AN EVALUATION OF AIRBORNE BERYLLIUM EXPOSURES DURING RECYCLING OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

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EXECUTIVE SUMMARY

In the years since the implementation of the European Union Waste Electrical and Electronic Equipment (WEEE) Directive, little has been published about the occupational exposures of workers to beryllium in the electronic recycling industry. This report presents the results of a quantitative airborne metal exposure survey conducted on workers shredding, picking and separating WEEE in a specialized, modern recycling facility in the United Kingdom. The results of personal lapel samples collected and analyzed for beryllium were all well below the respective Health and Safety Executive (HSE) of the United Kingdom's Workplace Exposure Limits (WEL) during shredding, picking and separating operations. The results of the occupational exposure assessment coupled with the analysis of the beryllium content of the electrical and electronic equipment demonstrate that processing WEEE utilizing modern processing techniques represents minimal risk of exposure to beryllium.

Keywords **- *electronic scrap; airborne beryllium exposure; shredding; WEEE; E-scrap; recycling***

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February 7, 2013

INTRODUCTION

Waste electrical and electronic equipment (WEEE) continues to be a rapidly growing scrap stream. This growth has resulted in the development of a number of directives in the European Union that require collection and end-of-life management of WEEE. The increase in the amount of WEEE being generated can be attributed to a decrease in product life cycle, caused by a technology advances, and an increase in the number of users of electronic equipment. Recycling is the preferred method of end-of-life management as recycling conserves landfill space and allows for the recovery of valuable, rare and critical metals and materials.

Electrical and electronic equipment (EEE) contain a variety of potentially hazardous substances that provide or improve the functionality of the equipment. There can be risks associated with end-of- life processing depending upon how the materials are processed.

One such substance is beryllium. Beryllium, mostly in the form of copper beryllium alloys which contain less than 2 percent beryllium, is used in EEE to increase electrical and thermal conductivity, enhance product performance, increase reliability and facilitate miniaturization of components and products. Consequently, products manufactured with these materials are more efficient, conserve energy and natural resources, and increase product life. Copper beryllium use within EEE components is generally limited to applications where its high performance and reliability characteristics are necessary. As a result, only a small amount of beryllium ends up in the final EEE product. For example, among EEE applications that use beryllium-containing alloys, cellular phones typically contain the highest amount of beryllium reaching 40 parts per million (ppm)[1] in some models.

To put this in perspective, the total world production of copper in 2008 was 18.3 million tonnes, of which 2.8 million tones was secondary refined copper, using copper scrap input, as obtained from WEEE recycling operation[2]. Of the total copper production, only 24%, or 4.4 million tonnes was used for electrical and electronic applications[2]. The total world production of beryllium was 402 tonnes[3], of which 75% was used as alloying additions to make copper beryllium alloys, and of that, electrical and electronic applications accounted for 42%, or approximately 126 tonnes[4]. If all of that beryllium ended up in WEEE, the average beryllium content encountered would be 28.3 ppm. In practice, beryllium alloys are used in specific components such as connectors and relays. Strip-down analyses of electrical and electronic devices[5] show that a typical smart phone such as an Apple I-Phone 5 contains 15.6 ppm beryllium, corresponding to the level estimated for all WEEE in the Danish Ministry of Environment Report[6].

It has been portrayed that exposure to beryllium poses a risk to workers involved in the recycling of electronic components. However, exposure assessment studies[7,8] previously conducted during the processing of electronic scrap and cellular phones indicate that exposure to airborne beryllium is rare and well below the applicable occupational exposure limits.

In its final report to the European Commission[9], the Öko-Institut e.V. concluded that beryllium and, therefore, beryllium-containing alloys did not "constitute significant health and environmental risks when used in electrical and electronic equipment". Accordingly in 2010, the European Parliament did not add beryllium to the list of restricted substances in the EU's recast of Directive on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS).

