RESEARCH ARTICLE

Environmental risk assessment of CRT and PCB workshops in a mobile e-waste recycling plant

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Abstract The mobile e-waste recycling equipment was chosen as the object of this study, including manual dismantling, mechanical separation of cathode ray tubes (CRTs), and printed circuit boards (PCBs) in the two independent workshops. To determine the potential environmental contamination, the noise, the heavy metals (Cu, Cd, Pb), and the environmental impacts of the e-waste recycling processes in the two workshops of the mobile plant have been evaluated in this paper. This study determined that when control measures are employed, the noise within the two workshops (<80 dB) will meet the national standards. In the CRT workshop, Pb was the most polluting metal, with 2.3 $\mu g/m^3$ and 10.53 mg/g in the air and floor dust, respectively. The result of a health risk assessment shows that noncancerous effects are possible for Pb (hazard index (HI)=3.54 in the CRT workshop and HI=1.27 in the PCB workshop). The carcinogenic risks to workers for Cd are relatively light in both the workshops. From the results of life cycle assessment (LCA), it can be seen that there was an environmental benefit from the e-waste recycling process as a whole.

Keywords E-waste · Risk assessment · Cathode ray tubes · Printed circuit boards · Mobile plant

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Introduction

With the ever-increasing development of the electronics industry and information technology, the final disposal of e-waste is a worldwide concern (Fu et al. 2012, 2013; Song et al. 2012a, 2013b). Worldwide, these industries generate 20–50 tons of e-waste each year, and this presents serious risks to environmental and human health (Bi et al. 2007; Huo et al. 2007; Leung et al. 2008; Luo et al. 2011).

China, the world's leading manufacturing country, has become the largest dumping ground for e-waste (Kahhat et al. 2008; Song et al. 2012c). E-waste management has made great progress in the last 10 years, and many environmental laws and regulations have been implemented in China (Li and Yu 2011; Ongondo et al. 2011; Premalatha et al. 2013), but informal e-waste recycling processes persist (Chi et al. 2011; Fujimori and Takigami 2014; Xu et al. 2012). Such informal processes apply crude methods to separate out desirable substances and materials from the original electrical/electronic equipment (Leung et al. 2007, 2013). How to effectively and universally implement the appropriate policies and measures is still an important question.

Presently, the standard e-waste recycling processes widely used in the formal e-waste recycling factories in China include the manual dismantling and mechanical separation of cathode ray tubes (CRTs) and printed circuit boards (PCBs) (Fang et al. 2013; Xue et al. 2012). After efficient disassembling, the power cord, speaker, demagnetized coil, and shell are separated and recovered as industrial raw materials. PCBs and CRTs can also be further dismantled but need special treatment. Semi-automatic cutting technology is used for CRT recycling, and an assembly-line crushing (pneumatic separation) corona electrostatic separation treatment is used for extracting valuable components from waste PCBs (Fang et al. 2013). Various methods are applied to recover metallic lead from the funnel glass, such as the vacuum-aided carbon

thermal reduction method and the mechanical activation method (Yuan et al. 2012). These physical processes are proven technologies for CRT and PCBs recycling.

Any solution to the e-waste problem requires careful attention to collection and treatment of the materials to be recycled. Based on the proven e-waste recycling technologies and the previous achievements of our research group on e-waste recycling processes and field plants, we designed and developed an integrated mobile recycling plant for industrial parks and small countries or regions. In view of the critical requirements of mobility and space, a large standard shipping container was chosen to hold the treatment and recycling equipment. In order to test the effectiveness of our newly designed mobile recycling plant, it was demonstrated in selected regions in China. Consequently, about 12.5 tons of e-waste, consisting of 846 computer host units, 200 CRT monitors, and 310 LCD monitors, were recycled and treated in the mobile plant. Because of the possible effects of the mobile units on the surrounding human population and the environment, it was important to carry out the research in the mobile plants as they would be normally implemented.

