Occupational Risks Associated with Electronics Demanufacturing and CRT Glass Processing Operations and the Impact of Mitigation Activities on Employee Safety and Health

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ABSTRACT

Cascade Asset Management, LLC has been engaged in electronics recovery since April 1999. Since that time, it has processed more than 4.5 million pounds of computers and other electronic equipment for reuse or recycling. The company operates a testing, refurbishing, demanufacturing and shredding facility, as well as a cathode ray tube glass-to-glass processing center in Madison, Wisconsin. As a result of these activities, Cascade has been presented with a variety of health and safety issues related to its operations. This paper will provide details on occupational health and safety testing protocols and results, with a specific emphasis on the impact of operational and training improvements to mitigate exposure to potential harm from airborne contaminants and other environmental hazards.

KEYWORDS

Industrial hygiene, OSHA, occupational health, CRT, shredding, demanufacturing, worker safety, lead, cadmium, noise, recycling.

INTRODUCTION

Workers in electronics demanufacturing and CRT recycling operations are exposed to a variety of occupational health and safety risks, including: release of heavy metals, such as lead and cadmium, during processing; exposure to brominated flame retardants from handled and shredded plastics; ergonomic strains and stress from manual lifting and operating hand equipment; and, long-term hearing loss related to the operation of heavy equipment. Some firms in the industry have suffered serious injuries and been subject to penalties for Occupational Safety and Health Administration (OSHA) violations due to workplace hazards (*see OSHA Inspection 303263164*.) As this industry matures, and new processors are born, it is important to recognize the potential impact of activities on worker health and safety and act to mitigate these hazards.

A significant amount of press has recently focused on the primitive and unsafe conditions of processing e-scrap in the Guangdong Province of China [1]. This paper, instead, focuses on working conditions in a typical small scale demanufacturing operation in a developed country.

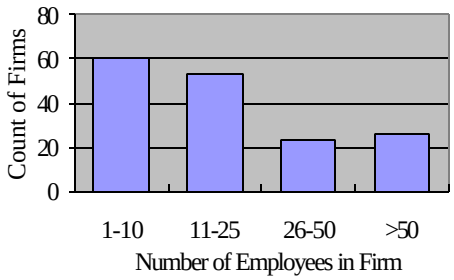

Figure 1: Distribution of Electronics Recyclers in USA, 2002 – by Employee Count [2]

In Resource Recycling's "Directory of the North American Recycling Industry" published in the spring of 2002, 162 unique electronics demanufacturing businesses were listed. Of this number, 113 firms claimed fewer than twenty-six employees [2]. Most companies this size operate a basic disassembly and sort operation to separate recyclable commodities and hazardous materials for further processing. Some firms may also perform size reduction by shredding or baling materials. A handful also crush CRTs in preparation for glass-to-glass recycling or lead smelting. Such firms may handle between 50,000 to 400,000 pounds of equipment per month. These firms generally are dependent on manual labor and hand tools to perform demanufacturing, and they do not employ mechanical separation technologies.

These firms also tend to have limited resources for developing and implementing environmental management and worker safety programs. Recognizing and following occupational safety requirements from government regulators can become a challenge for such companies. As one of these smaller electronics demanufacturing and processing firms, Cascade Asset Management, LLC (Cascade) has contended with the need to monitor and address health and safety concerns on a limited budget.

PROFILE OF CASCADE

Cascade now handles an average of 200,000 pounds of equipment per month at its processing facility. Approximately 90% of its volume is generated by businesses and institutions, with the remainder coming from residential us-

ers. Cascade performs data sanitizing on hard drives. It also tests equipment and conducts basic repair and part swapping on items to prepare them for resale. For equipment collected in 2002, 43% by weight was resold in whole or part, with the remainder of the equipment demanufactured for recycling.

