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Consumption of rice and fish in an electronic waste recycling area contributes significantly to total daily intake of mercury

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Mercury is a global pollutant due to its widespread use, emission, and long-range transport (Blum, 2013; Pacyna et al., 2010). It is considered a priority pollutant due to its neurological toxicity, persistence, and bioaccumulation (Pacyna et al., 2010; Sharma et al., 2015). Mercury pollution can occur when products that contain mercury are improperly disposed of and mercury is released into the air, water, and soil (Zhang and Wong, 2007). An estimated 22% of the annual world usage of mercury is in electrical equipment such as batteries, thermometers, and discharge lamps, and electronic devices such as monitors and mobile phones (Streets et al., 2005; Wang, 2007; Wong et al., 2006; Wu et al., 2006).

During the past two decades, global electronic waste produced by industrialized countries has been largely exported to developing countries such as China, Malaysia, India, and Kenya and other African countries (de Oliveira et al., 2012; Herat and Agamuthu, 2012; Shumon et al., 2014). An estimated 70% of electronic waste (e-waste) was exported to China in the early 2000s (Streets et al., 2005; Wang, 2007; Wong et al., 2006; Wu et al., 2006). Gold, copper, and other rare metals contained in electronic devices are the most valuable components recovered from recycling e-waste. E-waste recycling methods used in developing countries focus solely on the extraction of profitable metals and disregard the potential hazards of remaining materials. Mercury is predominantly released from the processes of dismantling and disposing of electronic waste. Disposal of mercury-containing waste results in mercury leaching into the air, water, and soil where it accumulates in plant and animal life. Low-cost recycling procedures such as burning, heating, and acid etching release mercury into the environment. In developing countries, these primitive operation methods are used with little or no personal protection equipment, posing increased risk to workers.

There is a lack of data on mercury pollution at local and regional levels, making it difficult to understand the role of e-waste recycling in mercury exposure. But with increasing industrial development, mercury pollution has started gaining attention from scientists in atmospheric, aquatic, and ecological research (Ancora et al., 2015; Du et al., 2015; Li and Cai, 2015). Various forms of mercury that cause many types of irreversible damage are found in the environment (Boening, 2000; Du et al., 2015). Exposure to inorganic mercury (I-Hg) may result in damage to the gastrointestinal tract, nervous system, and kidneys. A fraction of I-Hg can be converted to methylmercury (MeHg) by bacteria in anoxic environments and then accumulate in biota *via* the food chain (Renzoni et al., 1998). MeHg exposure can adversely affect the growing brain and nervous system of children (Nagashima, 1997). Negative impacts on cognitive thinking, memory, attention, language, fine motor skills, and visual spatial skills have been seen in children exposed to methylmercury in the womb (US EPA, 2015).

Both I-Hg and MeHg can be absorbed through the gastrointestinal tract, lungs, and skin (Airey, 1983). However, MeHg is more readily absorbed *via* ingestion than I-Hg compounds.

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Mercury can accumulate in many environmental matrices such as air, water, lake sediment, fish, and other food sources. Mercury is also deposited in hair as it grows, and this reflects the body burden of mercury (Airey, 1983). Thus, quantitative information on mercury species in these environmental samples can be used to estimate mercury exposure.

Cheng's group (Tang et al., 2015; Cheng et al., 2015) conducted a series of I-Hg and MeHg measurements around an e-waste recycling center in China and compared the values to a reference site to determine the potential Hg contamination and potential health risks to workers and local residents in e-waste recycling areas (Fig. 1). Environmental, food source, and hair samples were analyzed to determine the mercury concentrations in various distances from the e-waste recycling plants. Samples were taken from three separate locations: Fengjiang, an industrial e-waste recycling area; Baifengao, a village 3 km away from Fengjiang; and Wenling, a reference site 25 km from Fengjiang.

Tang et al. (2015) first measured air samples from each location and found that the total mercury (T-Hg) in the industrial area was twice that of the amount in Baifengao air and 4.3 times that of the amount in Wenling (the reference site) air. The T-Hg in the industrial area air was also 18 times the background level for all of China. Soil samples from the industrial area and Baifengao contained T-Hg levels 20 and 8 times higher, respectively, than the Chinese National Standard Agency (CNSA) recommended upper limits in arable soil, whereas the T-Hg levels in the reference site soil were under CNSA recommendations. Dust from workshop floors in the industrial area also contained elevated T-Hg levels 12 and 29 times higher than Baifengao and the reference site, respectively. T-Hg of all soil and dust samples contained less than 0.1% MeHg. This data shows that Hg levels in air, soil, and dust quickly decrease as the distance from e-waste facilities increases, highlighting the concern of Hg exposure for people who work and live in the industrial area.

