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Short Communication

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Metals and Particulates Exposure from a Mobile E-Waste Shredding Truck: A Pilot Study

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Abstract

The US electronics recycling industry has introduced a novel mobile electronic waste (e-waste) shredding truck service to address increasing needs for secure data destruction of e-waste. These trucks can shred small electronics with data security concerns at remote locations for a wide variety of clients. Shredding jobs usually involve hand-feeding electronic waste (e-waste) for 4–10 h day^{-1}, 1–5 days. Shredding of e-waste has been documented as a source of high metal exposures, especially lead and cadmium. However, no studies have been done to assess exposures on mobile e-waste shredding trucks. We conducted a pilot cross-sectional exposure assessment on a mobile e-waste shredding truck performing a 65-min shredding job (truck back door open and no local exhaust ventilation) in the Greater Boston area in 2019. We collected area air and surface wipe samples for metals along with real-time particulate measurements from different locations. The highest metal air concentrations (e.g. 2.9 µg-lead m^{-3}) were found next and 1.8 m away from the shredder operator inside the semi-trailer. Metal surface contamination was highest near the shredder (e.g. 1190 µg-lead 100 cm^{-2}) and extended to other parts of the truck. Near the shredder, the concentration of ultrafine particles was up to 250 000 particles cm^{-3} and particulate matter 2.5 mm or less in diameter ($PM_{2.5}$) was up to 171 µg m^{-3}, and neither returned to background levels after 40 min of inactivity. A diesel-electric generator was used to power the shredder and could have contributed to some of the particulate emissions. We found that mobile e-waste shredding trucks are a source of metals and particulates emissions. We recommend the industry adopts better controls for shredding inside trucks, such as local exhaust ventilation with proper filtration and use of personal protective equipment, to protect workers' health and the environment.

Keywords: electronics; exposure assessment; heavy metals; lead; new technologies; recycling

Introduction

Rapid technological innovation and market competition have shortened electronic products' life cycles (Aytac and Wu, 2013). These shorter life cycles have inevitably led to larger amounts of electronic waste (e-waste). Thus, the US electronics recycling (e-recycling) industry has shown tremendous growth. The industry workforce has grown from 6000 fulltime employees in 2002 to 532 000 jobs most recently (ISRI, 2018, 2019). E-recycling processes typically include sorting, testing, refurbishing, repairing, or shredding (Ceballos and Dong, 2016; Li *et al.*, 2017).

The increased need for more secure forms of data destruction (Terry, 2015; Ponemon Institute, 2018), has led e-recycling facilities to introduce mobile e-waste shredding trucks. This service provides onsite shredding of hard drives, solid-state drives, cell phones, laptops, and other media units containing confidential information. Some US e-recycling facilities commonly deploy one or more mobile e-waste shredding truck(s). Shredding jobs vary depending on customer's needs, but on average small shredders have capacities of 600–800 drives per day, and shredding jobs may span 1–5 days. The design of these novel trucks varies, but the majority consist of a combination of a tractor-unit, a diesel, or hybrid diesel generator to power the shredder, and a semi-trailer with a shredding device (Zeng *et al.*, 2015).

Shredding of e-waste can be a potential source of neurological and cardiovascular toxicants such as lead, cadmium, and airborne particles (Julander *et al.*, 2014; Ceballos *et al.*, 2017). The use of a diesel generator may introduce more particulate emissions (Zhu *et al.*, 2002; Wichmann, 2007). Ultrafine (UFP) and particulate matter 2.5 mm or less in diameter ($PM_{2.5}$) are efficiently deposited in all regions of the respiratory tract and are associated with respiratory and cardiovascular health outcomes (CONCAWE, 1999; Oberdörster, 2000). One study measured $PM_{2.5}$ from an e-recycler facility shredder in California and documented an elicited proinflammatory response in exposed mice (Kim *et al.*, 2015).

There are currently to our knowledge no exposure assessments of these mobile e-waste shredding trucks. The main objective of this pilot study was to characterize metals and particulates exposure from a mobile e-waste shredding truck.

