (e.g., shorts and tee-shirt, or perhaps the tee-shirts and work pants worn by the workers in the GBO).

If there is a CAF available, one should determine whether or not the screening criteria for the Action Limit (above) are exceeded, and if they are, then determine if the screening criteria for the TLV® (above) are exceeded (if the Action Limit criteria are not exceeded, continue to monitor work conditions). If the screening criteria for the TLV® are exceeded, a detailed analysis is recommended, including obtaining a task analysis that includes a time-weighted average of the "Effective WBGT" (the environmental WBGT plus the CAF) and the metabolic rate.

The next step is to review the results of the detailed analysis. If the detailed analysis indicates that the Action Limit is exceeded, but the TLV® is not (or the workers are acclimatized), then general controls should be implemented and monitoring of conditions continued. General controls include [ACGIH 2007]:

- Provide accurate verbal and written instructions, annual training programs, and other information about heat stress and strain
- Encourage drinking small volumes (approximately 1 cup) of cool, palatable water (or other acceptable fluid replacement drink) about every 20 minutes

- Permit self-limitation of exposures and encourage co-worker observation to detect signs and symptoms of heat strain in others
- Counsel and monitor those who take medications that may compromise normal cardiovascular, blood pressure, body temperature regulation, renal, or sweat gland functions; and those who abuse or are recovering from the abuse of alcohol or other intoxicants
- Encourage healthy life-styles, ideal body weight and electrolyte balance
- Adjust expectations of those returning to work after absence from hot exposure situations and encourage consumption of salty foods (with approval of physician if on a salt-restricted diet)
- Consider preplacement medical screening to identify those susceptible to systemic heat injury
- Monitor the heat stress conditions and reports of heat-related disorders

If the detailed analysis reveals that the "exposure exceeds the limits for acclimatized workers," the ACGIH® [2007] recommends that physiological monitoring (e.g., core body temperature, heart rate monitoring) as "the only alternative to demonstrate that adequate protection is provided." If physiological monitoring indicates that employees are experiencing excessive heat strain (the overall bodily response to heat stress), then job-specific controls should be implemented. These include [ACGIH 2007}:

- Consider engineering controls that reduce the metabolic rate, provide general air movement, reduce process heat and water vapor release, and shield radiant heat sources, among others
- Consider administrative controls that set acceptable exposure times, allow sufficient recovery, and limit physiological strain
- Consider personal protection that is demonstrated effective for the specific work practices and conditions at the location

Finally, ACGIH® [2007] notes that a program to manage heat stress is required when heat stress levels exceed the Action Limit or workers utilize clothing ensembles that limit heat loss, and that in either case, general controls should be utilized to protect workers.

V. RESULTS AND DISCUSSION

The work described here was conducted in August, 2007 at the Marianna FCI and FPC, UNICOR Recycling Factory electronic components recycling operations. During this testing air, surface wipe, bulk dust and heat data were collected in locations where the 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 and heat encountered 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 3, and results of personal breathing zone and area air sampling are shown in Table 4. Surface wipe sample results are contained in Table 5; bulk material sample results are presented in Table 6; environmental heat measurements are shown in Table 7; and estimated work rates and metabolic heat values are given in Table 8. Table 9 provides the results of the ventilation evaluation in the GBO. 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 OELs of those other metals, even when results for combined exposures as calculated by Equation 1 are considered.

A. Bulk Material Sample Results

Five bulk material samples of dust from locations within the GBO were collected in August 2007. These samples were analyzed for metals, and the results are presented in Table 6 for the metals of primary interest. The one metal present in all five samples in significant concentration is lead, which ranged from 2,200 to 35,000 mg/kg (0.22% to 3.5%). Nickel was measured at 0.2% in one sample. No beryllium was detected in these bulk samples. The entire data set (all 31 metals) is presented in Appendix B at the end of this report.

B. Surface Wipe Sample Results

The surface wipe sample results collected during the visit in the electronic recycling operations at the Marianna FCI are summarized below and in Table 5, and the entire surface wipe sample data set is contained in Appendix C. Results of spectrofluorometric analysis for beryllium only confirmed ICP measurements and are not repeated in the tables.

It is noteworthy that many of the cadmium wipe samples collected from work surfaces described as "rubber" or "mat(t)" have many of the highest levels of surface contamination, although the data were not analyzed for statistical significance since this technique is considered semi-quantitative. As Table 5 indicates, the majority of these mats were used as table coverings in the work area. The higher cadmium levels may indicate that these surfaces are more difficult to clean and retain dust, or they may be indicative of the operations taking place at those work stations. In either case, using cardboard or another disposable covering on top of the mats and discarding the covering after every shift would address the issue of contamination of these surfaces.

FCI Recycling Factory

Wipe samples taken in the UNICOR electronic recycling factory did not indicate levels of barium on work surfaces at levels of concern as discussed in Section IV above in the surface contamination subsection. The highest barium concentration detected was 80 μg/100 cm^2. No beryllium was detected in samples from the recycling factory; the limit of detection was 0.07 μg/100 cm^2. Many of the surfaces tested for lead indicated levels exceeding the OSHA-referenced HUD criteria of 21.5 μg/100 cm^2, including two in the breakdown area that contained 110 and 140 μg/100 cm^2. While there are no criteria for evaluating cadmium surface contamination, 3 of 23 of the cadmium measurements were 19 μg/100 cm^2 or greater, with a range from less than the limit of detection of 0.1 μg/100 cm^2 to 65 μg/100 cm^2. The highest level of nickel surface contamination was 68 μg/100 cm^2.

FPC

Three surfaces were wiped to measure surface metal contamination in the camp (Table 5) and one produced the highest levels of barium, cadmium and lead seen (320, 360, and 5100 μg/100 cm^2 respectively) and 52 μg of nickel/100 cm^2. This was a sample of accumulated dust collected on top of an electrical conduit attached to the back wall to the left of HFM-1 inside the containment area. This indicates insufficient cleaning in this area of airborne dust that escaped capture by the local exhaust system. It should be noted that the denominator (100 cm^2) is an approximation for this sample, which was collected from a rounded surface where a template could not be used. The other two samples here were well below the suggested maximum levels. However, one was obtained from the door of a locker used to store PPE, and the other was collected on top of the bookcase used to charge the PAPR battery packs, indicating that some contamination is present in these clean areas. This is confirmed by the results of the bulk sample of settled dust collected from on top of a locker in the GBO (Table 6).

C. Air Sample Results

Air measurements were collected during both routine and non-routine operations in the areas identified, including the GBO. Data presented here and in Table 4 are for the duration of the samples rather than for an 8-hour time weighted average since the concentrations of contaminants are so low in most cases. Measurements made during the filter change operation are presented at the bottom of Table 4 and discussed separately below since this was not a routine production operation. The full data set of all 31 metals is presented in Appendix D.

FCI Recycling Factory

Eighteen samples were collected in the UNICOR recycling factory for airborne metals during the August, 2007 study. These data can be identified by date in Table 4, but the magnitudes of the exposures were not generally different by date. Measurements during routine operations revealed that barium concentrations ranged between <0.05 and 0.26 $\mu g/m^3$ and were below occupational exposure limits. Beryllium levels also were all below the limit of detection. The minimal detectable concentration (limit of detection/sample volume) varied with sample volume, most being <0.03 $\mu g/m^3$. Cadmium, lead and nickel, likewise, were found at low levels ranging up to 0.091, 0.54, and 0.19 $\mu g/m^3$, respectively. Lead was the metal found in highest quantity, but only 6 samples were above the limit of detection and the highest was approximately 1% of the occupational exposure limits of 50 $\mu g/m^3$. Airborne particulate concentrations ranged up to 717 $\mu g/m^3$ (<0.1 to 0.7 mg/m^3).

FPC Recycling operations

Airborne metal concentrations in the FPC, in operations other than glass breaking, were generally lower than those in the FCI. Fourteen samples collected principally in trucking and breakdown operations were well below the most stringent occupational exposure limit. Two samples in this series were compromised. In one instance, an employee touched the inlet with her work glove and some lint was captured by the sampler. In the second, an employee was unloading recyclables and toner spilled on her front; some toner entered the sampling cassette. Airborne lead levels were all below the limit of detection when those two samples are excluded. No beryllium was detected in any of the samples. Nickel results were also less than the limit of detection, with the exception of one of the compromised samples. Barium and cadmium ranged up to 0.42 and 0.24 $\mu g/m^3$ respectively, when the compromised samples are ignored. Airborne total particulate concentrations ranged from <60 to 887 $\mu g/m^3$ when the compromised samples are excluded.

FPC Glass Breaking Room – Routine Production

While exposures in the GBO were of specific interest and anticipated to be higher than in other production processes, no detectable levels of beryllium or nickel were found in the twelve samples collected at the Marianna facility during the two days this process was monitored. Airborne levels of barium, cadmium and lead ranged up to 2.1, 6.8 and 20 $\mu g/m^3$, respectively. None of the samples exceeded the relevant occupational exposure limits as 8-hr TWAs (e.g., 6.8 $\mu g/m^3$ of cadmium in a 143 minute sample results in an 8-hr TWA of 2.0 $\mu g/m^3$). This cadmium result approached, but did not exceed, the OSHA Action Level. Particulate measurements ranged up to 891 $\mu g/m^3$. These results indicate that the HFMs do an effective job in controlling the breakers' exposures to levels below relevant occupational exposure criteria. The feeders' exposures indicate that their jobs should be reviewed to determine the source of their airborne exposures to determine if it originates from material handling or from dust escaping the enclosed booth area. When the results of sampling conducted during routine operations in the GBO are reviewed, the reader should recall that the GBO was operating on a shortened schedule due to the hot conditions.

FPC Glass Breaking Room – Non-Routine Filter Cleaning and Maintenance Operations
The filter change operation in the GBO, discussed in the Process Description (Section II), was the task of most concern regarding exposures of workers to toxic metals. As noted above, the filter change is a maintenance operation that occurs at approximately monthly intervals during which the ventilation system is shut down and all filters are removed and replaced. During this operation, two workers in spun-bonded olefin coveralls, gloves and PAPRs remove both sets of filters, clean the system, and replace the filters. They are assisted by two additional workers who wear spun-bonded olefin coveralls and gloves while working outside the glass breaking enclosure. The exhaust system components, including the accessible surfaces of the filters, are first HEPA vacuumed. The filters are then removed and bagged for disposal, and the area inside the filter housing is vacuumed. New filters are inserted to replace the old ones, the LEV system is reassembled, and any residual dust is HEPA vacuumed.

Air sampling preformed during this operation revealed that barium concentrations ranged from 1.0 to 16 $\mu g/m^3$. No beryllium or nickel was detected. Cadmium ranged from 0.74 to 12 $\mu g/m^3$ (0.069 to 1.4 $\mu g/m^3$ 8-hr TWA), and again lead was the metal found in the highest concentration, ranging from 5.6 to 105 $\mu g/m^3$ (0.53 to 12 $\mu g/m^3$ 8-hr TWA). Airborne total particulate measurements ranged from 270 to 5,000 $\mu g/m^3$.

Results of particle size measurements from the Aerodynamic Particle Sizer inside the enclosed area in the GBO are presented in Figure VII. These data indicate a low level of particle concentration (particles/cm^3) can be achieved during glass breaking through the use of local exhaust ventilation. As one would expect, the maximum particle number concentration occurred during the filter change operation on August 9. Our APS data show that the particle concentration during filter changing can reach approximately 325 particles/cm^3 in the 0.6 – 0.7 μm size range, with the number of particles in the larger particle size near 3 μm increasing to more than 150 particles/cm^3. Filter changing produced the highest particle counts, while routine daily cleaning produced higher number concentrations than routine glass-breaking operations. However, results indicated that none of the tasks were especially dusty when compared to other industrial environments and tasks [Alexander et al. 1999, Kuhlbusch et al. 2004, Evans et al. 2008].

D. Heat Measurement Results

The heat measurement data collected on August 8 and 9, 2007, are presented in Table 7. Measurements of indoor wet bulb globe temperature ($WBGT_{in}$) were calculated for one hour increments and are presented for each of the two days of the testing at that facility. Included are the heat stress data obtained in the various locations tested in both FCI and FPC. The GBO operation was limited to the morning because of the summer heat. However, no work-rest regimen was in place at any of the Marianna operations.

Having observed work at all Marianna locations evaluated, work rates in the FCI and FPC were determined as shown in Table 8. The metabolic heat values are taken from the ACGIH® TLV® documentation [ACGIH 2007]. They represent midpoints in the range of metabolic rates for the categories of work. Because all workers were not working at the same rate, even though they were assigned the same jobs, some tasks were given overlapping classifications.

Comparison of the Results with the NIOSH REL
Using the plot in Figure 7, entering a Metabolic Heat value of 300 Watts (W) and entering a WBGT value of 32.8 °C (adding the NIOSH clothing adjustment of 4 °C to the measured WBGT value of 28.8 °C) for the breakers, shows that the REL for continuous work (60 minutes/hour) was exceeded for the breakers during their first hour of work on August 8. Since that hour represented their minimum measured heat

exposure, the breakers' exposures exceeded the REL for continuous work for all of the measured periods. The feeders' estimated metabolic heat equaled or exceeded that of the breakers (e.g., they lifted and carried CRTs, while the breakers slid them and used breaking tools) and they shared the same environmental heat exposure and wore spun-bonded olefin coveralls over their work clothes. Therefore, the feeders were also exposed above the REL on both sampling days. Using the plot in Figure 7 and entering a metabolic heat value of 240 W (the average work rate for the outside workers in the GBO) on the horizontal axis and an unadjusted WBGT value of 28.8 °C, shows that the outside workers in the GBO were at or slightly over the REL for continuous work for that period, and likely exceeded the REL for continuous work during the period from 9:00 am to 10:00 am on August 9, when the WBGT value was 30.4 °C.

