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Persistent Organic Pollutants (POPs) in the Surroundings of Electronic Waste Recycling Sites in Kalasin Province, Thailand

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Contents

Abbreviations

ABS – acrylonitrile butadiene styrene
ADHD – attention deficit hyperactivity disorder
BAN – Basel Action Network
BDE – bromodiphenyl ether (ex. octaBDE – octabromodiphenyl ether, pentaBDE – pentabromodiphenyl ether)
BEQ – bioanalytical equivalent
BFRs – brominated flame retardants
BMI – body mass index
BTBPE – 1,2-bis(2,4,6-tribromo-fenoxy)ethane
CALUX – chemically activated luciferase gene expression
CFC – chlorofluorocarbon
DBDPE – decabromodiphenyl ethane
DMSO – dimethyl sulfoxide
DP – Dechlorane Plus
DIW – Department of Industrial Works
dl-PCBs – Dioxin-like polychlorinated biphenyls
d.w. – dry weight (dry matter)
EARTH – Ecological Alert and Recovery - Thailand
EFSA – European Food Safety Authority
EU – European Union
e-waste – electronic waste
f.w. – fresh weight
GC – gas chromatography
GC– MS-NCI - gas chromatography coupled with mass spectrometry and negative chemical ionisation
GPC – gel permeation chromatography
HBB – hexabromobenzene
HBCD – hexabromocyclododecane
HCB – hexachlorobenzene
HCBD – hexachlorobutadiene
HIPS – high-impact polystyrene
HRGC-HRMS – high resolution gas chromatography – high resolution mass spectroscopy
IARC – International Agency for Research on Cancer
IQ – intelligence quotient
IPEN – International Pollutants Elimination Network
LCDs – liquid crystal displays; type of flat panel display
LOQ – limit of quantification
nBFRs – novel brominated flame retardants
ndl-PCBs – Non-dioxin-like polychlorinated biphenyls
NGO – non-governmental organization (civil society organization)
NHANES – US National Health and Nutrition Examination Survey
OH–PBDE – hydroxylated polybrominated diphenyl ether, hydroxylated metabolites of polybrominated diphenyl ether;
OBIND – octabromotrimethylfenylindane
PBDD/Fs – polybrominated dibenzo-*p*-dioxins and dibenzofurans
PBDEs – polybrominated diphenyl ethers
PBEB – pentabromoethylbenzene
PBT – pentabromotoluene
PCBs – polychlorinated biphenyls
PCD – Pollution Control Department
PCDD/Fs – polychlorinated dibenzo-*p*-dioxins and dibenzofurans
PCDDs – polychlorinated dibenzo-*p*-dioxins
PCDFs – polychlorinated dibenzofurans
PCNs – polychlorinated naphthalenes
PeCB – pentachlorobenzene
PP – polypropylene
POPs – persistent organic pollutants
PVC – polyvinyl chloride
T3 – triiodothyronine
T4 – thyroxin
TBBPA – tetrabromobisphenol A
TCDD – (2,3,7,8-TCDD) - 2,3,7,8-tetrachlorodibenzodioxin
TEF – toxic equivalency factor(-s)
TEQ – toxic equivalent
THB – Thai Baht
TSH – thyroid stimulating hormone
USD – United States Dollar
VOCs – volatile organic compounds
vs. – versus
WHO – World Health Organization
WHO-TEQ – toxic equivalent defined by WHO experts panel in 2005
XRF – X-ray fluorescence

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Summary

Electronic waste and its imports from abroad represent a big burden for the environment and human health in Thailand. This study is mainly focused on research of community based informal e-waste separation and dismantling operations in the Khok Sa-ad subdistrict, Khong Chai district, Kalasin province in northeastern Thailand, where also a large dumpsite with substantial quantity of waste from electronic equipment and machineries is found. The main goal of sampling was determining the present levels of contamination in the area of interest. This study is focused on persistent organic pollutants (POPs), which are used as additives in electronic equipment and plastic used for its casing, such as, for example, brominated flame retardants (BFRs), Dechlorane Plus (DP) and others. We also focused on POPs produced unintentionally during the production of BFRs, and particularly during incineration and other thermal processes used for the disposal and recycling of plastics from e-waste. The spread of persistent organic pollutants into the environment caused by e-waste recycling was studied by sampling at various stages of the processing pathways of the waste and the POPs burden in local e-waste workers was studied, too.

Two main subcampaigns for taking environmental and food samples were conducted, i.e. at the dumpsite and its surroundings and in the villages (homes and small enterprises currently or formerly involved in e-waste dismantling and sorting, plastic shredding enterprise). The spread of selected and novel POPs caused by informal e-waste recycling into the environment was studied, i.e. the pathways of the waste processed in Khok Sa-ad were followed and sampled. The sampling was designed in order to describe how the processing of e-waste pollutes the whole area and different types of sites (enterprise, workshops, living areas, roads, dump, fields) and foodstuffs by spreading the pollution.

We took 61 samples of environmental matrices and foodstuffs in December 2021 and February 2022. Environmental sampling was focused on soil, sediment, dust, ash and waste. Sampled foodstuffs comprised rice, wild living aquatic animals occasionally gathered and consumed by locals and free-range chicken eggs rarely consumed by locals. A wide range of samples was taken at and nearby a dumpsite near Ban Nong Bua. Also formerly or currently operating small e-waste recycling workshops at workers homes in Ban Nong Ma Tho, Ban Noi, Ban Khok Prasit, Ban Don Kha and Ban Nong Bua villages were sampled as well as the environment at the plastic shredding enterprise in Ban Nong Bua.

Ten reference (background) samples of dust, soil, sediment, fish and snails were taken in a clean area of an organic farm in Ban Na Somboon,

Don Somboon subdistrict, Yang Talat district, Kalasin province. The rice reference sample was obtained at an organic rice farm in Ban Nong Khu village, Nong Pling subdistrict, Mueang district, Maha Sarakham province. A reference sample of chicken eggs was obtained in a supermarket in Maha Sarakham.

The POPs burden[1] in local e-waste workers was studied by taking human blood serum samples from 40 adults employed in e-waste recycling workshops in Ban Nong Ma Tho, Ban Nong Mek, Ban Nong Bua and Ban Noi villages, nearby Wat Pho Si temple in Ban Sa-ad and at the Nong Bua dumpsite. Blood samples were further taken from a control group of 26 adult organic farm workers and agriculturalists from the Ban Na Somboon village (Don Somboon subdistrict, Yang Talat district, Kalasin province) who have never worked in the e-waste processing business or lived in such an area. All blood samples were taken in November 2022.

The results of the analyses of 137 samples in total are evaluated in this study. **A wide presence of most of the studied POPs in the environment of the concerned e-waste recycling area as well as in e-waste workers themselves was confirmed. The found POP contamination of these communities can be linked to waste and e-waste recycling activities due to the following findings:**

- **Levels in the Khok Sa-ad environment and foodstuffs of animal origin are in comparison with reference samples considerably higher for Dechlorane Plus, PCDD/Fs and dl-PCBs, PBDD/Fs, HCB, PeCB, ndl-PCBs and PBDEs. A considerable difference is also found in concentrations of some nBFRs in dust, especially DBDPE.**
- **There is a substantial difference between the concentration of PBDEs and Dechlorane Plus in the blood serum of e-waste workers and the reference group of organic farmers and agriculturalists.**
- **Concentration gradients** of Dechlorane Plus, PBDD/Fs, PCDD/Fs and dl-PCBs, ndl-PCBs, HCB, PeCB, nBFRs and PBDEs were found in sediment and dust, eventually soil samples. The pollution by these substances was the highest at the dumpsite with substantial quantity of waste from electronic equipment and machineries or right next to this dumpsite and decreased with distance from it. Also, concentrations of Dechlorane Plus, PBDD/Fs, HCB, PeCB, TBBPA, nBFRs and PBDEs were generally higher in dust of working areas of households running an e-waste workshop when compared to resting and eating areas of these households.

Ingestion of contaminated dust is considered one of the major pathways for human POP exposure in e-waste recycling areas and elsewhere. Contamination of the local food chain in Khok Sa-ad is indicated by high concentrations of PCDD/Fs and PBDD/Fs in some of the sampled chicken eggs exceeding European legal limits by one order of magnitude. However, these eggs are not primarily intended for human consumption. Therefore, dietary exposure may only partly explain the blood serum Dechlorane Plus and PBDE concentration differences between e-waste workers and the control group.

The one clear danger of the found elevated Dechlorane Plus and PBDE levels in e-waste workers is alteration in thyroid function. Since thyroid hormone regulates human metabolism, anything that interfere with thyroid function increases risk of a variety of symptoms, ranging from altered cognitive function, altered energy levels, weight, and overall health. Hypothyroidism promotes obesity, tiredness, more fatigue, dry skin, and reduced energy while hyperthyroidism has the opposite effects. Since thyroid is a hormone that affects almost every aspect of human physiology, there can be other organ-specific effects.

1 Body burden is the term for the concentration (or amount) of chemical in the body at any given time. The final body burden is the result of absorption, distribution (tissue binding), metabolism, and excretion, the processes that are in dynamic equilibrium in the body.

Based upon the results of the study, recommendations for Kalasin e-waste workers were suggested including medical monitoring and personal protection measures for reducing exposure to contaminated dust and food with POPs. Measures recommended to be adopted at the dumpsite include immediate stop of waste burning. Finally, policy recommendations for POPs were formulated.

The extensive contamination by POPs in the Khok Sa-ad area, Kalasin province, reflects the conundrum of environmental restoration in Thailand. Currently, there is no clear example of successful restoration of POPs contaminated environment in Thailand. The lack of a specific law for environmental restoration and compensation in Thailand's national legal milieu is a big factor in this issue. It further highlights the importance of restoration and restitution for POPs contamination in developing countries within the context of the Stockholm Convention. The Khok Sa-ad site must receive environmental restoration as soon as possible, to protect those people living in the locality and working in e-waste recycling operations.

1. Introduction

Thailand is a destination of electronic waste (e-waste) and produces large volumes of this waste itself. Both official and unregistered e-waste dismantling and recycling facilities are run in Thailand, many of them being small-scale community-based workshops. Mismanagement of e-waste causes environmental pollution and affects human health.

Burning of electronic waste as a major source of dioxins and other unintentionally produced persistent organic pollutants (POPs) is partly covered under the "Smouldering of Copper Cables" category listed in Part III of Annex C to the Stockholm Convention as one of "*source categories that have the potential for comparatively high formation and release of these chemicals to the environment*" (Stockholm Convention 2010). Large quantities of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) can also be released from processes based on waste incineration that occur in e-waste "recycling" facilities as a way of disposing of residual plastics and other e-waste residues. This applies for dioxin-like polychlorinated biphenyls (dl-PCBs), pentachlorobenzene (PeCB) and hexachlorobenzene (HCB) to a certain extent as well. Other POPs, such as, for example, brominated flame retardants (BFRs), are intentionally produced and used as additives in electronic equipment and its plastic casings. Hexabromocyclododecane (HBCD) and polybrominated diphenyl ethers (PBDEs)

Figure 1: *Burning of non-utilizable leftovers from e-waste dismantling at a dumpsite in Thailand. Photo by Thitikorn Boontongmai, EARTH*

were all listed in Annex A of the Stockholm Convention: HBCD in 2013 (Stockholm Convention 2013a), commercial mixtures of Pentabromodiphenyl ether (PentaBDE) and Octabromdiphenyl ether (OctaBDE) in 2009 (Stockholm Convention 2009a, Stockholm Convention 2009b), and Decabromodiphenyl ether (DecaBDE) in 2017 (Stockholm Convention 2017a). Dechlorane Plus (DP) is the latest added flame retardant on the list of chemicals regulated by the Stockholm Convention (Stockholm Convention 2023a). Storage of e-waste and its processing, such as dismantling and shredding, can be a source of these POPs.

We focused on research of community-based official and informal e-waste separation and dismantling operations in the Kalasin province, northeastern Thailand, where a large dumpsite with a substantial quantity of waste from electronic equipment and machineries is found. The main goal of sampling was to comprehensively determine the present levels of contamination in the area of interest. As numerous studies dealing with pollution by heavy metals in Kalasin already exist, Arnika and EARTH focused on POPs contamination. The spread of these pollutants into the environment caused by e-waste recycling was studied by sampling at various stages of the processing pathways of the waste and by sampling selected local foodstuffs. The POPs burden in local e-waste workers was studied, too. Similar sites with small-scale e-waste recycling workshops as sampled in Kalasin, northeastern Thailand can be found in China, other Asian countries, and elsewhere in the world.

Figure 2: *Example of a community-based small-scale e-waste recycling workshop in Thailand, run within a household. Photo by Thitikorn Boontongmai, EARTH*

2. Background information

2.1 The problem of e-waste in Thailand

Since 2010, the volume of e-waste generated globally has been steadily rising. By 2019, approximately 53.6 million metric tons was produced. This was an increase of 44.4 million metric tons in just five years. Of this, only 17.4% was documented to be collected and properly recycled (Tiseo 2022). In Asia, a statistic from 2019 indicates Japan and South Korea as leading countries in domestic e-waste generation. A significant amount is also produced in Thailand (Table 1).

The amount of this type of waste has increased continually in Thailand. The Pollution Control Department under the Ministry of Natural Resources and Environment reported that in 2022, 676,146 metric tons of municipal hazardous waste were produced in Thailand. Most of this was waste from electrical and electronic equipment, making up 439,495 metric tons, or 65 %. Such waste is increasing as a result of the increasing popularity of and the population‘s demand for electronic equipment products. Moreover, rapid changes in technologies mean that electronic products are quickly rotated out of use and become waste. Some imported products are of low quality or not designed for longevity. Examples of prominent waste from electrical and electronic equipment produced domestically

Table 1: *Domestic e-waste generated per country in the Asian region in 2019 (Forti, Balde et al. 2020)*

Country	E-waste generated (kg/capita)
Cambodia	1.1
China	7.2
India	2.4
Indonesia	6.1
Japan	20.4
South Korea	15.8
Lao PDR	2.5
Malaysia	11.1
Thailand	9.2
Vietnam	2.7

in Thailand in 2022 include television sets, air conditioners, refrigerators, computers, washing machines, and mobile phones (PCD 2023).

The current policy of the Thai state places the responsibility of managing e-waste on local administrative organizations. However, according to the Pollution Control Department, only 10 % of all the wastes from electrical and electronic equipment are disposed of and managed in correct ways. Waste collectors from the informal sector may collect the rest to be separated in improper manners. The valuable parts may be sent to recycling factories, while the unusable parts may be dumped or openly burned, causing the spread of pollutants into the environment. Currently, Thailand has no specific law on e-waste management that local authorities can follow, nor are there any laws to ensure responsibility from the private sector (PCD 2023).

According to a report by Roberts-Davis and Saetang (2019), used batteries and scraps of electrical machinery were also exported to Thailand in bulk volumes (recorded under the Harmonized System code "8548.9090") from several countries, including the USA, China, and Japan. In 2014, the USA shipped over 25,560 kg worth 330,000 USD (10.3 million THB), increasing to nearly 11.8 million kg in 2018, worth 3.1 million USD (101.4 million THB). Japan sent 41,380 kg worth 16.4 million USD (533.17 million THB) in 2014, increasing to over 1.64 million kg, valued at 11.6 million USD (377.8 million THB). Meanwhile, China sent nearly 1.4 million kg in 2014, valued at 24.49 million USD (796 million THB), increasing to 1.84 million kg, worth 14.93 million USD (484.3 million THB).

The Basel Action Network extrapolated the export rates to developing countries from all of the 28 member states of the European Union and found a total of 352,474 metric tonnes exported per annum (BAN 2018). In 2017, Europe's 6 % exportation rate was far less than the 40 % rate the Basel Action Network found in the United States, which has no laws forbidding exports. The Basel Action Network also documented how used electronics can get to countries like Thailand. It showed that one of used LCDs tracked from Germany ended up in the Supcharoen Recycle Co. Ltd. factory, Chachoengsao province (BAN 2018). This factory was chosen as one of the hot spots for a recent study by Arnika and EARTH (Petrlik, Jeungsmarn et al. 2022), as it can be a potential source of contamination of the environment with POPs.

In response to the high volume of imports of e-waste and other types of plastic waste, including cases of illegal importation following China's ban on import of certain types of waste, Thai civil society began campaigning for a ban on waste (especially e-waste and plastic waste) imports in 2018. This led to the establishment of a governmental subcommittee on the issue. Eventually, the Thai Ministry of Commerce announced a ban on 428 types of e-waste in 2020. The ban considers e-waste under the statistical code "899" to be banned e-waste. In the context of the ban, the code "899" refers to "Electronic waste under the Basel Convention". The statistics for the import of e-waste, including illicit imports, showed that it was reduced in 2021 and 2022, following the ban (Piachan 2022). However, EARTH's investigation through the Ministry of Commerce's database found continued imports of certain types of e-waste through custom codes not specifically singled out by the 2020 ban. One such code, "8548", saw more than 43 million kg of imports in 2021 and more than 11 million kg of imports between January and March 2022.

Mismanagement of e-waste causes environmental pollution and affects human health. About 150 dismantling and recycling facilities were officially registered with the Department of Industrial Works under the Ministry of Industry (PCD-DIW 2021). However, the number would increase if unregistered facilities were included. This study is focused on small-scale community-based e-waste recycling workshops in the Kalasin province, northeastern Thailand.

2.2 Recycling of e-waste in Kalasin

The sites of interest for this study are located in Khok Sa-ad, a subdistrict of Khong Chai district in the Kalasin province, which is located approximately 400 km northeast of the capital city, Bangkok. Community-based informal e-waste separation and dismantling is a common source of income in local villages.

In 2009 and 2018, EARTH surveyed data on the quantity and type of material and electronic waste entering the 12 villages of Khok Sa-ad. The results of a survey of 228 people who worked in sorting scrap materials is presented in Table 2.

E-waste is being separated from domestic waste imported into Khok Sa-ad, then it is sorted and disassembled. Valued pieces are sold to brokers, while non-valued pieces are disposed of. A small plastic sorting and grinding enterprise is operating in Khok Sa-ad, too (see Figure 3 below).

The dump found in Khok Sa-ad is a large dumpsite with a substantial quantity of waste from electronic equipment and machineries. Burning of plastic and other remains of "recycled" gadgets and household appliances takes place at this dump, despite a ban issued by the Pollution Control Department and the governor of Kalasin in 2018. The dump is surrounded by rice fields. Inhabitants of villages situated within a 2 km radius from the dumpsite complain because of acrid smoke (The Isaan Record 2019).

2.3 Previous sampling

In 2009/2010, EARTH took soil samples at the dumpsite in Khok Sa-ad and found high levels of lead. Sampling conducted by official authorities thereafter confirmed this finding by determining high levels of lead and also other heavy metals in soil and water. During a visit by Arnika in 2019, two samples were taken; samples labeled KAL-A-1 (mixed dust/ash sample taken along the track within the dump) and KAL-D-1 (mixed floor dust sample from a plastic sorting and shredding enterprise located in Ban Nong Bua, a village in the Khok Sa-ad subdistrict). Both samples revealed high concentrations of PBDEs and PBDD/Fs, with KAL-A-1 exhibiting one to two orders of magnitute higher concentrations of PBDD/Fs than KAL-D-1. On the other side, the total PBDEs concentration was one order of magnitude higher in the KAL-D-1 sample when compared to KAL-A-1. Analysis of these samples for PCDD/Fs content was not conducted. These two samples are included in this report. In 2021, EARTH visited the dumpsite and witnessed burning of residues from old TVs and e-waste. The smoke contained very high particulate matter and VOC concentrations, i.e., concentrations at maximum measurable levels as detected by a screening portable measurement device. High levels of heavy metals in soil were measured by XRF (X-ray fluorescence) and a clear difference in concentrations outside and inside of the dumpsite was found.

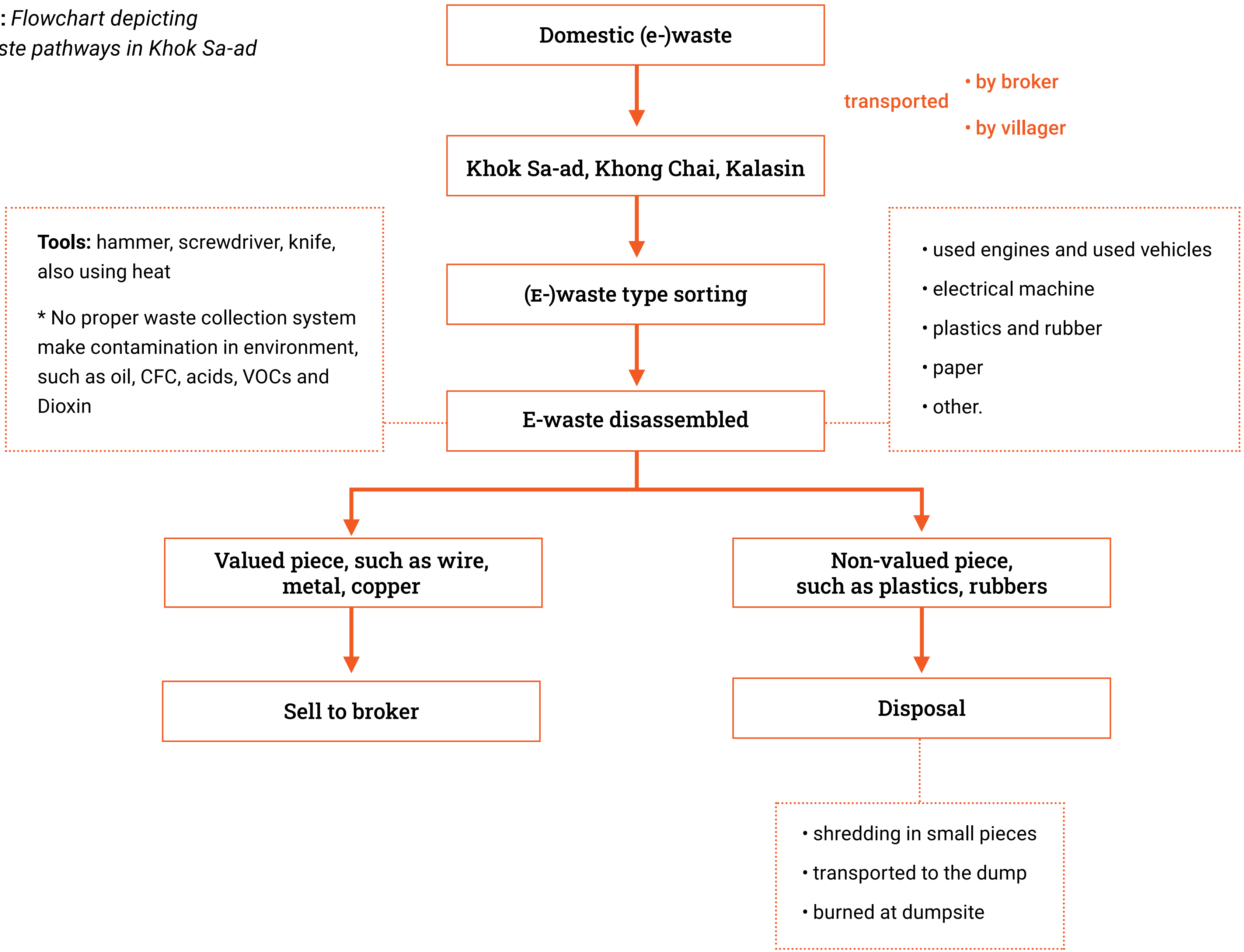
2.4 Related studies

A part of this report was already published on the occasion of the eleventh meeting of the Conference of the Parties to the Stockholm Convention (SC COP-11) in May 2023 as a specialized study on Dechlorane Plus contamination in Khok Sa-ad (Dvorska, Strakova et al. 2023). POPs were also analysed in samples taken by EARTH and Arnika from Thai localities affected by various industrial and waste disposal and recycling activities in a previous project between 2016 – 2019. Thus, results presented in this study can be compared with data summarized in the report "Toxic Hot Spots in Thailand" (Petrlik, Dvorska et al. 2018), and several abstracts

Table 2: *Type and quantity of old products entering Khok Sa-ad subdistrict area per month in 2009 (Saetang, Rojanapraiwong et al. 2009) and 2018 (Siamrathonline 2018)*

Type	List	Year 2009 Volume (Kg / month)	Year 2018 Volume (Kg / month)
1. Motorcycles, cars and parts	Motorcycles	160,880	217,000
	Motorbike machine	3700	
	Motorbike wheel	1000	
	Motorcycle shock	700	
	Motorcycle body	250	
	Motorbike casing	60	
	Motorbike bearings	50	
	Motorbike carburetor	25	
	Car mirror	1000	
	Battery	640	
	Shaft scrap	500	
	Cylinder block	100	
	Car	1 Car	
	Wheel rim	20 Pieces	
	Light plate	70	
	Alternator, starter parts	2500	
	TOTAL	171,475	
2. Electrical and electronic appliances	Fan	22,139	214,000
	Refrigerator	17,722	
	Television	12,330	
	Computer	4168	
	Washing machine	3205	
	Air conditioner	2074	
	Rice cooker	500	
	CD player	50	
	Freezer	1 freezer	
	Power cable	1966	
	TOTAL	64,154	
3. Plastic and rubber	Plastic bottle	100	
	PVC pipe	30	
	Linoleum	11,500	
	Rubber strap	500	
	Car tires	100	
	TOTAL	12,230	
4. Paper 10,220 kg per month	Paper	10,220	
5. Other	Boots	5020	324,000
	Shoe parts	5000	
	CD	140	
	Cotton	40	
	Broken glass bottles	1020	
	Engine oil	100	
	Oil container	30	
	Mixed scrap	4800	
	TOTAL	16,150	

Figure 3: *Flowchart depicting the e-waste pathways in Khok Sa-ad*



presented at international scientific Dioxin conferences (Petrlik, Teebthaisong et al. 2018, Teebthaisong, Petrlik et al. 2018, Teebthaisong, Saetang et al. 2021). A very recent study by Arnika and EARTH (Petrlik, Jeungsmarn et al. 2022) focused on POPs in surroundings of electronic waste recycling sites in Chachoengsao province. There are also a large number of studies looking at POPs levels at sites affected by e-waste dismantling in China (e.g. Zeng, Luo et al. 2016; Zeng, Huang et al. 2018), Vietnam (Anh, Tomioka et al. 2018; Nishimura, Suzuki et al. 2018; Anh, Tomioka et al. 2019) or Indonesia (Petrlik, Ismawati et al. 2020).

Several studies were found dealing with contamination and health problems in Khok Sa-ad; all of them focus on heavy metals. Parts of them study health impacts of informal e-waste recycling by describing workers' exposure to heavy metals. Also, heavy metal accumulation in rice near the dump containing a substantial quantity of waste from electronic equipment and machineries and related human health risks were described, together with the impacts of the released heavy metals on plants and wildlife (Arain, 2019; Neeratanaphan, Khamma et al. 2017; Nuasri, Kudthalang et al. 2019; Phoonaploy, Tengjaroenkul and Neeratanaphan 2019; Phoonaploy, Tengjaroenkul and Neeratanaphan 2020; Saksasitorn 2014; Thanomsangad, Tengjaroenkul et al. 2019; Tanee, Chaveerach et al. 2018; Langeland 2016; Seith, Arain et al. 2019). Three studies focused mainly on health effects in relation to increased levels of heavy metals in urine and blood and found some serious health impacts (Seith, Arain et al. 2019, Neitzel, Sayler et al. 2020, Shkembi, Nambunmee et al. 2021). No study dealing with POPs contamination in Khok Sa-ad was found. Generally, there is less data on PCDD/Fs (especially PBDD/Fs and PBDEs contamination in relation to informal e-waste recycling) in scientific literature as compared to heavy metals.