Cascade's demanufacturing operation is set up with three unique processing lines. One line is designed to handle computer boxes. A second line focuses on CRT containing devices. The third line is a catchall for any other electronic equipment such as laptop computers, photocopiers, printers, and cell phones. Workstations are laid out to efficiently handle each commodity with hand tools, including battery operated drill drivers, placed appropriately at the workstations. Cascade employees disassemble the equipment to remove hazardous commodities (i.e., batteries, CRTs, fluorescent lamps) from the units and to separate units for recycling into thirty-one different commodities.

Plastic casings are sent to a shredder line. The automatic feed shredder is designed to densify the cleaned and sorted plastic, with the nominal size of the shredded plastic being four to six inches. Alternatively, larger plastic pieces that cannot fit in the 27-inch shredder are baled in a vertical baler. Most demanufacturing operations similar in size to Cascade are baling plastic in order to densify loads to a point at which they are marketable for shipment and recycling.

Figure 2: Plastic Housings at Shredder Line

CRT glass is pulled at the CRT demanufacturing line and hauled to a separate Cascade facility located approximately four miles from the primary demanufacturing site. This facility exclusively processes CRTs for glass-to-glass recycling. The facility consists of two roller conveyors for staging CRTs. One worker cuts the metal implosion band from the CRT using a high speed, low torque electrical metal cut off tool. This person also uses a razor scraper to remove plastic and rubber fasteners used to hold the copper yoke in place over the neck of the tube. A second worker operates a water-cooled CRT saw built by Envirocycle of Hallstead, Pennsylvania for Cascade. The diamond tipped circular saw cuts the panel glass from the frit/funnel glass. This is done while the saw cabinet is closed. Panel glass, which still includes a damp phosphor powder, is then gravity crushed. The electron gun is next removed from the neck of the CRT by manually hammering off the glass from the steel. The remaining funnel glass is gravity crushed. All of the crushed glass is sent to Envirocycle for a final cleaning and processing prior to use as a feedstock for the manufacture of new CRTs.

Figure 3: CRT Glass Cutter

ENVIRONMENTAL AND MONITORING GOALS

Cascade's owners were concerned about the relative exposure of the company's employees to occupational health hazards. While the company had already developed a safety procedure handbook and training program, it was interested in monitoring the exposure of its workers to hazards on its shredding line as well as at the CRT processing facility. With this monitoring data, the company could better implement mitigation programs.

In response to prior research on the hazardous characteristics of CRTs, Cascade focused its sampling on lead and cadmium from its CRT operations. An industry survey of CRT production over time reported that an average 17" color monitor contained 2.08 lbs. of lead [3]. In a separate analysis, Townsend of the University of Florida sampled 36 television and monitor CRTs using the toxicity characteristic leaching procedure (TCLP) test and discovered the average lead concentration to be 18.5 mg/L [4]. According to US EPA standards, the TCLP threshold for lead is 5.0 mg/L. There has been much less rigorous study of cadmium concentration levels, though, it is known that many fluorescent coatings of CRTs contain cadmium. One study providing TCLP analysis on CRTs for cadmium reported a concentration of 0.099 mg/L, with the US EPA TCLP threshold for cadmium being 1.0 mg/L [5].

In addition to monitoring for these two hazardous elements, Cascade surveyed other heavy metals and particulates

around the CRT cutter. In particular, data were collected on barium, calcium, iron, and several other metals.

Also, there has been some research on the presence of flame retardants released in the work environments of electronics recycling plants. One study concluded that brominated and phosphorous containing additives to plastic materials are emitted to the indoor work environment in connection with dismantling and shredding of electronics [6]. Cascade was unable to conduct a thorough analysis of brominated hydrocarbon and phosphate ester flame retardant concentrations using its research tools, but remains interested in measuring particulate matter concentrations as a means of comparison with other research detailing the constituent matter of these particulates.

Finally, Cascade wanted to conduct a basic survey of typical worker safety and health hazards in an electronics recycling facility. As such, Cascade tested for noise levels, assessed ergonomics of workers and addressed hazard communication and training protocol with experts.