Using the same procedure, entering a metabolic heat value of 240 W for all FCI workers and hourly TWA WBGT values that ranged from 28.3 °C to 29 °C on August 8 and from 29.2 °C to 30.4 °C, the FCI workers' heat exposures approached or exceeded the REL for continuous work for several periods on both days. Using the plot in Figure 7, the WBGT values in Table 7, and a metabolic heat value of 300 W for the truck crew shows that their exposures approached or exceeded the REL for continuous work on both days as well. Only the other warehouse workers experience heat exposures that were below the REL for continuous work on both days, based on an estimated metabolic heat of 180 W and a maximum 1-hr TWA of 29.4 °C WBGT.

Comparison of the Results with the ACGIH® TLV®

Adjusting the TLV® and Action Limit values in Table 2 by a CAF reduction of 1°C for workers wearing spun-bonded olefin coveralls and comparing the results in Table 7 with those values utilizing the work rates noted above indicates that some of the tasks performed by workers at this facility result in exceeding recommended heat stress values under the conditions measured on August 8 and 9, 2007.

Specifically, the breakers' measured WBGT values of 28.8 °C and 29.7 °C on August 8 and 29.7 °C and 30.4 °C on August 9 exceeded the CAF-adjusted TLV® of 27 °C for moderate work performed continuously (45-60 minutes out of every hour), and it should be noted that the WBGT monitor was placed outside of the plastic enclosure wherein the breakers worked (because 4 of 6 GBO workers work outside this enclosure). The WBGT value may have been higher inside the enclosure due to heat generated by the electric motors in the HFMs. The same measured WBGT values represented the feeders' environmental heat exposures. Their moderate to heavy work also resulted in WBGT exposures in excess of the CAF-adjusted TLV®s of 27 °C for continuous moderate work and 26.5 °C for heavy work for a work cycle of 50% to 75% work in an hour. The filter change operation WBGT measurement of 31.2 °C on August 9 also exceeded the CAF-adjusted TLV® for continuous light work of 30 °C. No CAF adjustment is required for workers in other tasks, who wore typical summer work clothing.

For the outside workers in the GBO , the measured WBGT values of 28.8 °C and 29.7 °C on August 8 and 29.7 °C and 30.4 °C on August 9 and light to moderate work rates result in exposures that exceeded the TLV® for continuous moderate work and the Action Limit for continuous light work. Reviewing the WBGT values measured in the Warehouse on August 8 reveals that they ranged from 28.1 °C to 28.5 °C, while WBGT measurements on August 9 in the Warehouse ranged from 28.6 °C to 29.4 °C. Those values exceed the Action Limit for continuous light work of 28.0 °C. The WBGT monitor in the Warehouse was placed on the wooden reception counter at the loading dock entrance in an attempt to measure the exposures of both the warehouse workers and the crew unloading trucks. The truck crew workers exposures also exceeded the TLV® of 28 °C for continuous moderate work. WBGT temperatures measured in the FCI –Refurbish area ranged from 28.3 °C to 29.1 °C on August 8, and from 29.2 °C to

30.3 °C on August 9, exceeding the Action Limit for continuous light work. Finally, measured WBGT values in the FCI-Disassembly area ranged from 28.4 °C to 29.4 °C on August 8, and from 29.3 °C to 30.4 °C on August 9. These measurements exceeded the Action Limit for continuous light work.

E. Local Exhaust System Measurements

The tests described above were conducted with the variable speed control on both units set at 100%. The minihelic gauges on the left-hand HFM (s/n 11023-1) and on the right-hand HFM (s/n 11023-2) read 1.2 and 1.3 inches, respectively. The results of the velocity measurements are presented in Table 9. The average face velocity measured at HFM-1 (the one on the left when facing them from the front, s/n 11023-1) was 0.66 meters/second (m/sec) (130 feet/minute [fpm]); the average capture velocity at the edge of the front curtains was 0.37 m/sec (73 fpm). The average face velocity measurement was in close agreement with the manufacturer's test report of 0.66 m/sec (130 fpm) measured at the face of the HEPA filter with the fan operating at 100% capacity. However, the manufacturer's readings only varied from 0.64 to 0.68 m/sec (125 to 133 fpm) versus 0.35 to 1.07 m/sec (68 to 210 fpm) measured during this testing. The average face velocity measured at HFM-2 was 0.54 m/sec (106 fpm); the average capture velocity measured at the edge of the curtains in front of the unit was 0.40 m/sec (78 fpm). The manufacturer's test of the new unit reported an average face velocity of 0.76 m/sec (150 fpm) at the face of the HEPA filter (range 0.71-0.81 m/sec [140-160 fpm]). There were some gaps visible between the prefilters on both HFMs and there was a gap between HFM-2 and the angle-iron grate. The gaps between the prefilters may shorten the service life of the HEPA filter by allowing larger particles to reach it. The measurements of the face and capture velocity show that better capture is achieved in the central portion of both workstations; performance drops off considerably outside of the center part of the enclosure. These gaps may also account for the distribution of face velocities noted (some of which differed by more than 20% from the mean value) as air was exhausted through the gaps, flowing around, rather than through, the prefilters. The gap between the grate and the HFM may decrease the effectiveness of the HFM by increasing the distance from the face to the glass-breaking operation and may allow broken glass to escape collection and land on the floor resulting in an additional hazard and a longer clean-up time. Smoke released showed the air tended to flow into the enclosed area in front of each HFM as expected.

Both HFMs are in an area enclosed by plastic curtains on two sides and a building wall on the other two sides. The curtain enclosing the front of the area is composed of plastic strips. The side curtain is a continuous plastic sheet, except for a cut out framed in wood that allows the attending inmates to pass material to the tube breakers via a roller conveyor. The area in enclosed on top by plastic as well.

The HFMs discharge into the enclosure (rather than to the outside of the building, for example) recirculating the filtered air into the workplace. Since the air is recirculated, the enclosure is not under negative pressure with regard to the rest of the glass breaking facility. The American National Standards Institute and the American Industrial Hygiene Association note that recirculation of air from industrial exhaust systems into workroom air can result in hazardous air contaminant concentrations in the facility if not designed properly [ANSI/AIHA 2007]. They recommend performing an evaluation of the process and the toxicity of the materials used in the process before recirculating air to the workplace [ANSI/AIHA 2007]. That standard emphatically states "under no circumstances shall workroom air consist of 100% recirculated air." According to the ANSI/AIHA standard., the recirculation of exhaust air streams that contain highly toxic substances (as defined by the OSHA Hazard Communication Standard) requires the use of a continuous monitoring device for the contaminant in the exhaust stream; however a continuous monitoring of the pressure drop across the redundant filter may be acceptable if filter testing upon installation reveals the presence of no more than 10% of the acceptable concentration of the contaminant in the discharge ductwork [ANSI/AIHA 2007]. There are no continuous monitoring devices installed on these HFMs. While the samples collected during this evaluation were not collected in the discharge ductwork, the measured occupational exposures were very low. Monitoring of the pressure drop across the HEPA filter may be an acceptable means of monitoring filter loading and detecting any leaks. There are manometers installed on both HFMs.

Exhausting the HFMs to the outside of the building could create negative pressure within the glass-breaking booth with respect to the rest of the building to help contain airborne contaminants generated by that operation and eliminate the recirculation of exhaust air. Addition of tempered make-up air would cool the workers; the volume of makeup air supplied should be balanced with the exhaust volume to maintain the desired negative pressure. However, since the HFMs are not designed to exhaust externally, the manufacturer should be consulted before any modifications are attempted.

The OSHA lead standard includes requirements for the design and evaluation of mechanical exhaust systems in workplaces where the OSHA PEL of 50 $\mu g/m^3$ [29 CFR 1910.1025]. These include a requirement to perform measurements at least every 3 months (and within 5 days of any change that might impact upon exposure) which demonstrate the effectiveness of the system in controlling exposure, such as capture velocity, duct velocity, or static pressure. Where exhaust air is recirculated into the workplace, that regulation also requires the use of a high efficiency filter with reliable back-up filter and the use of controls to monitor the concentration of lead in the return air and to bypass the recirculation system automatically if it fails. The OSHA cadmium standard includes similar requirements and adds a requirement to utilize procedures to minimize employee exposure to cadmium when maintenance of ventilation systems and changing of filters is being conducted. However, none of the air samples revealed lead or cadmium exposures above the OSHA PEL in the GBO, so these requirements do not apply here.

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 study focused on the evaluation of airborne exposures and heat stress, with additional data collected on surface contamination. Measurements of environmental heat indicate exposures above safe levels for the work loads and work schedules. The results of air sampling during this August 2007 survey found that lead, cadmium, and other metals are generated and released during the recycling operations at this facility. No exposures to airborne metals or particulate were found that exceeded the OSHA Action Level for these substances during routine production or during non-routine operations, such as the monthly filter change operation. When the results of sampling conducted during routine operations in the GBO are reviewed, the reader should remember that the GBO was operating on a shortened schedule due to the hot conditions.

Although the whistleblower was concerned about beryllium and literature that pertains to e-waste recycling report that beryllium is present in electronic components, none was detected in air, wipe, or bulk samples collected at this facility. One explanation for this is based on the work of Willis and Florig [2002]. They note that beryllium "in consumer products is used in ways that are not likely to create beryllium exposures during use and maintenance." The recycling operations (except the GBO) involve disassembly of electronics and sorting of the components. While some breakage occurs during the disassembly process, the components likely to contain beryllium are not subject to further processing that might create the potential for beryllium exposures.

Recommendations are presented below to assure the continued safe conditions at Marianna Federal Correctional facility. While no overexposures were documented in air samples, the feeders' exposures during routine glass breaking operations require further scrutiny to determine the source of their airborne exposures. Many wipe samples in the FCI revealed levels of concern, notably those that exceeded the OSHA criteria for lead of 21.5 µg/100 cm^2, as well as samples for cadmium and nickel that produced results up to 66 µg of cadmium /100 cm^2 and 70 µg of nickel/100 cm^2. Modifications can be made to assure continued exposure control and to improve operations in general.

When reviewing the work practices for the inmates working in the GBO, one is struck by the approaches taken to worker protection. A typical work area where exposure levels dictate the use of protective clothing includes an outer change area where workers can remove and store their street clothing and don their work clothing and personal protective equipment before entering the work area (Figure VII). As Figure VII illustrates, in a typical facility where protective clothing is required, workers exit the work area through a "decon" area (e.g., where they vacuum the outer surface of their clothes) upon completion of their work, and then enter a separate, "dirty" locker area, where their soiled work clothes are removed and placed in receptacles for cleaning or disposal. The workers then pass through a shower area, and then enter the clean locker area, where they change into their street clothes again. In some cases (e.g., asbestos removal), respirators are worn into the shower and not removed until the exterior surfaces are rinsed.

In the Marianna GBO, air sampling revealed that the use of protective clothing, respirators or change rooms is not required by the OSHA lead or cadmium standards, since the PEL is not exceeded. However, management has chosen to require the use of respirators and protective clothing. At the time of this evaluation, the workers wore their prison uniforms into the work area and donned disposable spun-bonded olefin coveralls on top of them. Thus, their prison uniforms may become contaminated by their work, and the workers may be at risk of heat illness through their use of the outer garments. In addition, respirators and clean protective clothing are stored in lockers in the work area, where they are at risk of contamination. Since this facility already provides uniforms; a second set could be provided for workers in the GBO, collected, segregated and laundered separately and in accordance with good practices and applicable regulations. Using a different colored uniform for use in the GBO would aid in the segregation of work uniforms from "street clothes." Using a separate uniform inside the GBO and discontinuing the use of spun-bonded olefin coveralls over the normal prison uniform would improve heat loss and reduce the level of heat stress while protecting the workers from the environment.

Heat Stress Recommendations

The following additional recommendations are based on NIOSH, and ACGIH® recognized methods and/or procedures which can be used to reduce heat stress hazards at the Marianna FCI and FCP workplaces:

BOP should institute measures immediately to ensure compliance with the ACGIH® heat stress criteria in preparation for next summer. If UNICOR is not presently able to ensure such compliance, it should suspend glass breaking operations at Marianna during hot weather until a heat stress program can be developed and implemented to offset the potential health problems and/or consequences that may result from glass breaking activities and the elevated temperatures found during this investigation. If the BOP has an equally effective alternative to achieving compliance other than the development of a heat stress plan and the interim suspension of GBO, it should promptly notify the OIG.

1. Based upon the exposures to hot environments documented in this report, the site-specific health and safety program at Marianna must include a heat stress section, which includes, as a minimum:

a. Procedures that will be used to determine environmental and metabolic heat. NIOSH [1986] recommends establishing a WBGT or environmental profile for each hot work area during winter and summer months to help determine when to implement engineering and/or work practice controls. Additional measurements should be made to aid in the implementation decision when the profile indicates that excessive heat should be anticipated or if a heat wave is forecast.

b. Both routine and non-routine work practices should be carefully observed to estimate the metabolic heat associated with each job or task. Procedures for obtaining those estimates can be found in NIOSH [1986] and ACGIH [2007] publications.

c. NIOSH [1986] recommends instituting a medical surveillance program for all workers who may be exposed to heat stress above recommended limits, including preplacement and periodic examinations. The recommended content of the examinations and other relevant information can be found in that reference.

2. Engineering controls are the preferred method to reduce and/or eliminate occupational stressors in the workplace; therefore, cooling methods, such as air conditioning systems should be investigated to reduce the heat load in this work place. Portable air conditioners may be used in the trailers while the trailer crews are working, if monitoring shows their use is warranted.

3. In lieu of implementing engineering controls, work/rest schedules can be utilized to control worker exposure to heat stress. Provisions for a work/rest regimen should be established so that exposure time to high temperatures and/or the work rate is decreased. For example, a measured hourly TWA WBGT of 29 °C and a moderate work load dictates a work rest schedule of 30 to 45 minutes work per hour [ACGIH 2008]. In addition, the BOP needs to reassess its current use of PPE (i.e., the use of spun-bonded olefin, PAPRs, gloves, etc.) and consider adding personal cooling devices, such as, cooling vest or packs for workers in the GBO.