The free-range chicken egg samples from Khok Sa-ad are important for investigation of potential food chain contamination. The results of their analyses for POPs can be compared with data presented in two global studies recently: one was focused on sites affected by plastic waste management (Petrlik, Bell et al. 2021) and the other summarized PCDD/Fs, dl PCBs and PBDD/Fs levels in poultry eggs collected at various hot spots globally (Petrlik, Bell et al. 2022). Potential food chain contamination was studied also by sampling rice, as the Khok Sa-ad dump is surrounded by rice fields. Obtained data can be compared with studies on POPs concentrations in rice from e-waste areas (Cai, Liang and Song, 2020).

Wild living animals such as certain crab, fish and snail species are occasionally consumed by local people of Khok Sa-ad, too. In scientific studies, several animals such as fish, frogs and snails sampled in e-waste recycling areas have been investigated in regard to the distribution and contamination status of POPs (Cai, Liang and Song, 2020; Liu, Du et al. 2011). Studies exist on PBDEs concentrations in these animals (Anh, Nam et al. 2017; Ilyas, Sudaryanto et al. 2013); however, a scientific literature search did not reveal studies on PBDD/Fs concentrations. It is interesting to note that apple snails were used as bioindicators for spatial distribution of PCBs and PBDEs in e-waste dismantling regions (Fu, Wang et al. 2011; She, Wu et al. 2013).

3. Persistent organic pollutants (POPs)

Persistent organic pollutants (POPs) represent a large group of chemicals that persist for a long time in the environment, bioaccumulate, have potential for long-range environmental transport, and also have adverse effects on human health or the environment (Stockholm Convention 2010). Thirty one individual chemicals or their groups were already listed under the Stockholm Convention in 2019 (Stockholm Convention 2019a,b), and four additional were listed in 2022 (Stockholm Convention 2022) and 2023 (Stockholm Convention 2023a, Stockholm Convention 2023b). This covers some but not all chemicals that have the properties of POPs. Our report focuses on thirteen POPs listed under the Stockholm Convention, on six additional chemicals, and also on one group of chemicals not yet listed under this convention. Their basic characteristics follow. We focused on both intentionally and unintentionally produced POPs.

3.1 Intentionally produced POPs

Intentionally produced POPs considered in our study are mainly technical chemicals and their mixtures used intentionally in electric or electronic equipment or the automotive industry, as well as those used as additives to plastics.

3.1.1 Non-dioxin-like polychlorinated biphenyls (ndl-PCBs)

Polychlorinated biphenyls (PCBs) are a group of 209 different congeners[2] that can be divided into two subgroups according to their toxicological properties. Most of the PCB congeners do not exhibit dioxin-like toxicity and are referred to as non-dioxin-like PCBs (ndl-PCBs, European Commission 2011).

PCBs were produced until 1980s in large volumes and they were used in industry as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics (Stockholm Convention 2019a). There were approximately 1.3 to 2 million metric tonnes of PCBs industrially produced in various countries from 1929 to the 1980s (Breivik, Sweetman et al. 2002; Weber, Herold et al. 2018). Technical mixtures of PCBs are represented by six[3] or sometimes seven[4] indicator PCB congeners. Maximum levels in food are set for six indicator PCB congeners in food in the EU (European Commission 2012, European Commission 2016).

2 Congeners are chemical substances related to each other by origin, structure, or function.

3 PCB 28, PCB 52, PCB 101, PCB 138, PCB 153 and PCB 180

4 PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180

3.1.2 Polychlorinated naphthalenes (PCNs)

Polychlorinated naphthalenes (PCNs) were produced for similar uses as PCBs. PCNs make effective insulating coatings for electrical wires. Others have been used as wood preservatives, as rubber and plastic additives, for capacitor dielectrics and in lubricants. To date, intentional production of PCNs is assumed to have ended (Stockholm Convention 2017b). However, these chemicals are also unintentionally produced during high temperature processes in the presence of chlorine, similarly to PCDD/Fs and dioxin-like PCBs.

PCNs can induce toxic effects typical for dioxin-like compounds, e.g., they have been concluded to be potentially foetotoxic and teratogenic. A number of short- and medium-term tests prove high acute toxicity, i.e., weight loss, liver damage and delayed deaths at relatively low concentrations (~3mg/kg). Evidence for teratogenic effects and endocrine disrupting effects and effects on fertility have been described in rats. Occupational studies have proven negative effects on human health; some of them were also experienced in animal studies (dermal effects, liver disease, death). Some evidence for an association with the excess of specific cancers has been shown (POP RC 2012b).

3.1.3 Dechlorane Plus (DP)

Dechlorane Plus (DP) is a polychlorinated flame retardant that has been in use since the 1960s. It is used in electrical wire and cable coatings, plastic roofing materials, connectors in TV and computer monitors, and as a non-plasticizing flame retardant in polymeric systems, such as nylon and polypropylene plastic. DP is released to the environment during production, processing, and use, as well as from waste disposal and recycling activities. Since the listing of polybrominated diphenyl ethers (PBDEs) under the Stockholm Convention for global elimination, increased production, use, and environmental detection has been seen for DP (Rauert, Schuster et al. 2018). DP is persistent, i.e., it is chemically stable in various environmental compartments with minimal or no abiotic degradation. It is expected to bind to organic carbon in soil and sediments, reducing its bioavailability for microorganisms and hence the potential for biodegradation. Available scientific data show that DP is also bioaccumulative and is transported to locations far from production sites and places of use. Studies show that DP has adverse effects on the environment and that it can be toxic to mammals and humans. Studies have reported effects such as oxidative damage, indications for neurodevelopmental toxicity, and potential for endocrine disruption. The endocrine effects have also been seen in epidemiology studies, where associations between DP and effects on the sex- and thyroid hormone pathways were found (POP RC 2021). DP was listed in Annex A to the Stockholm Convention in 2023 (Stockholm Convention 2023a).

3.1.4 Brominated flame retardants (BFRs)

3.1.4.1 Polybrominated diphenyl ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are a group of brominated flame retardants that include substances listed in the Stockholm Convention for global elimination such as PentaBDE (listed in 2009), OctaBDE (2009) and DecaBDE (2017). PBDEs are additives mixed into plastic polymers that are not chemically bound to the material and therefore leach into the environment. They have already been identified in samples from other localities in Thailand (Petrlik, Kalmykov et al. 2017; Petrlik, Dvorska et al. 2018).

PBDEs have adverse effects on reproductive health as well as developmental and neurotoxic effects (POP RC 2006, POP RC 2007a, POP RC 2014). DecaBDE and/or its degradation products may also act as endocrine disruptors (POP RC 2014).

PentaBDE has been used in polyurethane foam for car and furniture upholstery, and Octa- and DecaBDE have been used mainly in plastic casings for electronics. OctaBDE formed 10%-18% of the weight (Stockholm Convention 2016) of CRT television and computer casings and other office electronics made of acrylonitrile butadiene styrene (ABS) plastic. DecaBDE forms 7%-20% of the weight (POP RC 2014) of many different plastic materials, including high-impact polystyrene (HIPS), polyvinylchloride (PVC), and polypropylene (PP) used in electronic appliances. As this study examines samples from sites affected by the presence of e-waste and/or by its incineration, all of the mentioned PBDEs were part of the main focus of our investigation.

3.1.4.2 Hexabromocyclododecane (HBCD)

Hexabromocyclododecane (HBCD) is a brominated flame retardant primarily used in polystyrene building insulation. HBCD is an additive mixed into plastic polymers that is not chemically bound to the material and therefore may leach into the environment. HBCD is highly toxic to aquatic organisms and has negative effects on reproduction, development and behavior in mammals, including transgenerational effects (POP RC 2010b). HBCD is also found in packaging materials, video cassette recorder housings and electric equipment.

HBCD was listed in Annex A of the Stockholm Convention for global elimination with a five-year specific exemption for use in building insulation that expired for most Parties in 2019 (Stockholm Convention 2013b).

3.1.4.3 Tetrabromobisphenol A (TBBPA)

Tetrabromobisphenol A (TBBPA) is the largest-volume flame retardant used worldwide (Kodavanti and Loganathan 2019), covering around 60% of the total global BFR market (Law, Allchin et al. 2006). While the majority of TBBPA is chemically bonded to the polymer matrix of printed circuit-boards, it is also applied as an additive flame retardant in the manufacture of ABS resins and HIPs as an alternative to PBDEs and HBCD, and to banned OctaBDE mixtures in ABS plastic in particular (POP RC 2008a; Abou-Elwafa Abdallah 2016). The main applications where plastic containing TBBPA may be used include TV-set back-casings and business equipment enclosures (ECHA 2008).

TBBPA is a cytotoxicant, immunotoxicant, and thyroid hormone agonist with the potential to disrupt estrogen signalling in humans (Kitamura, Jinno et al. 2002; Birnbaum and Staskal 2004). Recent studies have identified this chemical as “probably carcinogenic to humans” (Grosse, Loomis et al. 2016; IARC 2020). Human exposure studies have revealed dust ingestion and diet as the major pathways of TBBPA exposure in the general population (Abou-Elwafa Abdallah 2016). However, a more recent study concluded that: *“Studies on exposure routes in humans, a combination of detection methods, adsorbent-based treatments and degradation of TBBPA are in the preliminary phase and have several limitations”* (Miao, Yakubu et al. 2023).

TBBPA is also classified as very toxic to aquatic organisms and is on the OSPAR Commission’s List of Chemicals for Priority Action due to its persistence and toxicity (OSPAR Commission 2011).

There are no current restrictions on the production of TBBPA in the EU or worldwide.

3.1.4.4 Novel brominated flame retardants (nBFRs)

Six novel BFRs (nBFRs) were chosen for analysis in this study: 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE); decabromodiphenyl ethane (DBDPE); hexabromobenzene (HBBz); octabromo-1,3,3-trimethylphenyl-1-indane (OBIND); 2,3,4,5,6-pentabromoethylbenzene (PBEB); and pentabromotoluene (PBT).

Novel BFRs are a group of chemicals that replaced, in many cases, already-restricted BFRs. Different sources list different chemicals among this group, but only some of them are measured in environmental matrices.

Studies have shown that nBFRs have become widespread in the environment, including in food, particularly in some Asian countries (Shi, Zhang et al. 2016). The scientific panel of the EFSA (European Food Safety Authority) suggested that: *"Based on the limited experimental data on environmental behaviour, 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and hexabromobenzene (HBB) were identified as compounds that could raise a concern for bioaccumulation"* (EFSA CONTAM 2012). A more recent review suggests that: *"The toxicity data of nBFRs show that several nBFRs can cause adverse effects through different modes of action, such as hormone disruption, endocrine disruption, genotoxicity, and behavioral modification"* (Xiong, Yan et al. 2019). HBBz, PBEB and PBT were found to show bioaccumulation potential in aquatic species from a natural pond in south China (Wu, Guan et al. 2011; Xiong, Yan et al. 2019).

Decabromodiphenyl ethane (DBDPE) was introduced in the early 1990s as an alternative to DecaBDE in plastic and textile applications (Ricklund, Kierkegaard et al. 2010). It was used mainly in wire coatings and polystyrene, in both cases as a replacement for DecaBDE. This widespread contaminant is a highly hydrophobic compound (Covaci, Harrad et al. 2011).

The novel brominated flame retardant 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE) was first produced in the 1970s and is used as a replacement for OctaBDEs (Hoh, Zhu et al. 2005). It has the ability to bioaccumulate and to biomagnify in aquatic food webs (Law, Halldorson et al. 2006; Wu, Guan et al. 2011). Similar to DecaBDE, the commercial mixture of BTBPE was found to contain brominated dioxins (PBDD/Fs) and/or to support their formation during treatment of ABS plastic (Tlustos, Fernandes et al. 2010; Ren, Zeng et al. 2017; Zhan, Zhang et al. 2019).

HBBz has commonly been used for the manufacture of paper, woods, textiles, plastics and electronic goods (Yamaguchi, Kawano et al. 1988; Watanabe and Sakai 2003).

PBEB is a flame retardant that was used mainly in the 1970s and 1980s under the name FR-105. It was used in polymers and has been poorly characterized toxicologically, but the substance is a brominated analogue of ethyl benzene, a carcinogen (de Wit, Kierkegaard et al. 2010; Straková, DiGangi et al. 2018).

PBT is used in polystyrene casings for electronics, ABS plastics and other plastic polymers, and sold under the name FR-105 or Flammex (de Wit, Kierkegaard et al. 2010; Straková, DiGangi et al. 2018). Studies confirmed histologic changes on laboratory rats (Chu, Villeneuve et al. 1987).

OBIND is another replacement for PBDEs that is used in different plastics in electronic products (Straková, DiGangi et al. 2018). There is little information available on OBIND. It has previously been manufactured as FR-1808 (de Wit, Kierkegaard et al. 2010).

3.2 Unintentionally produced POPs

There is a large group of POPs that were not produced intentionally and added to any products, but they occur as unintentional by-products at any phase of production of chemicals or disposal (including incineration) of waste containing halogenated compounds. These POPs are listed in Annex C to the Stockholm Convention (Stockholm Convention 2010). We have also added polybrominated dioxins (PBDD/Fs) to our study, which are not listed in Annex C yet.

3.2.1 Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs)

Dioxins belong to a group of 75 polychlorinated dibenzo-*p*-dioxin (PCDD) congeners and 135 polychlorinated dibenzofuran (PCDF) congeners, of which 17 are of toxicological concern. Levels of PCDD/Fs and dl-PCBs are often expressed in total toxic equivalents (TEQ[5]), calculated according to toxic equivalency factors (TEFs) set by a WHO expert panel in 2005 (van den Berg, Birnbaum et al. 2006).

Polychlorinated dioxins and furans (PCDD/Fs) are known to be extremely toxic. Numerous epidemiologic studies have revealed a variety of human health effects linked to chlorinated dioxin exposure, including cardiovascular disease, diabetes, cancer, porphyria, endometriosis, early menopause, alteration of testosterone and thyroid hormones, and altered immune system response, among others (White and Birnbaum 2009; Schecter 2012). Laboratory animals given dioxins suffered a variety of effects, including an increase in birth defects and stillbirths. Fish exposed to these substances died shortly after the exposure ended. Food (particularly from animals) is the major source of exposure for humans (BRS 2017).

3.2.2 Dioxin-like polychlorinated biphenyls (dl-PCBs)

Out of 209 congeners, twelve PCB congeners are considered as dioxin-like PCBs (dl-PCBs) for their effects and similar properties to PCDD/Fs (van den Berg, Birnbaum et al. 2006; European Commission 2012). They are suggested to be a part of the total TEQ levels (van den Berg, Birnbaum et al. 2006), and this study includes their levels into total PCDD/Fs + dl-PCBs TEQ concentrations.

5 The “Toxic Equivalent” (TEQ) scheme weighs the toxicity of the less toxic compounds as fractions of the toxicity of the most toxic TCDD (2,3,7,8-tetrachlordibenzodioxin). Each compound is attributed a specific “Toxic Equivalency Factor” (TEF).

3.2.3 Polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/Fs)

With the broad use of BFRs, the question has arisen about the presence of polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/Fs) in the food chain, as they are found in different environmental compartments (Kannan, Liao et al. 2012). The WHO expert panel has concluded that PBDD/Fs and some dioxin-like polybrominated biphenyls (dl-PBBs) may contribute significantly to daily human background exposure to the total dioxin toxic equivalencies (TEQs) (van den Berg, Denison et al. 2013).

PBDD/Fs have been known to be potential byproducts of commercial PBDE mixtures since 1986 (Buser 1986). They were also found to be byproducts of some nBFRs like DBDPE (Brenner and Knies 1990) or BTBPE (Ren, Zeng et al. 2017; Zhan, Zhang et al. 2019). This is similar to PCDD/Fs that have been observed as impurities in PCBs and other chlorinated chemicals. PBDFs have also been found to be formed by sunlight exposure during normal use, as well as during disposal/recycling processes of flame-retarded consumer products (Kajiwara, Noma et al. 2008). PBDD/Fs were also found around an open burning site (Gullett, Wyrzykowska et al. 2010). PBDD/Fs are similar to the PCDD/Fs; however, they have been studied less extensively than their chlorinated analogues.

PBDD/Fs have been found to exhibit similar toxicity and health effects as their chlorinated analogues (PCDD/Fs) (Mason, Denomme et al. 1987; Behnisch, Hosoe et al. 2003; Birnbaum, Staskal et al. 2003; Kannan, Liao et al. 2012; Piskorska-Pliszczyńska and Maszewski 2014). They can, for example, affect brain development, damage the immune system and fetus, or induce carcinogenesis (Kannan, Liao et al. 2012). *“Both groups of compounds show similar effects, such as induction of aryl hydrocarbon hydroxylase (AHH)/EROD activity, and toxicity, such as induction of wasting syndrome, thymic atrophy, and liver toxicity”* (Behnisch, Hosoe et al. 2003).

Despite this, PBDD/Fs are less regulated than PCDD/Fs, and are not currently listed under the Stockholm Convention (Stockholm Convention 2010), although PCDD/Fs have been listed in Annex C of the Convention since its origin in 2001. In 2010, the Stockholm Convention POPs Review Committee recommended further assessment of PBDD/Fs (POP RC 2010a).

3.2.4 Hexachlorobenzene (HCB), pentachlorobenzene (PeCB), hexachlorobutadiene (HCBD)

Pentachlorobenzene (PeCB) and hexachlorobenzene (HCB) are primarily produced unintentionally during combustion, as well as during thermal and industrial processes. They also occur as a byproduct during the production of various chlorinated hydrocarbons or pesticides. In the past, they were produced intentionally as pesticides or technical substances. PeCB was used as a component in PCB products, in dyestuff carriers, as a fungicide, as a flame retardant and as a chemical intermediate for the production of the pesticide quintozene (POP RC 2008b).

In high doses, HCB is lethal to some animals and, at lower levels, adversely affects their reproductive success. Researchers also found out that HCB, similar to other organochlorinated compounds, has a transplacental transfer (Sala, Ribas-Fitó et al. 2001). Reed, Büchner et al. (2007) found that, in addition to cancer, the human health effects associated with HCB exposure encompass systemic impairment (thyroid, liver, bone, skin), and damage to the kidneys and blood cells, as well as the immune and endocrine systems. It also causes a teratogenic effect, and impairs nervous systems.

PeCB is moderately toxic to humans, very toxic to aquatic organisms, and may cause long-term adverse effects in the aquatic environment (POP RC 2007b).

Hexachlorobutadiene (HCBD) occurs as a byproduct during the production of the same chlorinated hydrocarbons as PeCB and HCB. It is also formed unintentionally during incineration processes of substances such as acetylene and chlorine. HCBD is very toxic to aquatic organisms, and has been shown to cause kidney damage and cancer in animal studies as well as chromosomal aberrations in occupationally exposed humans (Pohl, McClure et al. 2001; POP RC 2012a; Balmer, Hung et al. 2019).

HCBD is toxic after repeated and chronic exposure at low exposure levels (i.e., 0.2 mg/kg). The target organ of toxicity is the kidney; biotransformation to reactive compounds leads to organ toxicity, genotoxicity and carcinogenicity after lifelong dietary exposure conditions (POP RC 2012a).

4. Sampling and analytical methods

4.1 Sampling concept

The spread of persistent organic pollutants into the environment caused by e-waste recycling was studied by sampling at various stages of the processing pathways of the waste, and by sampling selected local foodstuffs. The POPs burden in local e-waste workers was studied, too. In the following chapters, the sampling concept is explained in more detail.

4.1.1 Environmental and food samples

One of the goals of the study was to comprehensively determine the present levels of contamination in the area of interest. Two main sampling subcampaigns for environmental and food samples were planned, i.e., at the dumpsite and its surroundings and in the villages (homes and small enterprises currently or formerly involved in e-waste dismantling and sorting operations, and a plastic shredding plant).

The spread of selected POPs caused by e-waste recycling into the environment was studied, i.e., the pathways of the waste processed in Khok Sa-ad subdistrict, Khong Chai district, Kalasin province (see Figure 3) were followed and sampled:

- The waste is (or was being) dismantled in small workshops at workers‘ homes or close by in Ban Nong Ma Tho, Ban Noi, Ban Khok Prasit, Ban Don Kha and Ban Nong Bua villages. Workers are mostly members of the same village/community as the workshop owner. Dust and chicken egg samples were taken.
- The plastic is sorted and ground down in small enterprises in Ban Nong Bua and Ban Don Kha. Dust, soil, waste and chicken egg samples were taken.
- Non-utilizable leftovers are transported to the dump near Ban Nong Bua and burnt there. Soil, sediment, dust, fish, snail, crab and rice samples were taken at the dump and its surroundings.
- Ash from the dumpsite is being brought back to a workshop and processed (ash sample).

The sampling was designed to describe how the processing of e-waste pollutes the whole area and different types of sites (enterprise, workshops, living areas, roads, dump, fields) and foodstuffs by spreading the pollution.

We took 61 samples of environmental matrices and foodstuffs in December 2021 and February 2022. Environmental sampling was focused on

Figure 4: *Sampling of dust. Photo by Jindrich Petrlik, Arnika*

soil, sediment, dust, ash and waste. Sampled foodstuffs were comprised of rice, wild living aquatic animals occasionally gathered and consumed by locals, and free-range chicken eggs rarely consumed by locals. No water was sampled, as the transportation of water samples is complicated. No passive air sampling was conducted due to unavailability of suitable (guarded) sites.

Ten reference (background) samples of dust, soil, sediment, fish and snails were taken in a clean area of an organic farm in Ban Na Somboon, Don Somboon subdistrict, Yang Talat district, Kalasin province. The rice reference sample was obtained at an organic rice farm in Ban Nong Khu village, Nong Pling subdistrict, Mueang district, Maha Sarakham province. A reference sample of chicken eggs was obtained in a supermarket in Maha Sarakham in February 2022.

Figure 5: *Example of sampled aquatic animal. Photo by Jindrich Petrlik, Arnika*

Figure 6: *Blood sampling. Photo by Prakaikan Phanphet, EARTH*

4.1.2 Blood samples

The POPs burden in local e-waste workers was studied by taking human blood serum samples from 40 adults between 45 and 64 years old, both men and women (25 and 15, respectively), employed in e-waste recycling in workshops in Ban Nong Ma Tho, Ban Nong Mek, Ban Nong Bua and Ban Noi villages, nearby Wat Pho Si temple in Ban Sa-ad and at the Nong Bua dumpsite. It should be noted that the environment and food samples were only partly paired with human blood samples, i.e., for organizational reasons mostly different workshops were chosen for environmental/food and blood sampling. Blood samples were further taken from a control group of 26 adult organic farm workers and agriculturalists from the Ban Na Somboon village (Don Somboon subdistrict, Yang Talat district, Kalasin province) between 46 and 68 years old, both men and women (7 and 19, respectively), who have never worked in the e-waste processing business or lived in such an area. All blood samples were taken in November 2022.

4.2 Sampling methods

4.2.1 Environmental and food samples

Almost all environmental and food samples were collected as pooled samples composed of multiple individual samples. Pooled samples of soil and sediments were composed of five point-samples; the specification for each sample is given in Table 3. Soil was taken at a depth of 1 to 10 cm from the surface with a stainless-steel shovel. Sediment samples were taken at a depth between 10 and 35 cm from the surface with a core device. Samples of soil and sediment were homogenised in a stainless-steel bowl. Quartering was conducted in case a pooled sample was too large.

Dust samples were collected using brushes, always in several stripes on a surface area of a few m^2, depending on the individual circumstances at the specific sampled site. Individual stripes are considered here as individual samples of dust. The number of individual dust samples is specified in Table 3. A dust field blank was collected by collecting ammonium sulfite powder (as a surrogate for dust) from a clean aluminum foil surface (Watkins, McClean et al. 2011), using the same method as when collecting regular dust samples.

The sampling equipment was cleaned with distilled water and technical alcohol (shovel and bowl), flushed with water from the sampled sediment spot, cleaned and dried with paper towels, and finally cleaned with distilled water (core sampling device) or used for one composite sample only (brushes). Brushes were checked for potential total bromine or chlorine content with a handheld XRF before they were used for sampling. None of them contained any brominated or chlorinated compounds, according to the results. Only brushes with wooden handles were used.

Sediment samples were transported in 250-ml PE plastic containers, and soil and dust samples were transported to the laboratory in PE plastic ziplock bags. All samples were kept in cool conditions during storage and transportation.

Shredded plastic pieces (waste samples) were sampled by gloved hands from a container with this product or by directly drawing off from the container into PE plastic ziplock bags that were also used for transportation of these samples. The composite ash sample was also transported in a PE plastic ziplock bag.

Eggs were collected into typical plastic egg packaging and were boiled for approximately seven minutes. The homogenates from the edible parts of the eggs were used for the analyses in the laboratories. The numbers of individual eggs in the pooled samples are specified in Table 3 and ranged from two to five eggs in each pooled sample. Fish, snails and crabs were caught using local fishing gear and the species was determined together with each animal´s size, weight and age. The number of individual animals in pooled samples is up to fifteen and is specified in Table 3. Muscle tissue (filets) with skin attached was dissected from the caught fish. These animal samples were placed in double PE plastic ziplock bags, and stored frozen and cooled during transportation. Later in the laboratory, soft tissue was dissected from the apple snails and crabs.

The Ban Nong Bua rice sample was collected by a local resident. The reference rice sample (rice grains with shells) was taken from a barn and previously harvested by a local farmer. Rice samples were transported in PE plastic ziplock bags.

A brief overview of the environmental and food samples is given in Table 3.

4.2.2 Blood samples

From each volunteer, 3 times approximately 9 ml of blood was collected into VACUETTE ® CAT Seru Clot Activator Tubes by medical professionals in a local hospital. The serum was isolated from the blood by centrifugation at 5000 rpm for 10 minutes and kept in a temperature below -20 °C in a hospital laboratory. Subsequently, the serum samples cooled with dry ice (approximate temperature -78 °C) were transported to the Czech Republic for chemical analysis. All participants signed an informed consent form (see Annex A) before participating in the study. The blood sampling was approved by the Institutional Review Board of the Ethic Committee for Human Research, Kalasin Provincial Public Health Office (Khong Chai Hospital) (see Annex B). A detailed questionnaire was completed for each participant covering age, gender, weight, height, lifestyle, health and working patterns (Annex C). Blood donors have been informed about the outcomes of the study and their individual POPs blood serum concentrations by a letter (Annex D).

4.3 Analytical methods

Seventy-one environmental and food samples, one field blank sample and sixty-six blood samples were analysed for this study. Three HBCD isomers[6,7], 16 PBDE congeners[8], six nBFRs[9] and TBBPA were analysed in

6 An isomer is each of two or more compounds with the same formula but a different arrangement of atoms in the molecule and different properties.

