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Evidence of environmental and health impacts of electronics recycling in China: an update

GREENPEACE RESEARCH LABORATORIES TECHNICAL NOTE 04/2008

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Creating a Toxic-Free Future

Since the publication by Greenpeace of "Recycling of Electronic Waste in China and India: Workplace and Environmental Contamination" (Brigden *et al* 2005) a number of studies have been published examining the state of the environment and the health of workers in areas where e-waste is handled. This short briefing reviews what new information has been discovered. The new studies are all focused on China, mainly on Guiyu, one of the two areas examined in Brigden et al (2005). In that study, Greenpeace focused to a large extent on the e-waste recycling processes and immediate environment surrounding the e-waste handling workshops. These new studies generally include the wider environment as well as different media (such as air and human blood). Therefore, in order to get a clear understanding of the nature of the recycling industry and its impacts in Guiyu, this document should be read in conjunction with the previous Greenpeace report (http://www.greenpeace.to/publications/electronic_waste_recycling_2005.pdf)

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Printed on 100% recycled
post-consumer waste with
vegetable based inks.

JN 117

Published in 2008
by Greenpeace International
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Part 1 Guiyu

1.1 Environment

Studies have now investigated a number of environmental media in Guiyu and report the extent of contamination. Air, soil, sediment and water have all been found to contain harmful pollutants.

1.1.1 Air

The nature of e-waste processing in Guiyu, notably the extensive use of grinding, melting, roasting and burning, provides many routes by which toxic substances can be emitted into the atmosphere. That the open, uncontrolled, burning of e-waste, as occurs in Guiyu, can result in atmospheric releases of both a range of metals and polychlorinated dioxins, furans and brominated analogues has been confirmed in a laboratory study (Gullett *et al* 2007). Over one month in 2004, Deng *et al* (2006 & 2007) collected samples of the air from the roof of a three storey building (approx 10 m above the ground), on a street where open burning and other e-waste processing operations occurred.

The air was found to contain particles loaded with a number of heavy metals (Deng *et al* 2006); chromium, copper, lead and zinc were found to be the most enriched in the two dust fractions analysed (total suspended particles or TSP, and fine particles with a diameter of less than 2.5 um termed PM2.5). With the exception of copper, these heavy metals were found to be predominantly located in the fine particle fraction. The atmospheric concentration of chromium (1161ng m^{-3} TSP) was found to be 36 times that of an industrial location in Taijon, Korea, and 190 times that of a location in urban Tokyo. Levels of copper, zinc and lead were also significantly higher than those encountered in a number of Asian cities (though, with the exception of zinc, much lower than are present in Hong Kong air).

Polycyclic aromatic hydrocarbons (PAHs), including persistent, bio-accumulative, mutagenic, and carcinogenic compounds (ATSDR 2003), were also found in Guiyu air in the same study. Levels were higher than those found in Guangzhou, widely acknowledged to be one of the most polluted cities in China. It is also noteworthy that, as was the case with the heavy metals, a high proportion of the toxins, (in this case approximately 70%) were associated with fine particulate matter. Levels of polychlorinated dibenzo dioxins/furans (PCDD/Fs), (persistent, bioaccumulative and toxic compounds (ATSDR 2003) often generated during the combustion of materials containing chlorine) were recorded simultaneously in Guiyu, Guangzhou, and Hong Kong (Deng *et al* 2007). The summed concentration of 17 PCDD/Fs in Guiyu (6521 fg m^{-3}) was found to be 1.5 times that of Guangzhou and 3.1 times that of Hong Kong. A subsequent, more comprehensive study conducted in 2005 looked for a much wider range of chlorinated dioxins and furans as well as brominated analogues (Li *et al* 2007). The levels detected (PCDD/F (tetra to octa) abundances of 64.9 -2365 ng m^{-3}) are reported to be the highest found in ambient air worldwide. Compared to World Health Organization guidelines, the estimated PCDD/Fs inhalation intake of Guiyu residents was estimated to be 15-56 times higher than the recommended Tolerable Intake Level of 1 -4 pg kg^{-1} day^{-1}. The authors assumed that inhalation contributes approximately 2.61% of the total daily intake (TDI) as was found to be the case in Japan.