4. An initial and periodic training program should be implemented, informing employees about the hazards of heat stress, predisposing factors and how to recognize heat-related illness signs and symptoms, potential health effects, first aid procedures, precautions for work in hot environments and preventing heat-induced illnesses, worker responsibilities, and other elements [NIOSH 1986].

5. An acclimation program should be implemented for new employees <u>or</u> employees returning to work from absences of three or more days.

6. Specific procedures should be developed for heat-related emergency situations, including provisions that first aid be administered immediately to employees displaying symptoms of heat related illness.

7. Workers should be permitted to drink water at liberty.

8. The ACGIH [2007] recommends the following general controls for limiting heat strain. Consult the documentation of the Heat Stress and Strain TLV for further information.

- Provide accurate verbal and written instructions, annual training programs, and other information about heat stress and strain
- Encourage drinking small volumes (approximately 1 cup) of cool, palatable water (or other acceptable fluid replacement drink) about every 20 minutes
- Permit self-limitation of exposures and encourage co-worker observation to detect signs and symptoms of heat strain in others
- Counsel and monitor those who take medications that may compromise normal cardiovascular, blood pressure, body temperature regulation, renal, or sweat gland functions; and those who abuse or are recovering from the abuse of alcohol or other intoxicants
- Encourage healthy life-styles, ideal body weight and electrolyte balance
- Adjust expectations of those returning to work after absence from hot exposure situations and encourage consumption of salty foods (with approval of physician if on a salt-restricted diet)
- Consider preplacement medical screening to identify those susceptible to systemic heat injury
- Monitor the heat stress conditions and reports of heat-related disorders

9. If the detailed analysis required by the TLV® reveals that the "exposure exceeds the limits for acclimatized workers," the ACGIH® [2007] recommends that physiological monitoring (e.g., core body temperature, heart rate monitoring) as "the only alternative to demonstrate that adequate protection is provided." If physiological monitoring indicates that employees are experiencing excessive heat strain (the overall bodily response to heat stress), then job-specific controls should be implemented. These include [ACGIH 2007]:

- Consider engineering controls that reduce the metabolic rate, provide general air movement, reduce process heat and water vapor release, and shield radiant heat sources, among others
- Consider administrative controls that set acceptable exposure times, allow sufficient recovery, and limit physiological strain
- Consider personal protection that is demonstrated effective for the specific work practices and conditions at the location

10. It is strongly recommended that the current version of the documentation of the ACGIH® TLV®s be referenced to assist in adding additional specific information when preparing a site-specific heat stress program for the Marianna facilities. Examples would be on a thorough understanding of the various clothing ensembles worn throughout the year (especially during the warmer seasons) and the role that PPE (i.e., the use of spun-bonded olefin suits, hoods, gloves, etc.) may play on the effects of heat stress. Additional emphasis should be placed on the TLV® Guidelines for Limiting Heat Strain and the Guidelines for Heat Stress Management. It is also recommended that that additional material on heat stress be investigated, such as OSHA's Heat Stress Card (OSHA Publication 3154). This and other relevant materials can be found on OSHA's web page (http://www.osha.gov/SLTC/heatstress/index.html).

Based on the data presented in this report, the following recommendations are made. These recommendations are divided into four categories, described as ventilation controls in the GBO, programmatic issues, procedural issues, and housekeeping issues.

Ventilation controls in the GBO:

1. The HFM ventilation controls maintain airborne metal and dust exposures in the GBO booth to concentrations below allowable limits. Typically, respirators would not be required in an environment where occupational exposures are below allowable limits. However, the PAPRs probably provide some heat stress relief by blowing air past the workers' heads. Their use should be continued.
2. There is currently no ventilation system supplying air to the GBO. The air in the breaking booth is filtered and recirculated by the HFMs. ANSI and AIHA [2007] recommend that "under no circumstances shall workroom air consist of 100% recirculated air." Providing tempered and filtered outside air would satisfy that recommendation and provide some relief from heat stress. However, any air supply system should be designed carefully. Adding a supply of air to the breaking booth without any exhaust would create a positive pressure in the booth and spread potentially contaminated air to the rest of the GBO. Ideally, a tempered air supply to the GBO would be balanced with exhaust air to create a slight negative pressure in the breaking booth with regard to the rest of the GBO. Depending on the source of their exposures, this pressure differential could result in lower exposures for the feeders. Consult with a qualified engineer and the HFM manufacturer to determine the best way to achieve this using the existing HFMs if possible. The addition of a change room should also be taken into account.
3. According to the ANSI/AIHA [2007] standard, the recirculation of exhaust air streams that contain highly toxic substances (as defined by the OSHA Hazard Communication Standard) requires the use of a continuous monitoring device for the contaminant in the exhaust stream; however a continuous monitoring of the pressure drop across the redundant filter may be acceptable. There

are no continuous monitoring devices present on the HFMs. However, there are pressure gauges mounted on the side of each unit. Consult with the manufacturer to determine if these are installed in order to monitor pressure drop across the HEPA filter and to determine what settings should lead to filter change (high pressure across the filter) or process shut down (low pressure setting). A visual or audio warning device should be added that would signal the worker if the HFM stops working or if the pressure drop across the filter exceeds the manufacturer's recommended settings.

Programmatic issues:

1. 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, housekeeping and personal hygiene practices. Written programs should be prepared and the programs implemented and updated as required to ensure that workers receive training in hazard communication, respiratory protection, working in hot environments, an the use of personal protective equipment.
2. 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, especially with regard to cleaning and storage practices. BOP should also be aware of the fact that the respirator manufacturer Global Secure PAPR is going through bankruptcy, and their approvals will likely soon be listed as 'Obsolete", meaning the manufacturer no longer supports them with replacement parts. If OEM replacement parts are needed and can't be purchased, the respirator will no longer be usable as a NIOSH approved device.
3. Frequently while conducting the on-site work, NIOSH researchers observed tasks being conducted in a manner which appeared to be biomechanically taxing, such as workers lifting large CRTs from Gaylord boxes and placing them on the roller conveyor in the GBO. Tasks should be evaluated to determine if there are awkward postures or lifting techniques that may result in repetitive stress trauma and if modifications in procedures or equipment would provide benefit to this workplace.
4. Heat stress should be periodically re-evaluated during hot weather (e.g., the summer months).
5. 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.
6. A program should be established within the Bureau of Prisons to assure that these issues are adequately addressed by competent, trained and certified health and safety professionals. 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."
7. 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.

Procedural issues:

8. 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.
9. Workers performing the filter change operation should 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.

10. 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. Use of different colored uniforms for work and "street" clothes would aid in the segregation process.
11. While levels of airborne contaminants were below acceptable limits (e.g., the OSHA PELs for lead and cadmium), best practices and the current use of protective clothing in the GBO suggest that change rooms should be modified to provide showers and separate storage facilities for protective work clothing and equipment and for street clothes that prevent cross-contamination. The use of properly constructed change rooms as described above would restrict any contamination to the work area and keep it out of residential areas of the facility.
12. The use of alternative methods to break cathode-ray tubes should be investigated by Marianna 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.
13. German authorities [BG/BIA 2001] have issued a set of best-practices for dismantling CRTs that should be reviewed for their applicability to these operations. Among those is a recommendation for the provision of washrooms and rooms with separate storage capabilities for street and work clothing.

Housekeeping:

14. Due to the levels of surface contamination of lead and other metals measured in the recycling facility, workers should wash their hands before eating, drinking, or smoking. While not observed here, remember that consumption of food, beverage or tobacco in the workplace should be prohibited to prevent accidental ingestion of hazardous substances.
15. 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.
16. Daily and weekly cleaning of work areas by HEPA-vacuuming and wet mopping should be continued, taking care to assure no electrical or other safety hazard is introduced. 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 μm and pass the assembled appliance test, 99.995% efficiency where 10% of the particles are smaller than 1.0 μm, 22% below 2.0 μm, and 75% below 5.0 μm. High levels of lead surface contamination was

measured in some work areas, indicating the need for improved 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; this includes the use of compressed air to clean parts or working surfaces.

17. The use of disposable coverings on work surfaces (e.g., cardboard from excess boxes) may aid housekeeping practices. Wipe sampling can be used initially to determine the frequency with which the coverings should be discarded. However, Marianna facility management must ensure that the contaminated coverings are disposed of properly.

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Table 3: Summary Statistics for Airborne Metal Measurements*
(Concentration units for means is μg/m^3)

	Ba	Be	Cd	Pb	Ni	Particulate
18 samples collected in the FCI UNICOR factory						
Arithmetic Mean (μg/m^3)	0.13	0.025	0.056	0.29	0.22	250
Arithmetic Standard Deviation (μg/m^3)	0.075	0.013	0.029	0.17	0.15	155
Geometric Mean (μg/m^3)	0.11	0.022	0.050	0.25	0.19	207
Geometric Standard Deviation (μg/m^3)	1.9	1.5	1.7	1.8	1.8	1.9
12 samples collected in the FPC UNICOR factory						
Arithmetic Mean (μg/m^3)	0.09	0.022	0.067	0.22	0.22	234
Arithmetic Standard Deviation (μg/m^3)	0.11	0.0078	0.058	0.078	0.078	304
Geometric Mean (μg/m^3)	0.067	0.022	0.055	0.22	0.22	140
Geometric Standard Deviation (μg/m^3)	2.0	1.3	1.8	1.3	1.3	2.6
12 samples collected in the FPC GBO						
Arithmetic Mean (μg/m^3)	0.80	0.037	1.1	6.1	0.37	435
Arithmetic Standard Deviation (μg/m^3)	0.74	0.0078	2.1	6.5	0.078	330
Geometric Mean (μg/m^3)	0.46	0.037	0.29	3.0	0.37	287
Geometric Standard Deviation (μg/m^3)	3.4	1.2	4.7	3.9	1.2	2.9
6 samples collected in the FPC GBO during filter change						
Arithmetic Mean (μg/m^3)	4.8	0.092	4.2	30	0.92	1567
Arithmetic Standard Deviation (μg/m^3)	5.7	0.013	4.2	38	0.13	1737
Geometric Mean (μg/m^3)	2.9	0.091	2.7	18	0.91	968
Geometric Standard Deviation (μg/m^3)	2.8	1.1	2.9	2.9	1.1	3.0

Where results were less than the limit of detection (LOD), the value LOD/√2 was used in calculating these statistics. These summary statistics exclude two samples collected in the FPC UNICOR factory that were compromised, MSMHF-9 and MSMHF-11. The employee who wore sample MSMHF-9 reported that toner "exploded" (spilled) as she unloaded recyclable components from a truck. This probably accounts for the high dust loading. The employee who wore sample MSMHF-11 touched the cassette inlet with her glove at 9:35 am. Some lint was transferred to the filter. This probably accounts for the high dust loading on this sample as well.

Table 4: Airborne Metal Measurements

Sample ID	Building	Date	Area / Personal	Sample Description	Sample Duration Minutes	Flow Rate L/minute	Ba μg/m^3	Be μg/m^3	Cd μg/m^3	Pb μg/m^3	Ni μg/m^3	Particulate μg/m^3
The following 18 samples were collected in the FCI UNICOR factory												
MCMWF-5	FCI	8/8/07	P	Break down	251	3.0	0.15	<0.03	(0.052)	(0.54)	(0.19)	717
MCMWF-6	FCI	8/8/07	P	Orderly (moves Materials)	253	3.0	0.26	<0.03	(0.079)	<0.1	(0.11)	369
MCMWF-7	FCI	8/8/07	P	Bailer	253	3.0	0.21	<0.03	(0.047)	(0.17)	(0.13)	277
MCMWF-8	FCI	8/8/07	P	Refurbishing	241	3.0	0.077	<0.03	<0.03	<0.1	(0.089)	373
MCMWF-9	FCI	8/8/07	P	Refurbishing	245	3.0	(0.063)	<0.03	<0.03	(0.35)	(0.15)	218
MCMWF-10	FCI	8/8/07	P	Dismantling	239	3.0	0.11	<0.03	(0.052)	<0.1	<0.08	265
MCMHF-1	FCI	8/9/07	P	Orderly	217	3.0	0.26	<0.03	(0.091)	<0.3	<0.3	307
MCMHF-2	FCI	8/9/07	P	Bailer	207	3.0	0.19	<0.03	(0.069)	<0.3	<0.3	306
MCMHF-3	FCI	8/9/07	P	Separator	269	3.0	0.17	<0.02	(0.056)	(0.40)	<0.2	235
MCMHF-4	FCI	8/9/07	P	Orderly refurbish	123	3.0	<0.05	<0.05	<0.1	<0.5	<0.5	<81
MCMHF-5	FCI	8/9/07	P	Disassembly refurbish	94	3.0	<0.07	<0.07	<0.1	<0.7	<0.7	<106
MCMHF-6	FCI	8/9/07	P	Disassembly refurbish	235	3.0	0.14	<0.03	<0.06	(0.37)	<0.3	213
MCMHF-7	FCI	8/9/07	P	Orderly	271	3.0	0.12	<0.03	<0.05	<0.2	<0.2	185
MCMHF-8	FCI	8/9/07	P	Disassembler	275	3.1	0.18	<0.02	<0.05	<0.2	<0.2	282
MCMHF-9	FCI	8/9/07	P	Disassembler	240	3.0	0.21	<0.03	<0.06	(0.44)	<0.3	333
MCMHF-10	FCI	8/9/07	P	Disassembly refurbish	237	3.0	(0.055)	<0.03	<0.06	<0.3	<0.3	(122)
MCMHF-11	FCI	8/9/07	P	Orderly refurbish	250	3.0	(0.039)	<0.03	<0.05	<0.3	<0.3	(76)
MCMHF-12	FCI	8/9/07	P	Disassembly refurbish	72	3.0	<0.09	<0.09	<0.2	<0.9	<0.9	<140
The following 14 samples were collected in the FPC UNICOR factory												
MSMWF-5	Camp	8/8/07	P	Lead truck crew	220	3.0	(0.055)	<0.03	<0.06	<0.3	<0.3	(102)
MSMWF-6	Camp	8/8/07	P	Dock unload/load	212	3.1	(0.041)	<0.03	<0.06	<0.3	<0.3	(117)
MSMWF-7	Camp	8/8/07	P	Truck work, sweeping	105	3.0	<0.06	<0.06	<0.1	<0.6	<0.6	<95
MSMWF-8	Camp	8/8/07	P	Truck crew, sweep/unload	206	3.0	(0.042)	<0.03	<0.07	<0.3	<0.3	178
MSMWF-11	Camp	8/8/07	P	Breakdown CPUs	166	3.0	0.42	<0.04	<0.08	<0.4	<0.4	<60
MSMWF-12	Camp	8/8/07	P	Breakdown CPUs	263	3.0	(0.063)	<0.03	<0.05	<0.3	<0.3	(110)
MSMHF-7	Camp	8/9/07	P	Truck crew	256	3.0	(0.049)	<0.03	(0.089)	<0.3	<0.3	872

< quantity less than the limit of detection. Parentheses indicate quantity between the limit of detection and limit of quantitation. †The employee who wore sample MSMHF-9 reported that toner "exploded" (spilled) as she unloaded recyclable components from a truck. *The employee who wore sample MSMHF-11 touched the cassette inlet with her glove at 9:35 am. Some lint was transferred to the filter. These incidents probably account for the high dust loading on both samples.