7 α-, β- and γ-HBCD

8 PBDE 28, 47, 49, 66, 85, 99, 100, 153, 154, 183, 196, 197, 203, 206, 207 and 209

9 BTBPE, DBDPE, HBBz, OBIND, PBEB and PBT.

Table 3: *Overview of environmental and food samples taken in December 2021 and February 2022.*

Locality	Sample ID	Matrix	Sampling date	No./dimension of individual samples in a pooled sample
Ban Nong Ma Tho workshops	KLD-12	dust	10 Feb/2022	lines in 0.5 m distance on areas of 2x2m + 2.5x2m
	KLD-13	dust	10 Feb/2022	lines in 0.5 m distance on area of 3x1.5 and 1x4.5 m
	KLD-18	dust	10 Feb/2022	3x3 m
	KLD-19	dust	10 Feb/2022	1.5 x 6 m
	KLD-20	dust	10 Feb/2022	1.5 x 6 m
	KLD-21	dust	10 Feb/2022	3x3 m
	KLD-22	dust	10 Feb/2022	3x2 + 1x1 + 2x1 m
	KLD-23	dust	10 Feb/2022	dusty area
	KL-EGG-03/22	chicken egg	7 Feb/2022	3
Ban Noi workshop	KLD-16	dust	10 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KLD-17	dust	10 Feb/2022	lines in 0.5 m distance on areas of 1x4m + 2.5x2m
Ban Khok Prasit workshop	KLD-14	dust	10 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KLD-15	dust	10 Feb/2022	1x4.5 m + 3x1.5 m areas, composite sample
Ban Don Kha workshops	KLD-10	dust	9 Feb/2022	lines in 0.5 m distance on area of 9x1 m
	KLD-11	dust	9 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KL-EGG-04/22	chicken egg	9 Feb/2022	5
	KL-W02	waste[1]	9 Feb/2022	several pieces of shredded plastic
Ban Nong Bua workshop	KL-EGG-01/22	chicken egg	7 Feb/2022	4
	KL-ASH-01	Ash	7 Feb/2022	several point samples
	KL-EGG-02/21	chicken egg	15 Dec/2021	2
	KL-EGG-02/22	chicken egg	7 Feb/2022	4
	KL-EGG-03/21	chicken egg	15 Dec/2021	3
Ban Nong Bua shredding enterprise	KLS-10	soil	9 Feb/2022	5
	KLS-09	soil	9 Feb/2022	5
	KAL-D-1	dust	6 Nov/2019	15
	KLD-06	dust	9 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KLD-07	dust	9 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KLD-08	dust	9 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KL-W01	waste[2]	9 Feb/2022	several pieces of shredded plastic
	KL-D-08/EGG	chicken egg	9 Feb/2022	3

Locality	Sample ID	Matrix	Sampling date	No./dimension of individual samples in a pooled sample
Ban Nong Bua dumpsite	KLS-07	soil	8 Feb/2022	5
	KLS-01	soil	8 Feb/2022	5
	KLS-02	soil	8 Feb/2022	5
	KLS-04	soil	8 Feb/2022	5
	KLS-05	soil	8 Feb/2022	5
	KLS-06	soil	8 Feb/2022	5
	KLS-08	soil	8 Feb/2022	5
	KL-S03	soil	8 Feb/2022	5
	KAL-A-1	ash	6 Nov/2019	25
	KLD-03	dust	8 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KLD-02	dust	8 Feb/2022	lines in 0.5 m distance on area of 1x9 m
	KLD-01	dust	8 Feb/2022	lines in 0.5 m distance on area of 1.5x6 m
	KLD-04	dust	8 Feb/2022	lines in 0.5 m distance on area of 3x2 m
	KLD-05	dust	8 Feb/2022	lines in 0.5 m distance on area of 3x3 m
	KL-SED02	sediment	8 Feb/2022	5
	KL-SED01	sediment	8 Feb/2022	5
	KL01-Shell	snail[3]	15 Dec/2021	4
	KL02-Shell	snail[3]	15 Dec/2021	2
	KL03-Shell	snail[3]	15 Dec/2021	7
	KL-SNAIL-DUMPSITE	snail[3]	8 Feb/2022	15
	KL02-crab	crab[4]	15 Dec/2021	1
	KL06-crab	crab[4]	15 Dec/2021	3
	KL08-crab	crab[4]	15 Dec/2021	4
	KL01-Fish-1	fish[5]	15 Dec/2021	1
	KL01-Fish-2	fish[6]	15 Dec/2021	1
	KL04-Fish-1	fish[5]	15 Dec/2021	1
	KL04-Fish-2-7,9-10	fish[7]	15 Dec/2021	8
	KL-06-FISH/1	fish[6]	9 Feb/2022	1
	KL-06-FISH/2-3	fish[5]	9 Feb/2022	2
	KL-07-FISH-1-2	fish[7]	9 Feb/2022	2
	KL-RICE	rice	15 Dec/2021	grains
Ban Na Somboon (reference)	NS-S-01	soil	11 Feb/2022	5
	NSD-01	dust	11 Feb/2022	Composite sample of 3x3 m area
	NSD-02	dust	11 Feb/2022	Composite sample of 1.5x6 m area
	NS-SED-01	sediment	11 Feb/2022	5
	NS-fish/1-4	fish[5]	11 Feb/2022	4
	NS-FISH/5-7	fish[8]	11 Feb/2022	3
	NS-FISH/8	fish[8]	11 Feb/2022	1
	NS-SNAIL/1-2	snail[3]	11 Feb/2022	12
Maha Sarakham (reference)	TH-REF-EGG 2022	chicken eggs	11 Feb/2022	5
	TH-REF-RICE	rice	11 Feb/2022	grains

[1] Green plastic

[2] Refrigerator insulation

[3] Apple snail (*Pomacea* sp.)

[4] Thai rice field crab (*Esanthelphusa* sp.)

[5] Climbing perch, climbing gourami (*Anabas testudineus*)

[6] Broadhead catfish (*Clarias macrocephalus*)

[7] Nile tilapia (*Oreochromis niloticus*)

[8] Catfish (*Clarias gariepinus*)

all samples. DP[10] was analysed in all but three samples. Selected samples of various matrices were analysed also for seven indicator PCB congeners, HCBD, 13 PCN congeners[11], PeCB, HCB, PCDD/Fs, PBDD/Fs and dl-PCBs. Additionally, selected food samples (eggs, rice and fish) and two dust samples were analysed by the DR CALUX® bioassay.

Brominated flame retardants (PBDEs, nBFRs) and DP were isolated from the samples by Soxhlet extraction followed by gel permeation chromatography (GPC) cleanup. The analysis was performed using gas chromatography coupled with mass spectrometry and negative chemical ionisation (GC-MS-NCI). HBCD isomers and TBBPA were isolated by acetonitrile and analysis was conducted by ultra high performance liquid chromatography coupled with tandem mass spectrometry with electrospray ionisation in negative mode (UHPLC-ESI-MS/MS). Selected PCB congeners, HCBD, PeCB, HCB, and PCNs were isolated from the samples by Soxhlet extraction followed by GPC cleanup. Analysis was conducted by gas chromatography coupled with tandem mass spectrometry and electron ionisation (GC-MS/MS-EI). All these analyses were conducted by the ISO/IEC 17025:2018 accredited Metrological and Testing Laboratory (University of Chemistry and Technology, Prague, Czech Republic).

The DR CALUX bioassay was conducted by the commercial laboratory of BioDetection Systems, Amsterdam, The Netherlands. For the sum parameter PCDD/Fs (separated TEQ), the method used is extraction with organic solvents; the extracts are cleaned on an acid silica column and separation is done with a florisil column. The cleaned extracts are dissolved in dimethyl sulfoxide (DMSO). The DR CALUX activity is determined (24h exposure) and benchmarked against 2,3,7,8-TCDD. The DR CALUX analysis is done according to the p-bds-051 in-house method. For the sum parameter dl-PCBs (separated TEQ), the sequence of operations is the same; however, separation is done with an alumina column.

For the method DR CALUX and the sum parameter PCDD/Fs expressed as bioanalytical equivalents (BEQ[12]; semi) and sum parameter PCDD/Fs and dl-PCBs (BEQ; semi), the method used is shake extraction with organic solvents (hexane); the extracts are cleaned on an acid silica column. The cleaned extracts are dissolved in DMSO. The DR CALUX activity is determined (24h exposure). The response of the sample is corrected for the background and subsequently corrected for the apparent bioassay recovery with a reference sample at the level of interest. The evaluation is done on the maximum levels for PCDD/Fs and for the sum of PCDD/Fs and dl-PCBs, from which cut off values have been established (2/3 of maximum levels). After the evaluation, an estimation is given of the samples in the form of BEQ outcomes. The DR CALUX analysis is done according to p-bds-051 in-house method and is accredited to ISO/IEC 17025. The analysis results comply with EU requirements as indicated in Commission Regulation (EU) 2017/644 of 5 April 2017, laying down methods of sampling and analysis for the control of levels of dioxins, dioxin-like PCBs and non-dioxin-like PCBs in certain foodstuffs. Maximum levels are established according to Commission Regulation (EU) 2015/704 of 30 April 2015.

Analyses of samples for their content of individual PCDD/Fs, dl-PCBs and PBDD/Fs was conducted by the experienced commercial MAS laboratory (Münster, Germany), whose testing methods are ISO/IEC 17025:2018 accredited. The basic steps of the analyses of soil, sediment, dust, ash and rice samples can be summarised as follows:

10 *syn-* and *anti-*DP

11 PCN 4, 9, 18, 20, 41, 42, 52, 56, 66, 70, 73, 74 and 75.

12 A bioanalytical equivalent (BEQ) is a unit of measure in the field of bioassays.

- homogenization and eventual drying of sample material
- addition of $^{13}C_{12}$-labelled PCDD/F and PCB internal standards to an aliquot of the sample material
- Soxhlet extraction with toluene/acetone (9:1/V:V)
- addition of $^{13}C_{12}$-labelled PBDD/F standards to the raw extract
- multi-step chromatographic cleanup of the extract aliquot under the separation of PHDD/Fs and PCBs
- addition of $^{13}C_{12}$-labelled PCDD/F and PBDD/F recovery standards to the PHDD/F fraction and of $^{13}C_{12}$-labelled PCB recovery standards to the PCB fraction
- separate HRGC/HRMS analyses for PCDD/Fs, PBDD/Fs and dl-PCBs
- quantification via the labelled internal standards (isotope dilution technique and internal standard technique)[13]

For the analysis of fish, egg and snail samples, drying was done using anhydrous sodium sulfate and Soxhlet extraction was conducted with toluene only. Because for three HexaBDF- and one HeptaBDF congener neither native nor isotope labelled standards are commercially available so far, the assignment of the peak signals of these congeners was accomplished by relative retention time comparison with the corresponding PCDFs. For this reason, results on these congeners have to be considered tentative.

All the analyses results are summarised in Tables 4-17. The field blank sample was analysed for the content of PeCB, HCB, HCBD, HBCD, PBDEs, nBFRs, DP, TBBPA, PCBs and PCNs. All concentrations were below the laboratory limit of quantification.

13 The ash sample KAL-A-1 was analysed for the content of PCDD/Fs and dl-PCBs by the State Veterinary Institute in Prague, Czech Republic. This laboratory is also ISO/IEC 17025:2018 accredited. Extraction was conducted with toluene/methanol (2/1) + MQ (pH<2).

5. Description of sampled localities and results of the analyses

5.1 Environmental and food samples

Isomer/congener sum values and PBDD/Fs, PCDD/Fs and dl-PCBs TEQs were calculated by using the value of half of the laboratory limit of quantification (LOQ)[14] for not quantified analytes. According to our knowledge, no generally accepted TE-factors have been established so far for PBDD/Fs. For this reason, as a first approach, TEQ-values for the PBDD/Fs were calculated by using the TEF-values specified for PCDD/Fs by the WHO in 2005. Accordingly, PBDD/Fs TEQ-values presented in this chapter have to be considered as tentative.

Due to the lower volatility of the PBDD/Fs, compared to the PCDD/Fs, the chemical analysis of the brominated compounds was less sensitive than that of PCDD/Fs analogues. Furthermore, higher fat amounts are usually taken for PCDD/Fs analysis than were available. This is why the LOQs for the PBDD/Fs were comparatively high.

14 LOQ stands for the smallest amount or the lowest concentration of a substance that is possible to be determined by means of a given analytical procedure with the established accuracy, precision, and uncertainty.

5.1.1 Workshops

The inspected workshops are located in several villages of the Khok Sa-ad subdistrict. In the visited premises, workers wore basic personal protection equipment (gloves, face cloth).

5.1.1.1 Ban Nong Ma Tho

Ban Nong Ma Tho is a village located about 1 km to the south from the Ban Nong Bua dumpsite. Four workshops were sampled in this village, i.e., workshop 1, workshop 2, workshop 4 and workshop 5.

Workshop 1 opened in 2000. Its main activities consist of waste collection, sorting, dismantling and collecting worthless residuals, with dismantling and separating copper and aluminum from e-waste being the dominating activities. The local family has lived in the workshop for their lifetime. The workshop operates 12 months a year with the intensity of operation depending on the amount of e-waste available. It is a large workshop with lots of old electronics (microwaves, refrigerators, fans etc.) being stored. The e-waste is disassembled mechanically right in the yard of the workshop. There is no insulation layer, and there are small pieces of plastic and metal on the ground. The kitchen is located 10 m from the workshop facility. The local family raises tamarind and mango trees for consumption and chickens for

Figure 7: *Example of a workshop specialised in separation of metals. Photo by © Karnt Thassanaphak, EARTH*

Figure 8: *Manual separation of metals from e-waste. Photo by © Karnt Thassanaphak, EARTH*

cock fights. Chicken are fed with purchased local feed. Neither chicken meat nor eggs are consumed. Straw is sometimes burnt outside of the household. Dust samples at this workshop were taken in the living area (KL-D20) and dismantling area (KL-D21). Eggs were sampled, too (KL-EGG-03/22).

Workshop 2 is a former e-waste workshop closed 10 years ago. Its yard is clean with no plastic or other waste. It is located right next to workshop 1. The main activities of workshop 2 were collection, sorting and dismantling of waste. Workshop 2 has two kitchens (inside and outside), and the outside kitchen is located close to the former workshop. Open burning of municipal waste, including plastic, takes place 2-3 times per month in the neighbourhood. Waste was burnt more often in the past when the workshop was operating. Dust samples at this workshop were taken in the living area (KL-D19) and former workshop area (KL-D18).

Workshop 4 was opened in 2016. The workshop has a banner indicating that it has been named “the model e-waste separation shop that is environmentally friendly” by the regional environmental office and the Pollution Control Department.There is a concrete insulation layer on which the e-waste is disassembled. Workshop 4 operates 12 months a year and focuses on collecting, sorting and dismantling of car engines, televisions and other e-waste. Collection of worthless residuals and temporary disposal of residual material also occurs in the workshop. One of the jobs performed in workshop 4 is separating lead, copper and aluminum from the e-waste with a hammer. Fireplaces for occasional wood burning exist, but no open burning of waste was witnessed at the site. The indoor kitchen of the household is situated 5 m from the workshop. Chickens are raised in the household and freely roam in the workshop. Chicken meat is consumed rarely by the workshop owners; eggs and meat are usually given to neighbours. Dust samples at this

Table 4: *Summarised results of the analyses of the samples from the Ban Nong Ma Tho workshops (dust and chicken eggs). The results are in ng/g of dry matter for dust and in ng/g of fat for eggs for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g of dry matter for dust and pg TEQ/g fat for eggs.*

Locality	Ban Nong Ma Tho workshops								
Sample ID	KL-D12	KL-D13	KL-D18	KL-D19	KL-D20[1]	KL-D21[2]	KL-D22	KL-D23	KL-EGG-03/22[3]
Matrix	Dust	Dust	Dust	Dust	Dust	Dust	Dust	Dust	Eggs
Fat content (%)	/	/	/	/	/	/	/	/	14.0
PCDD/Fs	/	/	/	5.32	1.82	11.9	/	/	40.6
dl-PCBs	/	/	/	0.773	<0.41	1.58	/	/	12.0
Total PCDD/Fs + dl-PCBs	/	/	/	6.09	2.03	13.48	/	/	52.6
PBDD/Fs	/	/	/	11.7	28.3	129	10.3	41.3	30.4
HCBD	/	/	/	/	/	/	/	/	<0.10
HCB	0.146	0.053	0.043	0.054	0.057	0.401	0.057	0.112	4.0
PeCB	0.165	0.066	0.078	0.087	0.041	0.340	0.060	0.105	2.72
6 iPCB	0.993	1.66	4.27	1.31	0.490	4.22	0.453	0.676	3.07
7 iPCB	1.003	1.68	4.43	1.39	0.524	4.58	0.516	0.743	3.61
13 PCN cong.	/	/	/	/	/	/	/	/	<0.20
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	9.60
PBDE 209	4827	825	39.50	17.10	86.3	662.0	80.6	836.5	65.4
sum PBDEs	5040	884	50.20	26.49	103.1	737.5	92.8	918.3	108
BTBPE	147	40.3	1.491	3.21	5.27	22.8	4.19	90.1	<0.30
DBDPE	6116	766	43.0	41.3	78.6	469	110	842	74.682
HBBz	1242	320	1.38	0.428	6.85	27.6	1.89	20.2	1.37
OBIND	46.6	21.1	<0.10	5.32	<0.10	<0.10	<0.10	<0.10	<1.5
PBEB	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.20
PBT	5.19	2.06	0.036	0.037	0.614	0.921	0.074	2.52	0.266
sum of nBFRs	7557	1149	45.9	50.3	91.3	521	116	954	77.3
sum DP	108	9.69	3.88	0.793	12.2	37.5	3.90	63.5	5.81
TBBPA	12.0	2.90	<1.5	<1.5	<1.5	2.23	1.61	22.8	<4.2

[1]For this sample, the CALUX *in vitro* cell bio-assay was conducted, too. The results are 12 and 43 pg TEQ/g for dl-PCBs and PCDD/Fs, respectively.

[2]For this sample, the CALUX *in vitro* cell bio-assay was conducted, too. The results are 39 and 130 pg TEQ/g for dl-PCBs and PCDD/Fs, respectively.

[3]For this sample, the CALUX *in vitro* cell bio-assay was conducted, too. The results are 240 and 330 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Figure 9: *Example of an eating and resting part of a household located right next to the workshop area. Photo by Jindrich Petrlik, Arnika*

workshop were taken on the concrete flooring in the resting part of house (KL-D13) and on the concrete floor of the workshop, a roofed working area (KL-D12). In the resting part of the household, drinking water is available and an open fireplace for cooking is nearby. Sample KL-D12 was a mix of dust with a few plastic parts.

Workshop 5 is focusing on the separation of small metal particles from e-waste. There are lots of piles in the backyard with e-waste bags waiting to be separated, and small plastic particles lay on the ground. The kitchen is located inside the house, and poultry is raised in the household or backyard. Chilli, mango, papaya and lemongrass are grown in the garden and consumed. Dust samples at this workshop were taken in the living area (KL-D22) and dismantling area (KL-D23).

The results of the analyses of the samples described above are summarised in Table 4.

5.1.1.2 Ban Noi

Ban Noi is located about 5 km south of the Ban Nong Bua dumpsite. There was one workshop sampled here, workshop 11_02. This workshop is a small one and focuses on the separation and sorting of metals from motor engines and small household appliances (TVs, fans, etc.). Workshop 11_02 operates 12 months a year. Dust samples at this site were taken in the eating and resting area of the workshop with a concrete floor (KL-D17) and in the roofed dismantling area (KL-D16). The dust samples had a weak oil smell. There were oil spills on the workshop flooring, and the floor was also fully covered by metal gear. The results of the analyses of these samples are summarised in Table 5.

5.1.1.3 Ban Khok Prasit

Ban Khok Prasit is located about 5 km south of the Ban Nong Bua dumpsite. There was one workshop sampled here, workshop 7, which started its

Table 5: *Summarised results of the analyses of the dust samples from the Ban Noi workshop. The results are in ng/g of dry matter.*

Locality	Ban Noi workshop	
Sample ID	KL-D16	KL-D17
Matrix	Dust	Dust
PCDD/Fs	/	/
dl-PCBs	/	/
Total PCDD/Fs + dl-PCBs	/	/
PBDD/Fs	/	/
HCBD	/	/
HCB	1.46	0.081
PeCB	0.295	0.070
6 iPCB	2.34	4.78
7 iPCB	2.44	5.96
13 PCN cong.	/	/
sum HBCD	<0.75	<0.75
PBDE 209	99.1	159.3
sum PBDEs	114.8	178.1
BTBPE	7.007	3.641
DBDPE	204	191
HBBz	79.5	2.39
OBIND	<0.10	<0.10
PBEB	<0.01	<0.01
PBT	0.109	0.049
sum of nBFRs	291	197
sum DP	10.8	7.08
TBBPA	<1.5	<1.5

Figure 10: *Example of a workshop disassembling motorcycles and machinery with motors. Photo by Jindrich Petrlik, Arnika*

operation 10 years ago. It is quite a big workshop focused on disassembling motors and other parts of cars, motorcycles and machinery with motors (fridges, fans, boilers). One of the jobs in workshop 7 is separating rare metals with a hammer. Parts of the ground are contaminated, most likely by machine oil. The outdoor kitchen, with an open fireplace, is located within the workshop at its end. Most of the food is kept enclosed in the fridge or cabinet. Chickens from a neighbouring household have free access to the workshop, and their meat is consumed 5-6 times per month. Vegetables are grown 10 m from the workshop. Dust samples in this workshop were taken in the kitchen and roofed resting part (KL-D15) and in the dismantling area, particularly in the middle of the waste storage area (KL-D14, contaminated by plastic pieces, oily smell). Both samples were taken at compacted soil floors.

The results of the analyses of these samples are summarised in Table 6.

Table 6: *Summarised results of the analyses of the dust samples from the Ban Khok Prasit workshop. The results are in ng/g of dry matter.*

Locality	Ban Khok Prasit workshop	
Sample ID	KL-D14	KL-D15
Matrix	Dust	Dust
PCDD/Fs	/	/
dl-PCBs	/	/
Total PCDD/Fs + dl-PCBs	/	/
PBDD/Fs	/	/
HCBD	/	/
HCB	0.115	0.127
PeCB	0.128	0.144
6 iPCB	23.9	10.5
7 iPCB	24.8	10.5
13 PCN cong.	/	/
sum HBCD	<0.75	<0.75
PBDE 209	1372	242.6
sum PBDEs	4317	281.0
BTBPE	172	18.42
DBDPE	673	326
HBBz	24.4	14.9
OBIND	10.0	<0.10
PBEB	<0.01	<0.01
PBT	0.302	0.240
sum of nBFRs	880	359
sum DP	12.6	10.9
TBBPA	2.08	<1.5

5.1.1.4 Ban Don Kha

Ban Don Kha is located about 6 km south of the Ban Nong Bua dumpsite. There were two e-waste recycling workshops sampled here, workshops 9 and 10.

In workshop 9 small electronic appliances are disassembled. Plastic parts are isolated, e.g., by knife, screwdriver and drill, then separated by color and shredded. Workshop 9 operates 12 months per year. The kitchen is located 10 m from the workshop, and food is covered. The workshop is surrounded by poultry yards and vegetable gardens. A composite chicken egg sample (KL-EGG-04/22) was taken at this workshop. The chicken are fed with purchased grains. Eggs are not consumed, while meat is consumed very rarely (1-2 chickens in 2-3 months).

Workshop 10 is quite new and has been operating only for 2 years. It is also focused on disassembling small electronic appliances in order to separate the plastic parts by color and shred them. It is also in operation the whole year. The kitchen is located 30 m from the workshop, and food is being covered only partly. Corn, papaya and vegetables are grown outside the fence of this workshop. The dust sample KL-D11 was taken at the entrance road to the workshop.

Workshop 10 owns plastic shredding machines where separated plastic from e-waste is being sorted and shredded. The working area is surrounded by walls. This workshop is smaller than the plastic shredding enterprise in Ban Nong Bua. KL-D10 is a sample of surface dust from inside this workshop taken close to the shredder. KL-W-02 is a sample of shredded green plastic pieces.

The results of the analyses of the samples described above are summarised in Table 7.

Table 7: *Summarised results of the analyses of the samples from the Ban Don Kha workshops (dust, waste and chicken eggs). The results are in ng/g of dry matter for dust, in ng/g for waste and in ng/g of fat for eggs for all pollutants except PBDD/Fs, where the results are in pg TEQ/g of dry matter for dust.*

Locality	Ban Don Kha workshops			
Sample ID	KL-D10	KL-D11	KL-EGG-04/22[1]	KL-W-02
Matrix	Dust	Dust	Eggs	Waste
Fat content (%)	/	/	17.9	/
PCDD/Fs	/	/	/	/
dl-PCBs	/	/	/	/
Total PCDD/Fs + dl-PCBs	/	/	/	/
PBDD/Fs	116	3.62	/	/
HCBD	/	/	<0.10	/
HCB	0.042	0.038	1.15	/
PeCB	0.045	0.036	1.15	/
6 iPCB	0.718	0.417	0.921	/
7 iPCB	0.803	0.427	1.09	/
13 PCN cong.	/	/	<0.20	/
sum HBCD	<0.75	<0.75	59.8	<0.5
PBDE 209	2226	23.1	150	52.4
sum PBDEs	2397	28.6	222	56.7
BTBPE	70.8	6.30	103	5.28
DBDPE	849	26.6	<3.3	<5.0
HBBz	15.9	0.074	<0.20	<0.5
OBIND	40.2	<0.10	<1.5	<1.0
PBEB	<0.01	<0.01	<0.20	<0.5
PBT	0.299	<0.01	<0.20	<0.5
sum of nBFRs	976	33.0	105	9.03
sum DP	8.14	0.288	0.965	<0.01
TBBPA	39.1	3.14	<4.2	1.10

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 6.8 and 12 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Figure 11: *Chicken roaming in an e-waste recycling workshop. Photo by © Karnt Thassanaphak, EARTH*

5.1.1.5 Ban Nong Bua

The Ban Nong Bua village is located about 2 km east of the Ban Nong Bua dumpsite. There was one workshop sampled here, workshop 13, and a household currently without a workshop.

Workshop 13 is a small workshop specialized in the separation of metals from motors, cables and other items. Various e-waste, motorcycles and other goods are dismantled using hammers, knives and other tools. Cables are collected, sorted and burnt at the Ban Nong Bua dumpsite in order to isolate copper. The ash is being brought to workshop 13, dried (sample KL-ASH-01) and searched for metals. Workshop 13 operates 12 months per year. The outdoor kitchen is located right next to the workshop, and food is being partly covered. Free-range chicken fed with purchased grains have access to the workshop and burnt leftovers (egg sample KL-EGG-01/22); however, their meat and eggs are not consumed.

Table 8: *Summarised results of the analyses of the samples from the Ban Nong Bua workshop and household (ash and chicken eggs). The results are in ng/g of dry matter for ash and in ng/g of fat for eggs for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g of dry matter for ash and pg TEQ/g fat for eggs.*

Locality	Ban Nong Bua workshop and household				
Sample ID	KL-EGG-01/22[1]	KL-EGG-02/21	KL-EGG-02/22[2]	KL-EGG-03/21	KL-ASH-01
Matrix	Eggs	Eggs	Eggs	Eggs	Ash
Fat content (%)	14.2	10.8	15.1	12.1	/
PCDD/Fs	59.5	1.93	3.21	3.95	/
dl-PCBs	16.0	0.996	1.11	2.07	/
Total PCDD/Fs + dl-PCBs	75.5	2.93	4.32	6.02	/
PBDD/Fs	81.3	2.10	2.54	1.35	165
HCBD	<0.10	<0.10	<0.10	<0.10	0.034
HCB	6.05	1.17	0.99	1.32	18.6
PeCB	5.39	0.472	0.641	0.623	32.4
6 iPCB	15.0	0.887	1.02	0.793	2.59
7 iPCB	17.6	0.937	1.07	0.843	2.92
13 PCN cong.	1.41	<0.20	<0.20	<0.20	1.79
sum HBCD	15.1	<4.2	<4.2	<4.2	<0.75
PBDE 209	97.3	39.1	3.40	1.97	5.76
sum of PBDEs	184	46.8	6.50	5.07	14.1
BTBPE	<0.30	<0.30	<0.30	<0.30	<0.01
DBDPE	<3.3	<3.3	<3.3	<3.3	<10.0
HBBz	<0.20	<0.20	<0.20	<0.20	5.63
OBIND	<1.5	<1.5	<1.5	<1.5	<0.10
PBEB	<0.20	<0.20	<0.20	<0.20	<0.01
PBT	<0.20	<0.20	<0.20	<0.20	0.321
sum of nBFRs	<3.3	<3.3	<3.3	<3.3	11.01
sum DP	7.16	12.64	<0.30	<0.30	1.73
TBBPA	<4.2	<4.2	<4.2	<4.2	<1.5

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 250 and 450 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

[2]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 7.7 and 12 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Figure 12: *Plastic shredding enterprise. Photo by Jindrich Petrlik, Arnika*

Egg sample KL-EGG-02/21 was taken from a household nearby workshop 13. This household doesn´t run a recycling workshop. The free-range chickens are raised in the backyard, fed with paddy and don´t have access to workshop 13. Egg samples KL-EGG-03/21 a KL-EGG-02/22 were taken from a household that used to have an e-waste recycling workshop in the past. The free-range chickens are raised in the backyard and are fed with bought paddy. The eggs are not consumed.