Methods

Study design

A cross-sectional exposure assessment pilot study was conducted at a mobile e-waste shredding truck parked at a Greater Boston e-recycling facility in 2019. The shredder was powered by a new hybrid diesel generator. The 65-min shredding job consisted of continuously hand feeding 200 confidential hard drives and solid-state drives for destruction inside the semi-trailer, with worker not moving away from the job during the whole task. There was no local exhaust ventilation and operation relied on natural ventilation with the back door opened. The worker did not use any personal protective equipment (PPE).

Sampling for metals on different locations of the truck included area air sampling during the shredding task and surface wipe sampling. We also collected real-time UFP and $PM_{2.5}$ at different locations before, during, and after shredding. Samples near the shredder were positioned as close as possible to the worker's head height. Sampling locations are described in Fig. 1.

Area air and surface wipe sampling and analysis

Active air samples were collected using pre- and postcalibrated AirChek XR5000 air sampling pumps (SKC Inc., Eighty-Four, PA, USA) at 4 l min^{-1} connected via Tygon tubing to 37-mm cassettes containing 37-mm diameter mixed-cellulose-ester membrane SKC-Solu-CAP filters cat. no. 225-8517—to account for wall deposits (Ceballos *et al.*, 2015).

Surface wipe samples were collected by the same researcher using one premoistened Ghost wipe towelette (SKC Inc., Eighty-Four, PA, USA, cat. no. 225-2414) and a 10 × 10-cm^2 disposable template per sample following a standard wiping protocol (Brookhaven National Laboratory, 2014).

Field and media blanks were collected for both area air and surface wipe samples. No blank corrections were necessary. Samples were shipped for analysis to the South West Research Institute Laboratory (San Antonio, TX, USA). Both air and wipe samples were analyzed according to NIOSH Method 7300 (NIOSH, 2018). Sample digestates were analyzed for a panel of 30 elements via Inductively Coupled Plasma Atomic Emission Spectrometry and Mass Spectrometry. Details of the quality assurance and quality control for the analysis method are in Supplementary Information S1, available at *Annals of Work Exposures and Health* online. A list of elements and detection limits are in Supplementary Table S1, available at *Annals of Work Exposures and Health* online.

Real-time measurement of particulates

Total UFP (0.01–1 µm) particle number concentrations were measured using a hand-held real-time condensation

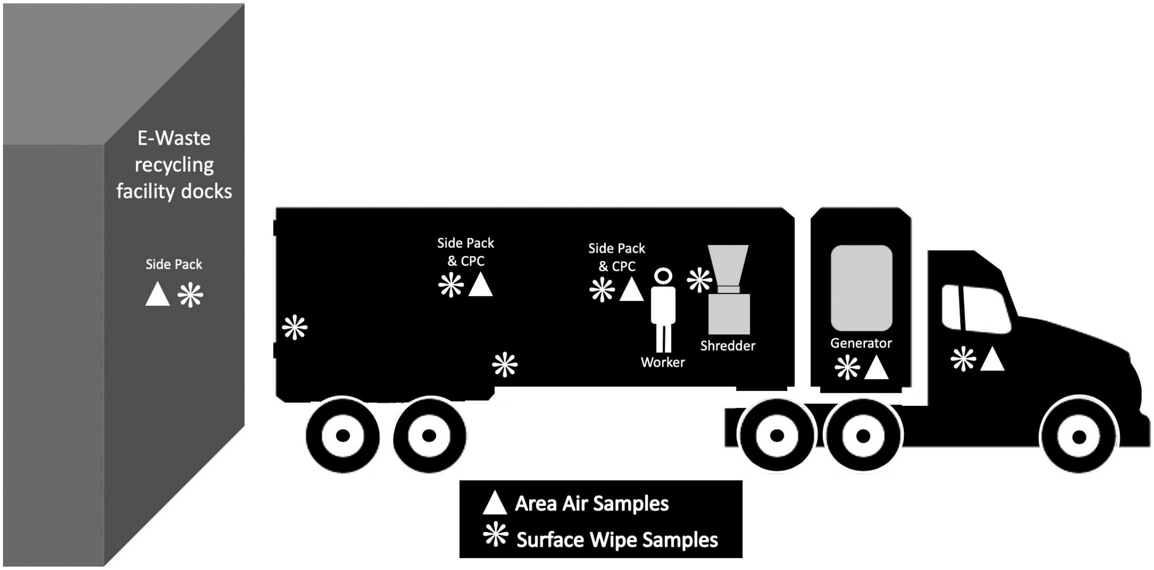

Figure 1. Layout of the mobile e-waste shredding truck and locations of the sampling.

