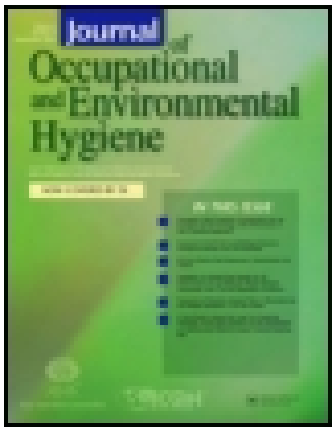

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Diana M. Ceballos[a], Wei Gong[a] & Elena Page[a]
[a] National Institute for Occupational Safety and Health
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Diana M. Ceballos*, Wei Gong, Elena Page

National Institute for Occupational Safety and Health

*Correspondence to: Diana M. Ceballos, National Institute for Occupational Safety and Health, 1090 Tusculum Ave, MS 11, Cincinnati, OH 45226-1998; e-mail: DCeballos@cdc.gov; Phone: 513 841-4439

ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) surveyed a randomly selected sample of electronic scrap (e-scrap) recycling facilities nationwide to characterize work processes, exposures, and controls. Despite multiple attempts to contact 278 facilities, only 47 responded (17% response rate). Surveyed facilities reported recycling a wide variety of electronics. The most common recycling processes were manual dismantling and sorting. Other processes included shredding, crushing, and automated separation. Many facilities reported that they had health and safety programs in place. However, some facilities reported the use of compressed air for cleaning, a practice that can lead to increased employee dust exposures, and some facilities allowed food and drinks in the production areas, a practice that can lead to ingestion of contaminants. Although our results may not be generalizable to all U.S. e-scrap recycling facilities, they are informative regarding health and safety programs in the industry. We concluded that e-scrap recycling has the potential for a wide variety of occupational exposures particularly because of the frequent use of manual processes. On-site evaluations of e-scrap recyclers are needed to determine if reported work processes, practices, and controls are

effective and meet current standards and guidelines. Educating the e-scrap recycling industry about health and safety best practices, specifically related to safe handling of metal dust, would help protect employees.

Keywords: electronic scrap recycling, electronic waste recycling, e-waste, e-scrap, survey, health and safety

Word count: 3263

ACCEPTED MANUSCRIPT

INTRODUCTION

As of November 2014, 25 states had laws mandating electronic scrap (e-scrap, also called e-waste) recycling. In 2012, the U.S. e-scrap recycling industry contributed approximately $20.6 billion to the U.S. economy, compared to less than $1 billion in 2002. In 2012, this industry sector employed more than 45,000 full-time employees, up from 6,000 employees in 2002.[1] Americans own almost 3 billion electronic products, including televisions, cell phones, computers, and peripherals (keyboards, scanners, faxes, etc.).[2] As new electronic products are developed and sold, obsolete or end-of-life products become e-scrap. Of the 2.3 million tons of e-scrap in 2007, only 18% was recycled.[3] In 2011, more than 4.4 million tons of used and end-of-life electronic devices were recycled.[1] E-scrap contains more than 1,000 substances, many of which are hazardous,[4] including metals (lead, cadmium, mercury, beryllium, indium, etc.),[5] flame retardants,[6] phthalates, and ozone depleting substances. The potential exists for employee exposure to these hazardous substances during recycling, but data are limited on the type and extent of exposures in developed countries.[7]

The rapid growth of the industry and the limited information about potential workplace health and safety hazards has revealed a need to learn more about the e-scrap recycling industry. To that end, the National Institute for Occupational Safety and Health (NIOSH) sought to characterize potential occupational exposures; evaluate work practices, programs, and policies; and provide recommendations to reduce worker exposures in e-scrap recycling facilities. NIOSH undertook two activities: (1) a pilot survey of e-scrap recycling facilities nationwide and (2) on-site evaluations at three e-scrap recycling facilities. This manuscript discusses the results of the pilot

survey. The results from the three workplace health hazard evaluations will be published separately.