Each crop measured from Baifengao contained T-Hg levels above CNSA tolerance limits for human foods. MeHg was present in crops at high concentrations relative to T-Hg which could result in adverse health effects to local residents due to the high bioavailability of MeHg. Furthermore, chicken and pigs contained T-Hg levels above CNSA recommendations. Fish are considered an important source of exposure to Hg due to the bioaccumulation of MeHg; however, of the fish analyzed, 93% were under the CNSA limits.

Human hair is a useful sample for measuring heavy metals since it is readily available and it gives temporal exposure information along the length of the hair. Workers in the industrial area had significantly higher hair I-Hg levels than the rest of the population. The highest concentrations were found in acid bath workers and metal recovery workers, which can be attributed to

Fig. 1 Site of an electronic-waste recycling center in China.
Photo courtesy of Drs. Jiping Cheng, Jing Ma and Wei Tang, Shanghai Jiaotong University, China.

inhalation of contaminated air, dust, and smoke when working with old methods and little personal protective equipment. However, residents of the industrial area and the reference site, who did not work in e-waste recycling, had the highest levels of MeHg. Since 80%-90% of all mercury present in fish is MeHg (EFSA, 2012), the high MeHg levels is attributed to the high occurrence of fish in the diets of these groups. Tang et al. conducted statistical analysis on the time spent in the industrial area and found a strong positive correlation with hair I-Hg but a strong negative correlation with hair MeHg. Furthermore, they found a strong positive correlation between fish consumption and MeHg but a strong negative correlation between fish consumption and I-Hg.

Tang et al. conducted a Hg exposure assessment for children and adults with their measured values. They found that daily dietary intake (DDI) contributed > 82% of T-Hg, I-Hg, and MeHg exposure, which is consistent with previous studies of total daily intake (TDI) of Hg. Furthermore, rice and fish contributed up to 83% of TDI. Daily air inhalation was a significant contributor to I-Hg exposure, which explains the high levels of I-Hg in the hair of workers in the industrial area. Overall exposure to I-Hg mercury in both adults and children and T-Hg exposure in adults were below CNSA recommendations. However, T-Hg and MeHg exposure in children and MeHg exposure in adults were significantly above World Health Organization (WHO) recommendations. In fact, the exposure of children to MeHg was 3 times higher than recommended exposures. While Hg concentrations in soil and atmosphere contribute a small amount to TDI, they are important factors to analyze as they could contribute to Hg accumulation in crops and other food sources, which compose the majority of Hg TDI.

The work of Tang et al. (2015) highlights the need for environmental assessments in large manufacturing and waste facilities to ensure residents in these areas are not negatively impacted. Incinerator and acid bath workers contained the highest amount of hair I-Hg; this could most likely be reduced by improving personal protective equipment to prevent inhalation of contaminated air and particulate matter. Of particular concern is the high exposure of young children to Hg and the impact Hg has on brain and nervous system development. Wang (2007) points out that the recycling techniques used in China are primitive and are a significant cause of Hg contamination. More stringent measures are required to prevent Hg from entering the environment through vapor or particulates.

Wu et al. (2013) conducted a nationwide study in China on umbilical cord blood mercury levels. The research analyzed 1323 cord blood samples from major hospitals in seven geographical regions in China. The risk of mercury exposure is positively correlated to the consumption of formula milk, rice, and marine fish. Higher income and good living conditions did not prevent mercury exposure.

E-waste disposal and recycling are a growing world-wide problem. Current Japanese and American environmental policy and regulations are the consequence of a number of environmental disasters in the 1950s and 1960s (Matsuo, 2003). Since the 1970s, mandatory recycling has been regulated by the government and trained workers are hired for e-waste recycling (Hickle, 2013; Menikpura et al., 2014). Despite the efforts to find environmentally sustainable recycling and disposal methods, e-waste is a growing problem that requires more environmentally sound disposal and tracking systems in both developed and developing countries.

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