Table 4: Airborne Metal Measurements (continued)

Sample ID	Building	Date	Area / Personal	Sample Description	Sample Duration Minutes	Flow Rate L/minute	Ba $\mu g/m^3$	Be $\mu g/m^3$	Cd $\mu g/m^3$	Pb $\mu g/m^3$	Ni $\mu g/m^3$	Particulate $\mu g/m^3$
MSMHF-8	Camp	8/9/07	P	Truck crew	297	3.0	(0.064)	<0.02	0.24	<0.2	<0.2	887
MSMHF-9	Camp	8/9/07	P	Truck crew	245	3.0	0.20	<0.03	0.49	(0.42)	<0.3	9,524†
MSMHF-10	Camp	8/9/07	P	Fork lift driver	254	3.0	(0.033)	<0.03	<0.05	<0.3	<0.3	(101)
MSMHF-11	Camp	8/9/07	P	CPU disassembly	301	3.0	1.6	<0.02	0.14	1.1	0.84	14,396*
MSMHF-12	Camp	8/9/07	P	CPU disassembly	251	3.0	(0.060)	<0.03	<0.05	<0.3	<0.3	(62)
MSMHF-13	Camp	8/9/07	P	CPU disassembly	207	3.0	(0.069)	<0.03	<0.06	<0.3	<0.3	(108)
MSMHF-14	Camp	8/9/07	P	CPU disassembly	269	3.0	0.16	<0.03	<0.05	<0.2	<0.2	161
The following 12 samples were collected in the FPC GBO												
MSMWF-1	Camp	8/8/07	P	Feeder	143	3.0	0.65	<0.05	6.8	3.7	<0.5	513
MSMWF-2	Camp	8/8/07	P	Feeder	140	3.0	0.69	<0.05	3.8	5.2	<0.5	619
MSMWF-3	Camp	8/8/07	P	Outside person	137	3.0	(0.11)	<0.05	(0.22)	<0.5	<0.5	<73
MSMWF-4	Camp	8/8/07	P	Outside person	135	3.0	(0.079)	<0.05	(0.21)	(0.57)	<0.5	(116)
MSMWF-9	Camp	8/8/07	P	Breaker, Front Side (left)	91	3.0	1.5	<0.07	0.59	12	<0.7	806
MSMWF-10	Camp	8/8/07	P	Breaker, Back Side (right)	88	3.0	0.42	<0.08	<0.2	(2.4)	<0.8	(140)
MSMHF-1	Camp	8/9/07	P	Outside person	150	3.0	0.49	<0.04	<0.09	3.1	<0.4	311
MSMHF-2	Camp	8/9/07	P	Outside person	148	3.0	(0.097)	<0.05	<0.09	(0.68)	<0.5	(173)
MSMHF-3	Camp	8/9/07	P	Feeder	147	2.9	2.1	<0.05	(0.18)	15	<0.5	891
MSMHF-4	Camp	8/9/07	P	Feeder	144	3.0	1.3	<0.05	(0.13)	8.8	<0.5	694
MSMHF-5	Camp	8/9/07	P	Breaker front side	109	3.0	2.0	<0.06	0.70	20	<0.6	856
MSMHF-6	Camp	8/9/07	P	Breaker back side	140	3.0	(0.13)	<0.05	<0.1	(1.0)	<0.5	<71
The following 6 samples were collected in the FPC GBO during filter change												
MSMHF-17	Camp	8/9/07	P	Filter change back, inside booth	45	3.0	5.0	<0.1	5.3	29	<1	1,704
MSMHF-19	Camp	8/9/07	P	Filter change front, inside booth	57	3.0	16	<0.1	12	105	<1	4,912
MSMHF-20	Camp	8/9/07	P	Filter change outside booth	62	3.0	1.6	<0.1	1.7	9.7	<1	753
MSMHF-21	Camp	8/9/07	P	Filter change outside booth	58	2.9	3.6	<0.1	4.4	22	<1	1,427
MSMHF-22	Camp	8/9/07	P	Filter change outside booth	47	3.0	1.3	<0.1	1.1	8.5	<1	(333)
MSMHF-23	Camp	8/9/07	P	Filter change outside booth	45	3.0	1.0	<0.1	(0.74)	(5.6)	<1	(274)

Table 5: Wipe Sample Results

SAMPLE I. D.	DATE	DESCRIPTION	Ba	Be	Cd	Pb	Ni
			Results in µg/100 cm^2				
SAMPLES TAKEN FROM THE FCI FACTORY							
MCMWG – 1	8/8/07	Cleaning area, table top where workers cleaning monitors	1.8	<0.07	0.49	5.6	2.7
MCMWG – 2	8/8/07	Table top near repair worker	15	<0.07	3.0	35	17
MCMWG – 3	8/8/07	Table top near breakdown worker, laminate surface	5.1	<0.07	1.1	37	3.9
MCMWG – 4	8/8/07	Table top near breakdown worker, surface is floor-mat material	16	<0.07	65	46	25
MCMWG – 5	8/8/07	Table top near breakdown worker, rough wood surface	8.9	<0.07	5.1	34	39
MCMWG – 6	8/8/07	Table top near testing worker, vinyl surface	5.9	<0.07	1.5	11	7.2
MCMWG – 7	8/8/07	Table top near sander, vinyl surface	20	<0.07	2.2	23	24
MCMWG – 8	8/8/07	Table top near worker doing copper stripping, Masonite surface	2.0	<0.07	0.73	14	3.7
MCMWG – 9	8/8/07	Table top near breakdown worker, rubber mat surface	2.6	<0.07	0.91	46	3.7
MCMHG – 1	8/9/07	Table top in breakdown area, rubber matt surface	18	<0.07	22	110	28
MCMHG – 2	8/9/07	Table top in breakdown area, smooth wood surface	0.60	<0.07	0.82	3.6	1.5
MCMHG – 3	8/9/07	Inside of Gaylord box containing small boards	1.0	<0.07	0.60	1.8	2.5
MCMHG – 4	8/9/07	Inside bailer in disassembly area	0.38	<0.07	(0.16)	2.5	1.2
MCMHG – 5	8/9/07	Rubber matt surface in breakdown area	21	<0.07	4.1	85	14
MCMHG – 6	8/9/07	Smooth wood surface in breakdown area	15	<0.07	3.0	17	7.3
MCMHG – 7	8/9/07	Smooth wood surface in breakdown area	80	<0.07	19	88	19
MCMHG – 8	8/9/07	Rough wood surface in breakdown area	11	<0.07	1.9	72	11
MCMHG – 9	8/9/07	Rough wood surface in breakdown area	62	<0.07	2.9	140	18
MCMHG – 10	8/9/07	Smooth work surface in copper stripping area	3.4	<0.07	0.54	9.8	2.7
MCMHG – 11	8/9/07	Top of sanding table in refurbish area, rubber surface	53	<0.07	3.0	33	68
MCMHG – 12	8/9/07	Table top for refurbishing large assemblies, very rough wood surface	1.4	<0.07	1.0	5.3	5.1
MCMHG – 13	8/9/07	Inside box containing "Frames with boards"	(0.16)	<0.07	<0.07	1.1	<0.3
MCMHG – 14	8/9/07	Smooth wood surface, disassembly operation in refurbish area	7.4	<0.07	1.1	36	3.9
SAMPLES TAKEN FROM THE CAMP FACILITY							
MSMWG – 1	8/8/07	Top of bookcase outside breaking area	1.3	<0.07	1.2	8.4	(0.75)
MSMWG – 2	8/8/07	Locker in GB area (top, under handle)	0.25	<0.07	0.31	2.9	(0.32)
MSMWG – 3	8/8/07	Top of conduit inside containment on interior wall	320	<0.07	360	5100	52

< Indicates a value less than the limit of detection. Numbers in parentheses indicate a result between the LOD and LOQ.

Table 6: Composition of Bulk Dust Samples from the Glass Breaking Operation

SAMPLE I. D.	DATE	SAMPLE DESCRIPTION	Ba	Be	Cd	Pb	Ni
MSMWB – 1	8/8/07	Bulk from filter in shop vac used for general cleaning	1000	<0.2	170	2200	1800
MSMWB – 2	8/8/07	Bulk from Nilfisk vac used outside containment area	890	<0.2	(1.3)	35000	7.7
MSMWB – 3	8/8/07	Bulk from Nilfisk vac used inside containment area	82	<0.2	(0.98)	2300	2.1
MSMWB – 4	8/8/07	Settled dust on top of locker	570	<0.2	130	2500	610
MSMHB – 1	8/9/07	Floor sweeping outside of curtained area during filter change using broom to sweep floor	470	<0.2	260	10000	31

All samples were taken from glass breaking room at the camp facility. Concentrations are in mg/kg. < indicates a value less than the limit of detection. A value in parentheses indicates a result between the limit of detection and limit of quantitation.

Table 7: Wet Bulb Globe Temperature Measurements, Marianna Federal Correctional Facility

Heat Stress Data – August 8, 2007		
Location	Times	Hourly TWA* WBGT$_{in}$ °C (°F)
Camp – Glass Breaking Room	8:52 a.m. to 9:52 a.m.	28.8 (83.8)
	9:53 a.m. to 10:45 a.m.	29.7 (85.5)
Camp – Warehouse	9:41 a.m. to 10:41 a.m.	28.1 (82.6)
	10:42 a.m. to 11:42 a.m.	28.4 (83.1)
	11:43 a.m. to 12:43 p.m.	28.5 (83.3)
	12:44 p.m. to 1:44 p.m.	28.5 (83.3)
	1:45 p.m. to 2:45 p.m.	28.2 (82.8)
FCI – Refurbish	10:24 a.m. to 11:24 a.m.	28.3 (82.9)
	11:25 a.m. to 12:25 p.m.	28.9 (84.0)
	12:26 p.m. to 1:26 p.m.	29.1 (84.4)
	1:27 p.m. to 2:27 p.m.	29.1 (84.4)
	2:28 p.m. to 3:28 p.m.	28.8 (83.8)
FCI – Disassembly	10:31 a.m. to 11:31 a.m.	28.4 (83.1)
	11:32 a.m. to 12:32 p.m.	29.0 (84.2)
	12:33 p.m. to 1:33 p.m.	29.1 (84.4)
	1:34 p.m. to 2:34 p.m.	29.4 (84.9)
	2:35 p.m. to 3:35 p.m.	29.2 (84.6)

Heat Stress Data – August 9, 2007		
Location	Times	Hourly TWA* WBGT$_{in}$ °C (°F)
Camp – Glass Breaking Room	7:59 a.m. to 8:59 a.m.	29.7 (85.5)
	9:00 a.m. to 10:00 a.m.	30.4 (86.8)
Glass Breaking Room during Filter Change	12:35 p.m. to 1:35 p.m.	31.2 (88.2)
Camp –Warehouse	8:44 a.m. to 9:44 a.m.	28.6 (83.5)
	9:45 a.m. to 10:45 a.m.	29.3 (84.8)
	10:46 a.m. to 11:46 a.m.	29.4 (84.9)
	11:47 a.m. to 12:47 p.m.	29.3 (84.7)
	12:48 p.m. to 1:48 p.m.	29.2 (84.5)
FCI – Refurbish	9:35 a.m. to 10:35 a.m.	29.2 (84.6)
	10:36 a.m. to 11:36 a.m.	29.6 (85.2)
	11:37 a.m. to 12:37 p.m.	29.7 (85.5)
	12:38 p.m. to 1:38 p.m.	29.7 (85.5)
	1:39 p.m. to 2:39 p.m.	30.1 (86.1)
	2:40 p.m. to 3:40 p.m.	30.3 (86.5)
FCI – Disassembly	9:04 a.m. to 10:04 a.m.	29.3 (84.7)
	10:05 a.m. to 11:05 a.m.	29.6 (85.3)
	11:06 a.m. to 12:06 p.m.	29.9 (85.9)
	12:07 p.m. to 1:07 p.m.	30.0 (86.0)
	1:08 p.m. to 2:08 p.m.	30.2 (86.4)
	2:09 p.m. to 3:09 p.m.	30.4 (86.8)

*Time weighted average

Table 8: Estimated Work Rates

Location	Task	Work Rate	Metabolic Heat (Watts)
FCI	All tasks	Light/moderate	180/300
FPC	Unloading trucks	Moderate	300
	Warehouse work	Light	180
	GBO* helpers	Light/moderate	180/300
	GBO feeders	Moderate/heavy	300/415
	GBO breakers	Moderate	300

Table 9: Air Velocity Measurements for HFM 1 and HFM 2

FACE VELOCITY MEASUREMENTS

1.07 (210)	0.81(160)	0.79 (155)
0.71 (140)	0.61(120)	0.66 (130)
0.48 (95)	0.76(150)	0.48 (95)
0.46 (90)	0.81(160)	0.35 (68)