The results of the analyses of these samples are summarised in Table 8.

5.1.2 Shredding enterprise

A plastic shredding enterprise is located at the southern end of the Ban Nong Bua village next to the road to the Ban Sa-ad village. Plastic is sorted and ground down in this enterprise. The enterprise is an open space without walls, covered by a roof and with a concrete floor. It operates a grinder. A small workshop is located right next to the enterprise. It is a small husbandry where a small pile of e-waste (TVs and pieces of other appliances) was noted.

The soil sample KL-S09 was taken at the storage area in front of the enterprise (close to dust sample KL-D07), while soil sample KL-S10 was taken in the nearby dried rice field approximately 30 m from the enterprise and belonging to the small workshop. Roaming buffaloes and chicken were witnessed at this field. The dust sample KL-D06 was taken inside the shredding enterprise, while dust samples KL-D07 and KL-D08 were taken at the entrance of the enterprise and dusty road outside of the enterprise, respectively. It is important to note that the enterprise was cleaned from dust before the Arnika and EARTH teams arrived, thus the only place with more dust in the middle of the enterprise concrete floor had to be chosen for the dust sample KL-D06. However, a floor dust sample from within the shredding enterprise was taken already in 2019 (KAL-D-1). Additionally, a sample of shredded refrigerator insulation pieces (KL-W-01) was taken at the spot of dust sample KL-D06. The chicken egg sample KL-D-08/EGG was taken at the small workshop at the spot of dust sample KL-D08. The results of the analyses of these samples are summarised in Table 9.

5.1.3 Dumpsite

The dumpsite with a substantial quantity of waste from electronic equipment and machineries is located in a rural landscape of rice fields approximately 2 km northwest of the Ban Nong Bua village and can be accessed

Table 9: *Summarised results of the analyses of the samples from the Ban Nong Bua shredding enterprise and workshop (dust, soil, plastic waste and chicken eggs). The results are in ng/g of dry matter for dust and soil, in ng/g for waste and in ng/g of fat for eggs for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g of dry matter for dust and pg TEQ/g fat for eggs.*

Locality	Ban Nong Bua shredding enterprise and workshop							
Sample ID	KL-S09	KL-S10	KL-D06	KL-D07	KL-D08	KAL-D-1	KL-W-01	KL-D-08/EGG[1]
Matrix	Soil	Soil	Dust	Dust	Dust	Dust	Waste	Eggs
Fat content (%)	/	/	/	/	/	/	/	13.8
PCDD/Fs	/	/	2.28	<0.634	1.47	/	/	1.62
dl-PCBs	/	/	0.415	<0.410	0.415	/	/	0.187
Total PCDD/Fs + dl-PCBs	/	/	2.70	<1.04	1.89	/	/	1.81
PBDD/Fs	/	/	149	<2.99	121	426	/	3.74
HCBD	/	/	/	/	/	<0.02	/	<0.10
HCB	/	/	0.209	0.027	0.079	0.165	/	2.72
PeCB	/	/	0.291	0.034	0.113	0.267	/	1.92
6 iPCB	/	/	0.896	0.213	0.907	3.923	/	2.60
7 iPCB	/	/	1.014	0.223	0.974	5.353	/	3.04
13 PCN cong.	/	/	/	/	/	/	/	<0.20
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.75	25.32	<0.5	<4.2
PBDE 209	787.7	32.3	4788	<5.0	4772	31,563	26.5	159
sum PBDEs	897.8	41.7	5061	3.25	5027	32,357	30.8	214
BTBPE	303	1.98	100	<0.01	88.5	195	607	13.10
DBDPE	158	<10.0	5105	<10.0	1557	10,882	<5.0	<3.3
HBBz	3.55	<0.01	27.1	<0.01	5.96	27.3	<0.5	<0.20
OBIND	<0.10	<0.10	68.1	<0.10	<0.10	32.8	<1.0	<1.5
PBEB	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.5	<0.20
PBT	<0.01	<0.01	0.392	<0.01	0.256	2.47	<0.5	<0.20
sum of nBFRs	465	7.05	5301	<10.0	1652	11,140	610	15.8
sum DP	4.91	0.119	21.3	<0.01	19.2	/	<0.01	0.736
TBBPA	56.3	2.63	48.5	<1.5	69.7	2041	17.6	<4.2

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are <0.4 (below LOQ) and 4.8 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Table 10: *Summarised results of the analyses of the soil samples from the Ban Nong Bua dumpsite locality. The results are in ng/g of dry matter.*

Locality	Ban Nong Bua dumpsite							
Sample ID	KL-S01	KL-S02	KL-S03	KL-S04	KL-S05	KL-S06	KL-S07	KL-S08
Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
PCDD/Fs	/	/	/	/	/	/	/	/
dl-PCBs	/	/	/	/	/	/	/	/
Total PCDD/Fs + dl-PCBs	/	/	/	/	/	/	/	/
PBDD/Fs	/	/	/	/	/	/	/	/
HCBD	/	/	/	/	/	/	/	/
HCB	/	/	/	/	/	/	/	/
PeCB	/	/	/	/	/	/	/	/
6 iPCB	/	/	/	/	/	/	/	/
7 iPCB	/	/	/	/	/	/	/	/
13 PCN cong.	/	/	/	/	/	/	/	/
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
PBDE 209	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
sum PBDEs	3.18	7.66	<5.0	<5.0	<5.0	5.94	<5.0	<5.0
BTBPE	<0.01	<0.01	<0.01	<0.01	<0.01	0.604	<0.01	<0.01
DBDPE	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
HBBz	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
OBIND	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	27.5	<0.10
PBEB	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PBT	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
sum of nBFRs	<10.0	<10.0	<10.0	<10.0	<10.0	5.67	32.5	<10.0
sum DP	0.084	0.754	/	<0.01	<0.01	1.32	<0.01	<0.01
TBBPA	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5

by road. It is surrounded by concrete walls; however, there are holes in these walls. Dumped plastic, foam, electronics, wires and other waste is regularly being burnt at the site, thus smoldering is a common issue. As a result, the dumpsite contains also large amounts of ash. There are water ponds both inside and outside the dump. The dumpsite is freely accessible for people as well as animals.

Soil was sampled on a sunny day without clouds on residual rice fields surrounding the dumpsite. The gradient sampling of soil consisted of taking two samples in each major direction (north, east, west, south) from the dump. The closer samples (KL-S02, KL-S04, KL-S06, KL-S08) were taken next to the dumpsite wall (less than 50 m distance). The farther samples (KL-S01, KL-S03, KL-S05, KL-S07) were taken approximately 300 m from the dump. Results of the analyses of these samples are summarized in Table 10.

The dust gradient sampling consisted of taking five samples on roads at various distances from the dumpsite and within the dumpsite itself. Sample KL-D01 was taken on the road between the Ban Nong Bua and Ban Non Tum villages. The sampling spot was chosen at the junction with a minor road branching off 250 m from the dumpsite. Sample KL-D02 was taken at this minor road 120 m from the dumpsite. Sample KL-D03 was taken at the entrance to the dumpsite. Samples KL-D04 and KL-D05 were taken on the trail within the dumpsite and thus consisted of dark grey dust, with sample KL-D04 also partly consisting of ash. A similar mixed sample of ash and dust (KAL-A-1) was taken along the trail within the dumpsite in 2019. Sediment sampling covered both the water pond within the dumpsite containing waste and ash residues (KL-SED-01), and the eutrophicated pond in between the dump wall and nearby rice field containing plastic waste, including fridge insulations (KL-SED-02, close to samples KL-S02 and KL-D02). Results of the analyses of these samples are summarized in Table 11.

Figure 13: *Dumpsite surrounded by rice fields.*
Photo by © Karnt Thassanaphak, EARTH

The apple snail samples KL-SNAIL-DUMPSITE and KL01-SHELL were taken at the same spot as the sediment sample KL-SED-02 in the eutrophicated pond in between the dump wall and nearby rice field (see above). Snail samples KL02-SHELL and KL03-SHELL were taken in other ponds approximately 10 m outside the dump. Crab samples were taken in various distances (17 - 170 m) south from the dump in water ponds or flooded puddles in the nearby rice fields. A sample of rice meant for sale was taken in a field 200 m south of the dumpsite entrance. Results of the analyses of these samples are summarized in Table 12.

Table 11: *Summarised results of the analyses of the dust, ash and sediment samples from the Ban Nong Bua dumpsite. The results are in ng/g of dry matter for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g of dry matter.*

Locality	Ban Nong Bua dumpsite							
Sample ID	KL-D01	KL-D02	KL-D03	KL-D04	KL-D05	KAL-A-1	KL-SED-01	KL-SED-02
Matrix	Dust	Dust	Dust	Dust	Dust	Ash	Sediment	Sediment
PCDD/Fs	36.2	215	395	681	404	691	2467	21.6
dl-PCBs	5.83	21.4	307	79.7	44.2	67	309	3.12
Total PCDD/Fs + dl-PCBs	42.0	236	702	761	448	758	2776	24.7
PBDD/Fs	64.6	936	1165	16,898	2508	17,458	1862	5.80
HCBD	<0.02	/	/	/	/	0.026	0.064	<0.02
HCB	<0.02	1.84	7.19	19.2	4.43	5.45	19.4	0.236
PeCB	1.140	3.38	11.8	29.7	8.78	10.9	34.2	0.401
6 iPCB	26.4	62.2	2007	53.8	69.4	42.86	82.8	0.165
7 iPCB	28.3	63.6	2181	56.5	70.2	44.59	95.9	0.204
13 PCN cong.	0.193	/	/	/	/	/	2.535	<0.02
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
PBDE 209	97.38	169.2	526.4	2460	422.6	2483	162.8	<5.0
sum PBDEs	196.8	290.5	733.4	4067	617.0	3304	293.8	3.69
BTBPE	2.74	23.7	48.6	943	27.0	559	14.1	<0.01
DBDPE	122	207	321	1746	1010	123	62.7	<10.0
HBBz	0.675	4.54	6.61	69.2	7.26	62.3	53.03	0.140
OBIND	<0.10	23.8	50.2	385	51.8	116	21.8	<0.10
PBEB	<0.01	<0.01	0.133	0.524	<0.01	<0.01	0.116	<0.01
PBT	0.071	0.232	0.741	4.35	0.790	2.44	0.508	<0.01
sum of nBFRs	126	259	428	3148	1097	863	152	5.21
sum DP	1.30	5.77	9.54	52.3	14.9	/	15.4	0.243
TBBPA	4.50	<1.5	140	7.17	42.8	834	1.67	<1.5

Table 12: *Summarised results of the analyses of various foodstuff samples from the Ban Nong Bua dumpsite. The results are in ng/g for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g.*

Locality	Ban Nong Bua dumpsite							
Sample ID	KL-SNAIL-DUMPSITE	KL01-SHELL	KL02-SHELL	KL03-SHELL	KL02-CRAB	KL06-CRAB	KL08-CRAB	KL-RICE[1]
Matrix	Snails	Snails	Snails	Snails	Crabs	Crabs	Crabs	Rice
Fat content (%)	0.5	0.5	0.5	0.7	4.7	15.7	22.8	/
PCDD/Fs	8.63	/	/	/	/	/	/	0.077
dl-PCBs	1.78	/	/	/	/	/	/	<0.082
Total PCDD/Fs + dl-PCBs	10.41	/	/	/	/	/	/	0.118
PBDD/Fs	1.71	/	/	/	/	/	/	<1.22
HCBD	/	/	/	/	/	/	/	<0.02
HCB	0.872	/	/	/	/	/	/	<0.02
PeCB	0.545	/	/	/	/	/	/	<0.02
6 iPCB	0.437	/	/	/	/	/	/	0.077
7 iPCB	0.478	/	/	/	/	/	/	0.087
13 PCN cong.	/	/	/	/	/	/	/	<0.02
sum HBCD	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.75
PBDE 209	0.101	<0.05	<0.05	0.383	<0.05	<0.05	<0.05	<5.0
sum of PBDEs	0.444	0.479	0.881	0.820	3.35	1.59	3.03	<5.0
BTBPE	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
DBDPE	<0.1	<0.1	<0.1	1.559	<0.1	<0.1	<0.1	<10.0
HBBz	0.008	0.011	0.020	0.007	<0.005	0.008	<0.005	<0.01
OBIND	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10
PBEB	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01
PBT	<0.005	<0.005	0.027	0.008	<0.005	0.114	0.013	<0.01
sum of nBFRs	0.093	0.096	0.130	1.61	<0.1	0.205	0.098	<10.0
sum DP	0.033	0.020	<0.003	0.005	<0.003	<0.003	<0.003	<0.01
TBBPA	0.635	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<1.5

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 0.14 and 0.37 pg BEQ/g for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Table 13: *Summarised results of the analyses of the fish samples from the Ban Nong Bua dumpsite. The results are in ng/g for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g.*

Locality	Ban Nong Bua dumpsite						
Sample ID	KL-06-FISH-1	KL-06-FISH-2-3	KL-01-FISH-1	KL-01-FISH-2	KL-04-FISH-1	KL-04-FISH-2-7, 9-10[1]	KL-07-FISH/1-2
Matrix	Fish	Fish	Fish	Fish	Fish	Fish	Fish
Fat content (%)	4.7	6.2	10.1	6.0	7.8	4.6	2.5
PCDD/Fs	/	/	/	0.157	/	2.09	3.42
dl-PCBs	/	/	/	<0.082	/	3.75	3.73
Total PCDD/Fs + dl-PCBs	/	/	/	0.198	/	5.84	7.15
PBDD/Fs	/	/	/	<1.22	/	<1.22	<1.22
HCBD	/	/	/	/	/	<0.005	/
HCB	/	/	/	/	/	1.04	2.13
PeCB	/	/	/	/	/	1.12	1.82
6 iPCB	/	/	/	/	/	5.75	/
7 iPCB	/	/	/	/	/	6.48	/
13 PCN cong.	/	/	/	/	/	0.089	/
sum HBCD	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PBDE 209	<0.05	<0.05	1.53	<0.05	0.155	0.154	0.328
sum of PBDEs	2.24	1.54	3.07	0.133	0.762	6.20	3.37
BTBPE	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
DBDPE	9.202	52.0	6.703	4.990	10.8	1.137	5.678
HBBz	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
OBIND	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PBEB	0.034	<0.005	<0.005	<0.005	<0.005	0.040	0.017
PBT	0.082	0.108	0.076	0.042	0.027	<0.005	<0.005
sum of nBFRs	9.35	52.1	6.81	5.07	10.9	1.21	5.73
sum DP	0.013	0.029	0.019	<0.003	0.008	0.080	0.101
TBBPA	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 3.7 and 7.3 pg BEQ/g f.w. for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Fish samples KL-06-FISH-1, KL-06-FISH-2-3, KL-01-FISH-1 and KL-01-FISH-2 were taken at the same eutrophicated pond in between the dump wall and nearby rice field as the sediment sample KL-SED-02 and snail samples KL-SNAIL-DUMPSITE and KL01-SHELL (see above). Fish samples KL-04-FISH-1, KL-04-FISH-2-7,9-10 and KL-07-FISH/1-2 were taken in water ponds inside the dumpsite. Results of the analyses of these samples are summarized in Table 13.

People working and also partly living at the dumpsite donated blood samples.

5.1.4 Reference sites

The organic farm used as a reference (background) site is located approximately 15 km to the north of the Ban Nong Bua dumpsite in the Ban Na Somboon village, Don Somboon subdistrict, Yang Talat district, Kalasin province, in northeastern Thailand. The organic farm raises buffalo, cows, and chicken, as well as a number of crops. The sample of dust labelled NSD-02 comes from the road located near the open space living area (kitchen and dining space), while the dust sample NSD-01 was taken from the living area itself. The soil sample was taken in a meadow near housing for buffaloes on the organic farm. It was a composite sample from five point-samples in a square 3x3 metres. A composite sample of sediment from five individual samples taken with a core tube device was taken in a small backyard pond on the organic farm. Fish and snails were caught in the same pond.

The results of the analyses of these reference samples are summarised in Table 14.

Figure 14: *Organic farm. Photo by Jindrich Petrlík, Arnika*

The rice reference sample was obtained at an organic rice farm in Ban Nong Khu village, Nong Pling subdistrict, Mueang district, Maha Sarakham province. A reference sample of industrially produced chicken eggs was obtained in a supermarket in Maha Sarakham in February 2022. The results of the analyses of these reference samples are summarised in Table 15.

Table 14: *Summarised results of the analyses of the reference samples from the Ban Na Somboon organic farm (dust, soil, sediment, fish and snail). The results are in ng/g of dry matter for dust, soil, and sediment and in ng/g for fish and snails for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g of dry matter for dust, soil and sediment and pg TEQ/g for fish and snails.*

Locality	Ban Na Somboon reference site							
Sample ID	NSD-01	NSD-02	NS-S-01	NS-SED-01	NS-fish/1-4[1]	NS-FISH/5-7[2]	NS-FISH/8	NS-SNAIL/1-2
Matrix	Dust	Dust	Soil	Sediment	Fish	Fish	Fish	Snails
Fat content (%)	/	/	/	/	3.0	3.2	4.3	0.3
PCDD/Fs	<0.63	<0.63	<0.63	0.64	0.079	0.084	/	<0.07
dl-PCBs	<0.41	<0.41	<0.41	<0.41	0.082	<0.08	/	<0.08
Total PCDD/Fs + dl-PCBs	<1.04	<1.04	<1.04	0.845	0.161	0.124	/	<0.15
PBDD/Fs	<2.99	<2.99	<2.76	<2.99	<1.22	<1.22	/	<1.22
HCBD	/	<0.02	<0.02	<0.02	/	/	/	/
HCB	<0.02	<0.02	<0.02	<0.02	/	0.105	/	0.016
PeCB	0.026	<0.02	0.037	<0.02	/	0.028	/	<0.005
6 iPCB	0.155	<0.02	0.280	<0.02	0.054	0.080	/	<0.005
7 iPCB	0.165	<0.02	0.290	<0.02	0.063	0.088	/	<0.005
13 PCN cong.	/	<0.02	<0.02	<0.02	/	/	/	/
sum HBCD	<0.75	<0.75	<0.75	<0.75	<0.01	<0.01	<0.01	<0.01
PBDE 209	<5.0	<5.0	<5.0	<5.0	0.191	0.137	<0.05	<0.05
sum of PBDEs	<5.0	4.57	<5.0	<5.0	0.282	0.363	<0.05	0.134
BTBPE	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.025
DBDPE	<10.0	<10.0	<10.0	<10.0	2.18	<0.1	4.59	1.08
HBBz	<0.01	<0.01	<0.01	<0.01	<0.005	0.022	<0.005	<0.005
OBIND	<0.10	<0.10	<0.10	<0.10	<0.05	<0.05	<0.05	<0.05
PBEB	<0.01	<0.01	<0.01	<0.01	<0.005	<0.005	<0.005	<0.005
PBT	<0.01	<0.01	<0.01	<0.01	<0.005	0.018	0.017	<0.005
sum of nBFRs	<10.0	<10.0	<10.0	<10.0	2.22	0.137	4.64	1.14
sum DP	<0.01	<0.01	<0.01	<0.01	<0.003	0.019	<0.003	0.006
TBBPA	<1.5	<1.5	<1.5	<1.5	<0.06	<0.06	<0.06	<0.06

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are <0.1 (below LOQ) and <0.2 (below LOQ) pg BEQ/g f.w. for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

[2]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are <0.09 (below LOQ) and <0.2 (below LOQ) pg BEQ/g f.w. for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Table 15: *Summarised results of the analyses of the reference samples from the Ban Nong Khu organic farm (rice) and supermarket in Maha Sarakham (chicken eggs). The results are in ng/g for rice and ng/g of fat for eggs for all pollutants except PCDD/Fs, dl-PCBs and PBDD/Fs, where the results are in pg TEQ/g for rice and pg TEQ/g fat for eggs.*

Locality	Reference sites	
Sample ID	TH-REF-RICE[1]	TH-REF-EGG 2022[2]
Matrix	Rice	Eggs
Fat content (%)	/	11.4%
PCDD/Fs	0.081	0.53
dl-PCBs	0.082	0.15
Total PCDD/Fs + dl-PCBs	0.163	0.68
PBDD/Fs	<1.22	<1.22
HCBD	<0.02	<0.10
HCB	<0.02	0.578
PeCB	<0.02	<0.10
6 iPCB	0.090	<0.50
7 iPCB	0.100	<0.50
13 PCN cong.	<0.02	<0.20
sum HBCD	<0.75	<4.2
PBDE 209	<5.0	<1.5
sum of PBDEs	<5.0	<1.5
BTBPE	<0.01	<0.30
DBDPE	<10.0	<3.3
HBBz	<0.01	<0.20
OBIND	<0.10	<1.5
PBEB	<0.01	<0.20
PBT	<0.01	<0.20
sum of nBFRs	<10.0	<3.3
sum DP	<0.01	<0.3
TBBPA	<1.5	<4.2

5.2 Blood samples

The main goal of blood sampling was the comparison between the POPs burden in e-waste workers and the reference group. Therefore, only a summary description of workshops employing the blood donors is provided; no evaluation of each particular workshop is conducted. Summary statistics were calculated by using the value of half of LOQ for not quantified analytes.

5.2.1 Workshops and dumpsite

Human blood serum samples were taken from 40 adult e-waste workers, both men and women (25 and 15, respectively), employed in e-waste recycling. Samples were donated by workers working and also partly living at the Ban Nong Bua dumpsite and by workers from e-waste recycling workshops in Ban Nong Ma Tho, Ban Nong Mek, Ban Nong Bua and Ban Noi villages and nearby Wat Pho Si temple in Ban Sa-ad. The workshops are of different sizes (small to large) and focused on the separation of small electronics or small metal parts from fans, refrigerators, electronic rice cookers, washing machines, TVs, old motorcycles, electronic circuit boards,

[1]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are 0.087 and 0.66 pg BEQ/g for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

[2]For this sample, the CALUX *in vitro* cell bioassay was conducted, too. The results are <0.3 (below LOQ) and 1.1 pg BEQ/g fat for PCDD/Fs and the sum of dl-PCBs and PCDD/Fs, respectively.

Table 16: *Summary statistics of the analyses results of blood serum samples donated by e-waste workers. The results are in ng/g lipid for all pollutants except TBBPA, which is given in ng/ml serum.*

	N	Above LOQ	Min	Max	Median	Mean
HCB	20	100 %	1.00	11.7	2.26	3.43
PeCB	20	90 %	<0.1	4.95	0.428	1.25
sum HBCD	40	0 %	<0.5	<0.5	<0.5	<0.5
PBDE 209	40	68 %	<1.5	77.7	11.5	14.7
sum of PBDEs	40	98 %	<1.5	171	19.9	33.3
BTBPE	40	0 %	<0.3	<0.3	<0.3	<0.3
DBDPE	40	3 %	<1.5	340	0.75	9.24
HBBz	40	0 %	<0.3	<0.3	<0.3	<0.3
OBIND	40	0 %	<1.5	<1.5	<1.5	<1.5
PBEB	40	0 %	<0.3	<0.3	<0.3	<0.3
PBT	40	0 %	<0.3	<0.3	<0.3	<0.3
sum of nBFRs	40	3 %	<1.5	341	0.75	9.27
sum DP	40	85 %	<0.3	89.3	7.27	12.57
TBBPA	40	0 %	<0.4	<0.4	<0.4	<0.4

etc. One workshop is also sorting copper from scrap wires, another one is washing and repairing old fans for sale, and one workshop is temporarily closed. In some workshops there are small children living. Next to the working spaces of some workshops, agricultural and farming areas and infrastructure (animal sheds, ponds, fields) are located. The results of the analyses of this blood donor group are summarised in Table 16.

Table 17: *Summary statistics of the analyses results of blood serum samples donated by organic farm workers and agriculturalists. The results are in ng/g lipid for all pollutants except TBBPA, which is given in ng/ml serum.*

	N	Above LOQ	Min	Max	Median	Mean
HCB	5	100 %	1.59	3.45	2.76	2.58
PeCB	5	100 %	0.118	1.21	0.262	0.451
sum HBCD	26	0 %	<0.5	<0.5	<0.5	<0.5
PBDE 209	26	27 %	0.750	15.0	0.750	3.07
sum of PBDEs	26	54 %	0.750	21.2	4.50	5.47
BTBPE	26	0 %	<0.3	<0.3	<0.3	<0.3
DBDPE	26	0 %	<1.5	<1.5	<1.5	<1.5
HBBz	26	0 %	<0.3	<0.3	<0.3	<0.3
OBIND	26	0 %	<1.5	<1.5	<1.5	<1.5
PBEB	26	0 %	<0.3	<0.3	<0.3	<0.3
PBT	26	0 %	<0.3	<0.3	<0.3	<0.3
sum of nBFRs	26	0 %	<1.5	<1.5	<1.5	<1.5
sum DP	26	4 %	<0.3	0.75	0.3	0.32
TBBPA	26	0 %	<0.4	<0.4	<0.4	<0.4

5.2.2 Reference site

Blood samples were taken from a control group of 26 adult organic farm workers and agriculturalists from the Ban Na Somboon village, both men and women (7 and 19, respectively), who have never worked in the e-waste processing business or lived in such an area. The results of the analyses of this reference group are summarised in Table 17.

6. Discussion of results

6.1 Detected levels of contamination and comparison with literature and legal limits

6.1.1 ndl-PCBs

ndl-PCBs presented by indicator congeners were measured at median concentrations several orders of magnitude higher in environmental samples from the e-waste area when compared to background samples (2.43 vs 0.082 ng/g d.w. in dust and 41.5 ng/g d.w. vs. concentration below laboratory LOQ in sediment). This situation is reflected in foodstuffs of animal origin where ndl-PCBs median concentrations are also considerably higher in samples from the e-waste area when compared to the background samples (1.01 ng/g fat vs. concentrations below LOQ in eggs, 5.75 vs. 0.067 ng/g in fish and 0.437 ng/g vs. concentrations below LOQ in snails). Interestingly, ndl-PCB concentrations in rice from the e-waste area are practically the same as in rice from the reference organic farm (see Figure 15).

When comparing dust ndl-PCBs concentrations in working and living areas of investigated e-waste recycling households, a clear concentration gradient could not be determined. This means that ndl-PCB concentrations in working areas were often but not always higher than in living areas. Moreover, ndl-PCB concentrations in the former working area of a closed workshop in Ban Nong Ma Tho (4.27 ng/g d.w.) were higher than in all but one of the working areas of functional workshops. This indicates that other sources of these POPs are more significant than the e-waste.