Polybrominated diphenyl ethers (PBDEs), likely to have been released into the air when plastics containing them as flame retardants were heated or burnt in fires, extensively contaminate the air of Guiyu (Deng *et al* 2007). Levels of all 22 congeners studied in Guiyu over one month in 2004 were 58 -691 times greater than those found at two sites in Gaungzhou and two in Hong Kong. The more toxic mono- to penta- substituted PBDEs accounted for between 79 and 96% of the total sum at all sites. These levels are 100 times greater than have been found at other sites worldwide, indicating the exceptional nature of environmental pollution in Guiyu.

1.1.2 Soil

Similarly, the soils of Guiyu are heavily contaminated both with chemicals originating in electronic goods and those generated by the dangerous disposal of non-recyclable components. Pollutants were found both at urban sites directly involved in e-waste processing and in soils from rice fields, some of which were located a considerable distance from the main processing areas.

Unsurprisingly sites directly involved in e-waste operations were heavily contaminated with PBDEs (Leung et al 2006, Leung et al 2007). Soils from an acid leaching site and a printer roller dump contained 2720-4250 and 593 – 2890 ug kg^{-1} dry weight (dw) respectively (based on three samples from each site) of 23 PDBE congeners (Leung et al 2007). Soil from a duck pond used to raise over one hundred ducks, close to fields used to burn e-waste, also contained elevated levels of the flame retardants (263-604 ug kg^{-1} dw). Soil from a rice field and the banks of a reservoir (located at some distance and used as a control) were much less contaminated (34.7 – 70.9 and 2.0 – 6.2 ug kg^{-1} dw PBDEs respectively). However, similar congeners dominated at these sites, the three more contaminated sites listed above and in combusted cable wiring and

plastic chip residue, suggesting a common source, namely e-waste burning. This hypothesis is supported by the finding that soils at open burning sites and near them are also contaminated (2906 -44,473 ug kg^{-1} and 85.0 – 201 ug kg^{-1}respectively) (Wong et al 2007a). Leung et at (2007) also found that deca-BDE (BDE-209), the most commonly commercially applied PBDE, was the most abundant congener at all sites.

Contamination of Guiyu soils with PAHs, PCDD/Fs, PCBs and heavy metals followed a similar pattern to that of PBDEs. Concentrations of all four classes of pollutant were greatest in soils from open e-waste burning and acid leaching sites, significant in the surrounding areas, and still elevated in rice fields from all over Guiyu compared to the relatively uncontaminated and distant reservoir control site (Wong *et al* 2007a, Yu *et al* 2007, Leung *et al* 2007). Concentrations of PCDD/Fs of 968 ug kg^{-1} have been reported at an e-waste open burning site (Wong *et al* 2007a). The toxicity equivalent of the dioxins present at this site exceeded the USEPA remediation value almost ten-fold. Soil from the rice fields contained concentrations of 2,3,7,8-TCCD (the most toxic congener) nearly three times greater than Canadian guidelines for soil for agricultural, residential, commercial or industrial purposes (Leung *et al* 2007).

1.1.3 River Systems (sediment, water and fish)

A number of rivers and small tributaries run through Guiyu. These receive inputs from the e-waste industry both indirectly (run-off and dust) and directly (dumped solid and liquid wastes), as well as untreated municipal waste water. Given that the rivers are used for both aqua-culture and agriculture (forming part of the irrigation system of rice paddy fields), contamination leads to the potential for human exposure to toxins through contaminated foods (Wong *et al* 2007a). Rice, for example, has been shown to take-up heavy metals (World Health Organization 1992). The two main rivers flowing through Guiyu, the Liangjiang and the Nanyang, are directly exposed to different parts of the e-waste processing chain. For example, the Nanyang has a number of acid leaching sites on its banks. The water and sediments in the rivers have been found to contain high levels of heavy metals.