METHODS

Facilities for the Survey

Following a script, a NIOSH contractor made 868 contacts (phone calls or e-mails) to 278 e-scrap recycling facilities in 43 states. The script contained information about the overall project, the survey, and NIOSH. After initial contact with the facility by the contractor, NIOSH sent a letter to the main facility contact to endorse the survey. Most of the facility contacts preferred to see the survey before agreeing to participate. They also preferred to complete the survey independently rather than during a scheduled phone call as initially planned. E-mail was the preferred method of correspondence for most representatives at the facilities contacted. The data were collected between September 2012 and April 2013. The contractor provided the data without the company identifiers to NIOSH for analysis.

NIOSH obtained a list of more than 1,300 e-scrap recycling companies that are subscribers to an industry magazine, and then selected 300 facilities using Research Randomizer (http://www.randomizer.org/) with a goal to obtain 100 responses. NIOSH personnel initially contacted these 300 facilities to see if they were still in operation. Of these, 178 facilities were still operating and the name and contact information was successfully used by the NIOSH contractor for followup. Eleven of these facilities had multiple locations and referred 19 sister facilities to provide a response to the survey. Because of the low response rate from those 197 facilities, NIOSH provided the contractor with information for an additional 100 facilities randomly selected from the list of magazine subscribers. NIOSH did not call these 100 additional

facilities prior to giving the information to the contractor. Of these, the contractor determined that 81 companies were still operating but none responded to the survey.

To promote the survey and increase visibility, information about the survey was posted on the NIOSH Health Hazard Evaluation Program webpage, Facebook©, NIOSH monthly e-newsletter, Occupational Health & Safety magazine (http://ohsonline.com/articles/2013/01/11/niosh-program-evaluating-controls.aspx), and E-scrap News, a leading electronic waste recycling newsletter.

Survey

The survey (Supplemental file A or Appendix A in NIOSH report[8]) asked about:

- Certification(s)
- Number of employees
- Major components processed
- Processes performed
- Personal protective equipment (PPE) used
- Type of general ventilation, engineering, and administrative controls
- Medical surveillance and industrial hygiene monitoring

The original survey included questions related to production quantities for each of the components processed but these questions were dropped mid-way through the project due to the reluctance of respondents to provide that information.

Data Management and Analysis

Password-protected electronic files were created to contain the survey information. Each facility was assigned a unique identifier, and a separate file containing all survey responses but without

facility identifiers was created and given to NIOSH. Data were analyzed using Microsoft Excel. Because of the small sample and low response rate, only counts are reported. Administrative controls were compared for facilities with lower and higher than 50 employees per facility; with 50 employees as the number of employees defining a small size enterprise.[9]

RESULTS

Nineteen companies, representing 47 facilities in 28 states completed the survey for a response rate of 17%. Details of contacts and contact attempts made are in the NIOSH report.[8] The following six certifications were reported: (i) Responsible RecyclingÊ (R2), 38 facilities; (ii) International Organization for Standardization (ISO) 14001, 38 facilities; (iii) e-Stewards®, 32 facilities; (iv) Occupational Health and Safety Advisory Services (OHSAS) 18001, 18 facilities; (v) Recycling Industry Operating Standard® (RIOS), 3 facilities; (vi) National Association for Information Destruction® (NAID), 3 facilities. Only two facilities had no certifications, seven facilities had one certification, and 38 facilities had two or more certifications.

The certifications involve promoting the proper environmental processing of e-scrap and employee health and safety in different manners. E-Stewards and R2 are specific to the e-scrap recycling industry and address export, landfilling, and incineration; use of prison labor; data security; and employee safety and health, among other things. OHSAS 18001 is an international occupational health and safety management system, and ISO 14001 is an environmental management system. RIOS is the scrap recycling industry's (including e-scrap) integrated management system standard for quality, environment, and health and safety. It includes elements of ISO 9001, ISO 14001, and OHSAS 18001. NAID verifies the qualifications of certified information destruction providers through an audit program.