We found no studies of occupational exposures to beryllium during recycling of EEE in Europe. The purpose of this study is to characterize worker airborne beryllium exposures, work practices and the engineering controls during shredding, picking and separating of WEEE at a representative WEEE recycling facility in the United Kingdom (UK). The information collected was used to help answer the following questions:

1. What are the airborne beryllium exposure levels of workers processing WEEE and how do they compare to the applicable occupational exposure standards?
2. What engineering controls and work practices are used to control dust?
3. What are the study's possible implications for the WEEE recycling industry?

THE WEEE RECYCLING PROCESS:

In this study, two types of WEEE were processed during the study at Sims Recycling Solutions facility in Newport Gwent, United Kingdom: small domestic appliances and computer base units. Small domestic appliances include items scrapped by consumers such as radios, remote controls, telephones, smart phones and gaming systems. This would also include items such as printers, fax machines, lawn mowers, vacuums and microwaves. Computer base units are bulk scrapped items that are either obsolete or excess inventory.

The incoming WEEE (1) is inspected, if necessary pre-shredded in a large mobile/stationary shredder, and stored in a bunker for further processing. A material handler, in an enclosed cab, loads the WEEE from the bunker into a hopper that feeds it onto a conveyor (2) which moves the WEEE into the Presort Area. As the WEEE passes through the Presort Area (3), workers remove paper, cardboard, electric motors, batteries and metal items too large to be further processed. Electric motors, batteries and other discrete recyclable items are manually segregated and dropped into chutes leading to bunkers for staging. The material in these bunkers is sold to other recyclers for processing specific to the particular scrap. The remaining presorted WEEE on the conveyor is bunkered and staged for further processing.

The presorted WEEE is loaded onto a second conveyor with a front end loader. The WEEE is conveyed upwards and dropped into a ventilated shredder (5). The shredded WEEE exits the shredder onto a magnetic separation conveyor (6) which separates magnetic and non-magnetic materials. When separated, both scrap streams exit the process via conveyors. The magnetic materials enter a picking shed (7) where employees remove electric motors, rubbish and batteries that are freed from the WEEE during shredding.

These materials are bunkered, staged and sold to steel works for recycling. Nonferrous metals and inert materials that pass the magnet are conveyed to an eddy current separator (ECS) (8).The nonferrous metals that pass through the ECS ("ECS Throws") are guided into a bunker and subsequently sold to smelters for refining and recovery of the base metals such as aluminium, copper, nickel and zinc.

The non-metallic materials that are dropped by the ECS ("ECS Drops") are conveyed through another picking shed (9) where employees remove rubbish, batteries and metal containing objects. The ECS Drops are bunkered before further processing by additional shredding, after which they are treated to separate metallic and nonmetallic materials by density (10). The residual plastic streams are bunkered and further treated (11) to segregate these materials into individual plastic streams and sold for recycling. Nonrecoverable materials such as rubbish, paper and cardboard removed during manual separation operations are sent to landfill for disposal.