A study of metals in sediment samples from the two rivers found the Liangjiang to be most contaminated (Wong et al 2007b). In this river, concentrations of cadmium, copper, lead and zinc in at least 7 of the 15 samples collected exceeded the Canadian Environmental Quality Guidelines predicted effect level (PEL) (CCME 2007). Above the PEL adverse biological effects are usually or always observed within the aquatic ecosystem. Copper levels were the most extreme with samples containing up to 4.5 g kg^{-1}. Much lower levels were reported in the Nanyang. In part, this was considered to be due to the large inputs of acid entering the river from acid leaching operations. Acidic conditions increase the solubility of metal ions, and thus, may allow them to migrate further downstream before finally accumulating in the sediment. Lead can occur as a number of different isotopes (different weight atoms). The relative abundance of these may be used to "fingerprint" different sources, as lead from non indigenous sources is likely to contain different isotope ratios than that native to the area. Different ratios were found in the two rivers despite their geographical proximity indicating that at least one of them receives considerable inputs of lead from a different geographic area.

Water from the rivers (sampled 7 months later in April 2006) were compared to that of Guiyu's reservoir (considered a valid indicator of local background concentrations) (Wong *et al* 2007c). Concentrations of a number of metals were found to be significantly elevated in both rivers. Interestingly, and in contrast to the sediment study, most metals were present at greater concentrations in the Nanyang River than in the Lianjiang. Samples collected near to an acid leaching site on the banks of the Nanyang contained significantly elevated silver, beryllium, cadmium, copper and nickel compared with upstream. This indicates how, due to the complex nature of electronic waste, multiple environmental contaminants may be easily released from one stage of recycling. The severe contamination of the Nanyang River was evidenced by the observation that many metal concentrations were greater than in an urban area of the Pearl River Delta.

Sediments from the riverbeds of both the Nanyang and the Liangjiang were found to contain PBDEs (55 -445 ug kg^{-1}dw and 51.3 -365 ug kg^{-1}dw respectively) (Luo et al 2007). Sediments on the banks of the Nanyang, which were covered in e-waste and ash, were extremely contaminated (4434 - 16088 ug kg^{-1}dw) – clearly indicating one source of the contamination. Contamination of the aquatic environment with these brominated compounds is not just limited to the sediment. Fish from the Guiyu rivers (tilapia Oreochromis spp and bighead carp Aristichthys nobilis) were also found to contain PBDEs (Luo et al 2007). The abundance of different congeners within the animals was found to correlate significantly with that of Guiyu's rivers, indicating the environmental source of the contamination. Concentrations of PBDEs in the muscle of Guiyu tilapia was two orders of magnitude greater than that of tilapia collected from a Hong Kong stream containing waste water.

1.2 Humans

A limited number of studies have investigated the levels of contaminants in bodies of e-waste processing workers in Guiyu. By the very nature of their work, these people are exposed regularly to a wide range of toxic substances, in significant amounts, daily. There is also evidence to suggest that residents in the vicinity are also receiving elevated exposures.

1.2.1 Lead in children's blood

Lead is a highly toxic metal with no known useful function in the human body (ATSDR 2003). Of particular concern is the effect of relatively low-level exposure on cognitive and behavioural development in children, including the lowering of IQ (ATSDR 2003). Exposure to lead is commonly measured through levels in blood. Historically, blood lead levels (BLLs) greater than 10 ug dL^{-1} have been considered elevated and potentially harmful. However, it is currently thought that there may be no level of blood-lead that does not produce a toxic effect, particularly in the developing central nervous system (ATSDR 2003, Canfield et al. 2003).

