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# Formal recycling of e-waste leads to increased exposure to toxic metals: An occupational exposure study from Sweden☆

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ABSTRACT

Electrical and electronic waste (e-waste) contains multiple toxic metals. However, there is currently a lack of exposure data for metals on workers in formal recycling plants. The objective of this study was to evaluate workers' exposure to metals, using biomarkers of exposure in combination with monitoring of personal air exposure. We assessed exposure to 20 potentially toxic metals among 55 recycling workers and 10 office workers at three formal e-waste recycling plants in Sweden. Workers at two of the plants were followed-up after 6 months. We collected the inhalable fraction and OFC (37-mm) fraction of particles, using personal samplers, as well as spot samples of blood and urine. We measured metal concentrations in whole blood, plasma, urine, and air filters using inductively coupled plasma-mass spectrometry following acid digestion. The air sampling indicated greater airborne exposure, 10 to 30 times higher, to most metals among the recycling workers handling e-waste than among the office workers. The exposure biomarkers showed significantly higher concentrations of chromium, cobalt, indium, lead, and mercury in blood, urine, and/or plasma of the recycling workers, compared with the office workers. Concentrations of antimony, indium, lead, mercury, and vanadium showed close to linear associations between the inhalable particle fraction and blood, plasma, or urine. In conclusion, our study of formal e-waste recycling shows that workers performing recycling tasks are exposed to multiple toxic metals.


## Relevant abbreviations and definitions

Breathing zone "Hemisphere (generally accepted to be 0.3 m in radius) extending in front of the human face, centered on the midpoint of a line joining the ears; the base of the hemisphere is a plane through this line, the top of the head and the larynx." (International Organization for Standardization, 2012)

Open face cassette (OFC) 37-mm cassette sampler for collecting airborne particles corresponding to OELV values. Has been called total dust sampler. Comparable with the 37-mm closed face cassette (CFC) in the NIOSH Manual of Analytical Methods: Particulates not otherwise regulated method no 0500, 1994.

Inhalable fraction "Mass of total airborne particles that is inhaled through the nose and mouth." (International Organization for Standardization, 2012)

Occupational exposure limit value (OELV) "Limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period." (International Organization for Standardization, 2012)

Personal sampling "Process of sampling carried out using a personal sampler" (International Organization for Standardization, 2012)

Personal sampler "sampler, attached to a person, that collects airborne particles in the breathing zone to determine exposure to chemical agents." (International Organization for Standardization, 2012)

☆ Previous publication: A small portion of the results presented in the paper have been published in a Swedish report for the funding agency. The dual publication regards metal concentrations (μg/m$^3$) for inhalable fraction and OFC fraction for lead, mercury, cadmium, chromium, cobalt and nickel. Additionally, the report presented mean values (μmol/l) in blood and urine of the same metals. Reference: Julander A, Gustavsson P, Jakobsson K (2012), Kunskapsöversikt 2012:17, "Kemisk exponering och hälsorisker vid hantering av elavfall," Swedish Work Environment Authority (SWEA), ISSN: 1650-3171.

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Static sampler (area sampler) "sampler, not attached to a person, that collects particles at a particular location." (International Organization for Standardization, 2012)

Total airborne particles "all particles surrounded by air in a given volume of air" (International Organization for Standardization, 2012); often impossible to measure because all instruments are size-selective to some extent.

## 1. Introduction

Each year, approximately 20–50 million tons of waste of electrical and electronic equipment (e-waste) are produced globally and this amount is estimated to increase 3–5% annually. Most likely, only about 10% of the global e-waste will be recycled in plants that are appropriately designed to reduce exposure of harmful substances, both on a technical scale and from a worker health point of view (Watson et al., 2010).

E-waste contains several toxic and allergenic metals as well as other toxic and harmful chemicals for example brominated flame retardants (BFRs) and polychlorinated biphenyls. The hazardous components in e-waste include cathode ray tubes (CRTs), liquid crystal display (LCD) screens, light-emitting diode (LED) lights, batteries, circuit boards, mercury-containing equipment, and plastic with BFRs. Some of the toxic metals used in electronics are antimony, arsenic, beryllium, cadmium, chromium, cobalt, indium, lead, mercury, nickel, and thallium. Several rare elements are also used (Frazzoli et al., 2010).