SURVEY METHODS AND RESULTS

Cascade contracted for monitoring and testing at its facilities on three separate occasions. The first test consisted of industrial hygiene air monitoring, which was conducted on April 26, 2001 for Cascade's CRT processing operation. The second consisted of a health survey and wipe sample analysis for CRT processing on July 17, 2001. These tests provide a benchmark for air and particulate composition prior to modifications implemented by Cascade to address any concerns identified by the testing. A more thorough follow-up and monitoring program was conducted on January 23, 2003 for Cascade's CRT processing operation and demanufacturing/shredding operation.

CRT Processing Area Air monitoring

The first industrial hygiene air monitoring sampling was conducted by ChemReport, Inc., an environmental and safety consulting firm from southeastern Wisconsin. The monitoring was conducted in the CRT processing area while CRTs were being handled under normal operating conditions. Three personal air-sampling monitors were used, for which one monitor was affixed to a Cascade employee and the remaining two monitors were affixed in locations in close proximity to the CRT cutting equipment.

Personal and ambient air sampling was conducted using personal sampling pumps. Air was drawn through the sampling trains at flow rates of 1.5 L/min., which was appropriate to measure the constituents and sampling apparatus, and for durations resulting in optimal sample volume for the analytical technique utilized in the laboratory. The sampling pumps were properly calibrated prior to use and were recalibrated by a ChemReports engineer following sample completion. Sampling pump calibration was performed using a precision rotameter calibrated to a primary standard (soap bubble meter).

The CRT operation was observed and personal and fixed location air samples were collected to determine if an exceedance of the OSHA Permissible Exposure Limit (PEL) occurred. The PEL for lead and cadmium is based on an entire 8-hour shift in which all exposures are averaged to obtain an 8-Hour Time Weighted Average (TWA) result.

Employee exposures to lead and cadmium during the monitoring event are demonstrated in the tables below. As the sampling events did not last an entire 8-hour shift, a calculated 8-hour TWA has been provided to access exposure values against the OSHA PEL.

Table 1: 2001 CRT Area Air Sampling Results

Monitoring Device Location	Lead	Cadmium
CRT operator	4.3	<0.1
Ambient air sample 1	0.42	<0.1
Ambient air sample 2	0.14	<0.1
OSHA PEL	50	5

8-hour Time Weighted Analysis - April 26, 2001

(micrograms of contaminant per cubic meter of air, mg/m^3)

Exposures for both lead and cadmium were well below the OSHA PELs of 50 $\mu g/m^3$ and 5 $\mu g/m^3$, respectively. As such, no remediation action was required.

The Wisconsin OSHA Consultation program conducted a second study on January 23, 2003 to provide a comparative analysis to the earlier study. A similar air sampling device was used, with these air samples collected on pre-weighed PVC filters. Upon returning to the lab, the filters were re-weighed on a Microbalance. For metals, the re-weighed PVC filters were digested in an appropriate mixture of acids. An aliquot of the sample was then analyzed for various elements using an Inductively Coupled Argon Plasma Atomic Emission Spectrometer (ICAP-AES).

For the second study, only two air readings were taken. One monitoring pump was worn by the CRT operator, similar to the first study. The second reading was taken from the breathing zone of another employee performing prep work on the CRTs in another area in the facility. The TWA of these samples are listed in Table 2.

Monitoring Device Location	Total Weight	Lead	Cadmium
CRT operator	720	<10	0.75
CRT prep worker	760	<10	1.5
OSHA PEL	15,000	50	5

Table 2: 2003 CRT Area Air Sampling Results

8-hour Time Weighted Analysis - January 23, 2003

(micrograms of contaminant per cubic meter of air, mg/m^3)

Results were again significantly lower than the OSHA PEL and no remediation action was required.

CRT Processing Area Wipe Samples

Cascade also contracted for a series of wipe sample tests in the CRT processing area to record the migration of various heavy metals throughout the processing area and into employee lounge and restroom areas. In response to concerns over deteriorating lead paint in homes with children, the US Department of Housing and Urban Development has set the hazard level for lead in dwellings that are in good condition at 50 $\mu g/ft^2$ on hardwood floors and 250 $\mu g/ft^2$ on interior window sills. This recommendation helped to serve as a benchmark for our research.