Huo et al (2007) compared the BLLs of children younger than 6 (none occupationally exposed to e-waste) in Guiyu to those of children from neighbouring Chendian, where textiles is the dominant trade and no e-waste processing occurs. In China, the mean BLL of children is 9.29 ug dl^{-1} with 33% having BLLs greater than 10 ug dl^{-1}. By comparison, in Guiyu children had a mean blood lead level of 15.3 ug dl^{-1} with 82 % having BLLs of greater than or equal to 10 ug dl^{-1}. One 5-6 year old had a BLL of 32.67 ug dl^{-1}, greater than three times the national average. The environmental exposure potentially causing the children's elevated lead levels is highlighted by comparing the children within four villages of Guiyu where different e-waste processing operations dominate. The highest mean level was found in Beilin village (19.34 ug dl^{-1}) where the number of workshops specializing in dismantling, circuit board baking and acid bath leaching was greatest. Dutou, where many workshops specialise in plastics sorting and stripping plastic materials from e-waste had the second highest average child BLL (17.86 ug dl^{-1}). 100% of the children in this village had BLLs greater than 10 ug dl^{-1}. Huamei which had e-waste work shops similar to those of Beilin, but fewer and less centralised, had a lower average BLL (14.23 ug dl^{-1}). The lowest BLL (13.13 ug dl^{-1}) was found in the village of Longgang. Here plastic collected from other villages is reprocessed and no e-waste is directly handled. Though slightly elevated, the mean BLL found in neighbouring Chendian (9.94 ug dl^{-1}) was much closer to the national average, indicating how the children of Guiyu are disproportionately exposed to a serious health threat.

1.2.2 Polybrominated Diphenyl Ethers

An investigation into PBDEs (Qu *et al* 2007) compared the levels of these flame retardant derived chemicals in the blood of Guiyu workers to those in the blood of residents living within 50 km of the e-waste workshops and a control group with no known occupational exposure. Concentrations of all congeners studied were significantly higher in the workers group compared to the other two. For example, the concentration of decabromodiphenyl ether in workers' blood was almost 15 times greater than in the control group. It is also notable that this, the most widely used PBDE congener, was the most abundant in all three groups. The concentration in one worker's blood was found to be 3436 ng g^{-1} lipid weight. Outside of Guiyu, the highest reported level worldwide is 270 ng g^{-1} lipid weight, found in a worker occupationally exposed to flame retarded rubber in Sweden (Thuresson *et al* 2005).

A second study (Bi *et al* 2007) compared levels of PBDEs, as well as PCBs and organochlorine pesticides, in the blood of Guiyu residents to those in the blood of residents from nearby Haojiang, where the fishing industry dominates. The mean sum concentration of PBDEs in the blood of Guiyu residents was found to be three times that of the members of the fishing community. Again, exceptional levels of deca-BDE were found in Guiyu (peaking at 3100 ng g^{-1} in one resident). The effect of local factors and occupations on exposure to pollutants was emphasised by the study. Sum concentrations of dichloro-diphenyl-trichloroethane and its derivatives (DDTs) were three times greater in the blood of the fishing community. Fish, known to accumulate DDT residues (ATSDR 2003), are consumed to a far lesser extent in Guiyu.

Part 2 Other areas in China

The scientific literature currently contains very few reports describing the environmental consequences of e-waste recycling elsewhere in China or in other parts of Asia.

2.1 PCBs

Two reports have been published examining the environmental and human effects of PCBs released from a large obsolete transformer and other e-waste disassembly plant in Zhejiang Province (south east China). Luqiao town in the far east of Zhejiang receives transformers and other electronic and electrical waste from all over China for disassembly. Zhao *et al* (2006) found that rivers, paddy soils, rice seeds, hens eggs and fish from the town all contained elevated levels of PCBs. These persistent and bioaccumulative toxins were used as coolants and insulators in transformers and capacitors, as well as additives in plastics, paints and rubbers, until the 1970s - 1980s and are likely to be present in very large quantities in electronic items currently being recycled. The mean total PCB levels (nine congeners) in sediment from a river near the site contained more than twice the Canadian fresh water sediment Predicted Effect Level (PEL). The same PCB congeners dominated contamination in the town's river water, rice grains from fields irrigated with it, and in silver carp muscle suggesting a causal pathway for the pollution of these foods. A calculation of the actual total dietary intake (ADI) for town's people suggested consumption of 1.09 ug kg^{-1} body weight (BW) day^{-1} by a 60 kg adult. This level is reported to be over 50 times that recommended as a maximum by the US Agency for Toxic Substances and Disease Registry, 0.02 ug kg^{-1} bw day^{-1} (ATSDR 2003).