The major objectives of this study were as follows: (1) to implement effective measures of noise reduction and to evaluate their effectiveness and feasibility; (2) to study the distribution characteristics of heavy metals in the CRT and PCB workshops and estimate the chronic risks to the recycling workers; and (3) to evaluate the total environmental impacts of the e-waste recycling processes.

Materials and method

The mobile e-waste recycling plant

The mobile e-waste recycling plant contains two standard 45-ft steel containers (13.58 m × 2.34 m × 2.71 m) (Fig. S1). Container 1 (the CRT workshop) was used for whole-unit dismantling and CRT recycling, while container 2 (the PCB workshop) focused on recycling waste printed circuit boards (PCBs). A schematic diagram of the plant, the integrated mobile recycling process and related equipment, is shown in Fig. 1. The mobile plant was designed for an annual treatment capacity of 48,000 units of integrated machine (e.g., TV set and PC) dismantling, 14,400 units of CRT recycling, and 500 tons of PCBs. Figure S2 presents the recycling processes and material flows of e-waste treatment in the mobile plant.

Sample collection and analysis

Noise was monitored in the two workshops using an integrated sound level meter (AWA 5610B) and an octave filter (AWA 5722). The sound level meter and octave filter were placed 1.2 m above the ground and 1 m away from the machines. Three values of noise level were recorded at the different positions.

Air samples were collected from 23 to 29 September 2011. A compatible high-volume air sampler was used to collect total suspended particulate (TSP) at a flow rate of 1–1.2 m³/min. The ambient air samples were taken from the atmosphere with inlet heights between 1.5 and 1.8 m above ground. For deposited surface dust, samples were collected by sweeping with a plastic brush.

Particulate-associated contaminants were isolated from the atmosphere by drawing air through a Whitman quartz fiber filter for approximately 24 h. After sampling, the filters were wrapped in aluminum foil and stored in Ziploc bags at −20 °C. The concentrations of TSP were determined by weighing the filters before and after exposure. The filters were then cut into seven strips and archived in cold storage (−20 °C). All treatments were carefully handled using a pair of stainless steel scissors. Four sample sites were setup: two exhaust outlets and two internal workshop sites (near the operating position), as shown in Fig. 2. We arranged these sampling points to assess the risk to occupational hygiene from the recycling lines.

At each sampling site, we collected three samples and calculated their mean concentrations. After the necessary sample pretreatment, all samples were digested according to the United States Environmental Protection Agency (US EPA) method and then were detected by the method of inductively coupled plasma-atomic emission spectrometry (ICP-AES, IRIS Advantage 1000, Thermo Electron Corporation, Waltham, MA). For quality control, a blank test was also conducted by the same method.

Health risk assessment of heavy metals

Workers are exposed to heavy metals through three main avenues: ingestion, inhalation, and dermal contact. For the purpose of evaluating the health risk of workers in the automatic line workshop, a health risk assessment was carried out in this study. The average daily dose contacted through ingestion (ADD_{ing}), inhalation (ADD_{inh}), and skin (ADD_{derm}) may be calculated as follows (USEPA 1997).