On the other hand, the Ban Nong Bua dumpsite and its traffic is a source of ndl-PCBs in various environmental compartments in its surroundings. This is indicated by ndl-PCB concentration gradients in sediment and dust. Sediment concentrations in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (0.165 ng/g d.w. and 82.8 d.w., respectively). Dust concentrations on the access road gradually decreased with distance, but ndl-PCBs were still present in a concentration of 26.4 ng/g d.w. in 250 m distance. Dust ndl-PCB concentrations were approximately three times higher on the track within the dumpsite (69.4 ng/g d.w.) and two orders of magnitude higher at the entrance of it (2007 ng/g d.w.). As not only e-waste is stored at the dumpsite, the sources of ndl-PCBs are indicated to be manifold (see chapter 3.1.1).

The median concentration of 1.01 ng/g fat for 6 PCB indicator congeners in pooled chicken egg samples from villages with e-waste recycling workshops is well under the limit value of 40 ng/g fat set for eggs in the European Un-

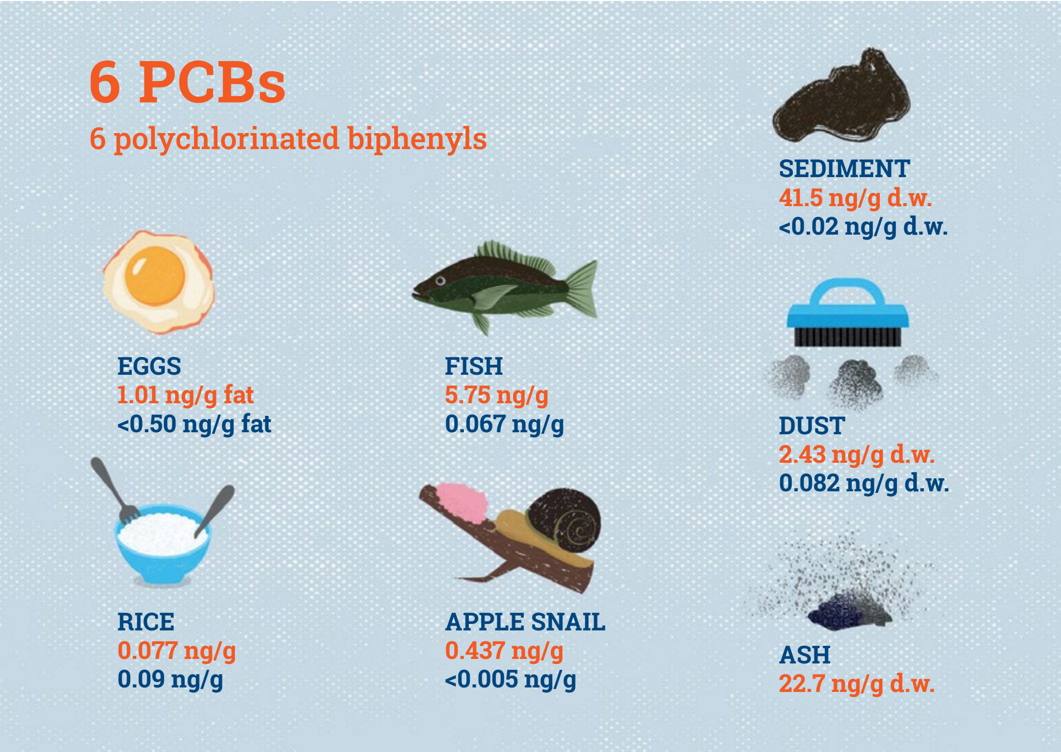


Figure 15: *Median concentrations of non-dioxin-like PCBs (6 indicator congeners) in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

ion (European Commission 2011). The highest concentration found in these chicken eggs (14.98 ng/g fat in a sample from Ban Nong Bua) is still less than half of the EU limit for eggs and these eggs are not consumed. The concentration of 5.75 ng/g for 6 PCB indicator congeners in a pooled fish sample from a water pond inside the Ban Nong Bua dumpsite is also well below the European limit value of 125 ng/g wet weight (European Commission 2011).

The median concentration (1.01 ng/g fat) for 6 PCB indicator congeners found in the Kalasin chicken eggs is the same as in a pooled egg sample from Khon Kaen, Thailand (a site influenced by mixed industry) and comparable to levels measured in egg samples from Saraburi, Thailand (cement industry), the vicinity of the Praeksa waste landfill (Thailand) or Map Ta Phut, Thailand (chemical industry). It is lower than concentrations found in egg samples from Samut Sakhon, Thailand (metallurgy and waste recycling, 7 – 11 ng/g fat), and several orders of magnitude lower than in eggs from various contaminated sites in Kazakhstan (Petrlik, Teebthaisong et al. 2018). Kalasin chicken eggs also have a lower burden of 6 ndl-PCBs when compared to eggs from a contaminated site in the Czech Republic (hazardous waste storage, 9 – 42 ng/g fat) (Mach, Petrlik and Strakova 2016).

6.1.2 PCNs

PCNs were measured in a small number of samples and were mostly below LOQ. Median concentrations in Khok Sa-ad dust and sediment were 0.193 ng/g d.w. and 1.27 ng/g d.w., respectively. The median concentration in Khok Sa-ad eggs was 0.1 ng/g fat, which is a low concentration resulting from the fact that most of the samples contained PCNs below the laboratory LOQ. Concentrations in all sampled background matrices were below laboratory LOQ (see Figure 16).

6.1.3 Dechlorane Plus

DP was present at concentrations above LOQ in 85% of samples of e-waste workers' blood serum, while only in 4% of samples donated by organic farm workers and agriculturalists (see Tables 16 and 17). The median concentration was 7.3 ng/g lipid and 0.3 ng/g lipid in e-waste workers and the reference group, respectively. All environmental samples from Khok Sa-ad had considerably higher DP concentrations when compared to background samples that did not have DP concentrations above LOQ at all. Dust is the most polluted environmental matrix in Khok Sa-ad, with a median concentration of 10.2 ng/g d.w. Eggs from Khok Sa-ad contained DP median levels of 0.965 ng/g fat, which is approximately three times the LOQ value (and which was not reached in the reference sample). Fish and snail samples from Khok Sa-ad contained median DP levels one order of magnitude above the LOQ, while DP could not be quantified in Khok Sa-ad crab samples. Rice samples did not contain levels above LOQ both in Khok Sa-ad and at the reference site (see Figure 17).

A clear concentration gradient can be determined when comparing dust DP concentrations in workshops, where dust from both working and living areas was sampled. Concentrations in the working areas were always higher than in living areas, with the most striking difference found in one of the Ban Nong Ma Tho functioning e-waste workshops (63.5 ng/g d.w. vs. 3.9 ng/g d.w.). This indicates that e-waste dismantling and recycling activities are a source of DP in household dust. Notably, the DP concentration gradient was also detected in dust of a closed workshop in Ban Nong Ma Tho even a decade after termination of the recycling activities (3.88 ng/g d.w. in the former working area vs. 0.793 ng/g d.w. in the living area).

The Ban Nong Bua dumpsite and its traffic is a source of DP contamination of various environmental compartments in its surroundings. This is indicated by DP concentration gradients in soil, sediment and dust. Sediment concentrations in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (0.243 ng/g d.w. and 15.4 ng/g d.w., respectively). Dust concentrations on the access road gradually decreased with distance, but DP was still present in a concentration of 1.3 ng/g d.w. at 250 m distance. Dust DP concentration on the track within the dumpsite was one order of magnitude higher (14.9 ng/g d.w.). Concentrations of DP in soil lower by at least one order of magnitude were detected 300 m south and east of the dumpsite when compared to samples taken right next to the dumpsite wall.

Because most studies reporting DP concentrations in dust are focused on indoor dust, the ability to compare the levels found in Kalasin outdoor household dust with other studies is limited. Wang, Tian et al. (2011) studied DP in indoor and yard dust of a large e-waste recycling area in Qingyuan county (South China) and determined a median concentration of 541 ng/g. The highest DP concentration in household dust in Kalasin found in one of the Ban Nong Ma Tho workshops (i.e. 108 ng/g d.w.) is considerably lower. Li, Chen et al. (2018) found DP concentrations of 3.8 to 2.1×10^3 ng/g d.w. in soil, 1.1×10^3 to 7.2×10^3 ng/g d.w. in sediment and 1.4×10^1 to 1.1×10^3 ng/g d.w. in road dust of the e-waste recycling town Guiyu in southeastern China. Although DP levels in the environment of these e-waste recycling

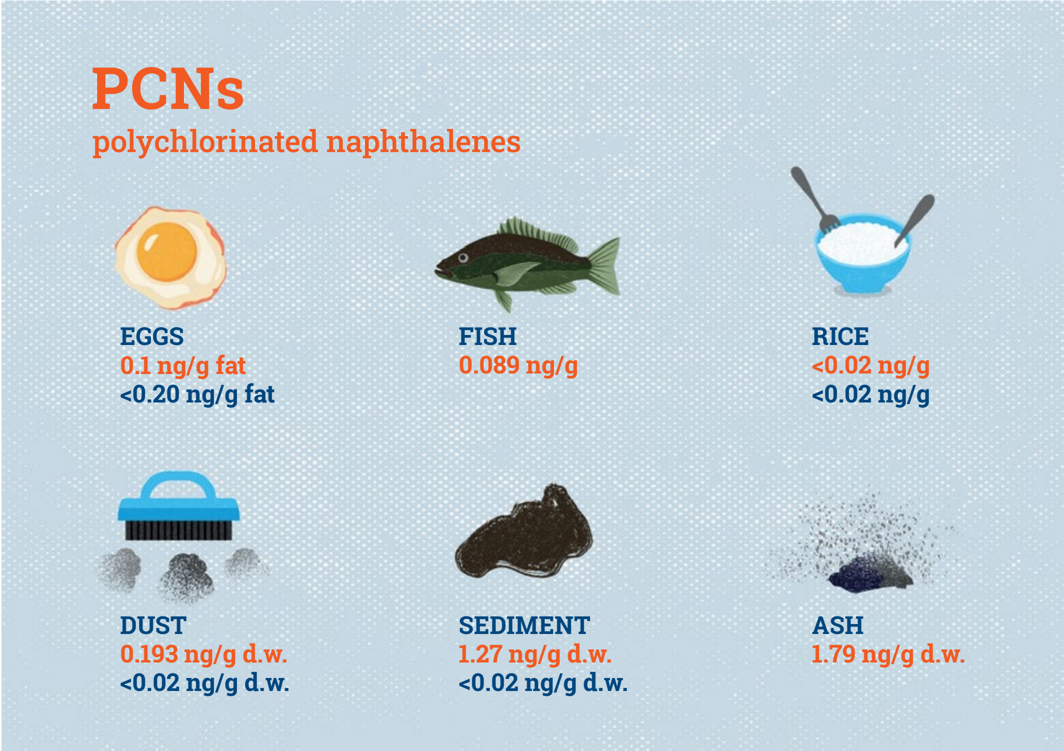
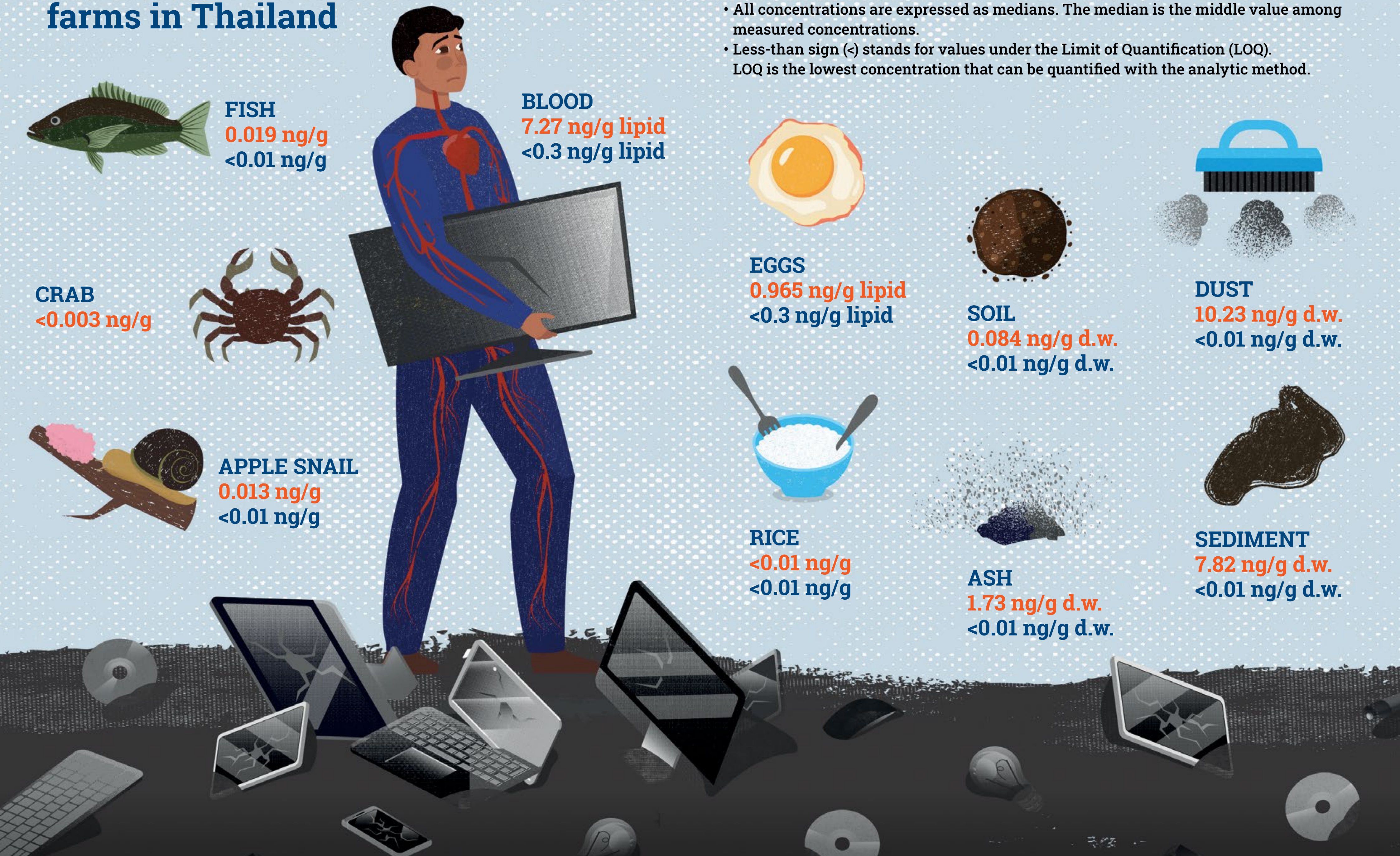


Figure 16: *Median concentrations of PCNs in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

Sources and levels of Dechlorane Plus exposure to workers in the e-waste recycling sector in Kalasin province compared to background concentrations in organic farms in Thailand

- All concentrations are expressed as medians. The median is the middle value among measured concentrations.
- Less-than sign (<) stands for values under the Limit of Quantification (LOQ). LOQ is the lowest concentration that can be quantified with the analytic method.



communities in China were higher than in Kalasin, it should be noted that these sites differ in size and period of operation.

The majority of the sampled Kalasin eggs contained DP concentrations above the LOQ with a maximum of 12.6 ng/g fat. The review by Ghelli, Cariou et al. (2021) found the highest mean concentration of DP in all categories of foodstuffs reported for Chinese chicken eggs (124 ng/g fat) that were collected in southern China as reference for egg samples from the large e-waste treatment area in Qingyuan county that contained 1599 ng/g fat (Zheng, Wu et al. 2012). This is several orders of magnitude higher than DP levels in Kalasin eggs; however, the Chinese e-waste site differs significantly in size. By contrast, DP median concentrations in Kalasin eggs (0.965 ng/g fat) are comparable to eggs from locations near various waste disposal sites in Tanzania, where median DP concentrations ranged from 0.5 ng/g fat to 2.8 ng/g fat (Haarr, Nipen et al. 2023).

Median DP blood serum concentrations in Kalasin e-waste workers (7.27 ng/g lipid) range from the same order of magnitude to two orders of magnitude lower than in e-waste and otherwise occupationally-exposed workers and residents of such areas from China. Chen, Zheng et al. (2015) found median serum DP concentrations of 190 ng/g lipid in e-waste workers from South China, which was lower than concentrations found in occupational workers in a DP manufacturing plant (median 860 ng/g lipid) and comparable to those found in non-occupationally-exposed residents near the manufacturing plant (median 240 ng/g lipid) (Zhang, Wang et al. 2013). Similar concentrations as in Chen, Zheng et al. (2015) were also found by Yan, Zheng et al. (2012) in southern Chinese e-waste workers (median of 150 ng/g lipid). One order of magnitude lower levels were, however, found by Dong and Li (2020) in e-waste workers of LQ town in southeastern China (median 53 ng/g lipid). Yin, Li et al. (2020) found median concentrations of 4 ng/g lipid in the serum of pregnant women living in Wenling, China, but not working in the local e-waste business. This is comparable to the DP levels found in Kalasin e-waste workers.

Figure 17: *Median levels of Dechlorane Plus in blood serum of e-waste workers and in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

6.1.4 BFRs

6.1.4.1 PBDEs

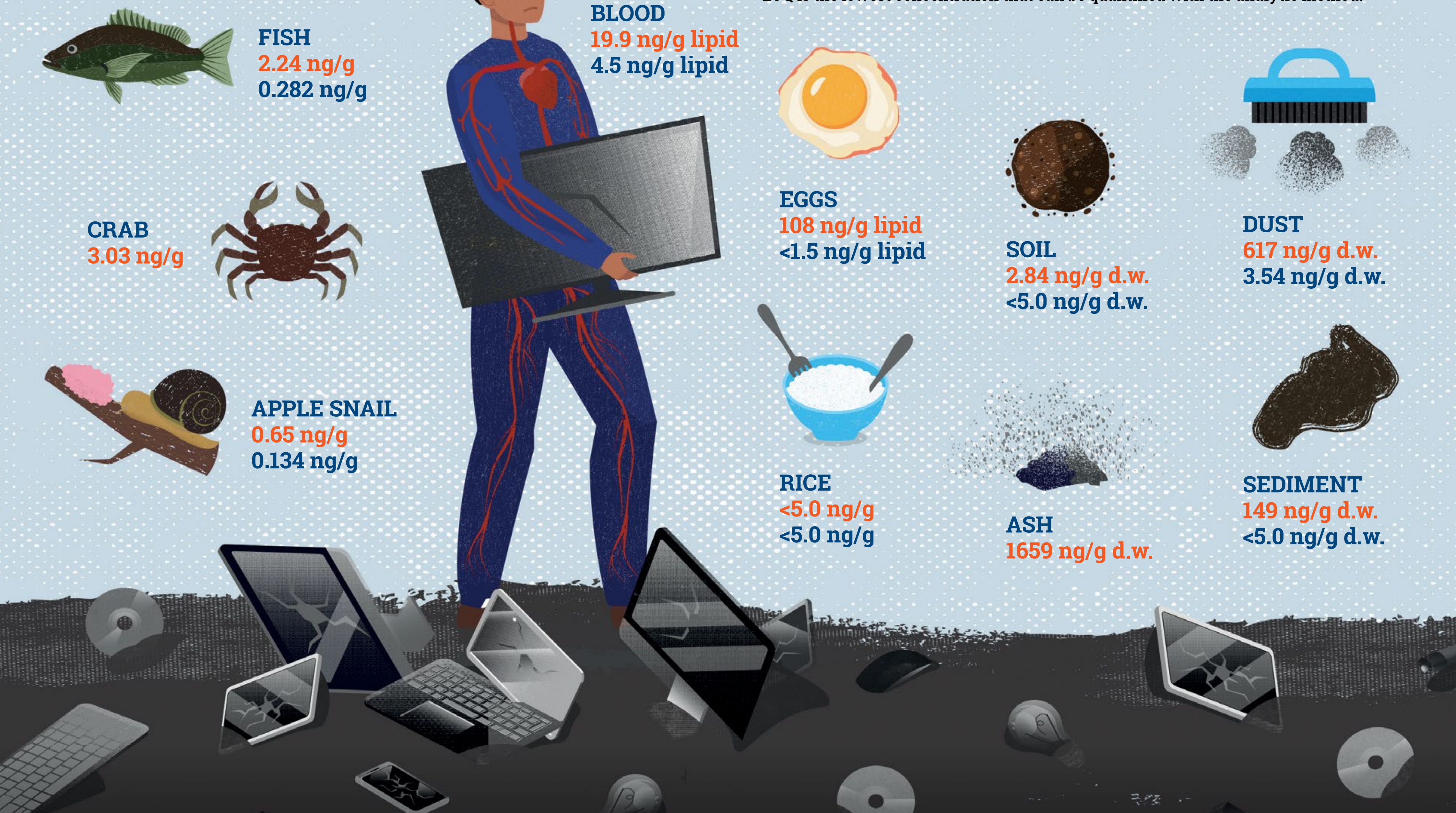
The sum of PBDEs was present at concentrations above LOQ in 98% of samples of e-waste workers' blood serum, while only in 54% of samples donated by organic farm workers and agriculturalists (see Tables 16 and 17). The median concentration was 19.9 ng/g lipid and 4.5 ng/g lipid in e-waste workers and the reference group, respectively. Median dust and sediment PBDE concentrations from Khok Sa-ad were two orders of magnitude higher when compared to background samples (617 vs. 3.54 ng/g d.w. and 149 ng/g d.w. vs. concentrations below LOQ in dust and sediment, respectively). Eggs from Kalasin contained a PBDE median level of 108 ng/g fat, which is two orders of magnitude higher than the LOQ value that was not reached in the reference sample. Fish and snail samples from Khok Sa-ad contained median PBDE levels several times higher when compared to background samples. Rice samples did not contain levels above LOQ in Khok Sa-ad nor at the reference site (see Figure 18).

A similar pattern as described above for the sum of PBDEs can also be observed for PBDE 209, which is included into this sum (Figure 19).

A concentration gradient can be determined when comparing dust PBDE concentrations in workshops, where dust from both working and living areas was sampled. Concentrations in the working areas were higher than in living areas in all but one of the functioning workshops, with the most striking difference found in the Ban Khok Prasit workshop (4317 ng/g d.w. vs. 281 ng/g d.w.). This indicates that e-waste dismantling and recycling activities are a

Sources and levels of polybrominated diphenylethers exposure to workers in the e-waste recycling sector in Kalasin province compared to background concentrations in organic farms in Thailand

- All concentrations are expressed as medians. The median is the middle value among measured concentrations.
- Less-than sign (<) stands for values under the Limit of Quantification (LOQ). LOQ is the lowest concentration that can be quantified with the analytic method.



source of PBDEs in household dust. Notably, the PBDE concentration gradient was also detected in dust of a closed workshop in Ban Nong Ma Tho even a decade after termination of the recycling activities (50.2 ng/g d.w. in the former working area vs. 26.5 ng/g d.w. in the living area).

The Ban Nong Bua dumpsite and its traffic are sources of PBDE contamination of various environmental compartments in its surroundings. This is indicated by PBDE concentration gradients in soil, sediment and dust. Sediment concentrations in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (3.7 ng/g d.w. and 294 ng/g d.w., respectively). Dust concentrations on the access road gradually decreased with distance, but PBDEs were still present in a concentration of 197 ng/g d.w. at 250 m distance. Dust PBDE concentrations at the entrance of the dumpsite and on the track within it were between 617 and 4067 ng/g d.w. Considerably lower concentrations of PBDEs in soil were detected 300 m south and east of the dumpsite when compared to samples taken right next to the dumpsite wall.