Most of these compounds are released during recycling. The workers are generally exposed through three different routes: inhalation, skin contact or ingestion (Grant et al., 2013). The exposure is however likely to vary, depending on where in the world the work is performed. In Europe and North America, workers generally perform recycling within plants designed for this specific purpose, with proper ventilation and protection of the workers. This is often described as formal recycling (Fujimori et al., 2012). In Africa, Asia, and South America, workers often perform informal recycling or backyard recycling, using techniques involving cutting, acid bathing, heating/smelting and open burning where workers may not be protected at all (Sthiannopkao and Wong, 2013). The general idea is that formal recycling as opposed to informal recycling should be better for both the workers and the environment.

Studies in formal recycling plants have found high concentrations of different polybrominated diphenyl ether (PBDE) congeners in air samples (Charles et al., 2005; Julander et al., 2005b; Pettersson-Julander et al., 2004; Rosenberg et al., 2011; Sjödin et al., 2001). Blood and serum samples from workers within such recycling plants also showed that the workers were more exposed to BFRs than workers in other occupational groups (Jakobsson et al., 2002; Julander et al., 2005a; Sjödin et al., 1999; Thomsen et al., 2001; Thuresson et al., 2006). Similar results have been reported from informal recycling sites in China (Bi et al., 2007; Qu et al., 2007); however, the concentrations of BFRs are higher than in European studies.

Metal concentrations in ambient air and exposure biomarkers in informal e-waste recycling workers in China, India and Ghana (Asante et al., 2012; Bi et al., 2010, 2011; Caravanos et al., 2011; Deng et al., 2006; Ha et al., 2009; Wang et al., 2009, 2011; Zheng et al., 2011) have been published. To the best of our knowledge, no similar studies are available from formal recycling in Europe or North America. Therefore, the main objective of this study was to characterize metal exposure in e-waste recycling workers in Sweden by measuring concentrations in both air samples and exposure biomarkers. We evaluated exposure to 20 toxic metals in four different work tasks at three e-waste plants. We used two different personal air sampling devices and sampling of blood and urine from 65 workers on two different occasions.

## 2. Materials and methods

### 2.1. Study design

We selected three companies of different sizes and degrees of automation for this study (Table 1) among a total of 30 companies performing e-waste recycling between 2007 and 2009 in Sweden. They all recycled similar types of goods, such as TV-sets and computers (flat screen and CRT screens), electronic tools, toys, and small and large household appliances (not including freezers and fridges). In total, 65 workers (71%) in the selected companies agreed to participate in the study. Of these, 55 (85%) worked with recycling and 10 (15%) were based in an office. We assessed the exposure on two occasions, 6 months apart. One company did not participate in the second round of measurements due to bankruptcy; therefore, only 32 workers participated in the second part of the study.

We identified four main work tasks performed on the days of sampling: *dismantling* (i.e., all work tasks involving manual dismantling of the goods), *indoor work* (i.e., tasks involving handling of goods except dismantling, for example, sorting of incoming and outgoing goods, truck driving, cleaning, supervision of work), *outdoor work* (e.g., mainly inspection tasks and transportation of goods within the different locations using trucks), and *office work* (i.e., computer work with no time in the production buildings). We used questionnaires to obtain information on work tasks and the use of protective equipment on the day of sampling, tobacco use, and dietary habits. We asked the study participants not to eat fish or shellfish 2 days prior to the sampling day to minimize the influence of dietary intake of arsenic (As) and mercury (Hg). The Regional Ethical Research Board in Stockholm approved the study, and the participants provided informed consent and were made aware of the findings of the study.

**Table 1**
Descriptive factors of participants and the three participating e-waste recycling plants in the Swedish study between 2007 and 2009.

| Factor | Company 1[A] | Company 2 | Company 3 |
|---|---|---|---|
| No. employees/no. participants | 30/27 | 20/16 | 45/24 |
| Gender (M/W) | 23/4 | 16/0 | 19/5 |
| Age (mean/range) | 35/20–52 | 44/28–62 | 36/21–63 |
| Current smoking (y/n) | 12/15 | 10/6 | 9/15 |
| Manual dismantling | Yes | Yes | Yes |
| Conveyor belt | Yes | No | Yes |
| Process ventilation[B] | Partly | No | Yes |
| Storage of goods | Outdoors | Indoors | Outdoors |
| Grinder | Partly outside | No | Indoors |
| Personal protective equipment[C] | Optional respiratory protection | No respiratory protection | Optional respiratory protection |
| Rotation of work tasks | No | Partly | Yes |

[A] Company did not partake in the second sampling occasion due to bankruptcy.
[B] The doors to the different halls in the plants were usually kept open; hence, the process ventilation may have been disrupted and not performing to optimal standards.
[C] Company policy demands that the worker wears work clothes, hardtop safety shoes, and gloves.