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \quad (1)$$

$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (2)$$

$$ADD_{ing} = \frac{C \times SA \times SL \times ABS \times EF \times ED}{BW \times AT} \quad (3)$$
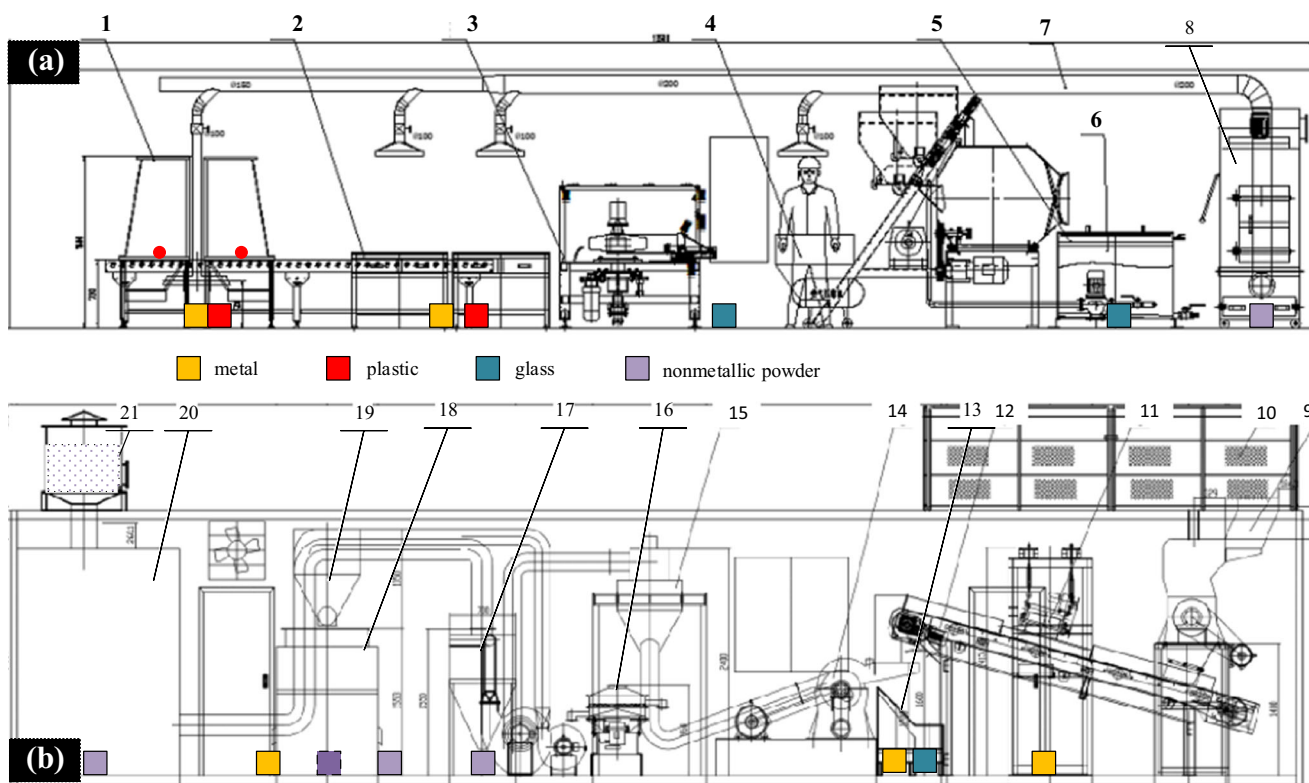
1. Special dismantling table; 2. Multi-functional dismantling table; 3. Separating equipment for funnel and panel glass; 4.Funnel glass breaker; 5. Cleaning machine; 6. Water tank; 7. Tube; 8. Fabric filter; 9. Crusher; 10. Guardrail; 11. Magnetic separator; 12. Conveyor; 13. Screener; 14. Grinder; 15. First air separator; 16. Resonance sieve; 17. Second air separator; 18. Electrostatic separator; 19. Third air separator; 20. Fabric filter; 21.Chimney with SLAC.

Fig. 1 Schematic mobile plant for integrated e-waste recycling process: **a** CRT workshop and **b** PCB workshop. *1* Special dismantling table, *2* multi-functional dismantling table, *3* separating equipment for funnel and panel glass, *4* funnel glass breaker, *5* cleaning machine, *6* water tank, *7* tube, *8* fabric filter, *9* crusher, *10* guardrail, *11* magnetic separator, *12* conveyor, *13* screener, *14* grinder, *15* first air separator, *16* resonance sieve, *17* second air separator, *18* electrostatic separator, *19* third air separator, *20* fabric filter, *21* chimney with SLAC