The surveyed facilities averaged 58 employees (range of 7 to 220 employees), with a median of 60 employees; most had between 70 and 79 employees. All surveyed facilities accepted printed circuit boards, and most accepted switches, batteries, cell phones, fluorescent lamps and bulbs, cathode ray tubes, desktop bases and laptops, computer peripherals, liquid crystal displays, printers, fax machines, and audio/video equipment. Other components accepted included computer hardware servers, power cords, kitchen appliances, electrical cords, chips, refrigeration equipment, and integrated circuits. All companies accepted at least one type of component that they did not process or recycle onsite. The most common item sent out for further processing was fluorescent lamps and bulbs, followed by batteries and cathode ray tubes. Forty two of the 47 facilities reported accepting cathode ray tubes (CRTs), devices known for their high lead content, and 26 reported actively processing the items. An average 18.63-inch CRT has a lead content that varies from 2.14 pounds to 2.63 pounds.[10]

Disassembly was the main process performed at 45 of the 47 surveyed facilities, followed by 37 facilities that performed separation, 28 that performed refurbishing, 18 that performed plastic processing, and 2 that performed metallurgical processing. Table I lists the types of disassembly, with manual dismantling being the most common followed by shredding and crushing. Table I also lists the separation methods performed, with manual sorting and magnetic separation (a type of automated separation) being the most common.

Two surveyed facilities performed pyro-metallurgical processing that uses heat to extract metals from e-scrap. No facility performed hydro- or bio-metallurgical processing, techniques that use biotechnology (microorganisms) to extract metals from e-scrap. No surveyed facility performed depolymerization (i.e., the process of converting a polymer into a monomer or a mixture of

monomers) or incinerated plastics. Some facilities reported baling plastics or collecting and separating plastics for subsequent recycling by downstream processors, although this question was not specifically asked. Some facilities reported reselling usable equipment, although this question was not specifically asked.

Forty five surveyed facilities had separate ventilation systems for office and production areas, but only 19 facilities had controlled supply and exhaust air flow into the production area, and seven facilities provided conditioned (heated and/or cooled) air in the processing areas. This suggests that most facilities relied on natural ventilation in production areas.

Of the surveyed facilities, 33 used some local exhaust ventilation (LEV) system(s). Eight LEV systems were ducted outside the facility and did not recirculate, 16 LEV systems filtered the exhaust air through a high efficiency particulate air (HEPA) filter before recirculating it back into the facility, four LEV systems recirculated the air back into the room without passing it through a HEPA filter, and we did not obtain information for the other 5 LEV systems reported.

Forty-four facilities reported having a safety and health committee with a non-management participant. Thirty-eight facilities had a dedicated safety and health employee(s). Forty-five facilities performed environmental/industrial hygiene sampling at least annually and performed housekeeping on a regular basis. No surveyed facilities allowed smoking in the production areas, but 13 allowed eating and drinking. All surveyed facilities reported having spill control and chemical storage policies and procedures, and formal safety and health training for employees. Thirty-nine surveyed facilities reported using HEPA-filtered vacuums for clean-up. Three facilities used compressed air during clean-up. Twenty of the surveyed facilities reported some

medical surveillance. The type of medical surveillance varied (Table II), with audiometry being reported most frequently. Some facilities noted that chest x-rays were performed for some production employees at the discretion of the company physician.

Over half of surveyed facilities supplied production employees with coveralls or uniforms that were laundered by the company. One facility had employees wash their uniforms at home. Over half of the surveyed facilities provided an area for employees to change clothes and shower. Although not specifically asked, some facilities commented that uniforms were only provided to certain production employees and 17 facilities commented that a third party laundered the uniforms. Facilities with more than 50 employees appeared to be more likely to have administrative controls such as biomonitoring and environmental/industrial hygiene sampling, and provide coveralls/uniforms at the worksite (Table III).