particle counter (CPC) 3007 (TSI Incorporated, Shoreview, MN, USA). $PM_{2.5}$ (<2.5 µm) concentrations were measured using a real-time TSI SidePak AM510 $PM_{2.5}$ monitor. Both devices measured at a time resolution of 1 min, were calibrated annually by TSI, and were blank and quality control checked on the day of sampling.

Statistical analysis

Basic and descriptive statistics were performed using R (3.5.1, R Core Team, Vienna, Austria) and Excel (365, Microsoft, Seattle, WA, USA). Most metals in the analysis were lognormal. Wilcoxon signed ranked test was used to compare production and non-production areas when possible ($\alpha = 0.05$).

Results

Table 1 shows area air sample results for metals and surface loading for a select group of elements. The highest concentration in air was found next to the shredder or 1.8 m away from the shredder. Specifically, the concentration for most metals next to the shredder was about 1–10 times higher than the concentration of the other locations. The highest level of surface contamination was found on top of the shredder, which showed dust accumulation from old shredding jobs. There were also detectable metals in the non-production area (i.e. generator compartment).

Fig. 2 shows the UFP and $PM_{2.5}$ during the shredding job. Particulates increased rapidly, UFP ≥250 000 particles cm^{-3} and $PM_{2.5}$ ≥171 µg m^{-3}, after the shredding began. UFP near and 1.83 m away from the shredder were similar throughout sampling. Unlike UFP, $PM_{2.5}$ measured higher near the shredder and decreased further away from the shredder. After shredding ended, particulates near the shredder did not return to baseline levels.

Discussion

In this initial assessment of metals and particulates exposure in a mobile e-waste shredding truck, both air and surface samples suggest that shredding inside a truck is an important source of exposure to toxic metals and particulates in workers.

For most metals, the area air concentrations were low during shredding with the highest levels found near and 1.8 m away from the shredder, confirming poor ventilation conditions. Lead air concentrations during shredding were similar to area air samples in other facilities from other studies that performed shredding in warehouses (NIOSH, 2014, 2015). If air concentrations were maintained for the whole work shift (e.g. 2.9 µg-lead m^{-3}), the lead concentration would not be likely higher than current occupational exposure limits (50 µg-lead m^{-3}) (OSHA, 2020a) but would be higher to the proposed permissible exposure limit (2.1 µg-lead m^{-3}) (CalOSHA, 2020). Although, if we sampled the breathing zone of the worker, lead concentrations would

Table 1. Mobile e-waste shredding truck area air concentrations (µg m^{-3}) and surface wipe loadings (µg 100 cm^{-2}) for selected metals in different sampling locations.