where C is the concentration of the contaminant in the dust (mg/kg) and C_{inh} is the concentration of the contaminant in air. For ingestion, the intake rate, $IngR$, of dust was 100 mg/day for an adult. For inhalation, the intake rate, $InhR$, for an adult male was 15.2 m³/day (USEPA 1997); the particulate emission factor (PEF) was 1.36×10^9 m3/kg (Wang et al. 2008). For dermal contact, the exposed skin area was SA=2253 cm²; the skin adherence factor, SL=0.2 mg/cm2/day; the dermal absorption factor, ABS=0.001 (Jing et al. 2009). The average body weight (BW) of Chinese people was 60 kg for adults (Leung et al. 2008). In this study, exposure frequency, EF= 250 days per year; the exposure duration, ED=10 years (the service life of the automatic line). The average time (AT) was 3650 days.

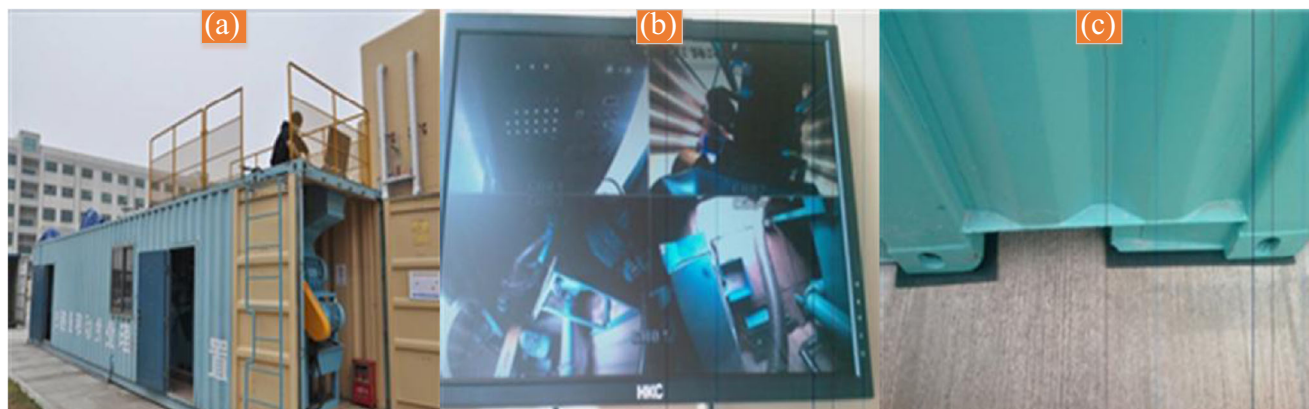Among the three metals studied, Cd is known to be carcinogenic. Because slow factors for carcinogenic risk

Fig. 2 PCB operations and noise control measures: (**a**) PCBs feeding system; (**b**) automatic monitoring system; (**c**) noise control measure

through ingestion and dermal contact were not given by the US EPA, this study considered only carcinogenic risk resulting from inhalation. For carcinogens, the lifetime average daily dose (LADD) was calculated as shown in Eq. 4 (USEPA 1997).

$$\text{LADD}_{inh} = \frac{C \times \text{Inh}R \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \quad (4)$$

where acronyms signified the same variables as in Eq. 2, but AT = 70 × 365 days.

A hazard quotient (HQ) refers to the non-carcinogenic risks of a single contaminant, differing from the hazard index (HI), which represents the total non-carcinogenic risks of different pollutants absorbed through the three avenues described above. The formulas for determining the HQ and HI are as follows (Ferreira-Baptista and De Miguel 2005; Ruan et al. 2012; USEPA 1997):

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}} \quad (5)$$

$$\text{HI} = \sum \text{HQ}_i \quad (6)$$

$$\text{Risk} = \text{LADD} \times \text{SF} \quad (7)$$

The reference dose (RfD) is an estimate of daily exposure below which adverse noncancerous health effects are unlikely. If the HQ < 1, then noncancerous effects are unlikely. If the HQ ≥ 1, then adverse health effects are possible. An HQ > 10 suggests high chronic risk (Fang et al. 2013; Leung et al. 2008). The HI is the sum of the HQ values.