Picture showing incoming WEEE

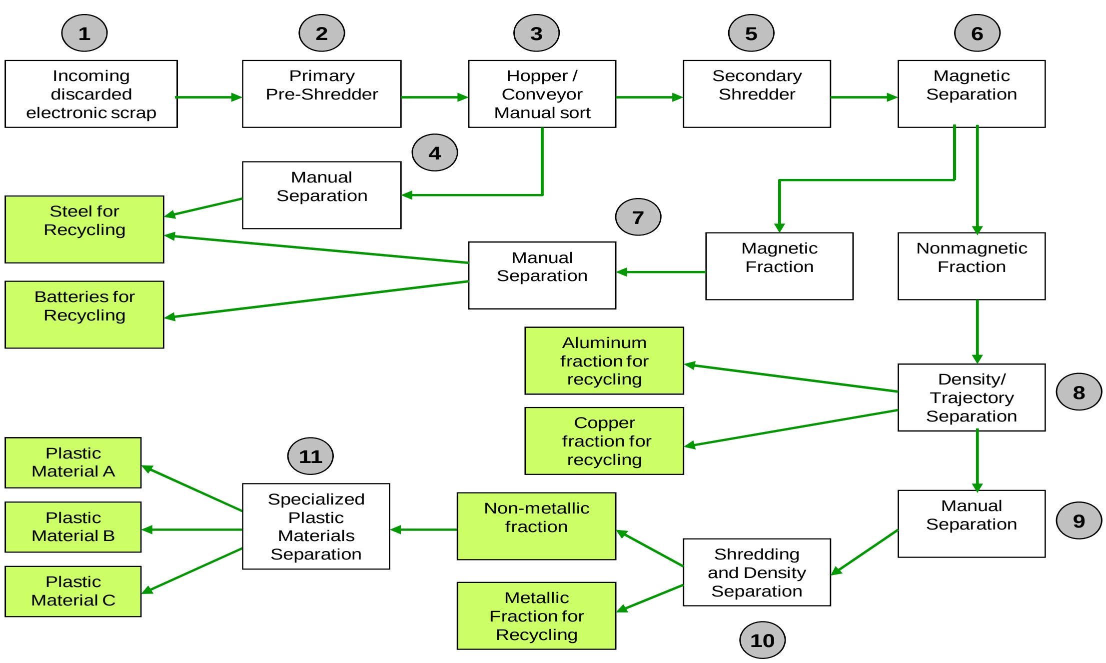
Methods

A. Air Samples

Personal air samples were collected on operators at eight work operations expected to have the highest potential exposure. The operations included:

1) Pre Sort
2) Shredder No. 1
3) Picking (Ferrous)
4) Picking (Eddy current drops)
5) Shredder No. 2
6) Metal Separation
7) Plastics Separation Stage 1
8) Plastics Separation Stage 2

Figure 1 – Flow Chart for WEEE Processing



Picture showing WEEE Shredder

For each operation, 15 to 17 full-shift, personal air samples were collected over an 8-week sampling period. Each sample was analyzed to determine the total mass of beryllium present in the breathing zones of workers processing WEEE. Methods specified in the Occupational Safety and Health Administration (OSHA) Technical Manual[10] and the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods [11] were used for sample collection and analysis. Sample analysis was performed at a laboratory accredited by the American Industrial Hygiene Association (AIHA).

Airborne beryllium exposure data was analyzed utilizing typical statistical principles[12]. Descriptive statistics, central tendency and characteristics of the upper tail of the distribution were calculated for each of the eight operations. The 95% upper confidence limit (UCL) was calculated for the 95th percentile of the distribution (the upper tolerance limit (UTL)[13] and for the fraction of the distribution that exceeded the Occupational Exposure Limit (OEL)[14]. Exceedance fraction is an estimate of the proportion of the distribution that is greater than a given exposure value. The uncertainty around point estimates is characterized by the 95% confidence limits, specifically the 95% UCL. A set of exposure measurements is generally considered to be well controlled if the exceedance fraction is less than or equal to 5% and the geometric standard deviation (GSD) is less than 2.5[15]. Values below the detection limit were divided by two for all statistical analyses.

Exposure data from this study were compared to the current Health Safety Executive (HSE), COSHH, EH40 2005 Workplace Exposure Limits (WEL) values for beryllium[16] of 2 microgram per cubic meter (µg/m^3) as well as the occupational exposure limit (OEL) for beryllium of 0.2 µg/m^3 adopted by Ireland, Poland and Spain.

B. Engineering Control Assessment

The type and design specifications of engineering control equipment used and hood locations were noted based on visual assessment. Ventilation flow rates were obtained from design drawings.

C. Bulk Samples

Twelve bulk samples, one from each stream in the recycling process, were collected and analyzed for beryllium according to NIOSH Method 7300 to determine the concentration of beryllium in the processed WEEE.