The wipe samples were collected on Whatman 42 filters that were wetted with distilled water just prior to the individual wipe. One side of the filter wiped an area of approximately one square foot. The wiped side of the filter was folded in on itself, and the area was wiped again. This process was repeated until a total of 4 wipings were collected on each sample area. A range of locations was wiped to record the potential migration of the sampled metals.

The wipe samples were then analyzed using methods based on NIOSH 7300 and OSHA ID 125G for ICAP metals. The wipes were wetted with distilled water and digested with the prescribed mixture of acids and made up to a volume of 50 ml. Smaller wipes are wetted with distilled water and digested with an appropriate mixture of acids and made up to 25 ml total volume. An aliquot of the sample is analyzed for metals, special metals or water-soluble metals using an ICAP-AES.

Two sets of wipe samples were both conducted by the Wisconsin OSHA Consultation Program, with the first set of samples collected on July 17, 2001. Based on these samples, some corrective actions were recommended and implemented, which will be described later in this paper. A follow-up set of samples was taken on January 23, 2003.

Table 3: Surface Metal Concentrations

Wipe samples, approximately 1 ft^2 each

	Barium		Cadmium		Calcium		Lead	
Test Date	*2001*	*2003*	*2001*	*2003*	*2001*	*2003*	*2001*	*2003*
Floor behind CRT cutter	3730	190	37	18	13800	2500	**1510**	430
Work table near CRT cutter	407	75	7.7	1.2	1580	<200	107	34
CRT prep table	169	120	3.7	54	1050	470	**1520**	**1100**
Central tracking area	111	70	15	27	13100	1900	252	98
Break room	3		<=0.6		447		6.2	
Wash room		25		12		450		31

(micrograms of contaminant per square foot of surface area mg/ft^2)

Although the OSHA standard only sets limits on airborne contamination, the surface contamination can pose an exposure risk to employees. Particles settling on the floor can become airborne through foot traffic or other disturbances, especially in a dry atmosphere. Additionally, whenever surface contamination is present in a location that facilitates the ingestion of the particles, such as in an eating area, it is more likely that these contaminants can enter a person's system.

Based on the benchmark listed by HUD for hazard levels of lead surface contamination, our monitoring found elevated lead levels on the floor behind the CRT cutter and on the CRT prep worker's table. A likely cause of the lead on the floor is the periodic spillage of water containing suspended fines from the holding tank of recycled water used to cool the cutting blade and trap residue from the cutting of the CRTs. Water may spill from the tank whenever the tank is rolled back away from the cutter for cleaning. Spilled water would evaporate, leaving a powder residue consisting of the suspended fines. Prior to the 2001 testing, Cascade had not developed a spill management procedure for this area.

The second area of concern with lead and cadmium is from the CRT prep table. At this workstation, employees scrape rubber, plastic and adhesives from the outside of the CRT funnel. They also manually break tubes that cannot be mechanically cut. All monochrome tubes are manually broken at this stage, though TCLP tests on monochrome glass do not indicate a significant presence of lead. In addition, up to 10% of color tubes are broken manually at this station. This may be due to the fact that the tubes do not fit into the mechanical cutting unit (it only can cut tubes between 12" and 25" screen size), or because the tube is cracked or compromised in a manner that would not allow the cutter to perform a clean cut on the unit. The wipe samples indicate a higher presence of lead and cadmium at a workstation that only handles approximately 10% of the volume handled at the CRT cutting table. The major difference in the work at these two locations is that the tubes at the cutter's table are wet from the cutting process while the manual breakage is a completely dry process.

Finally, these studies indicate a migration of lead into non-work areas, including the break room and wash room. The concentration of lead is minimal, but its accumulation over time in areas where there is a greater risk of exposure through ingestion is a concern.