HFM 1

0.69 (135)	1.02 (200)	0.76 (150)
0.53 (105)	0.66 (130)	0.64 (125)
0.30 (60)	0.48 (95)	0.15 (30)
0.51 (100)	0.36 (70)	0.36 (70)

HFM 2

CAPTURE VELOCITY MEASUREMENTS

0.19 (38)	0.35 (69)	0.14 (27)
0.18 (35)	0.89 (175)	0.23 (45)
0.43 (85)	0.93 (184)	0.11 (21)
0.15 (30)	0.71 (140)	0.15 (30)

HFM 1

0.17 (33)	0.80 (157)	0.27 (53)
0.18 (36)	0.81 (160)	0.25 (50)
0.20 (39)	0.55 (108)	0.24 (47)
0.64 (125)	0.50 (99)	0.16 (31)

HFM 2

Units in meters/second (feet/min)

Appendix A
Occupational Exposure Criteria for Metal/Elements

TABLE 2. EXPOSURE LIMITS, CAS #, RTECS

Element (Symbol)	CAS #	RTECS	Exposure Limits, mg/m³ (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	YW240000	–	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

Appendix B
Metallic Composition of Bulk Dust Samples from the Glass Breaking Operation

Concentrations are in mg/kg

Please see Table 6 for sample dates and descriptions.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMWB-1	MSMWB-2	MSMWB-3	MSMWB-4	MSMHB-1
Al	3900	120	54	5000	410
Sb	110	<3	<3	100	(8.3)
As	<7	<7	<7	<7	<7
Ba	1000	890	82	570	470
Be	<0.2	<0.2	<0.2	<0.2	<0.2
Cd	170	(1.3)	(0.98)	130	260
Ca	18000	770	150	26000	700
Cr	53	1.9	2.3	87	23
Co	5.2	<0.2	<0.2	18	0.63
Cu	210	28	3.5	320	52
Fe	9200	1100	800	18000	4300
La	<0.1	<0.1	<0.1	2.3	(0.12)
Pb	2200	35000	2300	2500	10000
Li	(3.2)	(0.14)	<0.09	(15)	0.44
Mg	1800	72	16	3800	77
Mn	220	290	4.6	370	50
Mo	4.2	(1.1)	<0.4	6.0	(0.42)
Ni	1800	7.7	2.1	610	31
P	790	(33)	<10	2800	57
K	2700	190	190	3700	400
Se	<20	<20	<20	<20	<20
Ag	13	0.30	<0.08	1.8	<0.08
Sr	130	32	18	150	140
Te	<2	<2	<2	(3.5)	(4.0)
Tl	<5	(6.8)	(8.5)	(9.7)	<5
Sn	67	<4	<4	65	(7.9)
Ti	44	2.8	1.0	58	3.2
V	6.5	(0.10)	<0.1	15	<0.1
Y	2100	19	31	2300	5800
Zn	5900	4500	390	7700	13000
Zr	(2.0)	(20)	<2	(2.6)	(3.8)

Appendix C
Metallic Composition of Wipe Samples

Concentrations are in µg/100 cm^2

Please see Table 5 for sample dates and descriptions.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MCMWG - 1	MCMWG - 2	MCMWG - 3	MCMWG - 4	MCMWG - 5	MCMWG - 6	MCMWG - 7	MCMWG - 8	MCMWG - 9	MCMHG - 1	MCMHG - 2	MCMHG - 3	MCMHG - 4
As	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ba	1.8	15	5.1	16	8.9	5.9	20	2.0	2.6	18	0.60	1.0	0.38
Be	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Cd	0.49	3.0	1.1	65	5.1	1.5	2.2	0.73	0.91	22	0.82	0.60	(0.16)
Cr	1.1	6.0	2.7	8.2	12	2.4	4.7	2.3	3.2	9.8	(0.89)	(0.56)	(0.56)
Co	(0.18)	2.5	(0.25)	0.98	1.1	0.34	0.79	2.0	1.1	1.2	<0.09	(0.15)	(0.10)
Cu	5.1	35	12	68	130	14	36	14	51	83	3.3	3.3	2.2
Fe	58	567	137	667	3197	187	447	267	167	2297	21	49	95
La	<0.05	0.34	(0.077)	<0.05	1.3	(0.082)	0.37	(0.14)	(0.11)	0.87	<0.05	<0.05	(0.058)
Pb	5.6	35	37	46	34	11	23	14	46	110	3.6	1.8	2.5
Mn	1.8	18	4.4	22	110	7.0	15	35	22	35	(0.35)	1.4	1.8
Mo	<0.2	0.66	<0.2	2.9	2.2	<0.2	(0.34)	(0.22)	<0.2	0.71	<0.2	<0.2	<0.2
Ni	2.7	17	3.9	25	39	7.2	24	3.7	3.7	28	1.5	2.5	1.2
P	<6	301	13	22	<6	53	<6	<6	<6	<6	<6	<6	<6
Se	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Ag	0.16	0.76	0.29	9.7	5.2	0.28	0.32	(0.10)	0.26	3.7	(0.069)	(0.068)	<0.04
Sr	0.50	3.8	2.3	3.4	3.8	1.1	1.7	0.91	0.78	2.7	0.47	0.48	(0.36)
Te	<0.5	(0.72)	<0.5	<0.5	(0.51)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tl	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sn	<3	19	32	44	39	(5.4)	13	11	95	190	(3.1)	<3	(3.6)
V	<0.05	0.29	(0.12)	(0.13)	(0.14)	<0.05	<0.05	<0.05	(0.076)	(0.13)	<0.05	<0.05	<0.05
Y	(0.065)	1.3	0.91	2.9	0.41	0.20	0.51	(0.11)	0.19	1.4	(0.056)	<0.04	<0.04
Zn	108	638	348	598	728	178	178	138	558	708	218	138	98
Zr	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Appendix C (Continued)
Metallic Composition of Wipe Samples

Concentrations are in µg/100 cm^2
Please see Table 5 for sample dates and descriptions.
<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MCMHG - 5	MCMHG - 6	MCMHG - 7	MCMHG - 8	MCMHG - 9	MCMHG - 10	MCMHG - 11	MCMHG - 12	MCMHG - 13	MCMHG - 14	MSMWG - 1	MSMWG - 2	MSMWG - 3
As	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ba	21	15	80	11	62	3.4	53	1.4	(0.16)	7.4	1.3	0.25	320
Be	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Cd	4.1	3.0	19	1.9	2.9	0.54	3.0	1.0	<0.07	1.1	1.2	0.31	360
Cr	6.7	2.7	6.5	4.1	10	2.7	9.3	2.1	(0.25)	2.0	(0.33)	(0.39)	13
Co	36	(0.14)	1.3	0.87	19	(0.22)	1.5	(0.17)	<0.09	(0.098)	<0.09	(0.11)	0.59
Cu	94	18	43	19	77	31	95	21	1.3	13	1.5	(0.8)	29
Fe	1897	157	887	501	1897	1797	527	267	7.3	177	10	1.7	1297
La	0.58	(0.055)	0.90	0.29	0.92	0.55	0.24	(0.13)	<0.05	(0.071)	<0.05	<0.05	1.5
Pb	85	17	88	72	140	9.8	33	5.3	1.1	36	8.4	2.9	5100
Mn	44	3.0	49	110	450	110	24	12	0.51	14	<0.1	<0.1	22
Mo	(0.27)	0.70	2.9	<0.2	<0.2	<0.2	(0.39)	(0.28)	<0.2	<0.2	<0.2	<0.2	(0.47)
Ni	14	7.3	19	11	18	2.7	68	5.1	<0.3	3.9	(0.75)	(0.32)	52
P	<6	<6	12	<6	<6	<6	20	<6	<6	<6	<6	<6	80
Se	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Ag	1.1	0.30	1.6	0.58	9.3	(0.066)	0.55	4.3	<0.04	0.58	<0.04	<0.04	1.2
Sr	2.4	1.2	4.7	1.7	2.6	0.94	2.8	0.79	(0.32)	1.8	0.91	0.72	170
Te	3.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tl	<2	<2	<2	<2	<2	(2.2)	<2	<2	<2	<2	<2	<2	<2
Sn	170	27	62	120	160	(4.1)	19	(4.0)	<3	43	<3	<3	12
V	(0.092)	(0.054)	(0.080)	0.21	0.56	<0.05	(0.14)	<0.05	<0.05	(0.073)	<0.05	<0.05	0.33
Y	0.14	(0.11)	1.1	3.3	2.0	(0.11)	0.45	(0.054)	<0.04	0.27	1.0	0.49	810
Zn	628	278	698	488	1298	488	308	148	91.3	378	118	148	3098
Zr	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Appendix D

Metallic Composition of Airborne Dust Samples

Concentrations are in $\mu g/m^3$

Please see Table 4 for sample dates, description, duration and flow rate.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MCMWF-5	MCMWF-6	MCMWF-7	MCMWF-8	MCMWF-9	MCMWF-10
Aluminum	2.8	2.6	2.4	(1.8)	(1.5)	(1.3)
Antimony	<0.5	<0.5	<0.5	<0.6	<0.5	<0.6
Arsenic	<1	<1	<1	<1	<1	<1
Barium	0.15	0.26	0.21	0.077	(0.063)	0.11
Beryllium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cadmium	(0.052)	(0.079)	(0.047)	<0.03	<0.03	(0.052)
Calcium	17	17	12	9.1	7.8	8.1
Chromium	(0.24)	(0.13)	(0.18)	<0.1	<0.1	(0.22)
Cobalt	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Copper	(0.29)	(0.33)	(0.17)	<0.1	0.53	(0.20)
Iron	5.4	5.9	6.1	3.5	2.3	4.2
Lanthanum	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	(0.54)	<0.1	(0.17)	<0.1	(0.35)	<0.1
Lithium	<0.009	<0.009	<0.009	<0.01	<0.01	<0.01
Magnesium	1.3	1.1	0.96	1.2	0.53	0.67
Manganese	0.15	0.21	0.11	(0.093)	(0.12)	(0.13)
Molybdenum	<0.052	<0.08	<0.08	<0.08	<0.08	<0.08
Nickel	(0.19)	(0.11)	(0.13)	(0.089)	(0.15)	<0.08
Phosphorus	<4	<4	<4	<4	<4	<4
Potassium	1.6	1.0	0.82	(0.33)	(0.40)	(0.39)
Selenium	<3	<3	<3	<3	<3	<3
Silver	<0.03	<0.03	<0.03	<0.03	<0.3	(0.050)
Strontium	0.077	0.066	0.057	0.050	0.039	0.049
Tellurium	<0.4	<0.4	<0.4	(0.44)	<0.4	<0.4
Thallium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.6
Tin	<0.5	<0.5	<0.5	<0.5	<0.5	<0.6
Titanium	(0.065)	0.076	(0.054)	(0.044)	<0.03	(0.045)
Vanadium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Yttrium	<0.008	<0.03	<0.03	<0.01	<0.02	<0.02
Zinc	7.7	6.1	5.7	5.8	3.4	2.9
Zirconium	(0.20)	(0.16)	<0.1	<0.1	<0.1	<0.1

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples
Concentrations are in $\mu g/m^3$

Please see Table 4 for sample dates, description, duration and flow rate. <indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MCMHF-1	MCMHF-2	MCMHF-3	MCMHF-4	MCMHF-5	MCMHF-6
Aluminum	(2.2)	<1	(1.4)	<2	<2	(1.8)
Antimony	<0.5	<0.5	<0.4	<0.8	<1	<0.4
Arsenic	<2	<2	<1	<3	<4	<1
Barium	0.26	0.19	0.17	<0.05	<0.07	0.14
Beryllium	<0.03	<0.03	<0.02	<0.05	<0.07	<0.03
Cadmium	(0.091)	(0.069)	(0.056)	<0.1	<0.1	<0.06
Calcium	14	9.5	12	<5	<7	(6.5)
Chromium	<0.2	<0.2	<0.1	<0.3	<0.4	<0.1
Cobalt	<0.06	<0.06	<0.05	<0.1	<0.1	<0.06
Copper	<0.3	<0.3	<0.2	<0.5	<0.7	<0.3
Iron	(4.6)	(3.5)	(4.7)	<5	<7	<3
Lanthanum	<0.01	<0.01	<0.01	<0.02	<0.03	<0.01
Lead	<0.3	<0.3	(0.40)	<0.5	<0.7	(0.37)
Lithium	<0.02	<0.02	<0.01	<0.03	<0.04	<0.01
Magnesium	<1	<1	<1	<2	<3	<1
Manganese	0.20	(0.12)	0.16	<0.08	<0.1	(0.13)
Molybdenum	(0.18)	<0.2	<0.1	<0.3	<0.4	<0.1
Nickel	<0.3	<0.3	<0.2	<0.5	<0.7	<0.3
Phosphorus	<5	<5	<4	<8	<11	<4
Potassium	1.0	(0.74)	0.90	<0.3	<0.4	(0.55)
Selenium	<5	<5	<4	<8	<11	<4
Silver	(0.022)	(0.018)	(0.012)	<0.03	<0.04	(0.017)
Strontium	(0.052)	(0.042)	(0.042)	<0.03	<0.04	(0.030)
Tellurium	<0.5	<0.5	<0.4	<0.8	<1	<0.4
Thallium	(0.77)	<0.6	<0.5	<1	<1	<0.6
Tin	<0.8	(0.82)	<0.6	<1	<2	<0.7
Titanium	(0.037)	(0.032)	(0.059)	<0.05	<0.07	<0.03
Vanadium	(0.031)	<0.02	<0.01	<0.03	<0.04	(0.014)
Yttrium	(0.014)	0.27	<0.01	0.20	<0.03	<0.01
Zinc	4.9	5.2	5.6	1.1	(0.74)	6.2
Zirconium	(0.18)	<0.2	<0.1	<0.3	<0.4	<0.1