RESULTS AND DISCUSSION

A. Airborne Beryllium Exposure Characterization of Shredding, Picking, Separating (Table 1)

All exposure measurements for airborne beryllium were below the level of analytical detection (<0.0069 µg/sample) and therefore below the HSE WEL of 2.0 µg/m^3. Based on this, exposures will be below the HSE WEL greater than 95 percent of the time. In addition, all airborne beryllium exposures were below the Ireland, Poland and Spain OELs of 0.2 µg/m^3 and statistical analysis demonstrated that exposures are anticipated to be below this level greater than 95 percent of the time.

B. Bulk Sample Analysis (Table 2)

As would be expected, concentrations of beryllium in the processed WEEE were low ranging from <0.55 to 6.1ppm. Beryllium concentrations above the limit of detection were found in only 25% of the bulk samples.

Table 1 - Summary of Airborne Beryllium Exposure Analysis

	Number of Samples (N)	Results (µg/sample)	2.0 µg/m^3/0.2 µg/m^3 Exceedance UCL (%)[a]	GSD
Pre Sort	15	<0.0069	0.000/0.000	1.052
Shredder No. 1	15	<0.0069	0.000/0.000	1.063
Picking (ECS)	16	<0.0069	0.000/0.000	1.045
Picking (Steel)	15	<0.0069	0.000/0.000	1.032
Shredder No. 2	16	<0.0069	0.000/0.000	1.081
Metals Separation	17	<0.0069	0.000/0.000	1.038
Plastics Separation Stage 1	15	<0.0069	0.000/0.000	1.065
Plastics Separation Stage 2	15	<0.0069	0.000/0.000	1.097

[a] Occupational exposure limit exceedance fraction upper confidence limit (UCL) – upper 95% confidence limit for fraction of samples that exceed a given occupational exposure limit.

Table 2 - Bulk Sample Analysis for Beryllium

	Concentration (ppm)
ECS Throws	<0.55
Shredder No. 2 Fines	<0.55
Shredder No. 2 Fines (<4µm)	6.1
Plastics Stage 1	<0.55
Plastics Stage 2A	(0.074)
Plastics Stage 2B	(0.15)
Large Plastic Metal Separation	<0.55
Small Plastic Metal Separation	<0.55
Large Separated Metal Grade 1	<0.55
Small Separated Metal Grade 2	<0.55
Large Separated Metal Grade 1	<0.55
Small Separated Metal Grade 2	<0.55

< - indicates the concentration was less than the detection limit.
( ) – indicates the concentration was between the detection limit and the quantification limit.

C. Engineering Control and Work Practice Assessment

Local exhaust ventilation (LEV) is the main method used to control the generation of airborne particulate during shredding of WEEE. A 15,000 cubic feet per minute (CFM) dust collector is used to ventilate and contain dusts generated by Shredder #1. A canopy style hood is used above the exit conveyance of Shredder #1 to further capture any fugitive dusts generated by shredding the WEEE. None of the other operations evaluated were equipped with LEV.

Good work practices such as, systematic cleaning of the facility and avoiding activities that result in airborne dust creation such as dry sweeping or use of compressed air are utilized. These work practices are common in many industrial operations involving hazardous materials and are also important to managing potential worker exposures to beryllium.

CONCLUSION

In this study, the results of sampling for airborne beryllium at operations associated with processing WEEE were all below the HSE WEL and the 0.2 µg/m^3 OEL utilized in other countries in Europe. In addition, exposures to beryllium at this facility meet the definition of "well controlled" based on common industrial practice for assessing occupational exposures in the workplace. Based on the results of this study, processing WEEE at modern facilities utilizing similar control equipment and work practices is not expected to result in an inhalation hazard to airborne beryllium. This study and the previous studies of recycling of electronic wastes demonstrate that processing WEEE utilizing modern techniques presents minimal inhalation exposure risks to beryllium.

ACKNOWLEDGMENT

The authors wish to thank the management and operators at Sims Recycling Solutions for their patience and cooperation during the exposure assessment period. Financial support for this exposure assessment study was provided by Materion Brush Inc., a producer of beryllium and beryllium-containing materials.

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