Sample locations	Al	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Mg	Mn	Ni	Sr	Ti	Zn
Area air concentrations (µg m^{-3}) during 65-min shredding task															
Air MDC (µg m^{-3})	9.64	0.193	0.482	0.0385	0.0385	0.482	0.0385	0.482	0.724	4.82	0.482	1.93	0.482	0.482	4.82
Production															
Table next to shredder (at worker's head height)	51.1	0.192a	**38.8**	0.384a	0.384a	1.33	**1.64**	12.5	**2.91**	**40.3**	0.569	**5.00**	**0.807**	**12.5**	8.34
1.8 m away from shredder	**58.0**	0.192a	30.1	0.384a	0.384a	1.31	1.21	**10.4**	2.49	30.0	**0.752**	4.34	0.691	9.67	**10.4**
4.3 m away from shredder outside truck)	13.0	0.195[a]	4.52	0.3849[a]	0.3849[a]	1.07	0.286	3.32	2.43	27.4	0.224[a]	1.95	0.534	2.14	5.06
GM(GSD)	34(2)	0.19(1)[a]	17(3)	0.4(1)[a]	0.4(1)[a]	1.2(1)	0.83(3)[a]	7.6(2)	2.6(1)	32(1)	0.45(2)	3.5(2)	0.67(1)	6.4(3)	7.6(1)
Non-production															
Generator compartment between trailer and front cabin	14.9	0.192[a]	1.57	0.384[a]	0.384[a]	1.14	0.0385[a]	1.39	0.192[a]	29.5	2.11	0.480[a]	0.588	1.30	4.80[a]
Surface wipe loadings (µg 100 cm^{-2})															
Surface wipe LOQ (µg sample^{-1})	2.50	0.0070	0.050	0.010	0.010	0.125	0.010	0.050	0.188	1.25	0.050	0.500	0.050	0.125	1.25
Production															
Top of shredder	**121 000**	**125**	**38 400**	**0.742**	**4.45**	**271**	**1020**	**14 500**	**1190**	**3010**	**520**	**12 700**	**175**	**10 800**	**14 100**
Floor next to shredder & table	3840	0.007[b]	1520	0.0433	1.79	26.5	105	828	80.3	316	50.2	424	20.8	438	692
Right inside wall of semi-trailer	314	**125**	105	0.010[b]	0.010[b]	3.60	12.6	47.0	6.62	30.1	3.43	29.7	1.97	30.5	137
Table next to shredder	185	0.0070[b]	87.1	0.010[b]	0.0904	1.97	6.79	30.9	4.72	35.5	3.56	23.1	1.49	30.6	133
Table on dock outside of truck	285	0.625	99.5	0.010[b]	0.56	2.97	5.77	36.4	7.22	78.4	13.2	19.2	2.50	32.7	196
Handles of truck backdoor	413	1.88	98.0	0.010[b]	0.0573	10.7	27.0	37.5	8.64	96.7	12.6	43.0	2.21	20.8	138
Top of generator	247	0.0070[b]	57.5	0.010[b]	0.01[b]	2.79	5.71	35.3	2.91	25.0	2.26	32.1	1.55	14.0	117
GM(GSD)	966(11)[c]	0.48(83)	314(11)[c]	0.022(5)	0.16(11)	8.9(6)[c]	26(7)[c]	135(11)[c]	18(8)[c]	110(5)	14(7)	100(11)[c]	5.1(6)[c]	88(11)[c]	343(6)
Non-production															
Dashboard of driver seat	174	0.0070[b]	29.9	0.010[b]	0.0417	1.56	2.13	20.2	2.37	50.4	4.47	8.97	1.28	9.73	110
Driving steering wheel and clutch	159	0.0070[b]	27.7	0.010[b]	0.142	2.25	2.69	23.5	2.68	56.9	3.58	13.7	1.6	8.42	158
Dashboard of passenger seat	167	0.0070[b]	21.2	0.010[b]	0.0874	1.43	1.98	15.9	2.22	47.8	4.43	7.87	1.16	6.75	97.5
Door handle to the generator compartment	33.2	0.0070[b]	3.90	0.010[b]	0.161	0.614	0.255	7.21	1.75	24.9	0.958	1.77	0.396	2.07	215
Door handle of driver seat	55.0	0.0070[b]	6.95	0.010[b]	0.0253	0.661	0.331	3.50	0.866	33.7	1.52	1.43	0.454	3.06	84.2
GM(GSD)	97(2)	0.007(1)[b]	14(2)	0.01(1)[b]	0.073(2)	1.15(2)	0.99(3)	11(2)	1.8(2)	41(1)	2.5(2)	4.8(3)	0.84(2)	5(2)	125(1)

Al = aluminum, As = arsenic, Ba = barium, Be = beryllium, Cd = cadmium, Co = cobalt, Cu = copper, GM = geometric mean, GSD = geometric standard deviation, Pb = lead, MDC = minimum detection concentration, Mg = magnesium, Mn = manganese, Ni = nickel, Sr = strontium, Ti = titanium, and Zn = zinc. Bolded numbers represent the highest values per sample media. *Note*: E-waste sources for the elements measured in the electronics shredded are listed in Supplementary Table S1, available at *Annals of Work Exposures and Health* online.