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in μg/m^3
Please see Table 4 for sample dates, description, duration and flow rate.
<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MCMHF-7	MCMHF-8	MCMHF-9	MCMHF-10	MCMHF-11	MCMHF-12
Aluminum	(1.0)	(1.3)	(2.5)	<1	<0.9	<3
Antimony	(0.42)	<0.4	<0.4	<0.4	<0.4	<1
Arsenic	<1	<1	<1	<1	<1	<5
Barium	0.12	0.18	0.21	(0.055)	(0.039)	<0.09
Beryllium	<0.03	<0.02	<0.03	<0.03	<0.03	<0.09
Cadmium	<0.05	<0.05	<0.06	<0.06	<0.05	<0.2
Calcium	7.1	11	15	(3.0)	<3	<9
Chromium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5
Cobalt	<0.05	<0.05	<0.06	<0.06	<0.05	<0.2
Copper	<0.2	<0.2	<0.3	<0.3	<0.3	<0.9
Iron	(3.9)	(2.6)	(6.3)	<3	<3	<9
Lanthanum	<0.01	<0.01	<0.01	<0.01	<0.01	<0.04
Lead	<0.2	<0.2	(0.44)	<0.3	<0.3	<0.9
Lithium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Magnesium	<1	<0.9	<1	<1	<1	<4
Manganese	(0.11)	(0.086)	0.22	(0.089)	(0.041)	<0.1
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5
Nickel	<0.2	<0.2	<0.3	<0.3	<0.3	<0.9
Phosphorus	<4	<4	<4	<4	<4	<14
Potassium	(0.43)	1.2	1.5	(0.27)	<0.1	<0.5
Selenium	<4	<4	<4	<4	<4	<14
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Strontium	(0.022)	(0.041)	(0.047)	<0.01	<0.01	<0.05
Tellurium	<0.4	<0.4	<0.4	<0.4	<0.4	(2.1)
Thallium	<0.5	<0.5	<0.6	<0.6	<0.5	<2
Tin	<0.6	<0.6	(0.75)	<0.7	<0.7	<2
Titanium	<0.03	<0.02	(0.061)	<0.03	<0.03	<0.09
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Yttrium	<0.01	0.075	<0.01	(0.066)	<0.01	<0.04
Zinc	3.4	5.6	7.9	2.5	0.77	<0.4
Zirconium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in μg/m^3

Please see Table 4 for sample dates, description, duration and flow rate.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMWF-1	MSMWF-2	MSMWF-3	MSMWF-4	MSMWF-5	MSMWF-6
Aluminum	(2.8)	(4.3)	<2	<2	<1	<1
Antimony	<0.7	<0.7	<0.7	<0.7	<0.5	<0.5
Arsenic	<2	<2	<2	<2	<2	<2
Barium	0.65	0.69	(0.11)	(0.079)	(0.055)	(0.041)
Beryllium	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
Cadmium	6.8	3.8	(0.22)	(0.21)	<0.06	<0.06
Calcium	28	36	<5	<5	(3.6)	(4.3)
Chromium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cobalt	<0.09	<0.1	<0.1	<0.1	<0.06	<0.06
Copper	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3
Iron	(8.2)	(9.8)	<5	<5	(3.9)	<3
Lanthanum	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01
Lead	3.7	5.2	<0.5	(0.57)	<0.3	<0.3
Lithium	<0.02	<0.02	<0.02	<0.03	<0.02	<0.02
Magnesium	<2	<2	<2	<2	<1	<1
Manganese	(0.17)	(0.16)	<0.07	<0.07	<0.05	<0.05
Molybdenum	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nickel	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3
Phosphorus	<7	<7	<7	<7	<5	<5
Potassium	2.3	3.1	<0.2	<0.2	(0.18)	(0.20)
Selenium	<7	<7	<7	<7	<5	<5
Silver	(0.023)	<0.02	<0.02	<0.03	<0.02	<0.02
Strontium	0.19	0.29	(0.027)	<0.03	<0.02	<0.02
Tellurium	<0.7	(0.88)	<0.7	(0.94)	<0.5	<0.5
Thallium	<0.9	<1	<1	<1	<0.6	<0.6
Tin	<1	(1.3)	<1	<1	<0.8	<0.8
Titanium	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
Vanadium	<0.002	<0.02	<0.02	<0.03	<0.02	<0.02
Yttrium	2.1	2.3	0.36	0.17	<0.01	<0.01
Zinc	49	36	2.7	2.0	0.70	(0.43)
Zirconium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in µg/m^3

Please see Table 4 for sample dates, description, duration and flow rate.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMWF-7	MSMWF-8	MSMWF-9	MSMWF-10	MSMWF-11	MSMWF-12
Aluminum	<2	<1	<3	<3	<1	<0.9
Antimony	<1	<0.5	<1	<1	<0.6	<0.4
Arsenic	<3	<2	<4	<4	<2	<1
Barium	<0.06	(0.042)	1.5	0.42	0.42	(0.063)
Beryllium	<0.06	<0.03	<0.07	<0.08	<0.04	<0.03
Cadmium	<0.1	<0.07	0.59	<0.2	<0.08	<0.05
Calcium	<6	(3.6)	23	<8	<4	<3
Chromium	<0.3	<0.2	<0.4	<0.4	<0.2	<0.1
Cobalt	<0.1	<0.07	<0.1	<0.2	<0.08	<0.05
Copper	<0.6	<0.3	<0.7	<0.8	<0.4	<0.3
Iron	<6	(3.6)	<7	<8	<4	<3
Lanthanum	<0.03	<0.02	<0.03	<0.03	<0.02	<0.01
Lead	<0.6	<0.3	12	(2.4)	<0.4	<0.3
Lithium	<0.03	<0.02	<0.04	<0.04	<0.02	<0.01
Magnesium	<3	<1	<3	<3	<2	<1
Manganese	<0.1	<0.05	<0.1	<0.1	<0.06	<0.04
Molybdenum	<0.3	<0.2	<0.4	<0.4	<0.2	<0.1
Nickel	<0.6	<0.3	<0.7	<0.8	<0.4	<0.3
Phosphorus	<10	<5	<11	<11	<6	<4
Potassium	<0.3	(0.23)	3.4	(0.46)	(0.24)	<0.1
Selenium	<10	<5	<11	<11	<6	<4
Silver	<0.03	<0.02	<0.04	<0.04	<0.02	<0.01
Strontium	<0.03	<0.02	0.59	(0.12)	(0.026)	<0.01
Tellurium	<1	<0.5	<1	<1	<0.6	<0.4
Thallium	<1	<0.6	<1	<2	<0.8	<0.5
Tin	<2	<0.8	<2	<2	<1	<0.6
Titanium	<0.06	<0.03	<0.07	<0.08	<0.04	<0.03
Vanadium	<0.03	<0.02	<0.04	<0.04	<0.02	<0.01
Yttrium	0.28	<0.02	26	7.5	1.2	0.11
Zinc	(0.86)	0.63	66	16	3.8	0.96
Zirconium	<0.3	<0.2	<0.4	<0.4	<0.2	<0.1

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in $\mu g/m^3$

Please see Table 4 for sample dates, description, duration and flow rate.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMHF-1	MSMHF-2	MSMHF-3	MSMHF-4	MSMHF-5	MSMHF-6
Aluminum	(2.7)	<2	8.9	(5.3)	(5.2)	<2
Antimony	<0.7	<0.7	<0.7	<0.7	<0.9	<0.7
Arsenic	<2	<2	<2	<2	<3	<2
Barium	0.49	(0.097)	2.1	1.3	2.0	(0.13)
Beryllium	<0.04	<0.05	<0.05	<0.05	<0.06	<0.05
Cadmium	<0.09	<0.09	(0.18)	(0.13)	0.70	<0.1
Calcium	(9.3)	(5.4)	33	32	19	<5
Chromium	<0.2	<0.2	<0.2	<0.2	<0.3	<0.2
Cobalt	<0.09	<0.09	<0.09	<0.09	<0.1	<0.1
Copper	<0.4	<0.5	<0.5	<0.5	<0.6	<0.5
Iron	(5.1)	<5	16	(8.3)	(8.9)	<5
Lanthanum	<0.02	<0.02	<0.02	<0.02	<0.03	<0.02
Lead	3.1	(0.68)	15	8.8	20	(1.0)
Lithium	<0.02	<0.02	<0.02	<0.02	<0.03	<0.02
Magnesium	<2	<2	(2.3)	<2	<2	<2
Manganese	(0.10)	<0.07	(0.19)	(0.18)	<0.09	<0.07
Molybdenum	<0.2	<0.2	<0.2	<0.2	<0.3	<0.2
Nickel	<0.4	<0.5	<0.5	<0.5	<0.6	<0.5
Phosphorus	<7	<7	<7	<7	<9	<7
Potassium	1.4	(0.45)	5.9	3.7	4.3	<0.2
Selenium	<7	<7	<7	<7	<9	<7
Silver	<0.02	<0.02	<0.02	<0.02	<0.03	<0.02
Strontium	(0.067)	(0.025)	0.33	0.23	0.73	(0.055)
Tellurium	<0.7	<0.7	<0.7	(1.3)	<0.9	(0.86)
Thallium	<0.9	<0.9	<0.9	<0.9	<1	<1
Tin	<1	(1.3)	<1	<1	<2	<1
Titanium	<0.04	<0.05	<0.05	<0.05	<0.06	<0.05
Vanadium	<0.02	<0.02	<0.02	<0.02	<0.03	<0.02
Yttrium	8.0	0.60	52	23	37	1.7
Zinc	17	2.0	84	49	80	3.8
Zirconium	<0.2	<0.2	<0.2	<0.2	<0.3	<0.2

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in µg/m^3
Please see Table 4 for sample dates, description, duration and flow rate.
<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMHF-7	MSMHF-8	MSMHF-9	MSMHF-10	MSMHF-11	MSMHF-12
Aluminum	(1.0)	(1.7)	3.9	<0.9	27	<0.9
Antimony	<0.4	<0.3	(0.52)	<0.4	(0.43)	<0.4
Arsenic	<1	<1	<1	<1	<1	<1
Barium	(0.049)	(0.064)	0.20	(0.033)	1.6	(0.060)
Beryllium	<0.03	<0.02	<0.03	<0.03	<0.02	<0.03
Cadmium	(0.089)	0.24	0.49	<0.05	0.14	<0.05
Calcium	(4.4)	7.9	16	<3	177	<3
Chromium	0.19	0.12	5.0	<0.1	0.48	<0.1
Cobalt	<0.05	<0.05	0.30	<0.05	<0.04	<0.05
Copper	<0.3	<0.2	<0.3	<0.3	1.7	<0.3
Iron	208	168	2449	(3.9)	48	<3
Lanthanum	0.082	0.081	0.97	<0.01	<0.01	<0.01
Lead	<0.3	<0.2	(0.42)	<0.3	1.1	<0.3
Lithium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Magnesium	<1	(1.1)	9.9	<1	13	<1
Manganese	2.5	2.8	27	(0.051)	0.91	(0.15)
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.3	<0.2	<0.3	<0.3	0.84	<0.3
Phosphorus	<4	<3	<4	<4	(8.7)	<4
Potassium	(0.23)	(0.34)	0.78	<0.1	45	<0.1
Selenium	<4	<3	<4	<4	<3	<4
Silver	<0.01	<0.01	<0.01	<0.01	0.099	<0.01
Strontium	<0.01	(0.039)	(0.054)	<0.01	0.47	<0.01
Tellurium	<0.4	<0.3	(0.50)	<0.4	<0.3	<0.4
Thallium	<0.5	<0.4	<0.5	<0.5	<0.4	<0.5
Tin	<0.7	<0.6	(0.69)	<0.7	<0.6	<0.7
Titanium	<0.03	<0.02	(0.050)	<0.03	0.85	<0.3
Vanadium	<0.01	<0.01	<0.01	<0.01	(0.027)	<0.01
Yttrium	<0.01	0.32	(0.050)	<0.01	0.097	<0.01
Zinc	2.3	3.0	20	0.51	24	1.3
Zirconium	<0.1	<0.1	<0.1	<0.1	(1.0)	<0.1

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples

Concentrations are in µg/m^3

Please see Table 4 for sample dates, description, duration and flow rate.

<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMHF-13	MSMHF-14	MSMHF-17	MSMHF-19
Aluminum	<1	<0.9	(7.1)	30
Antimony	<0.5	<0.4	<2	<2
Arsenic	<2	<1	<7	<6
Barium	(0.069)	0.16	5.0	16
Beryllium	<0.03	<0.03	<0.1	<0.1
Cadmium	<0.06	<0.05	5.3	12
Calcium	<3	(4.6)	<15	47
Chromium	<0.2	<0.01	<0.7	<0.6
Cobalt	<0.06	<0.05	(0.36)	0.82
Copper	<0.3	<0.3	<1	<1
Iron	<3	(3.6)	<15	41
Lanthanum	<0.01	<0.01	<0.07	(0.056)
Lead	<0.3	<0.2	29	105
Lithium	<0.02	<0.01	<0.07	<0.06
Magnesium	<1	<1	<6	<5
Manganese	<0.05	(0.048)	<0.2	(0.35)
Molybdenum	<0.2	<0.1	<0.7	<0.6
Nickel	<0.3	<0.2	<1	<1
Phosphorus	<5	<4	<22	<18
Potassium	<0.2	(0.38)	5.6	23
Selenium	<5	<4	<22	<18
Silver	<0.02	<0.01	<0.07	<0.06
Strontium	<0.02	(0.012)	2.1	7.6
Tellurium	<0.5	<0.4	<2	<2
Thallium	<0.6	<0.5	<3	<2
Tin	<0.8	<0.6	<4	<3
Titanium	<0.03	<0.03	<0.1	(0.23)
Vanadium	<0.02	<0.01	<0.07	<0.06
Yttrium	<0.01	<0.01	200	438
Zinc	2.3	3.6	467	1053
Zirconium	<0.2	<0.1	<0.7	<0.6

Appendix D (Continued)
Metallic Composition of Airborne Dust Samples
Concentrations are in µg/m^3

Please see Table 4 for sample dates, description, duration and flow rate.
<indicates a result less than the limit of detection. Values in parentheses represent results between the limit of detection and limit of quantitation.