Environmental impact assessment

In order to better understand the total environmental effects of e-waste recycling in the two mobile e-waste recycling containers, life cycle assessment (LCA) was adopted in this study. The function unit is 12.5 tons of e-waste processed in the mobile e-waste recycling plant, consisting of 846 units of computer host, 200 units of CRT monitors, and 310 units of LCD monitors.

The inventory analysis for the LCA was obtained directly by the research activity within the e-waste mobile units for the quantitative and qualitative data (reagents and energy) for the equipment processes. The production processes of the chemicals and energy are available in the EcoInvent 2.2 database. For energy, the power mix produced in China was used in all of the processes, unless otherwise specified. The data sources as well as the assumptions and limitations described in Table S1 were used in this study.

For the impact assessment, the well-known Dutch LCIA methods (CML methodology) was used by the SimaPro 7.2 software integrated with the EcoInvent database v.2.2. The CML method, on the other hand, is an example of the so-called problem-oriented or mid-point approach (Song et al. 2012b, 2013a). It is based upon the publication of Guinée (2001), acknowledged as a proven reference in the field of LCA and also known as the "CML Guide."

Results and discussion

Assessment of noise

Noise monitoring in the workshops

The major sources of noise were the mechanical elements of e-waste treatment, including the crusher, grinder, vibrating screen, the cleaning machine of funnel glasses, and the bag-type dust collector.

Table 1 shows the monitoring result of noise generated by each facility in the two workshops. It is clear that the major noise sources in the automatic line workshop are crushing machines and funnel-glass cleaning machines. The noise level exceeded the Occupational Safety and Health Standards (US OSHA.). The maximum permissible limit for the equivalent continuous sound level (Leq) is 90 dB (A) for workers who work 8 h per day in the workshop. From the known relationship between noise levels and the incidence of auditory impairment and disease, it can be calculated that the rates of hearing impairment and disease for operators working in the CRT recycling workshop for 10 years were 20 and 17 %, respectively. Due to the greater quantity of mechanical treatment in the PCB recycling workshop, its rate of hearing impairment and incidence of disease for operators for 10 years were 32 and 29 %, respectively. It is suggested that control measures be taken to decrease the noise pollution of the crushing

Table 1 Noise generated by the recycling facilities in the workshops (dB)

Noise sources	Shredder	Hammer grinder	Cleaning machines	Vibrating screen	Cyclone	Dust collector	Total
CRT	–	–	91.4	–	–	76.8	94.0
PCB	91.2	83.5	–	65.7	60.4	78.5	98.3

Table 2 Heavy metal concentrations in the inside air of the workshops (µg/m³)

Heavy metals	TSP	Pb	Hg	Cd	Cu
CRT	246.5	2.3	–	0.036	1.25
PCBs	650.7	1.2	0. 015	0.024	1.48

process. In addition, there was a positive relationship between the length of exposure to noise and the rate of hearing impairment and disease.

Management strategy

In this situation, there is a potential for significant negative health effects. In order to solve the problem of excess noise, the following arrangements were adopted. *CRT workshop*: For the main noise source—funnel glasses cleaning—the cleaning machines would be run only when at least 90–100 kg of funnel glasses had accumulated, and these would need to run for only 20 min. According to the current CRT separation capacity, the cleaning machines need be operated only twice daily. Therefore, in order to reduce the health effects of the noise, the cleaning of funnel glasses would be arranged at break time for the workers, and only one worker would be needed to monitor the operation outside the CRT workshop (where the noise is lower than 80 dB). *PCB workshop*: In the PCB workshop, when the PCB recycling machines were started, there would be no workers inside the workshop, and the doors of the workshop would be closed to reduce the noise. The container can be seen as the acoustic hood, which can reduce the noise. As shown in Fig. 2a and b, only two workers are needed to monitor the PCBs feeding: one on the container roof and another monitoring the operation through the automatic monitoring system (located at the CRT workshop). Therefore, the adverse effects of noise on the workers are limited.