Shredding Area Air Monitoring Program

Cascade began its shredding activity in November 2002. It serves two purposes for the company. First, it provides on-site destruction of electronic media to satisfy data security requirements of customers. Second, it enables Cascade to more efficiently densify mixed plastic for shipment. Prior to shredding plastic, Cascade used a vertical baler for densifying mixed plastic for recycling. This activity was very time consuming and presented its own occupational hazards. Cascade purchased and modified a refurbished Mitts & Merrill model MS-2817 shredder and conveyor system with a hydraulic ram assist. The shredder chamber spans

28" x 17", and produces a plastic fraction between 4" – 6" long by 2" wide.

Cascade was aware of the concerns related to the release of particulate matter from shredding operations, which may also lead to the inhalation of hazardous constituents including various flame retardant chemicals. One reason for configuring the shredder to produce such a rough fraction was to minimize any dust and resulting particulate matter that would carry hazardous constituents through the work environment.

Cascade tested this hypothesis by performing industrial hygiene air monitoring on two employees operating the shredder during an 8-hour work shift. Using the same protocol as for the CRT cutter, the OSHA Consultant sampled total particulate levels, as well as concentrations of lead and cadmium (to provide a comparison to the CRT cutting operation), and several other metals. The results are offered in Table 4

Table 4: Atmospheric Concentrations at Shedder Line
8-hour Time Weighted Analysis - January 23, 2003

	Total Weight	Cadmium	Lead
Shredder Operator	191	0.273	1.37
Shredder Feeder	322	0.280	1.36
OSHA PEL	15,000	5	50

(micrograms of contaminant per cubic meter of air, mg/m^3)

In addition to lead and cadmium, the chemist also looked for, but did not detect or detected in amounts too small to quantify: aluminum, barium, chromium, cobalt, copper, iron, magnesium, manganese, molybdenum, nickel, strontium, and zinc.

In general, the total particulate matter and heavy metal concentrations are well below those allowed and recommended by OSHA. One explanation for the low readings is that the shred size is too large to generate much dust in the shredding process. Another is that the operators are located several feet from the shredding point.

By comparison, an air monitoring program conducted in an electronics disassembly and shredding plant in Sweden recorded total particulate matter at 200 $\mu g/m^3$, which is fairly consistent with the findings from Cascade [6]. Additional research was conducted on the concentrations of several brominated hydrocarbon and phosphate ester flame retardants. They reported elevated levels of these additives in their captured particles. While this paper does not purport any presence of these additives, it is recommended that additional research be conducted in this area.

Noise Levels and Exposures

Concurrent analyses were conducted at both the CRT processing area and shredding line to test for noise levels. Many electronics demanufacturing operations operate equipment or process inventory in a manner that generates significant noise. Pneumatic tools, crushing/baling plastic, and operating machinery all contribute to noise problems. Cascade does not use pneumatic hand tools for disassembly, but does operate a compressor for the CRT cutting device.

On January 23, 2003, Cascade workers were fitted with noise sampling instruments to measure both the decibels reached when performing certain activities, as well as a TWA for all noise exposure during an 8-hour shift. The sampling instruments included a Quest Micro-15 Noise Dosimeter which was affixed to a worker. This multifunction sound analyzing instrument provides information as a dosimeter (80 dB and 90 dB thresholds) accumulating noise over the time period sampled and as a sound level meter. A second sampling instrument was used for taking readings of particular events. The Quest Model 215 Sound Level Meter measures A-scale slow response with a range of 40 to 130 dBA.

Table 5: Noise Levels and Exposure

Location/Employee	dBA	Remarks
CRT Cutter operator	72	Background, cutter off
	80-82	Adjacent air compressor running
	82-88	Cutter operating
	90	Using compressed air gun
	84.3 dBA Equiv.	8-hour TWA reading
Shredder Operator	84-96	Operating shredder (background noise is lower)
	83.4 dBA Equiv.	8-hour TWA reading
Shredder Feeder	82-96	At feed conveyor during shredding
	82.8 dBA Equiv.	8-hour TWA reading
OSHA PEL	90.0 dBA Equiv.	8-hour TWA reading
OSHA Action Limit	85.0 dBA Equiv.	8-hour TWA reading

January 23, 2003

(decibels measured on the 'A' scale, dBA)

Results of testing on this day showed employee average noise exposures to be within OSHA limits. With increased production and operation of equipment, new monitoring should be conducted to evaluate if there is an increased risk of hearing loss.