Personal Protective Equipment

The types of personal protective equipment used are listed in Tables IV and V. Most surveyed facilities required some PPE (gloves, eye protection, hearing protection, or steel-toed boots) during certain tasks. Gloves were required for most employees with the exception of those performing refurbishing. Where respiratory protection was used, most respondents reported using filtering facepiece respirators, but some reported using half-mask or full facepiece elastomeric respirators. Although not specifically asked, 13 facilities reported doing industrial hygiene monitoring to determine if respirators and hearing protection were needed.

Of the 31 facilities that reported using respirators in any process, all reported that they had written respiratory protection programs and provided respirator training to employees. However, only 23 of the 31 facilities performed medical clearance and fit testing. Of the facilities that did

not perform medical clearance and fit testing, four facilities required some employees to wear a respirator.

DISCUSSION

We conducted a pilot survey to characterize occupational health and safety practices in the U.S. e-scrap recycling industry. Other surveys of the U.S. e-scrap recycling industry include one published in 2011 by the International Data Corporation[11] and another published in 2013 by the Coalition for American Electronics Recycling (CAER).[12] The International Data Corporation survey documented company size and other business information from 103 facilities but did not include questions related to workplace health and safety. The CAER survey included 21 CAER member companies representing 89 facilities. The surveyed facilities averaged 205 employees (median of 100 employees). The CAER survey reported that 45% of employees were involved in demanufacturing, 21% in asset recovery and disposition functions, and 18% in shredding operations.[12] Asset recovery and disposition functions were defined as certified data destruction and disposition of assets where the recycler has the capability to record make, model, and serial number, and in some cases engages in refurbishment of equipment for resale.

In our survey, several facilities reported having general ventilation and local exhaust ventilation; some reported filtering and then recirculating exhaust air back into the room. We also do not have information to determine if the facilities that had a controlled supply and exhaust air flow into the work areas included those facilities that reported conditioning the air in processing areas. We also do not have enough information to know if the LEV systems were used in processes that may be producing potentially contaminated air. If this was the case for some of the LEV systems, the Occupational Safety and Health Administration (OSHA) prohibits recirculation of air

containing metals such as lead through non-HEPA filters (29 CFR 1910.1025).[13] The recirculation of process air into the work environment of highly hazardous substances (as defined by the OSHA hazard communication standard) requires both an effective cleaning device (filtration) and a continuous monitoring device that is capable of detecting a concentration as low as 10% of the acceptable level in the discharge duct.[14]

The most common type of medical surveillance reported was audiometry, followed by measuring blood lead levels. Audiometry and blood lead level tests are good practices for an e-scrap recycling facility given that lead and noise are common hazards in this industry.[5,15, 16] It was encouraging to see that all 22 facilities that reported blood lead monitoring had a pre-placement assessment of the employees. However, it is unclear why only five facilities followed their employees annually and four bi-annually. We could not determine from this brief survey whether blood lead monitoring met current recommended practices and whether all potentially exposed employees were included or just those thought to have the greatest potential for exposure to lead (e.g., those who handled cathode ray tube glass). It is important to include all employees potentially exposed to lead in the medical surveillance program, even those employees not directly exposed to lead contaminated air.[17] Lead contamination on surfaces outside of the production area and contamination of surfaces in common areas such as break rooms can result in ingestion of lead which contributes to the overall exposure of all affected employees. Some facilities allowed food and drinks in the production area, a practice that can lead to ingestion of hazardous substances from contaminated hands and food and drinking surfaces.