Three other measures were also carried out to further reduce the noise. First, we used cushion blocking under the container to reduce the vibration and noise, as shown in Fig. 2c. Secondly, glass glue was used to seal the doors and windows to reduce the noise released from workshop. Thirdly, some protective tools were adopted to prevent the noise effect on workers (e.g.,

Table 4 The concentration of heavy metal in floor dust (mg/g)

Heavy metals	Pb	Cu	Cd
CRT	10.53	6.56	0.027
PCBs	3.78	17.87	0.015

ear plugs). Fourth, the PCB feeding equipment can be modified to further protect the feeding worker from the noise effects: one belt-feeding device outside of the PCB workshop can be used.

Heavy metal risk assessment

Mass concentration of TSP and heavy metals in the workshops

The mass concentrations of TSP in the CRT and PCB workshops for recycling e-waste were 246.5 and 650.7 µg/m³, respectively. The average concentrations in the CRT workshop fell below the Chinese Grade III guideline (applied to specific industrial zones), whose limit was 500 µg/m³ for TSP (Xue et al. 2012). However, because much of the crushing and air separation operations for PCBs were carried out in the PCB workshop, the TSP concentration there exceeded the emission limit value. Because no workers were present in the PCB workshop, though, the human health effects of TSP can be ignored.

The concentrations of Cu, Cd, Hg, and Pb in the exhaust gas and indoor air of the two workshops are presented in Tables 2 and 3. All the four metals were detected in all the air samples, with the exception of Hg, which was not found in the CRT workshop indoor air. This shows that the e-waste recycling process released toxic metals into the air in both workshops. The heavy metal concentration in the indoor air in the two workshops were found to be higher than those in the exhaust gas, because the polluted air extracted through the exhaust fan was processed by the bag-type dust collector. The heavy metal concentrations in the exhaust gas from the two workshops were in order of Pb>Cu>Hg>Cd for the CRT workshop. However, the Cu concentration was the highest in the PCB workshop, mainly because of the composition of CRTs and PCBs: funnel glasses in the CRTs are made of lead silicate glass containing approximately 20 wt% PbO (Herat 2008); therefore, a good deal of Pb was released to the

Table 3 Heavy metal concentrations of exhaust gas in the workshops

Heavy metals	Pb		Hg		Cd		Cu	
	Concentration (µg/m3)	Emission (kg/h)	Concentration (µg/m³)	Emission (kg/h)	Concentration (µg/m³)	Emission (kg/h)	Concentration (µg/m³)	Emission (kg/h)
CRT	16	4.7×10^{-5}	0.11	5.8×10^{-7}	0.049	2.6×10^{-7}	3.0	3.2×10^{-5}
PCBs	8.9	2.0×10^{-5}	0.036	4.5×10^{-8}	0.055	6.9×10^{-8}	4.9	6.2×10^{-6}

Table 5 Average daily doses and hazard quotients for each noncancerous metal and exposure pathway

Item	ADD_{ing}	ADD_{inh}	ADD_{derm}	RfD_{ing}	RfD_{inh}	RfD_{derm}	HQ_{ing}	HQ_{inh}	HQ_{derm}
CRT workshop									
Pb	1.20E−02	1.34E−06	5.42E−05	3.50E−03	3.52E−03	5.25E−04	3.43E+00	3.82E−04	1.03E−01
Cu	7.49E−03	8.37E−07	3.37E−05	4.00E−02	4.02E−02	1.20E−02	1.87E−01	2.08E−05	2.81E−03
Cd	3.08E−05	3.44E−09	1.39E−07	1.00E−03	1.00E−03	1.00E−05	3.08E−02	3.44E−06	1.39E−02
PCB workshop									
Pb	4.32E−03	4.82E−07	1.94E−05	3.50E−03	3.52E−03	5.25E−04	1.23E+00	1.37E−04	3.70E−02
Cu	2.04E−02	2.28E−06	9.19E−05	4.00E−02	4.02E−02	1.20E−02	5.10E−01	5.67E−05	7.66E−03
Cd	1.71E−05	1.91E−09	7.72E−08	1.00E−03	1.00E−03	1.00E−05	1.71E−02	1.91E−06	7.72E−03