As most studies reporting PBDEs concentrations in dust are focused on indoor dust and the number of analysed individual PBDE congeners vary, their comparison with levels found in Khok Sa-ad outdoor household dust is estimative. Zhang, Shi et al. (2019) found concentrations in the range of 158,070 – 669,810 ng/g (sum of 7 PBDEs) in indoor dust in formal e-waste recycling workshops in Changzhou city of Jiangsu province, China. Zheng, Xu et al. (2015) focused on villages located in some of the largest e-waste dismantling and recycling sites in China (Guangdong province) and found concentrations of the sum of 8 PBDEs in the range of 173 – 237,000 ng/g in indoor dust from workshops and nearby residence houses. Tue, Takahashi et al. (2013) determined PBDE levels (sum of 40 congeners) in indoor dust

Figure 18: *Median levels of the sum of PBDEs in blood serum of e-waste workers and in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations.*

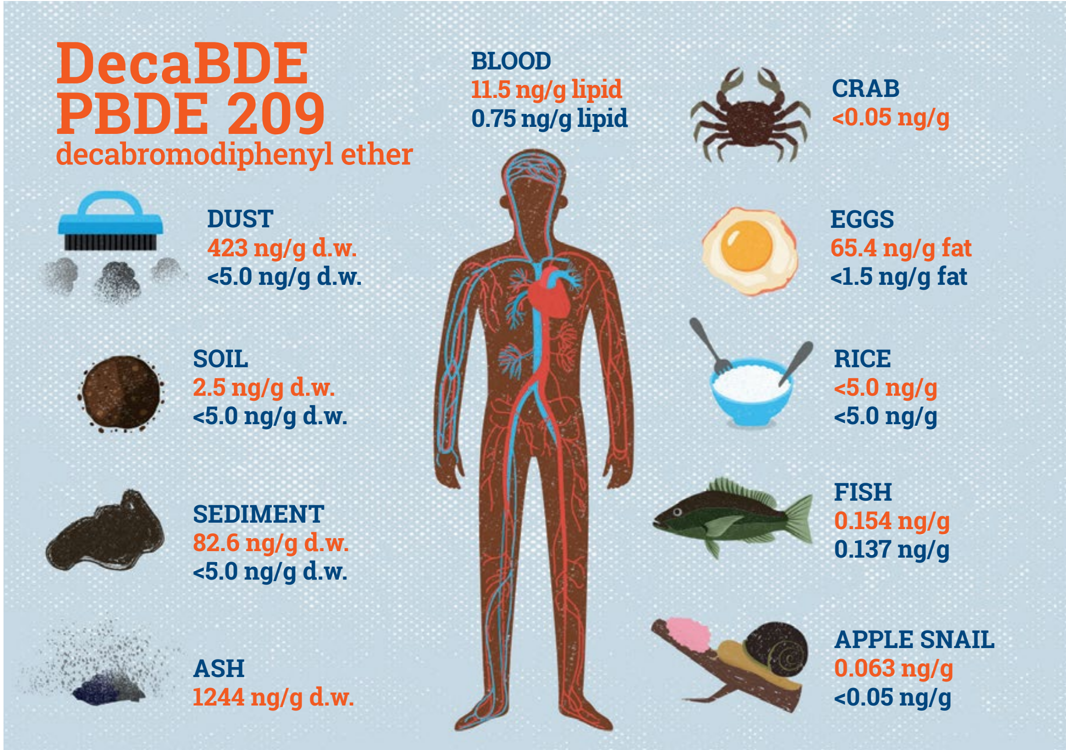
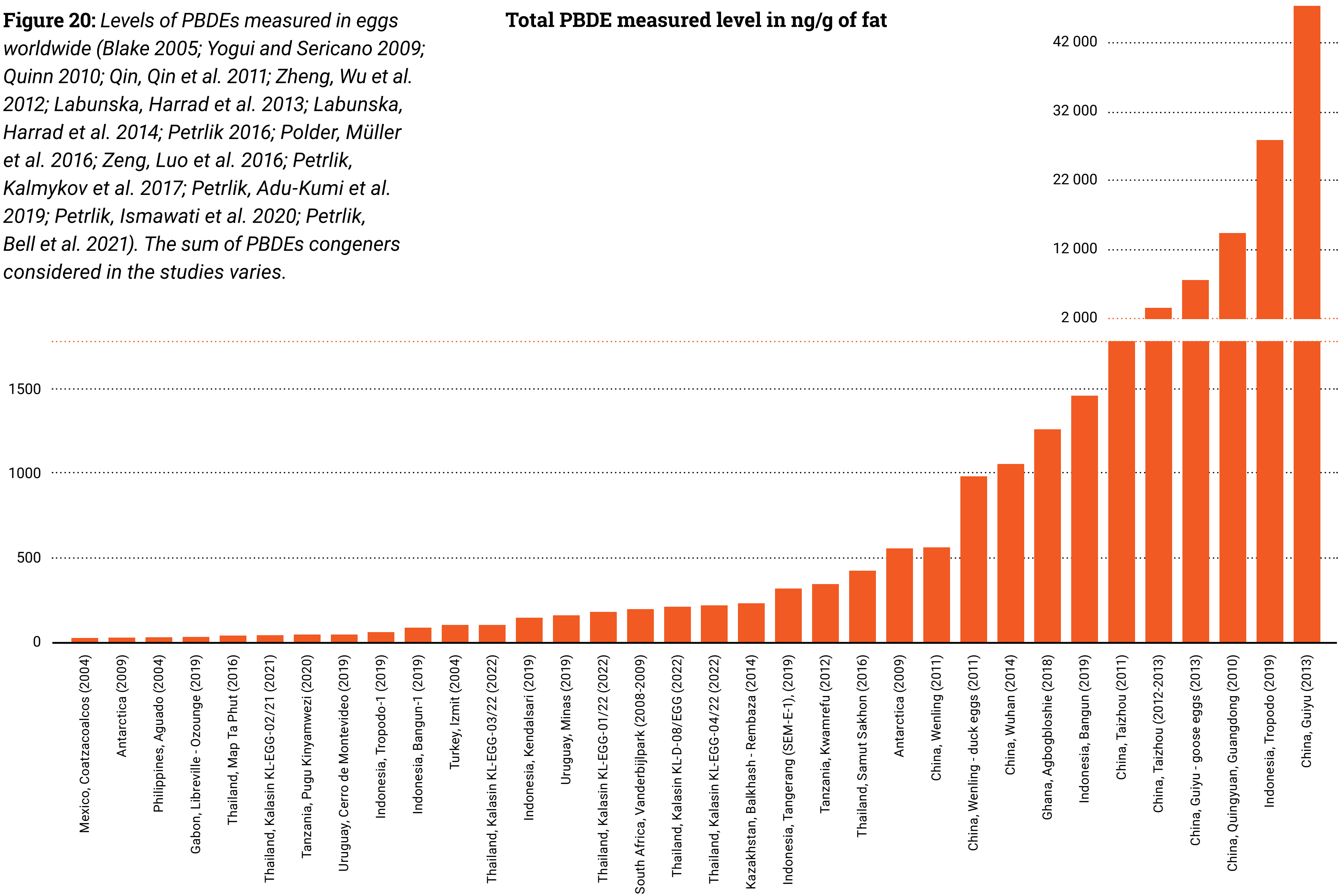


Figure 19: *Median levels of PBDE 209 in blood serum of e-waste workers and in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

from houses in Vietnam at ranges of 38 – 610 and 130 – 12,000 ng/g at urban/suburban and informal e-waste recycling sites, respectively. The levels at urban/suburban sites are considerably lower, while the levels from e-waste recycling sites are higher than those observed in Khok Sa-ad non-shredding workshops (range 26.5 – 5,040 ng/g d.w., sum of 16 PBDE congeners). Muenhor, Harrad et al. (2010) determined a median concentration of 28,000 ng/g (range 320 - 290,000 ng/g) for the sum of 21 PBDEs in indoor dust at e-waste storage facilities in Ayutthaya and Nonthaburi

Figure 20: *Levels of PBDEs measured in eggs worldwide (Blake 2005; Yogui and Sericano 2009; Quinn 2010; Qin, Qin et al. 2011; Zheng, Wu et al. 2012; Labunska, Harrad et al. 2013; Labunska, Harrad et al. 2014; Petrlik 2016; Polder, Müller et al. 2016; Zeng, Luo et al. 2016; Petrlik, Kalmykov et al. 2017; Petrlik, Adu-Kumi et al. 2019; Petrlik, Ismawati et al. 2020; Petrlik, Bell et al. 2021). The sum of PBDEs congeners considered in the studies varies.*



provinces, Thailand. These are higher levels when compared to the shredding enterprise in Ban Nong Bua (maximum 32,357 ng/g of the sum of 16 PBDE congeners), which can be considered a similar type of facility.

Matsukami, Tue et al. (2015) and Luo, Luo et al. (2009) studied PBDEs in surface soil at footpaths next to e-waste dismantling sites in northern Vietnam and road soils in an e-waste dismantling region in South China and determined levels in the range of 67 – 9,200 (sum of 14 congeners) and 191 – 9,156 ng/g d.w. (sum of 22 congeners), respectively. Maximum levels are an order of magnitude higher than levels in soil from the entrance part of the shredding enterprise in Ban Nong Bua. Levels determined by Matsukami, Tue et al. (2015) in soil from footpaths around rice fields are comparable to those determined in soil in the vicinity of Ban Nong Bua dumpsite.

Levels of the sum on the PBDEs in pooled egg samples from Khok Sa-ad (KL-EGG-02/21, KL-EGG-03/22, KL-EGG-01/22, KL-D-08/EGG1 and KL-EGG-04/22) belong to the highest measured from hot spots in Thailand. The only higher concentration (427 ng/g fat) was determined in a sample from Samut Sakhon (Petrlik, Dvorska et al. 2018). The PBDEs concentration in duck eggs from a village near Supcharoen Recycle Co. Ltd. Factory in Chachoengsao province (Petrlik, Boontongmai et al. 2022) was comparable to levels in the Khok Sa-ad egg samples KL-EGG-02/22 and KL-EGG-03/21. A comparison with eggs sampled worldwide is visible in Figure 20.

Median levels of PBDEs in blood serum of workers from Khok Sa-ad (19.9 ng/g lipid) as well as residents in a control group from Ban Na Somboon (4.5 ng/g lipid) are considerably lower when compared to blood serum concentrations of Chinese e-waste workers and a control group (Zhao, Qin et al. 2010; Xu, Lou et al. 2015). This is well in agreement with findings in the review by Cai, Song et al. (2020): *"Compared with other countries, the PBDE levels in the blood of workers and residents in China could be more serious - at least an order of magnitude higher."* Workers dismantling e-waste in Sweden had PBDEs levels similar to workers from Khok Sa-ad (26 ng/g ww, Sjödin, Hagmar et al. 1999).

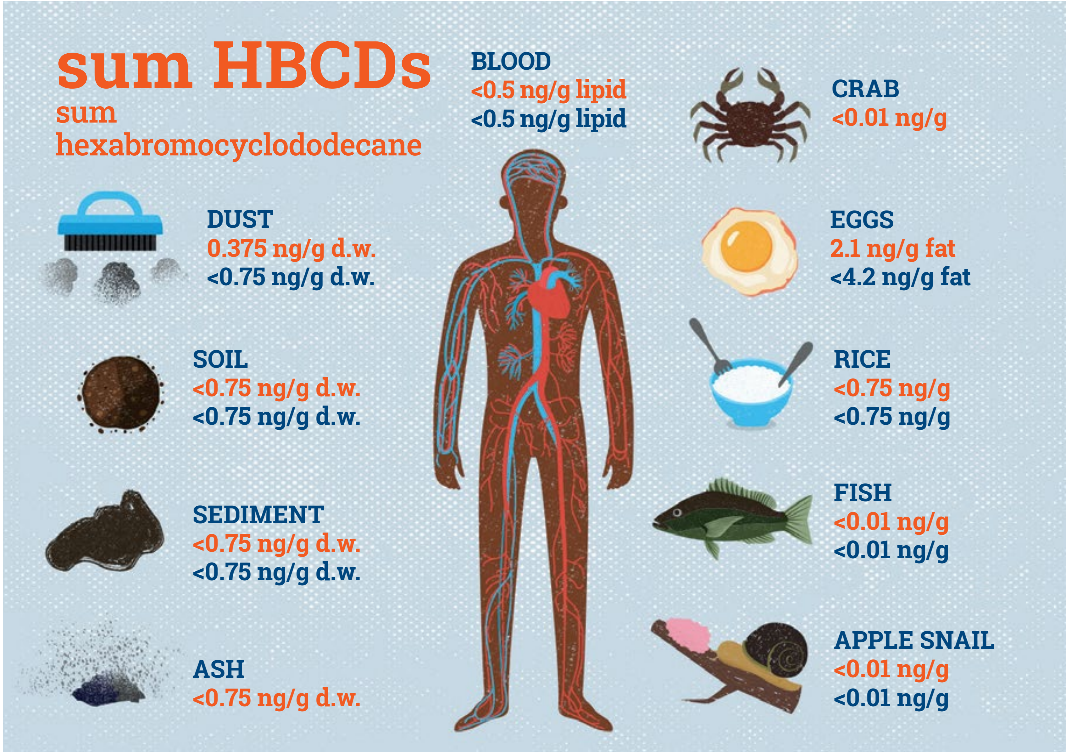


Figure 21: *Median concentrations of the sum of HBCD isomers in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

6.1.4.2 HBCD

HBCD concentrations were below LOQ with the exemption of a few dust and egg samples. This is reflected in their median concentrations (see Figure 21).

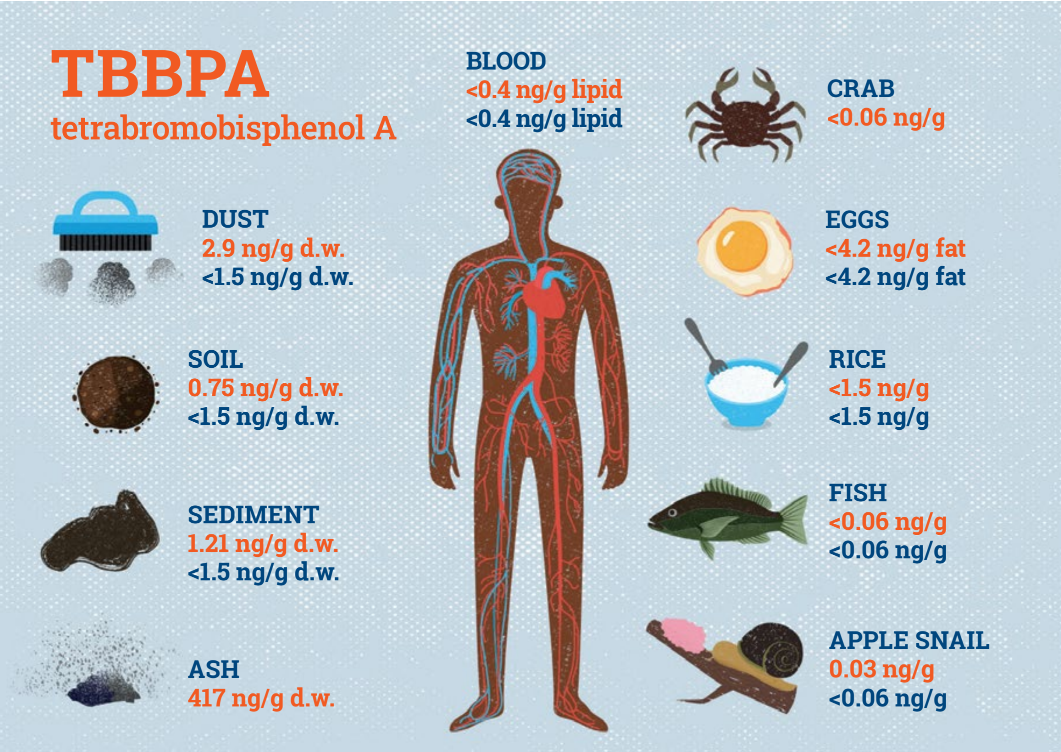


Figure 22: *Median concentrations of TBBPA in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

6.1.4.3 TBBPA

TBBPA concentrations in blood serum samples were below LOQ and median concentrations in environmental samples were close to LOQ. TBBPA concentrations in foodstuffs samples were all below LOQ with the exemption of one snail sample (see Figure 22).

A concentration gradient can be determined when comparing dust TBBPA concentrations in workshops, where dust from both working and living areas was sampled. Concentrations in the working areas were higher than in living areas, with the most striking difference found in one of the Ban Nong Ma Tho functioning e-waste workshops (22.8 ng/g d.w. vs. 1.61 ng/g d.w.). This indicates that e-waste dismantling and recycling activities are a source of TBBPA in household dust. TBBPA concentrations in dust of a workshop closed about a decade ago in Ban Nong Ma Tho were below LOQ. A TBBPA concentration gradient around the Ban Nong Bua dumpsite is not really indicated by the analyses results.

TBBPA has been detected in almost all environmental compartments all over the world, rendering it a ubiquitous contaminant (Abou-Elwafa Abdallah 2016). Heavily polluted e-waste dismantling sites have been shown to have high TBBPA levels (Liu, Ma et al. 2020). Dust TBBPA concentrations in Khok Sa-ad, Kalasin province, ranged between levels below LOQ and 2041 ng/g d.w., with the highest levels measured in dust at the Ban Nong Bua dumpsite and plastic shredding enterprise. A similar range of TBBPA concentrations in indoor house dust from the e-waste dismantling area in Kalasin (median = 720 ng/g; range = 44–2300 ng/g) were reported in a recent study (Waiyarat, Boontanon et al. 2022). However, comparison with literature data is complicated, as most studies focus on indoor dust and sampling methods vary. Still, Khok Sa-ad is suggested to be less polluted by TBBPA than, e.g., the extremely polluted e-waste dismantling area in Guiyu, South China (concentrations between 5.50×10^3 to 2.38×10^4 ng/g, Liu, Ma et al. 2020). Interestingly, although TBBPA has been found to bioaccumulate in, for example, peregrine falcon eggs (Schwarz, Rackstraw et al. 2016), eggs from Khok Sa-ad as well as the large Ghanian e-waste recycling site Agbogbloshie (Petrlik, Adu-Kumi et al. 2019) did not contain TBBPA above LOQ.

6.1.4.4 nBFRs

Except for one sample donated by an e-waste worker, all blood serum samples contained nBFR concentrations below LOQ. Median nBFR concentrations in dust and sediment samples from Khok Sa-ad were considerably higher when compared to background samples that did not have nBFR concentrations above LOQ. Dust is the most nBFR polluted environmental matrix in Khok Sa-ad, with a median concentration of 428 ng/g d.w. The majority of eggs from Khok Sa-ad contained nBFR levels below LOQ. Fish sample nBFRs median concentrations were higher in Khok Sa-ad when compared to background samples (6.81 vs. 2.22 ng/g, respectively), while for apple snail samples the relation is opposite (0.113 vs. 1.14 ng/g in Khok Sa-ad and background samples, respectively). Rice samples did not contain levels above LOQ in Khok Sa-ad nor at the reference site (see Figure 23).

Out of nBFRs investigated in this study, BTBPE, DBDPE and HBBz are monitored more often in environmental samples (Munschy, Héas-Mois-

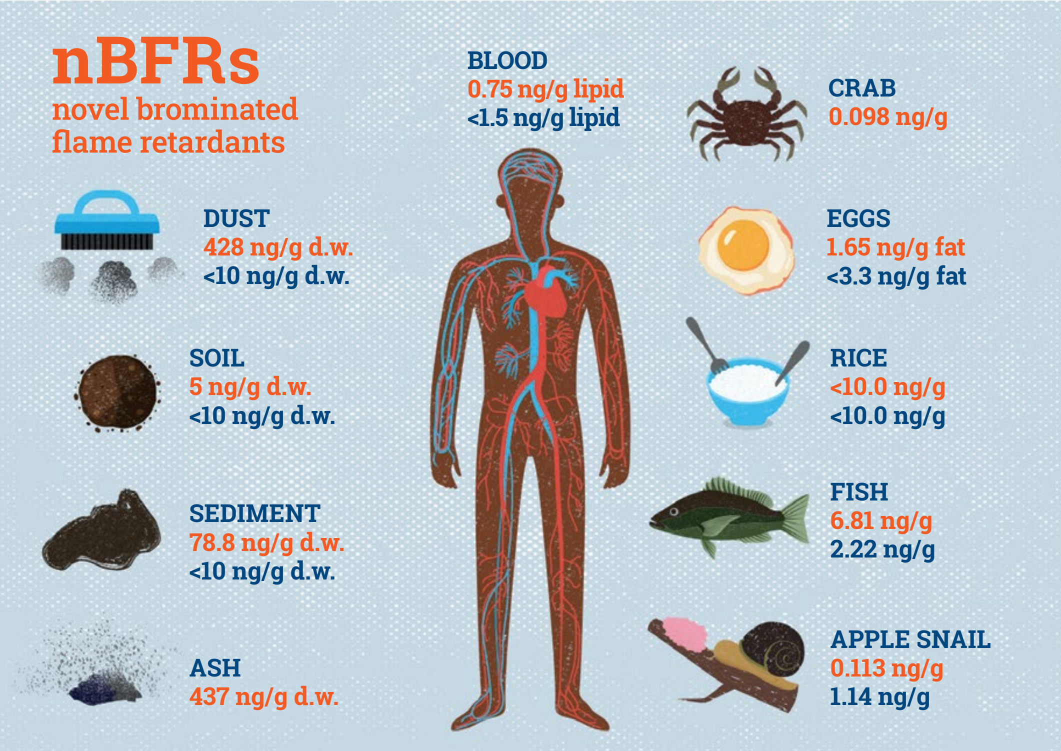


Figure 23: *Median concentrations of the sum of novel BFRs in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

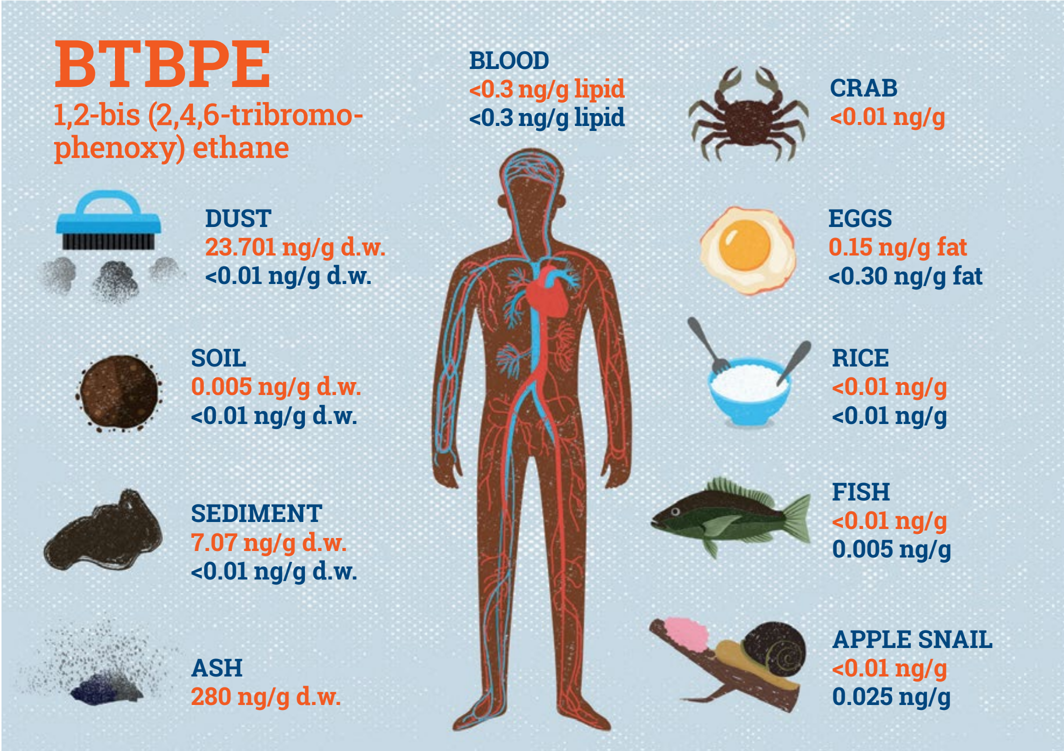


Figure 24: *Median concentrations of the sum of BTBPE in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

an et al. 2011; Mohr, García-Bermejo et al. 2014; Poma, Volta et al. 2014; Vorkamp, Bossi et al. 2015). This is also reflected in the findings from Khok Sa-ad (Figures 24-29).

Concentrations of nBFRs in the working areas were always higher than in living areas of households with functioning e-waste recycling workshops. The most striking difference was found in one of the Ban Nong Ma Tho workshops (954 ng/g d.w. vs. 116 ng/g d.w.). This indicates that e-waste dismantling and recycling activities are a source of nBFRs in household dust. Dust from a workshop in Ban Nong Ma Tho closed for a decade contained one to two orders of magnitude lower concentrations of BFRs (i.e. 45.9 ng/g d.w. in the former working area and 50.3 ng/g d.w. in the living area) when compared to households with functioning workshops.

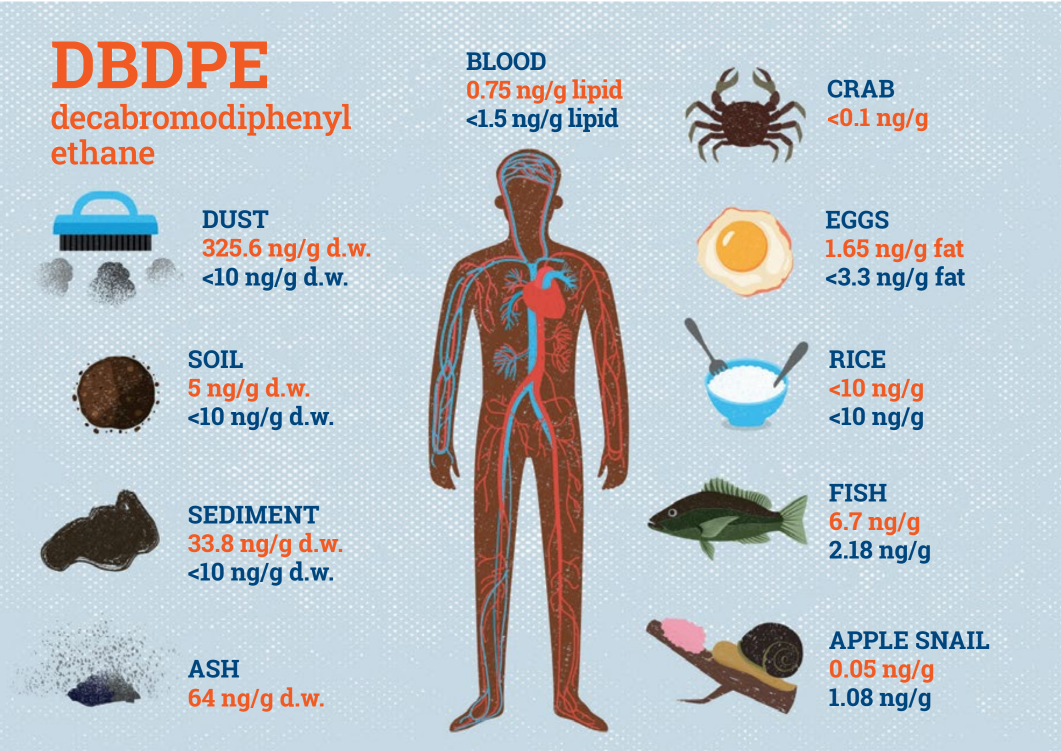


Figure 25: *Median concentrations of the sum of DBDPE in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

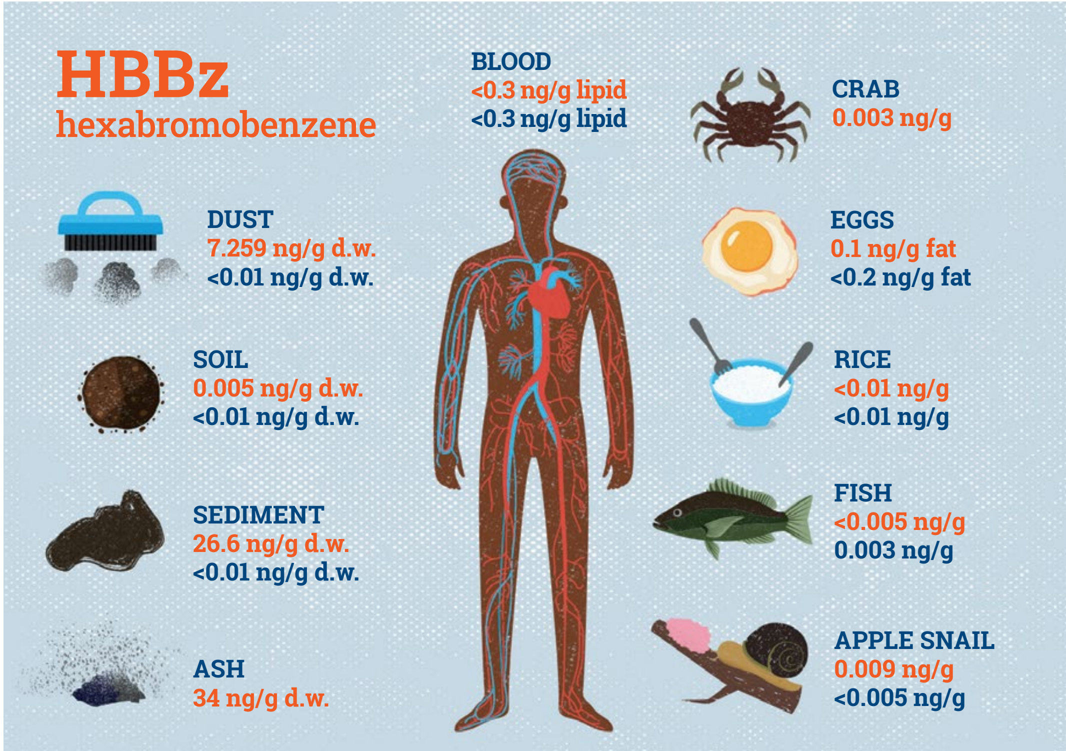


Figure 26: *Median concentrations of the sum of HBBz in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