The study also found a correlation between levels of PCBs in maternal cord blood and in meconium (the first faeces passed by a new born baby), indicating potential biotransfer from mother to baby. A follow-on study by the same researchers (Zhao *et al* 2007) examined prenatal exposure to PCBs in the town in more detail. Levels of PCBs in cord blood and meconium from the town were found to be significantly greater than those in two other areas of the same province where no known e-waste industries exist.

2.2 PCDD/Fs

The electronic waste recycling and disposal processes used at Luqiao, especially open air burning and acid leaching, can lead to the generation of PCDD/Fs. Chan et al (2007) investigated the body burden of these highly toxic chemicals in new mothers from Luqiao. Samples of human milk, placenta and hair were collected from the women in the days immediately following delivery. These were analysed alongside a set of reference samples collected from new mothers of a similar age living in Lin'an City, 245 kilometres away. The researchers found that the WHO-TEQ[1] concentration of PCDD/Fs in all three sample types was greater in the population from Luqiao. Levels of PCDD/Fs in human milk were approximately two times greater than in the control population, though the difference was not statistically significant, partially as a result of the very small sample sizes. However, the increased concentrations detected in both hair and placenta samples (6 and 3 times greater respectively) were both statistically significant.

Concentrations of pollutants in different biological media can provide information about possible exposure pathways. Hair has been identified as a suitable bioindicator of short and long-term exposure to dioxins (Schramm *et al* 1992). The profile of dioxins in the hair of Luqiao residents was found to resemble closely that of the hair of municipal solid waste incinerator workers in Japan (Nakao *et al* 2005); suggesting a prominent role for combustion sources in the case of the Luqiao residents also.

The study also assessed the estimated daily intake of dioxins by breast fed babies. The intake by both Luqiao and reference site babies exceeded the WHO tolerable daily intake for adults by at least 25 and 11 times respectively. However, it is important to note that the study only involved 5 sets of samples from each site and so it is not possible to draw any certain population level conclusions from these results.

1 World Health Organisation Toxicity Equivalent 1998 - a toxicity-weighted concentration that expresses the concentration of all dioxins measured as an overall equivalent concentration of the most toxic dioxin, 2,3,7,8-TCDD

Part 3 Conclusion

This report summarises the growing evidence for negative environmental impacts and health concerns arising from dangerous and poorly controlled recycling and disposal of electronic waste in parts of China, with a particular focus on Guiyu, the area subject to most study to date. The studies discussed above describe the widespread contamination of all environmental compartments with pollutants derived, at least in part, from such recycling operations and provide an initial insight into the potential for these to harm the local population. Contamination is widespread and, in some cases, severe. For example, levels of polychlorinated dioxins are among the highest found in ambient air worldwide, whilst, the concentration of one commonly used flame retardant, decabromodiphenyl ether (deca-BDE), in a worker's blood was the highest ever reported.

The findings clearly demonstrate the need for the development and enforcement of effective legislation to protect human health and the environment and to ensure that the recycling sectors in China operate more sustainably. Existing legislation in Europe, including the Directives on Waste Electrical and Electronic Equipment (WEEE) and Restrictions on the use of Hazardous Substances (RoHS), could well provide the model for parallel legislation in China and other nations. However, the presence of chlorinated and brominated dioxins, as well the widespread contamination by deca-BDE, clearly demonstrate the need to remove all brominated flame retardants and other halogenated materials (including PVC) from electronics products in order to begin to tackle the burden of contamination in Guiyu and other areas engaged in similar activities. Therefore, the EU legislation should only be seen as the starting point. Ultimately legislation is required that prevents the use of all hazardous substances in electronics and ensures that producers are responsible for all end of life processing.

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