[a]Samples below MDC or the minimum detection concentration. MDC was calculated as the concentration in air from the reporting mass limits provided by the laboratory over the average air volume of all samples (air volume was calculated from the average airflow during sampling multiplied by the duration of the task).

[b]Samples below LOQ or the limit of quantitation. LOQ was equal to the reporting mass limits provided by the laboratory in units of µg 100 cm^{-2} because all samples were taken in an area of 100 cm^{2}.

[c]Production areas were significantly higher than non-production areas, determined by Wilcoxon signed rank test at $\alpha = 0.05$.

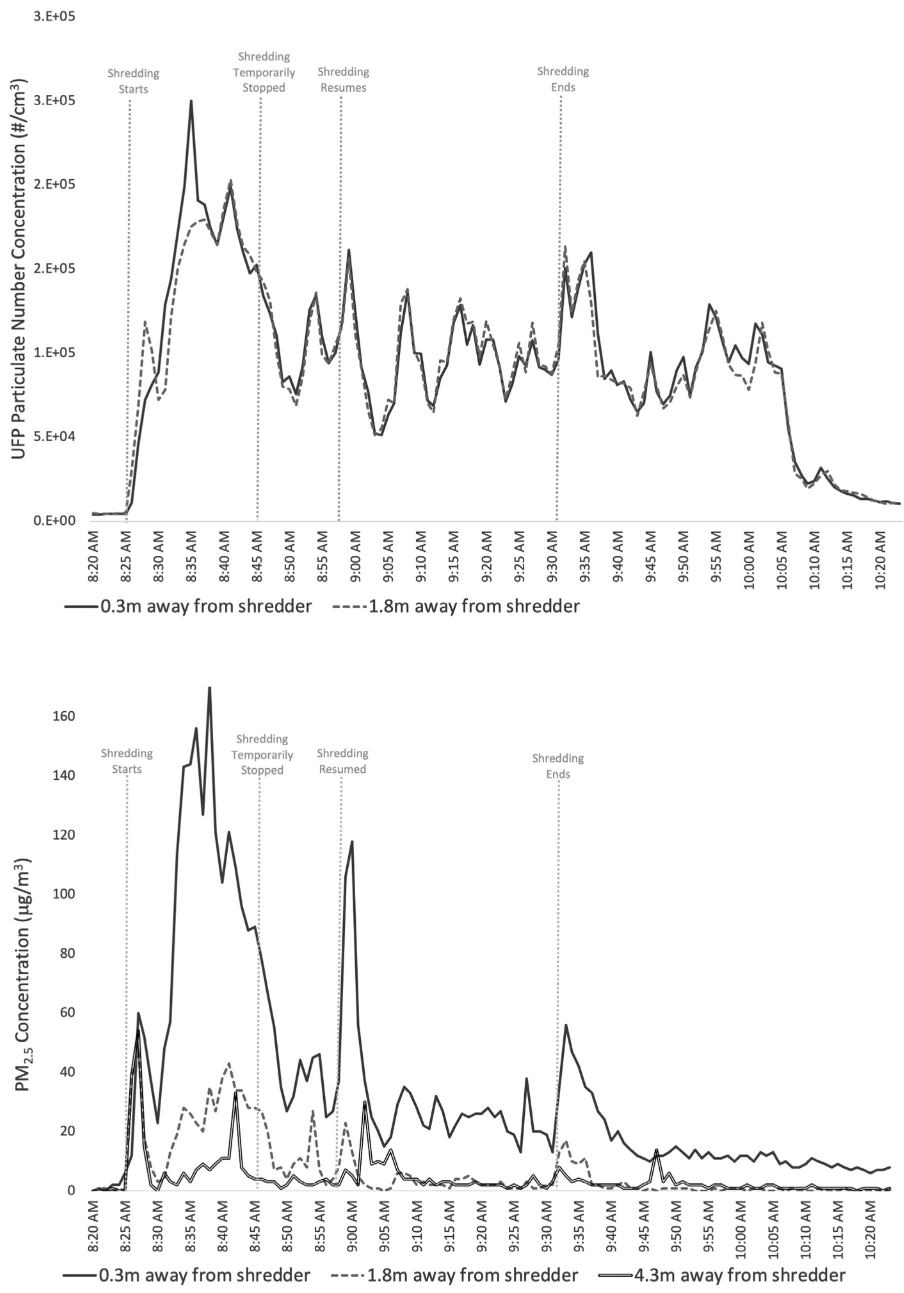

Figure 2. Ultrafine (UFP) particulate count concentration (# cm^{-3}) and $PM_{2.5}$ (µg m^{-3}) concentration during a shredding task in a mobile e-waste shredding truck.

likely be higher than the measured area samples as is typical in the e-recycling industry (Ceballos *et al.*, 2017).

Surface contamination measured in our study was highest on top of the shredder and was comparable to those found in shredders inside e-recycling facilities (NIOSH, 2014, 2015). Surface sampling can provide information about the potential for exposure by other than the inhalation route such as the skin or mouth. The recommended criteria in work surfaces for arsenic, chromium, and lead [100, 50, and 500 µg 100 cm^{-2}, respectively (Brookhaven National Laboratory, 2014)] were all exceeded on the shredder surface (125, 271, and 1190 µg 100 cm^{-2}, respectively). Lastly, although we found low levels of contaminants in the cabin, this suggests some migration to unsuspected areas.

During shredding, particulates reached their peak within minutes with the highest concentrations near the worker. Particulate data suggest that more than natural ventilation is needed to effectively remove or dissipate particulates that are generated from a shredding job. Similar UFP at different locations is likely due to the much lower settling velocity and longer settling time compared with $PM_{2.5}$ (Tsuda *et al.*, 2013). We would expect particulate concentrations even higher, along other toxic exposures such as carbon monoxide, if the diesel generator was older and not hybrid.