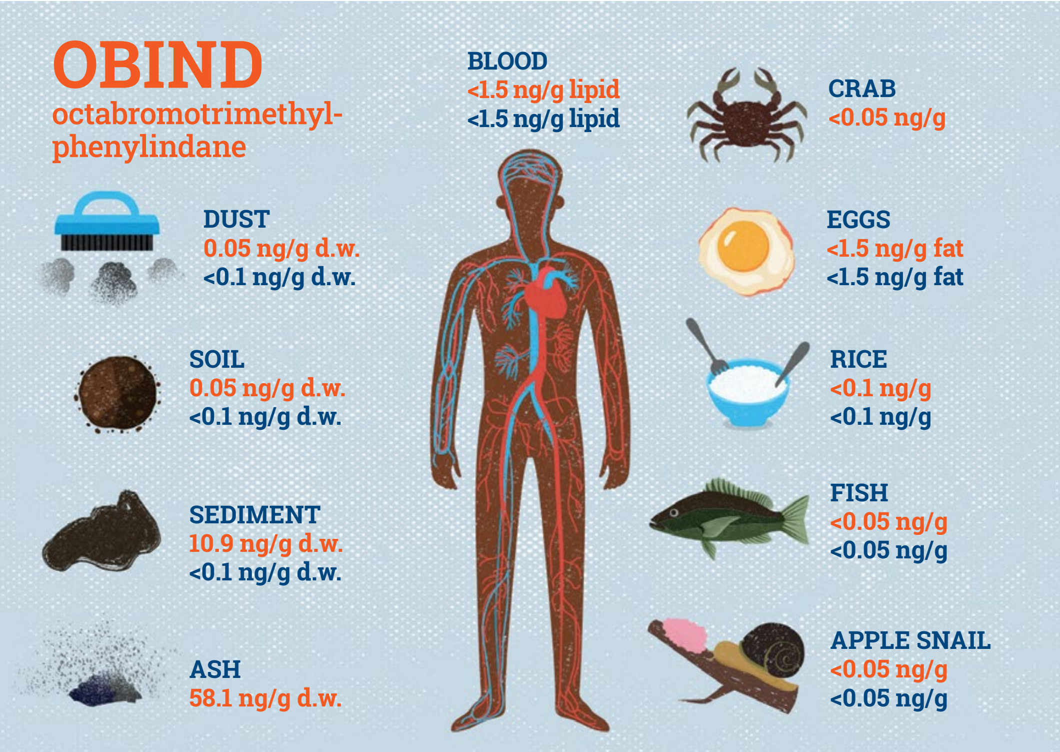


Figure 27: *Median concentrations of the sum of OBIND in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

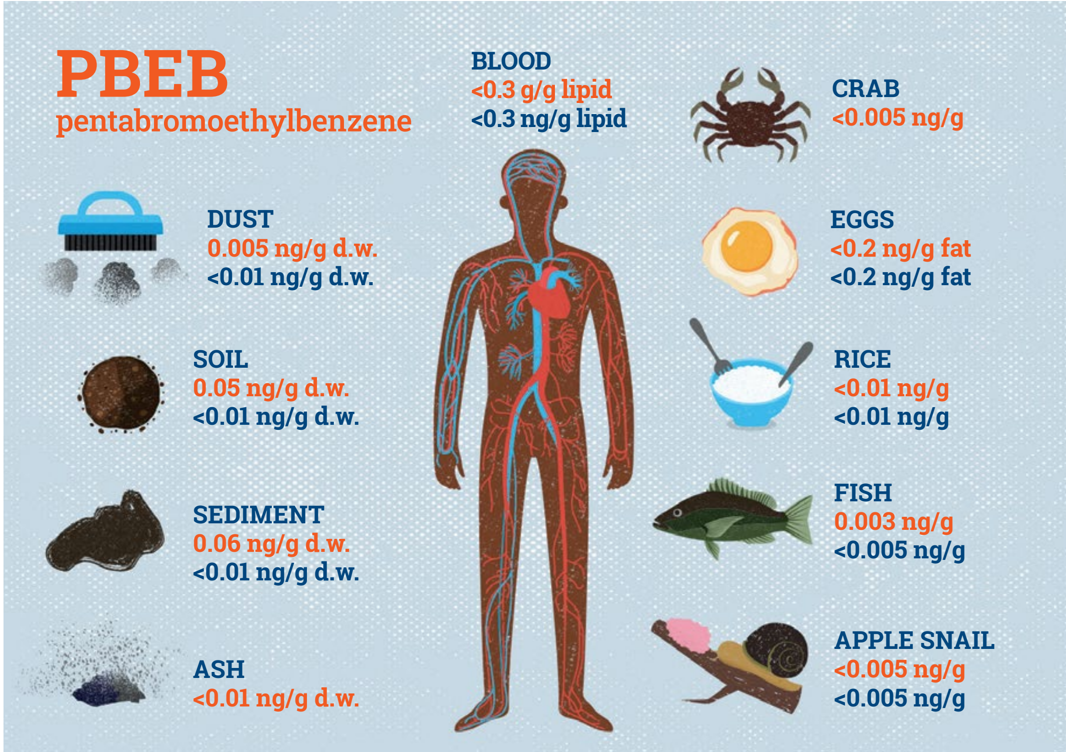


Figure 28: *Median concentrations of the sum of PBEB in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

The Ban Nong Bua dumpsite and its traffic are a source of nBFRs in various environmental compartments in its surroundings. Sediment concentrations in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (5.21 ng/g d.w. and 152 ng/g d.w., respectively). Dust concentrations on the access road gradually decreased with distance; i.e., nBFR concentrations were 126 ng/g d.w. 250 m away, rose to 259 ng/g d.w. 120 m away, and were between 428 ng/g d.w. and 3148 ng/g d.w. at the entrance of the dumpsite and within it.

The concentrations of nBFRs in Khok Sa-ad dust samples ranged from concentrations below LOQ to 11,140 ng/g d.w., with the highest levels measured in dust in one of the Ban Nong Ma Tho workshops, at the Ban Nong Bua dumpsite and plastic shredding enterprise. As most studies

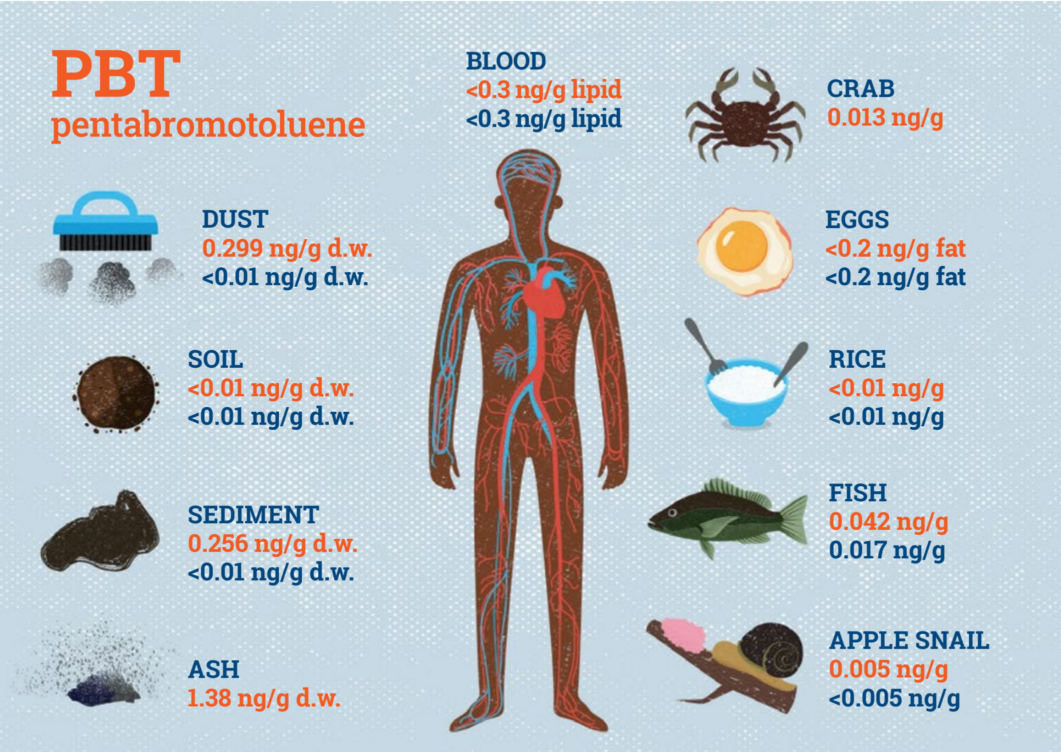


Figure 29: *Median concentrations of the sum of PBT in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

reporting nBFRs concentrations in dust are focused on indoor dust, the possibility to compare the levels found in Kalasin outdoor household dust with other studies is limited. The majority of studies are also limited to analysis of DBDPE.

Zheng, Xu et al. (2015) studied flame retardants in indoor dust from several e-waste recycling sites in South China and found levels of DBDPE up to 201,000 ng/g d.w., which is one order of magnitude higher than the highest concentration found in Khok Sa-ad (10,882 ng/g d.w. in sample KAL-D-1 from the Ban Nong Bua shredding enterprise). Tue, Takahashi et al. (2013) determined DBDPE levels in indoor dust from houses in Vietnam at ranges of 15 – 150 and 31 – 470 ng/g at urban/suburban and informal e-waste recycling sites, respectively. These levels are considerably lower than those observed in Khok Sa-ad workshops (41.3 – 6,116 ng/g d.w.). Muenhor, Harrad et al. (2010) determined a median concentration of 890 ng/g (range 43 - 8700 ng/g) of DBDPE in indoor dust at e-waste storage facilities in Ayutthaya and Nonthaburi provinces, Thailand. These levels are similar to those found in dust sampled inside the shredding enterprise in Ban Nong Bua (5105 and 10,882 ng/g), which can be considered a similar type of facility.

BTBPE is the only nBFR that reached significant levels in eggs from Khok Sa-ad. The highest concentration of 103 ng/g fat (Ban Don Kha, sample KL-EGG-04/22) is higher than the maximum concentration of 78 ng/g fat determined in eggs from Guiyu e-waste site in China (Zeng, Luo et al. 2016). Polder, Müller et al. (2016) studied BFRs in eggs from Arusha, Tanzania and determined BTBPE levels up to 9.8 ng/g fat, which is comparable to egg samples from the vicinity of the shredding enterprise in Ban Nong Bua.

6.1.5 PCDD/Fs and dl-PCBs

6.1.5.1 Bioassay results

The CALUX *in vitro* cell bioassay is a bioanalytical tool that is used for the screening and relative quantification of dioxins and dioxin-like compounds in sample extracts. Because CALUX analyses provide a biological response to all aryl hydrocarbon receptor active compounds present in a given sample extract containing a complex mixture of chemicals, interpretation of results is significantly more complex than of chemical analyses (Windal, Denison et al. 2005). The numerically indicated results of screening methods are suitable for demonstrating compliance or suspected noncompliance or exceedance of action thresholds and give an indication of the range of levels in case of follow-up by confirmatory methods. They are not suitable for purposes such as evaluation of background levels or estimation of intake (European Commission 2014). The EU Regulation No 709/2014 sets out the cut-off values of the DR CALUX analysis determined. In case of egg samples, the cut-off values are 1.7 pg BEQ g^{-1} fat and 3.3 pg BEQ g^{-1} fat for PCDD/Fs and the sum of PCDD/Fs and dl-PCBs, respectively. In case of fish samples, the cut-off values are 2.3 pg BEQ g^{-1} f.w. and 4.3 pg BEQ g^{-1} f.w. for PCDD/Fs and the sum of PCDD/Fs and dl-PCBs, respectively. For rice and dust samples, no cut-off values according to the EU Regulation No 709/2014 were established. Samples below the cut-off values are declared compliant, samples equal or above the cut-off values are suspected to be non-compliant and analysis by a confirmatory method is recommended. Except for the fish and egg reference samples and PCDD/Fs in the egg sample taken right next to the Ban Nong Bua shredding enterprise (KL-D-08/EGG), DR CALUX results for all the egg and fish samples were above the cut-off values.

6.1.5.2 Congener-specific chemical analysis

PCDD/Fs and dl-PCBs expressed as TEQ were determined at median levels several orders of magnitude higher in environmental samples from the e-waste area when compared to background samples (13.5 pg TEQ/g d.w. vs. levels below LOQ in dust and 1400 vs. 0.845 pg TEQ/g d.w. in sediment). Foodstuffs of animal origin contain PCDD/Fs + dl-PCBs median levels that are also considerably higher in samples from the e-waste area when compared to the background samples (5.17 vs. 0.68 pg TEQ/g fat in eggs, 5.84 vs. 0.143 pg TEQ/g in fish and 10.4 pg TEQ/g vs. concentrations below LOQ in snails). Interestingly, PCDD/Fs + dl-PCB levels in rice from the e-waste area are practically the same as in rice from the reference organic farm (see Figure 30). It has to be emphasized that PCDD/Fs are produced through a variety of incineration processes, including burning of trash and biomass burning (NIEHS 2022). Therefore, e-waste recycling is certainly not the only source of PCDD/Fs in the analysed foodstuffs.

A concentration gradient between working and living areas of e-waste recycling workshops could not be determined for PCDD/Fs + dl-PCBs due to an insufficient number of such samples analysed for these POPs.

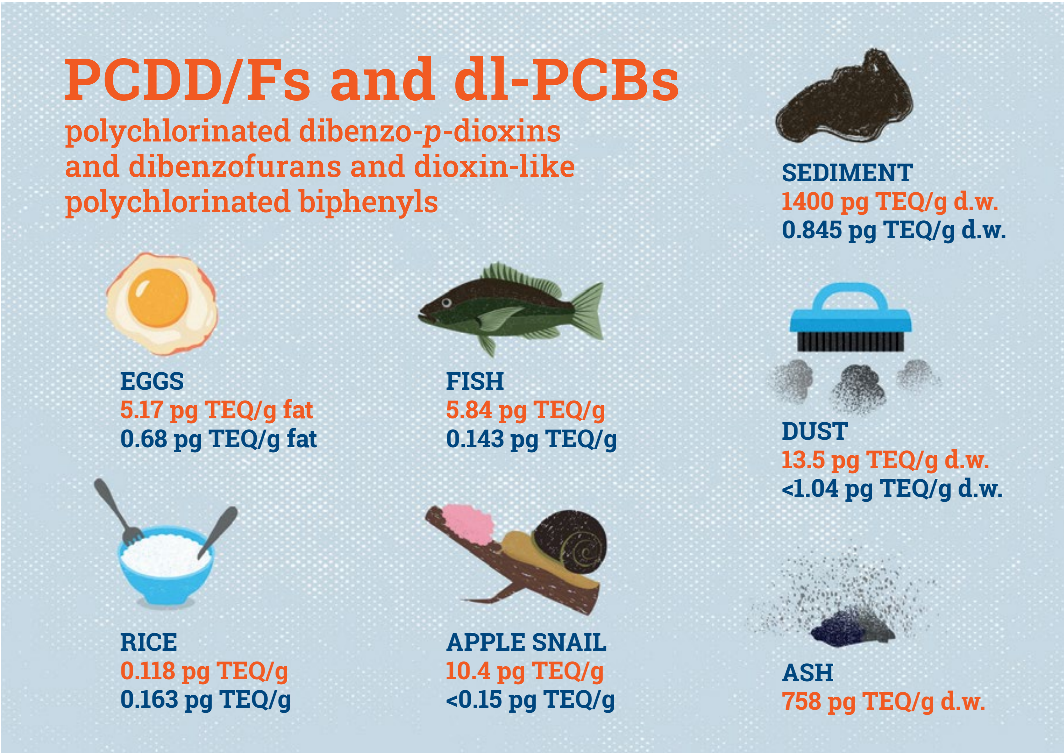
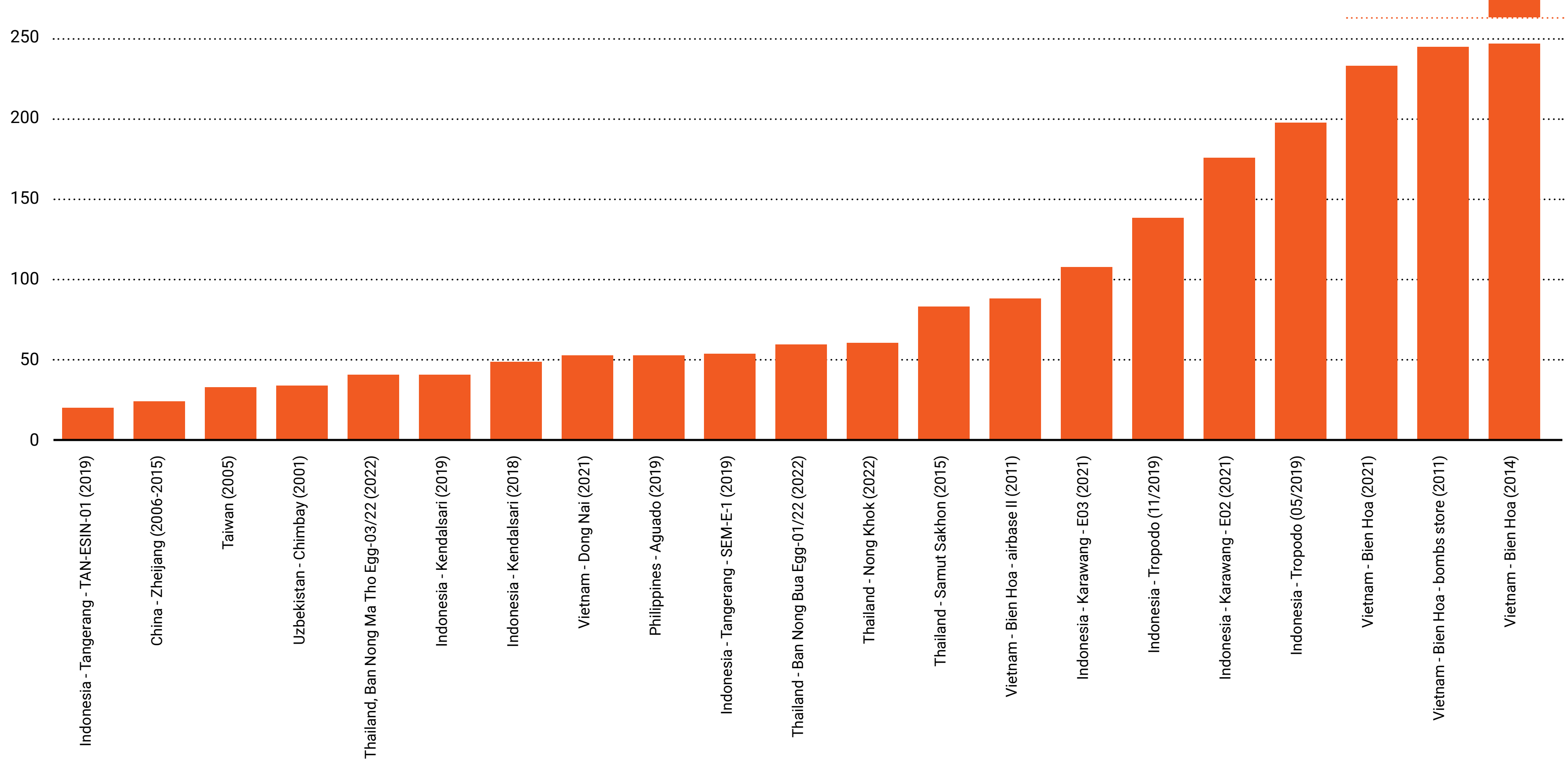


Figure 30: *Median levels of PCDD/Fs + dl-PCBs expressed as TEQ in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

Figure 31: *Highest levels of PCDD/Fs measured in poultry eggs from Asian countries (Muntean, Jermini et al. 2003; Nghiem, Hoang et al. 2022; Kudryavtseva, Shelepchikov and Brodsky 2020; Petrlik, Dvorska et al. 2018; Petrlik, Bell et al. 2021; Petrlik, Bell et al. 2022; Petrlik, Boontongmai et al., 2022; Petrlik, Ismawati et al. 2020; Petrlik, Ismawati et al. 2022; Shen, Guan et al. 2017; The Epoch Times 2005; Traag, Hoang et al. 2012). Levels of congeners below LOQ were substituted by half of the LOQ in most of the cited studies; a minority of the studies used lowerbound or upperbound concentrations.*



However, concentration gradients in sediment and dust samples indicate that the Ban Nong Bua dumpsite and its traffic are sources of PCDD/Fs + dl-PCBs contamination of its surroundings. Sediment concentrations in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (24.7 pg TEQ/g d.w. and 2776 pg TEQ/g d.w., respectively). Dust concentrations on the access road gradually decreased with distance from the dumpsite. PCDD/Fs + dl-PCBs were present at levels of 42 pg TEQ/g d.w. 250 m away, while at the entrance to the dumpsite and within it, the levels were between 448 and 761 pg TEQ/g d.w.

In order to compare the PCDD/Fs and dl-PCBs levels in Kalasin foodstuffs with European legal limits, recalculation of the analysis results were done on the assumption that all the values of the different congeners below the LOQ are equal to the LOQ (upperbound concentrations). These levels are slightly higher than levels reported in chapter 5.1 and Figure 29 (calculation with half of LOQ concentration). The median level of 5.21 pg TEQ/g fat in pooled chicken egg samples from villages with e-waste recycling workshops slightly exceeds the limit value of 5 pg TEQ/g fat for the sum of PCCD/Fs and dl-PCBs set for eggs in the European Union (European Commission 2011). The highest levels were found in samples KL-EGG-01/22 (76.0 pg TEQ/g fat) and KL-EGG-03/22 (52.6 pg TEQ/g fat); they exceed European legal limits by more than 10 times. However, these eggs are not intended for human consumption. The median level of 5.85 pg TEQ/g for PCDD/Fs and dl-PCBs in pooled fish samples from the Ban Nong Bua dumpsite surroundings is slightly below the European limit value of 6.5 pg TEQ/g wet weight (European Commission 2011). However, the level of 7.16 pg TEQ/g for PCDD/Fs and dl-PCBs in fish sample KL-07-FISH/1-2 exceeds the European limit value. Levels of PCDD/Fs dominate in all egg samples when compared to dl-PCBs, while this pattern is not visible in the fish samples.

Levels of 40.6 pg TEQ/g fat of PCDD/Fs in pooled egg samples from Ban Nong Ma Tho (KL-EGG-03/22) and 59.5 pg TEQ/g fat from Ban Nong Bua (KL-EGG-01/22) are among the highest levels measured in Asia. These values correspond to levels determined in a pooled duck egg sample from the Nong Khok village, Chachoengsao province in Thailand, where e-waste recycling is also carried out. However, they are significantly lower than the content of PCDD/Fs in chicken eggs from Samut Sakhon, Thailand, a site affected by the metallurgical industry. A comparison can be seen in Figure 31. The limit value for PCDD/Fs in eggs is set to 2.5 pg TEQ/g

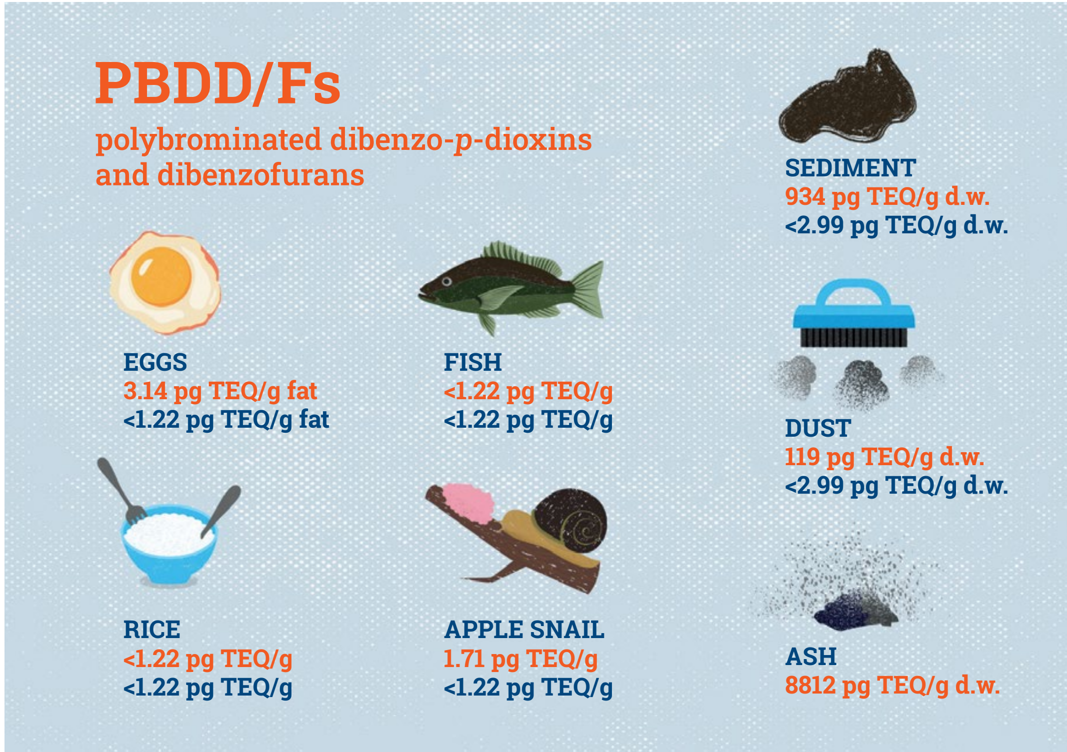


Figure 32: *Median levels of PBDD/Fs expressed as TEQ in various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

fat in the European Union (European Commission 2011), which is eight times lower than the lowest concentration of 20 pg TEQ/g fat included in Figure 31. The findings from this study can be also compared with global egg data using the publication by Petrlik, Bell et al. (2022).

6.1.6 PBDD/Fs

PBDD/Fs are a very relevant group of unintentionally produced POPs at sites affected by e-waste and/or plastic waste business due to the content of BFRs in such waste. This was demonstrated in studies; e.g., from Agbogbloshie, Ghana (Hogarh, Petrlik et al. 2019) and Samut Sakhon, Thailand (Teebthaisong, Petrlik et al. 2018).

PBDD/Fs expressed as TEQ were determined at median levels about two orders of magnitude higher in environmental samples from the Khok Sa-ad e-waste area when compared to background samples (119 pg TEQ/g d.w. vs. levels below LOQ in dust and 934 pg TEQ/g d.w. vs. levels below LOQ in sediment). Eggs from Khok Sa-ad contained PBDD/Fs median levels of 3.14 pg TEQ/g fat, which is approximately three times the LOQ value that was not reached in the reference sample. Snail samples from Khok Sa-ad contained PBDD/Fs levels slightly above the LOQ (1.71 pg TEQ/g), and again this level was not reached in the reference samples. Fish and rice samples did not contain levels above the LOQ in Khok Sa-ad nor at the reference site (see Figure 32).