	MSMHF-20	MSMHF-21	MSMHF-22	MSMHF-23
Aluminum	<4	(6.5)	<5	<5
Antimony	<2	<2	<2	<2
Arsenic	<5	<6	<7	<7
Barium	1.6	3.6	1.3	1.0
Beryllium	<0.1	<0.1	<0.1	<0.1
Cadmium	1.7	4.4	1.1	(0.74)
Calcium	<11	(12)	<14	<15
Chromium	<0.5	<0.6	<0.7	<0.7
Cobalt	<0.2	(0.24)	<0.3	<0.3
Copper	<1	<1	<1	<1
Iron	<11	<12	<14	<15
Lanthanum	<0.05	<0.05	<0.06	<0.07
Lead	9.7	22	8.5	(5.6)
Lithium	<0.05	<0.06	<0.07	<0.07
Magnesium	<4	<5	<6	<6
Manganese	<0.2	<0.2	<0.2	<0.2
Molybdenum	<0.5	<0.6	<0.7	<0.7
Nickel	<1	<1	<1	<1
Phosphorus	<16	<18	<21	<22
Potassium	(2.5)	4.8	(1.3)	(1.2)
Selenium	<16	<18	<21	<22
Silver	<0.05	<0.06	<0.07	<0.07
Strontium	0.81	1.5	0.57	0.49
Tellurium	<2	<2	<2	<2
Thallium	<2	<2	<3	<3
Tin	<3	<3	<4	<4
Titanium	<0.1	<0.1	<0.1	<0.1
Vanadium	<0.05	<0.06	<0.07	<0.07
Yttrium	51	131	38	24
Zinc	124	333	92	59
Zirconium	<0.5	<0.6	<0.7	<0.7

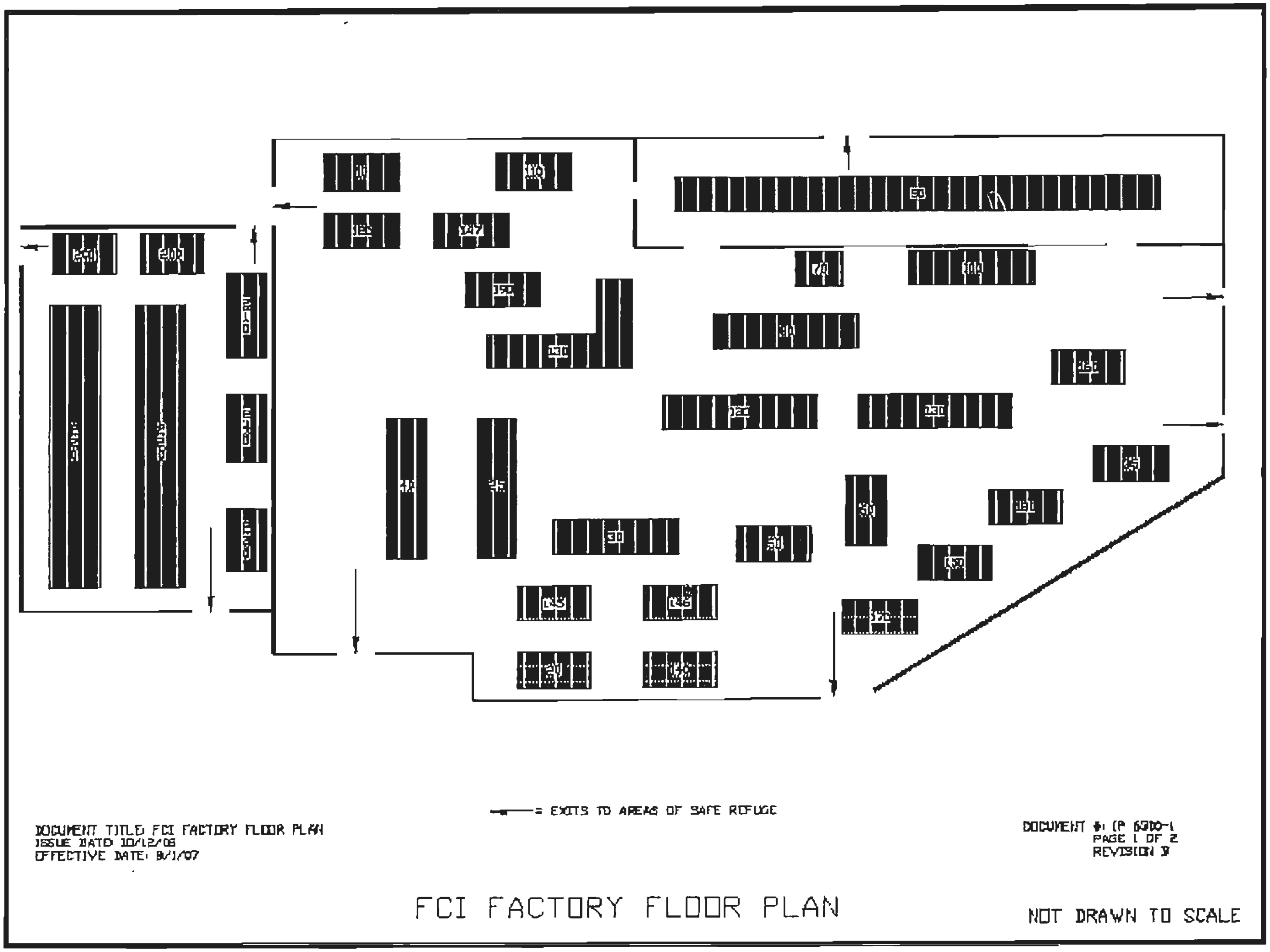


Figure I: Marianna FCI UNICOR Factory Floor Plan

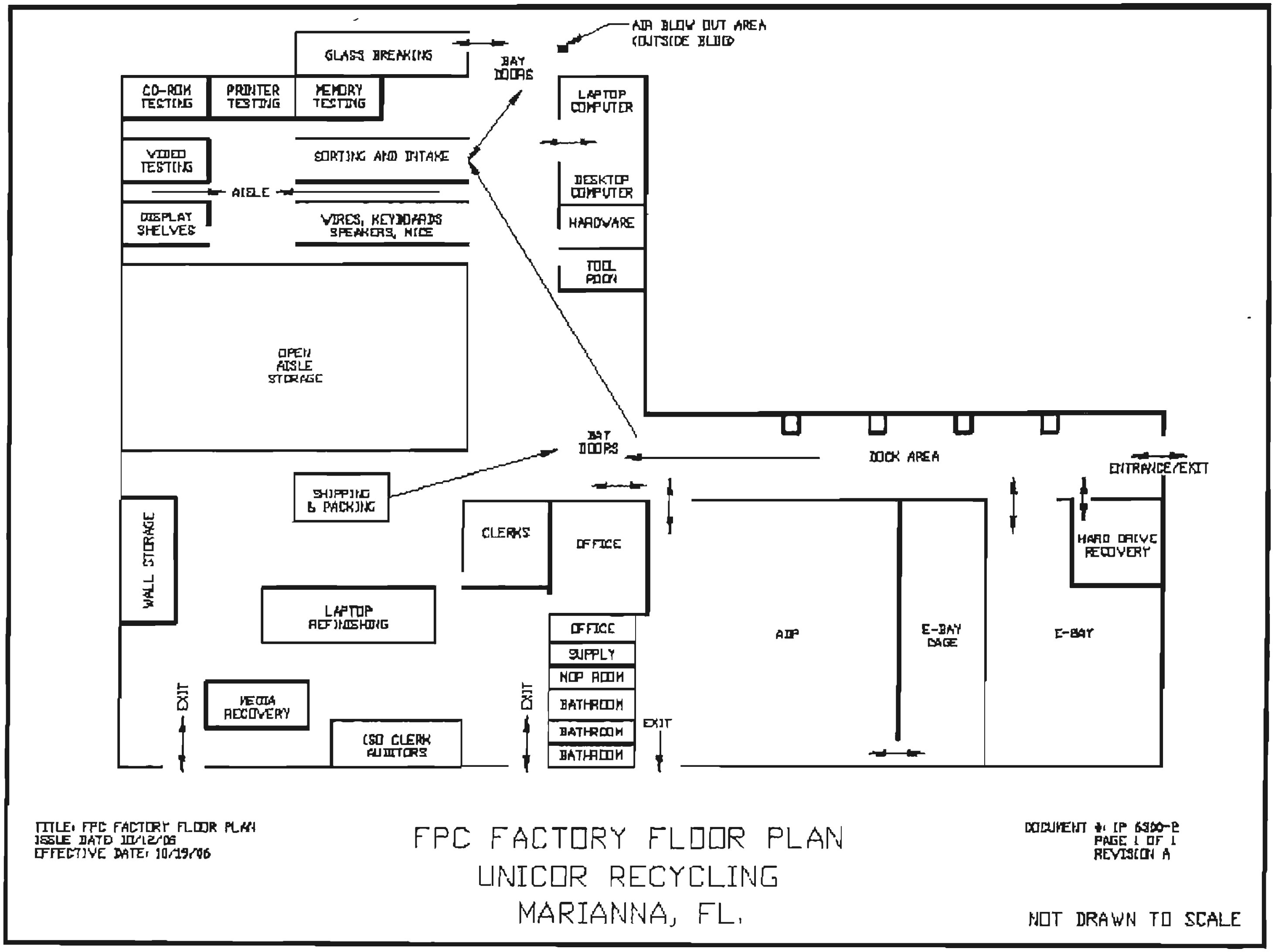


Figure II: Marianna FPC UNICOR Factory Floor Plan

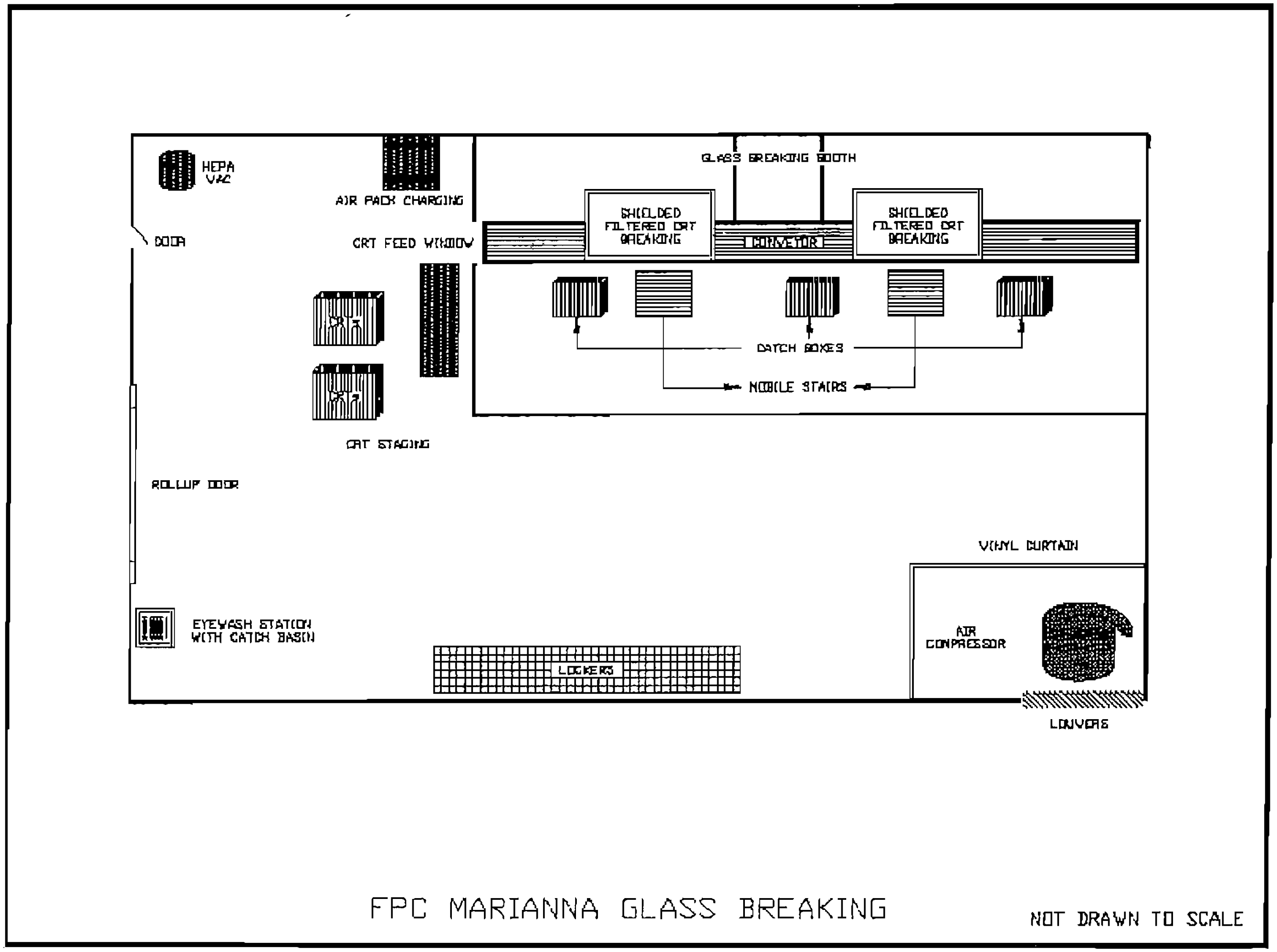


Figure III: Marianna FPC Glass Breaking Area

Figure IV: Marianna FPC Glass Breaking Booth
(Includes box of CRTs on hand truck below window in plastic curtain)