Many facilities provided uniforms and facilities to change clothes and shower before leaving work, but one facility commented that they allowed employees to launder their work uniforms at

home. This practice may provide a route of take-home exposure to family members. OSHA requires uniforms and showers for employees exposed to metals like lead and cadmium above the occupational exposure limit. However, it is good practice to provide uniforms, laundering, and showers to all employees potentially exposed to these substances.[17] Uniforms and showers are among the most effective workplace measures in preventing take-home exposures.[18] Current OSHA occupational exposure limits for lead are outdated; more recent information suggests that health effects can be experienced by employees at much lower levels.[19]

Current occupational exposures limits may prevent overt symptoms of lead poisoning, but do not protect workers from leadôs contributions to conditions such as hypertension, renal dysfunction, reproductive, and cognitive effects.[20-23] Generally, acute lead poisoning with symptoms has been documented in persons having BLLs above 70 µg/dL. These blood lead levels are rare today in the United States, largely as a result of workplace controls put in place to comply with current occupational exposure limits. When present, acute lead poisoning can cause many adverse health effects including abdominal pain, hemolytic anemia, and neuropathy. In very rare cases lead poisoning has progressed to encephalopathy and coma.[24] People with chronic lead poisoning, which is more likely at current occupational exposure levels, may not have symptoms or they may have nonspecific symptoms that may not be recognized as being associated with lead exposure. These symptoms include headache, joint and muscle aches, weakness, fatigue, irritability, depression, constipation, anorexia, and abdominal discomfort.[24]

Some facilities reported using compressed air for cleaning. It was not known from the survey responses if the compressed air was used for cleaning clothing, equipment, or both. Regardless, this practice can result in contaminants entering the employeesô breathing zone or spreading

contamination throughout the facility. Noise from compressors used to provide compressed air for cleaning can contribute to hearing loss if employees do not use appropriate hearing protection. Noise is important to control in an e-scrap recycling facility because it is known that lead exposures in the presence of noise, can further impair hearing or increase the potential for hearing loss.[25-27] Cleaning with compressed air can also dislodge particles that could enter eyes or abrade skin. Wet mopping and vacuuming with HEPA filters are recommended cleaning practices.

Although a high percentage of surveyed facilities used PPE and reported environmental/industrial hygiene monitoring, this survey did not evaluate the effectiveness of these programs. We do not know to what extent PPE use was enforced and how many employees participated in any personal exposure monitoring for lead or other contaminants as prescribed by OSHA.[27] The four facilities that required the use of respirators but did not provide employees with medical clearance or fit testing were not following the OSHA respiratory protection standard (CFR 1910.134).[13,28]

This survey had limitations. The main limitation was the low response rate. At the beginning of the pilot survey, we did not provide the targeted facilities with preliminary information about NIOSH, or information about the purpose of the survey prior to making the initial phone call. Because many facilities were not familiar with NIOSH, on the initial call, they misidentified our surveyor as being from a competitor or market research firm. Once we began sending an introductory letter to facilities prior to the initial call, informing them of the purpose of the survey, and providing them information about NIOSH, our participation improved. Initial respondents were reluctant to share information about the quantities of materials processed; this

line of inquiry was later dropped from the survey, which also improved the survey participation. Finally, smaller facilities who chose not to participate often reported that our survey questions did not match their own activities (e.g., most facilities with fewer than five employees did not dismantle electronics, but sorted items and shipped them to other facilities for processing). Although our results may not be generalizable to all U.S. e-scrap recycling facilities, they are informative regarding health and safety programs in the industry. Focusing on processing of CRTs would be desirable in future surveys as CRT were documented as one of the most processed electronics in this survey. Further, there is an estimate that between 2013 and 2022, 6.2 million tons of devices containing CRT displays will find their way from our basements, closets, and guest bedrooms into the U.S. e-scrap stream.[29] Focusing on the processing of newer technologies such as liquid crystal and touchpad displays may also be needed as the recycling of electronics transitions due to changes in production and use of electronics. Further information is needed on the health and safety needs of the industry and its employees. While mailed or telephone surveys can be useful, workplace evaluations are needed to determine if programs and controls reported by e-scrap managers meet current standards and guidelines.

CONCLUSIONS

This pilot survey of the U.S. e-scrap recycling industry provided information on health and safety programs and practices at 47 facilities among a rapidly increasing and changing industry. To expand our knowledge and to respond to the expectations of growing health and safety needs in this industry, resources need to be directed to this industry to better understand the occupational hazards and their health consequences. Efforts to evaluate, support, and promote

good health and safety practices in the growing and dynamic e-scrap recycling industry are needed to prevent occupational illnesses and injuries.