The main limitation of this study is the limited sampling time in only one facility that makes results not generalizable. Due to privacy and data security concerns typical of outside clients, we were unable to travel with employees to a remote location to sample a longer session. However, these preliminary data are important to create awareness of potential health and safety issues with the use of this novel technology. In future studies, it would be interesting to measure air and surface levels of other metals such as mercury. Besides, since shredding can generate particles with diameters in the range of 100 µm, a comprehensive assessment of the size distribution of the airborne particle personal exposures (including inhalable and total) dust exposures should be conducted. Our preliminary findings show that personal exposure assessments of the inhalation and dermal exposures of the operators, and other workers involved in the mobile shredding processes are needed.

Mobile e-waste shredding truck services are relatively new in the e-recycling industry, and many of these trucks have not been retrofitted with ventilation to accommodate a shredder in the semi-trailer. Our findings suggest that an e-recycling facility with shredding operations inside a truck(s) should develop health and safety procedures striving, as a minimum, to use the same controls typically recommended for shredding inside e-recycling facilities (e.g. local exhaust ventilation, PPE, and housekeeping). Other safety and health considerations should also be in mind with shredding operations inside a truck. Rotating parts could create an injury or a spark in an area that could be inadvertently closed (back door could close with a worker inside) and generate a hazardous temporary confined space—confined space is defined as a space large enough for an employee to enter and perform work; with limited or restricted means for entry or exit; and not designed for continuous occupancy (OSHA, 2020b). Dangerous conditions can be further exacerbated if the truck was parked for long periods exposed to extreme weather conditions at a client's remote location. There are also potentials for noise and non-ergonomic workstations, among other hazards typical of the industry (Ceballos *et al.*, 2014; OSHA, 2020c). Future research is necessary to further characterize exposures and other health and safety issues in these trucks to assure the health of both workers and the environment.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of Interest

The authors declare no conflict of interest.

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