ADD average daily dose (mg/kg/day); *RfD* reference dose (mg/kg/day); *HQ* hazard quotient (unitless)

surrounding air during the CRT separation and crushing processes. The Cu level of PCBs is about 10–20 % (Guo et al. 2008; Li et al. 2007), which is much higher than the other metals, and therefore, higher Cu levels were found in the PCB workshop.

The concentrations of Cu, Cd, and Pb in floor dust collected in the two workshops are presented in Table 4. The values demonstrate that toxic metals are also released into floor dust in the workshops. Pb and Cu were released into the environment of the recycling lines more easily than Cd. Similar to the distribution of heavy metals in the air, it can be seen that Pb (10.53 mg/g) was the most enriched metal in the CRT workshop, followed by Cu (6.56 mg/g), and the dust in the workshop contained a higher Cu level (17.87 mg/g) than the air.

Heavy metal risk assessment

Risk assessment for non-carcinogenic metals in the workshops The model of health risk assessment from the US EPA was applied to evaluate the HIs of Cu, Cd, and Pb in dust samples, and the values of HQs and HIs for each non-carcinogenic metal in the two workshops were shown in Table 5. For the average daily dose of heavy metals, the ADD_{ing} was the most important exposure source, accounting for about 99 % of the total daily dose. For ingestion, the HQs of the heavy metals showed a sequential order as Pb>Cu>Cd in the two workshop, while in the two workshops, the HQ_{derm} of Cd was higher than that of Cu. The total HQ of the CRT workshop was 3.77, to which Pb made the maximal contribution (93.78 %), while in the PCB workshop, the total HQ was

2.81, of which the Pb contribution was 70.07 %. For inhalation, the HQs (0.00041 in the CRT workshop and 0.00020 in the PCB workshop) were both far below the health risk boundaries. For dermal exposure, the contributions of Pb, Cu, and Cd to the total HQ were 86.07, 2.35, and 11.09 % in the CRT workshop, and those of Pb, Cu, and Cd were 70.66, 14.62, and 14.72 %, respectively, in the PCB workshop, with the total HQ being less than 1 (the safety level). In short, the values of HQs calculated for all three avenues of exposure showed the following pattern: ingestion>dermal contact>inhalation.

On the other hand, according to Table 5, the HIs of Pb, Cu, and Cd were 3.54, 0.19, and 0.04, respectively, in the CRT workshop and 1.27, 0.52 and 0.02, respectively, in the PCB workshop, indicating that, in both workshops, only Pb might create non-carcinogenic risks to the workers. The reason for the higher Pb levels might be that Pb had a high concentration in the particulates and could be released into the air more easily than the other heavy metals, during the recycling processes. Also, it can be seen that the total HI (3.77 and 2.81) of the three metals exceeded the safety level. In summary, Pb was the main contaminant among the three heavy metals that could possibly cause human health risks. **Carcinogenic metal risk**

Table 6 Lifetime average daily doses and risk for carcinogenic metal (Cd) via inhalation

Item	$LADD_{inh}$ (mg/kg/day)	SF_{inh} (mg/kg/day)$^{-1}$	Risk
CRT workshop	2.41E−08	6.30	1.52E−07
PCB workshop	1.34E−08	6.30	8.44E−08