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The findings and conclusions in this manuscript are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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TABLE I. Type Of Processes Performed At The Surveyed Facilities

Process type	Specific process	Number of facilities/ total facilities responding
Disassembly	Manual dismantling	40/47
	Shredding	29/47
	Automated crushing	20/47
	Manual crushing	6/47
Separation	Manual sorting*	22/25*
	Magnetic separation**	19/47
	Eddy current separation**	5/47
	Gravity separation**	1/47

*Only 25 facilities responded to this question because this question was added midway through the project.

**These three types of separation are often considered automated separation.

TABLE II. Medical Surveillance Performed At The 47 Facilities

	Number of facilities	Frequency
Blood lead levels	22	22 Pre-placement 5 Annual 4 Bi annual
Blood cadmium levels	3	3 Pre-placement 3 Annual
Urine cadmium levels	5	5 Pre-placement 3 Annual 2 Bi annual
Urine mercury levels	4	4 Pre-placement 3 Annual 1 Bi annual
Beryllium lymphocyte proliferation testing	1	1 Pre-placement 1 Every 3 years
Examination by doctor or other licensed health care professional	24	24 Pre-placement 22 Annual
Spirometry	9	9 Pre-placement 5 Annual 4 Bi annual
Chest x-ray*	20	18 Pre-placement 5 Annual 13 Every 3 years
Audiometry	31	31 Annual

*Some facilities noted that x-rays were only done at the discretion of the physician.

TABLE III. Comparison Of Health And Safety Controls By Facility Size At The 47 Facilities

Control	Number of facilities with that number of employees (Number of employees)		
	Medium size enterprise	Small size enterprise	All sizes
	28 (> 50)*	19 (< 50)*	47
Controlled supply and exhaust air flow into the work area	11	8	19
HEPA filtered vacuums used for clean-up	25	14	39
Environmental/industrial hygiene sampling and monitoring performed on a regular basis (at least annually)	28	17	45
Blood lead level monitoring	16	6	22
Coveralls/uniforms supplied at the worksite	20	8	28
Have facilities for employees to change clothes and shower	18	9	27

*Fifty employees was considered as a reference to define a small size enterprise.

TABLE IV. Personal Protective Equipment Use By Dismantling Process

Type of PPE		Manual dismantling n = 40	Shredding n = 29	Automated crushing n = 20	Manual crushing n = 6
Filtering facepiece*	Required	15	16	9	3
	Voluntary	16	9	11	2
Half- or full face elastomeric*	Required	1	12	0	1
	Voluntary	0	1	0	0
Gloves	Required	40	24	20	6
	Voluntary	0	4	0	0
Eye protection	Required	37	24	16	6
	Voluntary	1	0	0	0
Hearing protection	Required	29	28	17	4
	Voluntary	9	0	3	2
Steel-toed boots	Required	34	24	14	4
	Voluntary	4	0	2	2

*NIOSH-approved respirator

TABLE V. Personal Protective Equipment Use, By Separation, Plastic, And Refurbishing Processes

Type of PPE		Manual sorting n = 22	Magnetic separation n = 19	Eddy current separation n = 5	Plastic processing n = 18	Refurbish n = 28
Filtering facepiece*	Required	0	5	0	0	0
	Voluntary	8	3	2	2	8
Half- or full face elastomeric*	Required	0	1	1	0	0
	Voluntary	4	0	0	0	0
Gloves	Required	20	19	5	17	7
	Voluntary	1	0	0	0	7
Eye protection	Required	16	19	5	18	8
	Voluntary	1	0	0	0	0
Hearing protection	Required	5	19	5	18	1
	Voluntary	14	0	0	0	11
Steel-toed boots	Required	16	18	5	18	5
	Voluntary	1	1	0	0	2

*NIOSH approved respirator