These data also demonstrate the amplified noise generated from air powered tools. Cascade primarily based its decision to not use air tools due to the high noise factor. Other demanufacturing operations employing the use of air tools may wish to evaluate their impact on noise levels and compliance with OSHA requirements. There may be quieter tools available from the manufacturers.

MITIGATION ACTIVITIES

While monitoring results provided an assurance that Cascade is operating within OSHA standards for air hazards and noise levels, it also demonstrated a potential problem

related to the accumulation of hazardous concentrations of dust and particles in the work environment. After the initial air and surface contamination testing was conducted in 2001, Cascade worked with the OSHA Consultation program to reduce contamination that was detected and implement procedures to prevent further contamination. The following actions were then taken:

- All cleaning of spills and tables are performed using wet methods (e.g., a damp rag);
- Eating, drinking or smoking is prohibited at work stations;
- Employees must wash their face and hands before they eat, drink, smoke or apply cosmetics;
- Employees in the CRT processing area are to wear smocks over their personal clothing to prevent contamination of their clothing. The smocks are to be professionally laundered by a service capable of handling industrial contamination;
- Employees in the CRT processing area are not to enter the common break room or eating area with contaminated clothing or before they wash their face and hands;
- Spills from the CRT cutter must be cleaned up before they have a chance to dry. If the spill does dry, wet methods or a HEPA vacuum must be used to clean the residue; and,
- A regular cleaning schedule was developed and implemented.

These new mitigation activities produced significant improvements in some areas of the CRT processing operation, while having relatively little impact on others. By aggressively cleaning spills from the cutter as they occur, surface lead levels behind the cutter were reduced by nearly 72% while cadmium levels declined by 51%. Lead levels also dropped significantly in other work areas. Cadmium levels were reduced in every area except at the CRT prep table, where they rose by 53%. This increase is likely related to the activity of manually breaking the CRTs for recycling giving rise to a greater risk of exposure to the dry, fluorescent powder coating the inside of the panel glass. This should be a significant concern to other facilities that rely heavily on manual breaking of CRTs for recycling.

Cascade is also working on mitigating noise levels at its shredding and CRT cutting lines. One technique being employed is using simple sound absorption materials, including wrapping the shredder's feed hopper with fiberglass insulation to absorb some of the shock and noise generated as plastic pieces are crushed and forced into the shredder's shears.

CONCLUSIONS

Workers in electronics demanufacturing and CRT glass recycling operations may be exposed to heightened levels (near or above OSHA required limits) of lead, cadmium, chromium, barium and other heavy metals, as well as other workplace hazards. Through industrial hygiene programs and processing technologies, these risks can be mitigated to provide a work environment well within the levels permitted by OSHA standards. At the same time, companies can also provide a safe and productive workplace for their employees.

With its limited budget and expertise, Cascade was able to solicit assistance from the State of Wisconsin's Occupational Health Consultation program to monitor the health and safety impacts of various processes at Cascade. Supported by funding from OSHA at the federal level, the Consultation Program delivers the expertise of safety and health professionals to small businesses who request help in establishing and maintaining a safe and healthful workplace. The Division of Public Health in Wisconsin manages Wisconsin's OSHA Consultation Program, with similar programs available in other states. The service is free to employers, with the only obligation as a requesting employer being a commitment to take necessary corrective actions where a serious hazard is found.

The authors recommend companies with similar operations and resources in the United States utilize the OSHA Consultation Program as a tool to monitor workplace hazards and put in process procedures to minimize these hazards. Such an approach was taken by Cascade and the resulting impacts of such measures have proven favorable in terms of reducing workplace hazards, satisfying workers, reducing worker's compensation premiums, and improving long-term profitability. Prospective and current customers also tend to highly value Cascade's efforts to manage its operations safely. Cascade has discovered that the long-term benefits of going through the program far exceed the investment of effort and time.

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