Worker feeds CRTs from box at left into enclosure where glass is broken. Two horizontal flow modules (HFMs) are visible in the enclosed area. Those units collect and filter air and recirculate the filtered air into the enclosure. The booth is enclosed on two sides by concrete block walls and on two sides by plastic curtains. It is enclosed on top by plastic. There is no mechanical ventilation in the GBO besides the HFMs

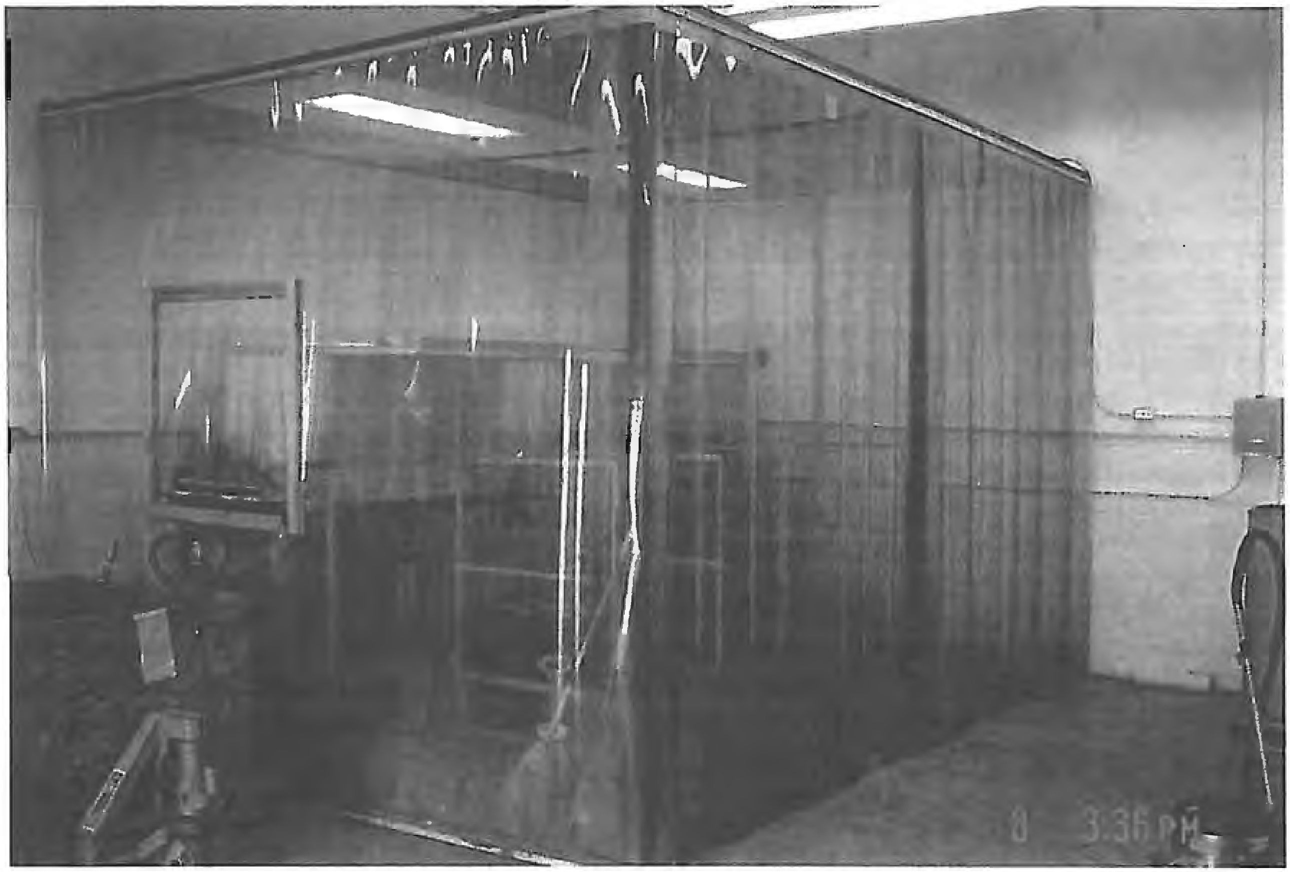


Figure V: Marianna FPC Glass Breaking Booth Work Stations
(Plastic curtain pulled to the left to show first work station)

Worker takes CRT from left, removes gun, breaks funnel glass, and passes to right where second worker breaks panel glass. The horizontal flow modules (HFMs) collect and filter the air and recirculate the filtered air inside the booth. The booth is enclosed on four sides and on top. There is no mechanical ventilation in the GBO besides the HFMs inside the booth..

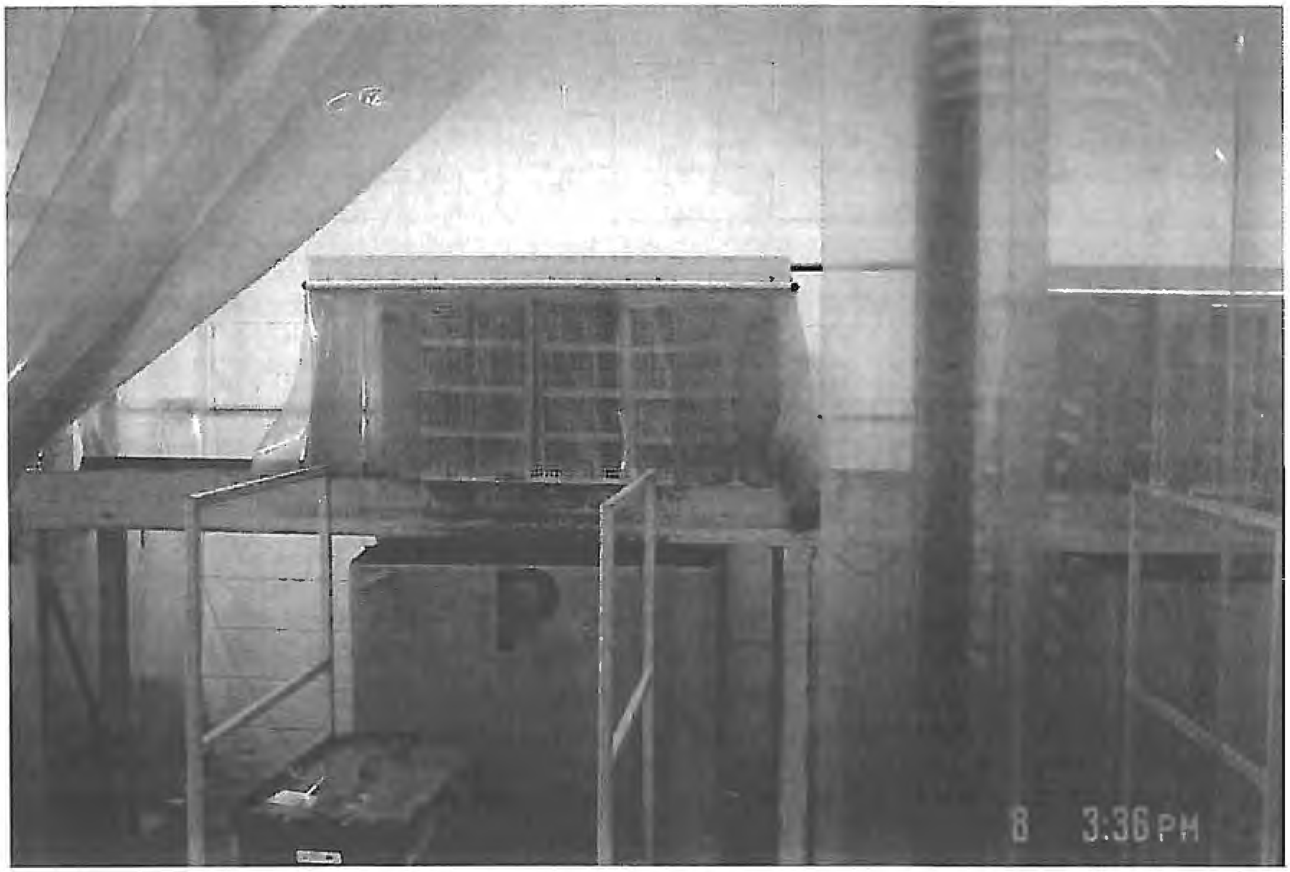
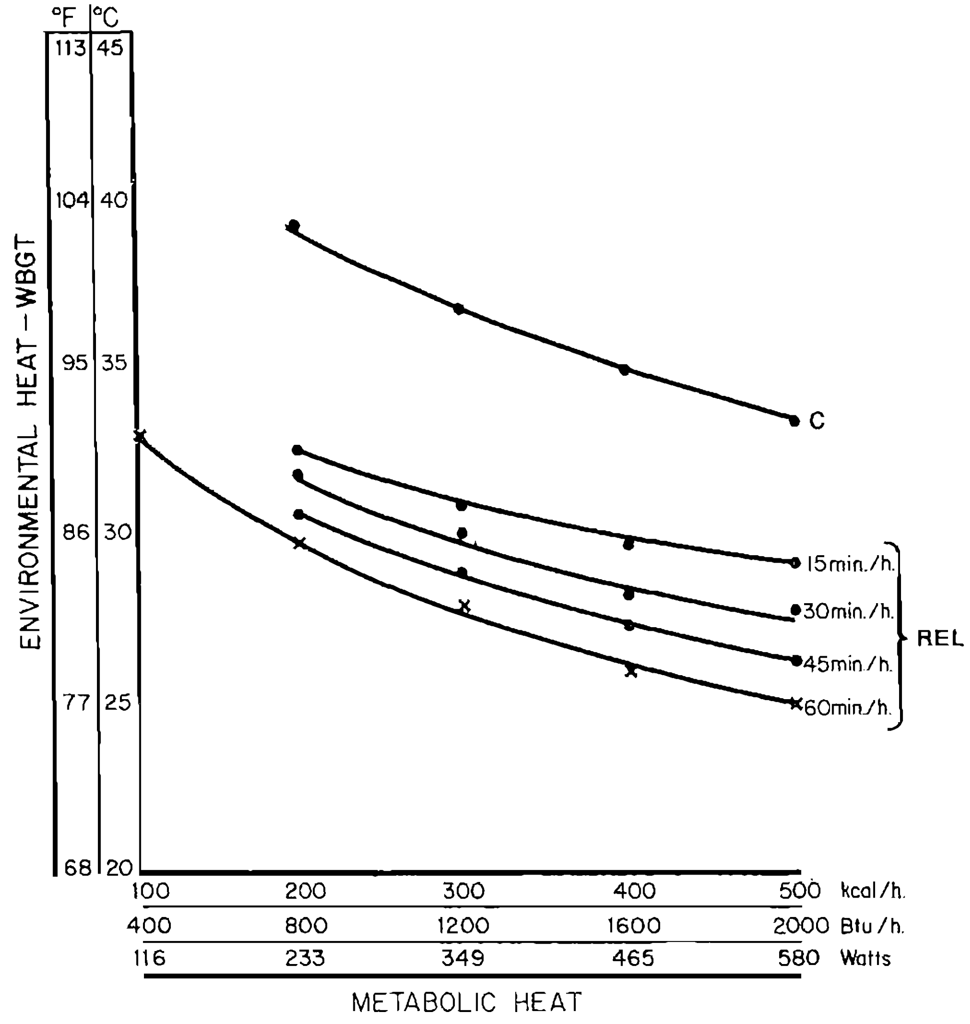


Figure VI: NIOSH Recommended Heat-Stress Exposure Limits for Heat-Acclimatized Workers [NIOSH 1986]



C = Ceiling Limit

*for "standard worker" of 70 kg (154 lbs) body weight and 1.8 m^2 (19.4 ft^2) body surface.

Figure VII: Recommended Layout of Typical Facility where Protective Clothing is Required [DOD 1987].

Note the arrows showing the movement of the workers to segregate contaminated equipment and clothing from clean items. Workers shower before re-entering clean locker rooms after removing contaminated clothing.

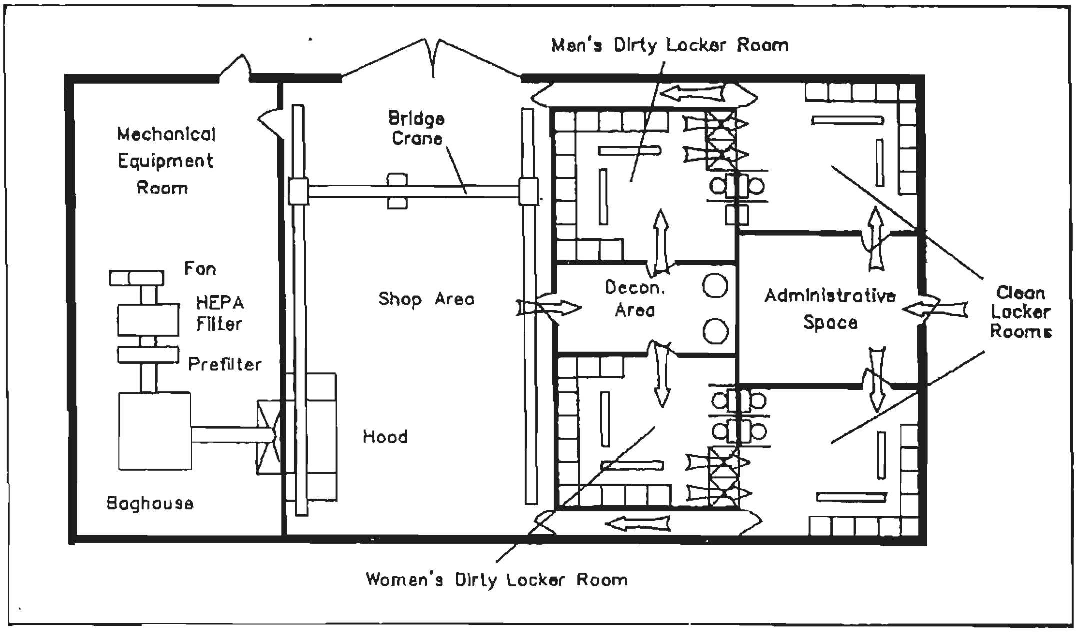


Figure VIII: Size Distribution of Airborne Particles