Table 7 Environmental impacts of e-waste recycling in the mobile plant

Categories	Characterization		Normalization
	Unit	Emission	
Abiotic depletion	kg Sb eq	−2.55E+02	−1.50E−07
Acidification	kg SO_2 eq	−5.03E+02	−7.50E−07
Eutrophication	kg PO^{4-} eq	−2.68E+02	−5.38E−07
Global warming (GWP100)	kg CO_2 eq	−2.80E+04	−1.11E−07
Ozone layer depletion (ODP)	kg CFC-11 eq	−2.13E−03	−2.13E−09
Human toxicity	kg 1,4-DB eq	−2.26E+05	−1.20E−06
Photochemical oxidation	kg C_2H_4	−2.54E+01	−1.38E−07

assessment Table 6 shows the LADD and risk of Cd through inhalation. The LADDs for Cd in the CRT workshop and the PCB workshop were 2.41×10^{-8} and 1.34×10^{-8}, respectively. From Table 6, it can be seen that the trend was that risks in the CRT workshop is greater than the risks in the PCB workshop. Any cancer risk less than the threshold value (10^{-6}) is considered negligible by the US EPA (USEPA 1997). From the results, we could see that the lifetime cancer risk from Cd clearly did not exceed the threshold, and there was no cancer risk to the e-waste recycling workers.

Management measures

Considering the health risk of heavy metals, many suggestions to guarantee the health of workers have been put forward and may be implemented in the future. (1) Special highly effective masks that filter the maximum amount of particulate matter and dust offer the most direct protection to the workers. (2) The e-waste recycling operation, especially the manual dismantling and separation, should be carried out within improved recycling facilities that afford a closed or semi-closed environment. (3) If each physical part of the automatic line (e.g., shredder, grinder, and separator) were to be isolated by acoustic hoods, the diffusion of particles into the surroundings would be greatly reduced, so that the concentrations of particles could be kept at a low level. It is also necessary to enhance the interior air purification by the bag house. (4) Due to the potentially serious health effects of Pb, the removal of Pb during the CRT and PCB recycling processes must be more efficient in order to significantly cut down the noncarcinogenic risks. (5) Other effective measures, such as sprinkling small amounts of water on workshop floors, would also help to reduce the particles in the air and dust.

Environmental impact assessment of e-waste recycling

As shown in Table 7, estimates of the environmental impacts of e-waste recycling in the two workshops were carried out in the categories of abiotic depletion, acidification, global warming, eutrophication, ozone layer depletion, human toxicity, and photochemical ozone creation. All the results showed negative values for the environmental impacts, which indicated there was an environmental benefit for the whole e-waste recycling process, since recycling the useful resources can be expressed as "avoided primary production." From Table 7, it can be seen that recycling e-waste can alleviate these seven types of environmental impact. Based on the normalization value, we can see that human toxicity was the greatest environmental impact avoided, equal to avoiding the human health effects of 2.26×10^5 kg 1,4 dichlorobenzene (1,4-DB). This is followed by acidification (avoiding about 503 kg SO_2 eq emission) and eutrophication (reducing about 268 kg

PO^{4-} eq emission to water). In addition, for the public concern about global warming (GWP100), it is equivalent to a reduction of about 2.80×10^4 kg CO_2 emission to the environment.

Conclusions

The working environment for recycling e-waste in the mobile plants was greatly improved through effective measures. Production line noise in the two workshops was effectively controlled. What is more, the hazard indexes of Cu and Cd were lower than their threshold values. However, the HQ contacted through ingestion for Pb was 3.54 and 1.27 in the CRT workshop and PCB workshop, respectively, which indicates that adverse health effects are possible, especially for Pb. Due to the potential health effects of Pb, the technologies to remove Pb during the CRT and PCB recycling processes must be made more efficient to significantly cut down the noncarcinogenic risks. Although e-waste recycling can cause some potential adverse environmental and human health effects, overall, it offers net benefits in seven areas of environmental impact, especially human toxicity, equivalent to avoiding the human health effects of 2.26×10^5 kg 1,4-DB. The findings indicate that e-waste recycling processes that include effective personal protective devices and pollution control equipment are necessary to successfully address e-waste issues. It is hoped that the results may improve the current e-waste treatment situation in China by assisting in the standardization of the technology used and by providing relevant information.

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