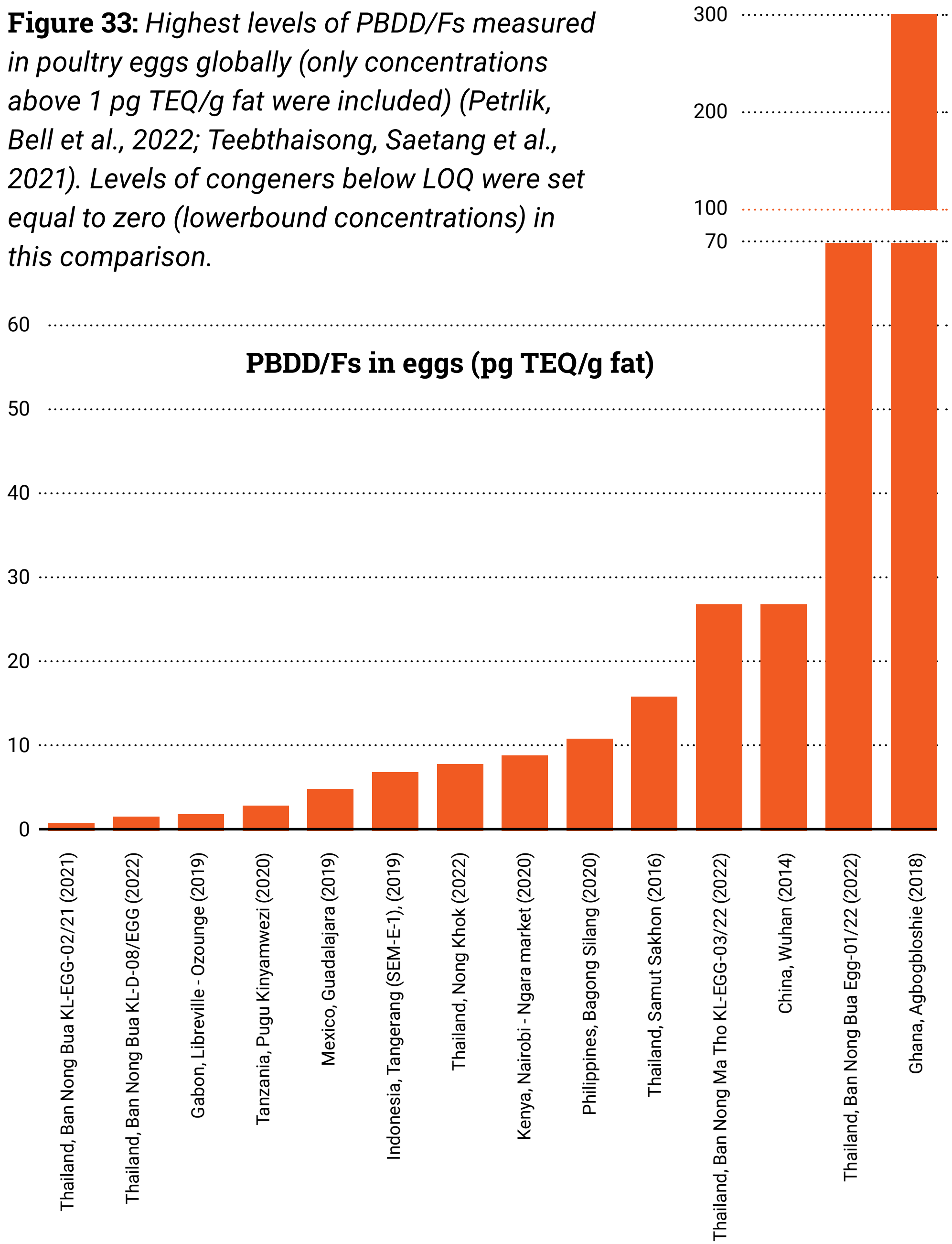
Dust PBDD/Fs concentration gradients were inspected in two Ban Nong Ma Tho workshops; relevant dust samples from the other workshops were not analysed for PBDD/Fs. In both cases concentrations in the working areas were considerably higher than in living areas, with the bigger difference reaching one order of magnitude (129 pg TEQ/g d.w. vs. 28.3 pg TEQ/g d.w.). This indicates that e-waste dismantling and recycling activities are a source of PBDD/Fs in household dust.

The Ban Nong Bua dumpsite and its traffic are a source of PBDD/Fs contamination of various environmental compartments in its surroundings. This is indicated by concentration gradients in sediment and dust. Sediment concentrations in a pond outside the dumpsite were three orders of magnitude lower than in a pond within the dumpsite (5.80 pg TEQ/g d.w. and 1862 pg TEQ/g d.w., respectively). Dust levels on the access road gradually decreased with distance, but PBDD/Fs were still present in a concentration of 64.6 pg TEQ/g d.w. 250 m away. Dust PBDD/Fs levels on the track within the dumpsite were two orders of magnitude higher (2508 pg TEQ/g d.w.), and a mixed dust and ash sample from within the dumpsite contained 16 898 pg TEQ/g d.w.

There is no limit value set for PBDD/Fs in foodstuffs. However, PBDD/Fs are considered to have similar toxicity as their chlorinated analogues (van den Berg, Denison et al. 2013), and a comparison of determined PBDD/Fs levels with various TEQ-based PCDD/Fs limit values has been conducted previously (Budin, Petrlik et al. 2020). Taking into account the limitations of such a comparison, it has to be concluded that two of the Kalasin egg samples (upperbound concentrations of 34.0 pg TEQ/g fat and 92.9 pg TEQ/g fat in KL-EGG-03/22 from Ban Nong Ma Tho and KL-EGG-01/22 from Ban Nong Bua, respectively) exceed the European limit value of 2.5 pg TEQ/g for PCDD/Fs in eggs (European Commission 2011) many times. The exceptional contamination of some of the Kalasin egg samples is also demonstrated in Figure 33, where the highest PBDD/Fs concentrations in poultry eggs globally are depicted.

In February 2022, EARTH and Arnika also took two composite dust samples from a village nearby the Supcharoen Recycle Co. Ltd. factory and one composite dust sample from next to the CT Steel Co. Ltd. factory in Khao Hin Son subdistrict, Phanom Sarakham district, Chachoengsao province. Both factories focus on e-waste dismantling and recycling. PBDD/Fs levels in these dust samples were between 3.9 and 10.2 pg TE-

Figure 33: *Highest levels of PBDD/Fs measured in poultry eggs globally (only concentrations above 1 pg TEQ/g fat were included) (Petrlik, Bell et al., 2022; Teebthaisong, Saetang et al., 2021). Levels of congeners below LOQ were set equal to zero (lowerbound concentrations) in this comparison.*



Q/g d.w. (Petrlik, Boontongmai et al. 2022), which is one to two orders of magnitude less than the median level of PBDD/Fs in dust from Khok Sa-ad (119 pg TEQ/g d.w.).

6.1.7 HCB, PeCB and HCBD

Higher concentrations of HCB in environmental and foodstuffs samples were measured in Khok Sa-ad when compared to the reference site. HCB was present at median concentrations one to two orders of magnitude higher in environmental samples from the e-waste area when compared to background samples (0.112 and 9.83 ng/g d.w. in Khok Sa-ad dust and sediment, respectively, vs. concentrations below laboratory LOQ in the background samples). This situation is reflected in foodstuffs of animal origin where HCB median concentrations are also one order of magnitude higher in samples from the e-waste area when compared to the background samples (1.32 vs. 0.578 ng/g fat in eggs, 1.59 vs. 0.105 ng/g in fish and 0.872 vs. 0.016 ng/g in snails). Median concentrations of HCB in blood serum of e-waste workers and the reference group of organic farmers and agriculturalists were similar (see Figure 34).

A similar pattern as described above for HCB can be observed also for PeCB, although levels in environmental samples are generally slightly higher, in foodstuffs of animal origin slightly lower, and in blood serum one order of magnitude lower than for HCB (Figure 35).

A likely concentration gradient of HCB is indicated when comparing dust concentrations in workshops, where dust from both working and living areas was sampled. Concentrations in the working areas of all but one functioning workshop were usually one order of magnitude higher than in living areas. The biggest difference was found in the Ban Noi workshop (1.46 ng/g d.w. vs. 0.081 ng/g d.w.). This indicates that waste and e-waste dismantling and recycling activities may be a source of

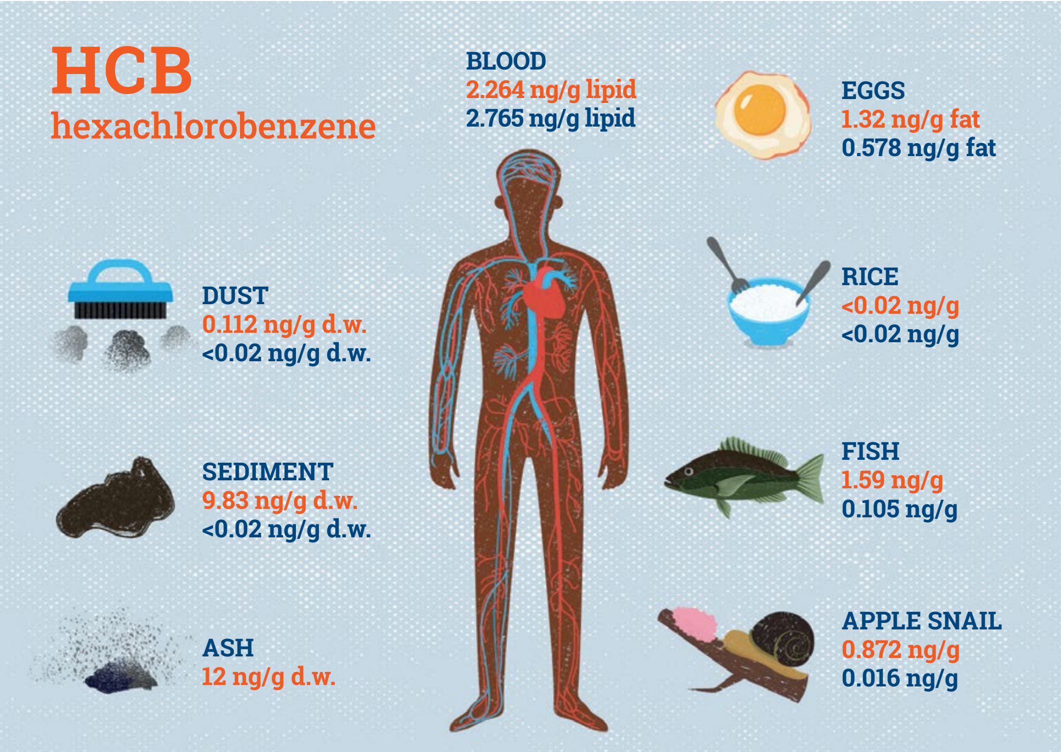


Figure 34: *Median concentrations of HCB in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

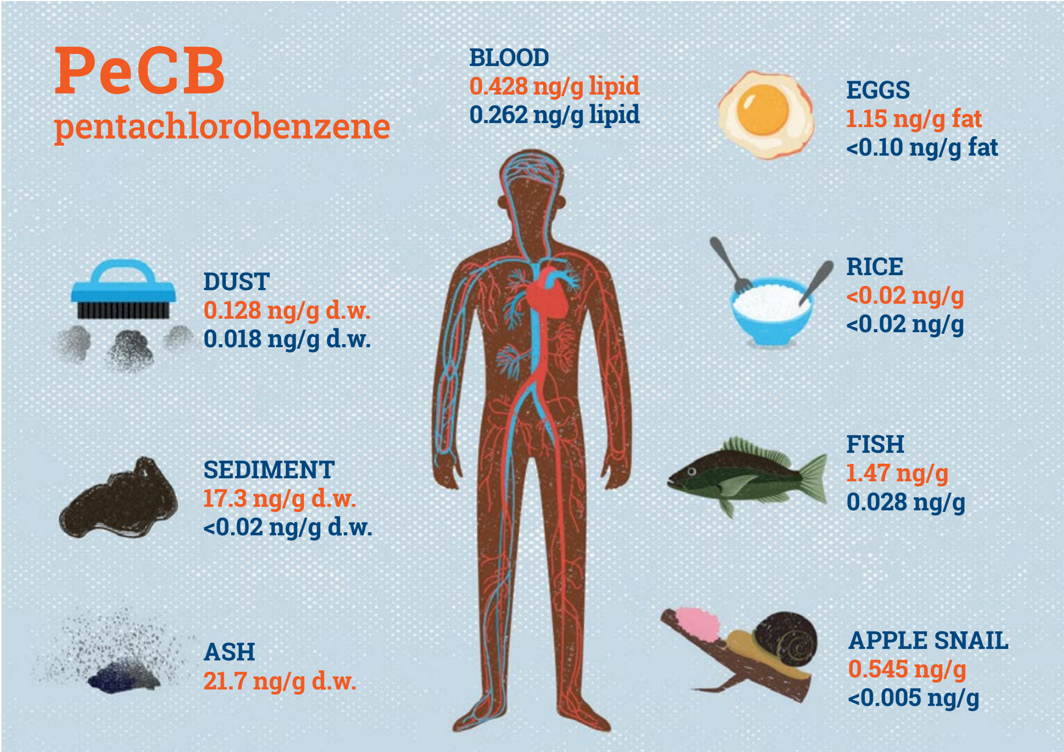


Figure 35: *Median concentrations of PeCB in blood serum of e-waste workers and various environmental compartments and foodstuffs of the Khok Sa-ad e-waste recycling area compared to background concentrations*

HCB in household dust. However, HCB concentrations in living areas of the households are only slightly above the laboratory LOQ. Also, HCB concentrations in dust of a closed workshop in Ban Nong Ma Tho a decade after termination of the recycling activities are only slightly above LOQ (0.043 ng/g d.w. in the former working area and 0.054 ng/g d.w. in the living area). The very same pattern can be recognized in the samples for PeCB.

The Ban Nong Bua dumpsite and its traffic are a source of HCB and PeCB in various environmental compartments in its surroundings. This is, in detail, illustrated for HCB. Sediment concentrations of this POP in a pond outside the dumpsite were two orders of magnitude lower than in a pond within the dumpsite (0.24 ng/g d.w. and 19.4 ng/g d.w., respectively). Dust concentrations on the access road gradually decreased with distance; i.e., HCB concentrations were below LOQ 250 m away, rose to 1.84 ng/g d.w. 120 m away, and were between 4.43 ng/g d.w. and 19.2 ng/g d.w. at the entrance of the dumpsite and within it.

Concentrations of HCB in Khok Sa-ad free-range egg samples were between 1.15 ng/g fat and 6.05 ng/g fat with a median value of 1.32 ng/g fat. These are one to two orders of magnitude lower concentrations when compared to egg samples taken nearby a municipal waste incinerator in Wuhan, China. Otherwise, the findings from Khok Sa-ad are quite comparable with other free-range poultry egg samples from Thailand and other Asian countries taken in the vicinity of various potential pollution sources (Table 18).

Table 18: *Overview of HCB concentrations measured in free-range chicken and duck eggs from localities in Asian countries*

Country	Locality	Year	HCB (ng/g fat)	Potential source of contamination	Reference
Armenia	Alaverdi	2018	1.7	Metallurgical industry	Petrlik and Strakova 2018
China	Wuhan 1	2014	481	Municipal waste incinerator	Petrlik 2016
China	Wuhan 2	2014	28.9	Municipal waste incinerator	Petrlik 2016
India	Eloor	2005	7.7	Chemical industry	DiGangi and Petrlik 2005; Jayakumar, DiGangi et al. 2005
India	Lucknow	2005	3.8	Hazardous waste incinerator	Agarwal, Kuncova et al. 2005; DiGangi and Petrlik 2005
Kazakhstan	Shabanbai Bi	2014	6.25	Unknown	Petrlik, Kalmykov et al. 2016
Kazakhstan	Baskuduk	2016	2.94	Municipal waste dumpsite	Petrlik, Kalmykov et al. 2016
Kazakhstan	Shetpe	2016	6.29	Cement kiln - potential hazardous waste co-incineration	Petrlik, Kalmykov et al. 2016
Kazakhstan	Balkhash	2014	4.39	Metallurgical industry	Petrlik, Kalmykov et al. 2016
Pakistan	Peshawar	2005	1.1	Municipal waste dumpsite	DiGangi and Petrlik 2005; Petrlik, Khwaja et al. 2005
Philippines	Aguado	2005	1.7	Hazardous waste incinerator	Calonzo, Petrlik and DiGangi 2005; DiGangi and Petrlik 2005
Thailand	Nong Khok	2022	6.1	E-waste factory	Petrlik, Boontongmai et al. 2022
Thailand	Map Ta Phut	2016	6.8	Chemical industry	Petrlik, Dvorska et al. 2018
Thailand	Samut Sakhon	2015	4.21	Metallurgical industry	Petrlik, Dvorska et al. 2018
Thailand	Khon Kaen	2016	5.52	Mixed industrial sources	Petrlik, Dvorska et al. 2018
Thailand	Map Ta Phut	2016	3.61	Chemical industry	Petrlik, Dvorska et al. 2018
Thailand	Koh Samui	2016	1.84	Municipal waste landfill	Petrlik, Dvorska et al. 2018
Thailand	Map Ta Phut	2016	4.79	Chemical industry	Petrlik, Dvorska et al. 2018

HCBD was analysed in less than half of the samples from Khok Sa-ad and concentrations were mostly below LOQ. The only exemptions are sediment and ash samples, which are reflected in median concentrations slightly above LOQ (see Figure 36).

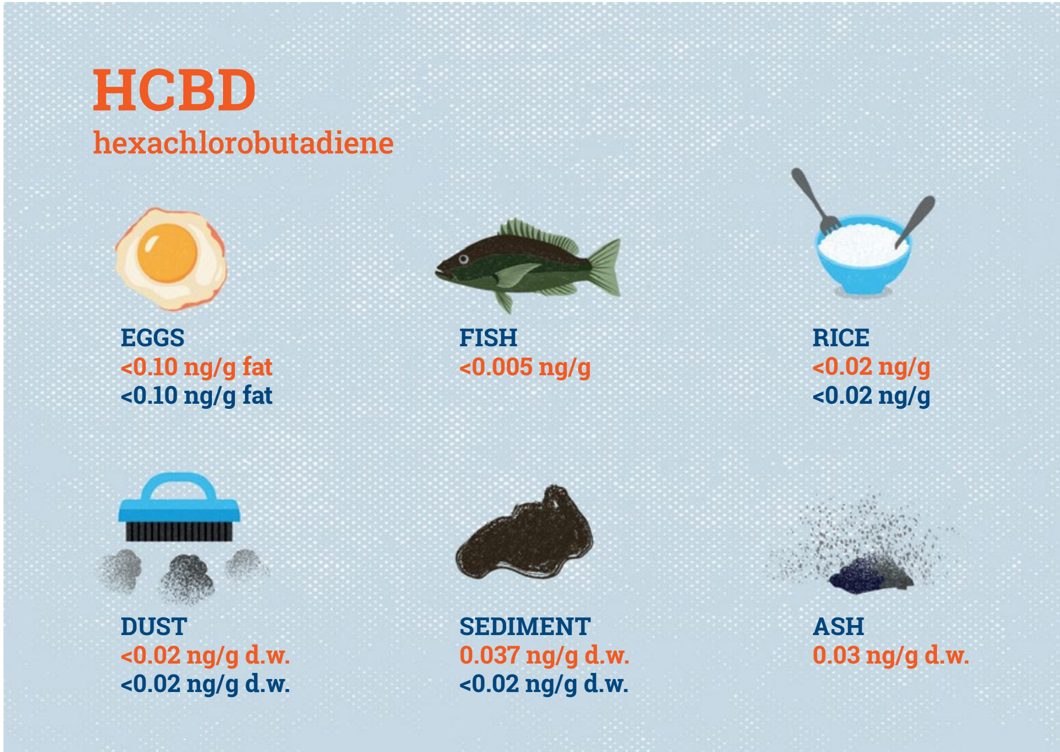


Figure 36: *Median concentrations of HCBD in various environmental compartments and foodstuffs of the Kalasin e-waste recycling area compared to background concentrations*

6.2 Health effects of BFRs and DP[15]

PBDEs have historically been the most used brominated flame retardants, but because of their known toxicity, many newer chemicals containing bromine are in use but have not been as intensively studied. Therefore, we have the most complete information on the PBDEs, but it is likely that other brominated flame retardants share similar problems, even though they may not be as persistent in the environment or in the human body. This chapter will focus on human studies, although the results from animal and cellular studies are more definitive.

The best studied and documented effects of PBDEs are on human thyroid function. Although there are a number of reports of effects in humans, not all results are consistent, which may reflect different effects of different PBDE congeners. Using the US National Health and Nutrition Examination Survey (NHANES) data derived from a random sample of Americans, Allen, Gale et al. (2016) found that PBDE 47, 99, and 100 concentrations in women were associated with an increase in unspecified thyroid disease. In a study of Canadian women, exposure to four congeners and total PBDEs was associated with an increased risk of hypothyroidism, greater in younger adult women than older (Oulhote, Chevrier et al. 2016). Total PBDE levels in children ages 1 to 5 have been found to be associated with elevated thyroid-stimulating hormone (TSH), the hormone released from the hypothalamus that drives the thyroid gland, and reduced lower levels of thyroxine (T4) that was not bound to proteins (free T4) (Jacobson, Barr et al. 2016), consistent with hypothyroidism. Huang, Wen et al. (2014) found that different PBDE congeners had different effects, with TSH positively correlated with PBDEs 17, 28, 47 and 183, but negatively correlated with PBDE 99. Liu, Zhao et al. (2017) also found different effects of different PBDE congeners, as well as their hydroxylated metabolites. Using wrist bands to monitor

15 This chapter is authored by David O. Carpenter, Institute for Health and the Evironment, University at Albany, USA chemicals in air, Wang, Romanak et al. (2020) reported significant positive associations between PBDE 99, 100, 197 and 208, but negative associations with hexabromobenzene in females. However, TSH levels during pregnancy were reported to be reduced by 10-18.7% in relation to every 10-fold increase in PBDE exposure (Chevrier, Harley et al. 2010), but levels of free and total T4 were not significantly altered. Some (Makey, McClean et al. 2016) but not all (Vuong, Webster et al. 2015) studies report a decrease in T4, which is unusually attributed to competitive binding of some brominated flame retardants to thyroid hormone transport proteins like transthyretin (Meerts, van Zanden et al. 2000), which results in metabolism of T4. Animal studies have also shown that exposure to PBDEs results in a reduction in T4 more than triiodothyronine (T3), without significant effect on TSH (Hallgren, Sinjari et al. 2001; Zhou, Ross et al. 2001). T3 is the more active thyroid hormone and has one less iodine molecule than T4.

It is well known that hypothyroidism during pregnancy results in reduced cognitive function in the child (Haddow, Palomaki et al. 1999). There is strong evidence that prenatal PBDE exposure alters cognitive function in the child, but it is unclear whether this is totally due to altered thyroid function. While Gascon, Vrijheid et al. (2011) did not find any change in thyroid hormones in relation to the level of PBDE 47, they found increased risk of ADHD. Chen, Yolton et al. (2014) found that a 10-fold increase in levels of PBDE 47 was associated with a significant 4.5 decrease in full-scale IQ and a 3.3-fold increase in hyperactivity score in children ages 2-5. In a meta-analysis of 10 studies, Lam, Lanphear et al. (2017) concluded that there was sufficient evidence to conclude that exposure to PBDE during development was associated with a reduced intelligence. Rodent studies show clear decrements in learning and memory after exposure to individual PBDE congeners (Viberg, Fredriksson et al. 2003) or PBDE mixtures (Branchi, Capone et al. 2003).

PBDEs also alter other endocrine systems, as summarized in a review by Dishaw, Macaulay et al. (2014), especially those related to body mass and obesity, but once again the results are complex. Erkin-Cakmak, Harley et al. (2015) found evidence that *in utero* exposure to PBDEs increases body mass index (BMI) in boys, but decreased it in girls at 7 years of age. Hoppe and Carey (2007) have reported that daily exposure of rats to penta-BDE caused an increase in lipolysis of adipocytes and a large suppression of T4 levels. Developmental exposure of rats to low-dose PBDE 99 causes impaired spermatogenesis (Kuriyama, Talsness et al. 2005), although male reproductive function was not found to be altered by PBDEs in humans (Toft, Lenters et al. 2014). *In vitro* studies have shown that several PBDE congeners, OH-PBDEs and brominated bisphenol A are agonists at estrogen receptors alpha and beta (Meerts, Letcher et al. 2001).

One major problem is that there has not been much study of other brominated compounds, either in animals or humans. While shorter chain compounds are usually more easily metabolized, and therefore less persistent, exposure is often continuous, so this does not mean that they are less toxic. And it is likely that they influence the same organ systems.

The other compound of concern is Dechlorane Plus (DP), which is also a flame retardant used in electronic equipment that ends up in e-waste sites, where it has been found to cause human exposure (Ma, Stubbings et al. 2021). This compound is even less studied than the brominated flame retardants, but has been found to bind to thyroid receptor α (Zhu, Zhao et al. 2022), promote adipogenesis in human preadipocytes (Peshdary, Calzadilla et al. 2019) and adipose tissue dysfunction and glucose intolerance in mice (Peshdary, Styles et al. 2020). It causes neurobehavioral changes in zebrafish (Chen, Chen et al. 2019). Thus it is likely that DP has all of the same potential adverse human health effects that characterize PBDEs and other brominated flame retardants.

The level of threat to human health of other persistent chemicals has been less studied. Decabromodiphenyl ethane is used in plastics and textiles, also is persistent and lipophilic, and is now widely used as a replacement for other PBDEs, albeit without adequate study of its toxicity. It has been reported to cause both neuro (Wang, Zeng et al. 2022) and hepatic toxicity (Sun, Wang et al. 2020). PBDE 209 is of special interest because it is still currently in widespread use, while lower brominated PBDEs have been widely restricted, and has been suggested to promote obesity (Yanagisawa, Koike et al. 2019), reproductive issues (Li, Liu et al. 2021) and neurotoxicity (Costa and Giordano 2011). But much more study of the toxicity of these compounds is needed.

6.2.1 Levels of studied substances in e-waste workers in Thailand

On average, the e-waste workers did not show marked differences in concentrations of HCB, PeCB, sum HBCD, BTBPE, HBBz, OBIND, PBEB, PBT or TBBPA. However, on average e-waste workers had 4.5 times the concentration of PBDE 209, 6.08 times the concentration of the sum of PBDEs and 39.3 times the concentration of DP when compared to the concentrations in blood of donors from the reference site. The concentrations in human blood roughly reflect those found at the different sites, and although there is some variability in both the environmental concentrations at the different sites and human concentrations among individuals, these chemicals with clear elevations in e-waste workers as compared to blood donors at the clean (reference) site indicate those chemicals of greatest concern. The elevations in concentrations of DP are particularly striking, which emphasizes how important it is to further study its health effects.

These chemicals that have elevated concentrations in Thai e-waste workers have relatively similar forms of human toxicity. The one clear danger is alteration in thyroid function. Because thyroid hormone regulates human metabolism, anything that interferes with thyroid function increases the risk of a variety of symptoms, ranging from altered cognitive function and energy levels to weight and overall health. Hypothyroidism promotes obesity, tiredness, fatigue, dry skin, and reduced energy, while hyperthyroidism has the opposite effects. As the thyroid is a hormone that affects almost every aspect of human physiology, there can be other organ-specific effects.

Medical monitoring of exposed e-waste workers should include annual measurements of TSH and both free and total T3 and T4, as there are medications that can treat thyroid diseases. There should also be monitoring of fasting glucose levels, since obesity is such a major risk factor for development of diabetes. However, the most important thing that should be done is to take steps to reduce exposure in the first place. This should include wearing respiratory protection while dismantling e-waste, avoiding eating and drinking in areas where dust containing these chemicals is found, and frequent cleaning of the area where e-waste is being dismantled, nearby areas where workers relax, and homes where e-waste workers may unintentionally introduce chemical contaminants from their clothes.

7. Conclusions

The main goal of this study was to comprehensively describe the levels of selected intentionally and unintentionally produced POPs in e-waste recycling communities in Khok Sa-ad, a subdistrict of Khong Chai district in the Kalasin province, northeastern Thailand. The analysis of the concentration of numerous flame retardants, technical chemicals and byproducts of industrial as well as waste disposal processes in over one hundred samples of various environmental matrices, selected foodstuffs and blood serum of e-waste workers **is a significant source of information about pollutant levels and distribution in an e-waste area such as Khok Sa-ad.** The extensity of the presented work is in contrast to most previously published studies, where only a few have investigated concentrations of the POPs in question in multiple matrices in e-waste recycling areas.

The results of this study confirm a wide presence of most of the studied POPs in the environment of the concerned e-waste recycling areas as well as in e-waste workers themselves. The POPs contamination found in these communities can be linked to waste and e-waste recycling activities due to the following facts and findings:

- The POPs studied are used in electronics and plastics, and their releases can be linked to certain waste and e-waste disposal practices (open burning).
- **Levels in the Khok Sa-ad environment and foodstuffs of animal origin are in comparison with reference samples considerably higher for Dechlorane Plus, PCDD/Fs and dl-PCBs, PBDD/Fs, HCB, PeCB, ndl-PCBs and PBDEs. A considerable difference is also found in concentrations of some nBFRs in dust, especially DBDPE.**
- **There is a substantial difference between the concentration of PBDEs and Dechlorane Plus in the blood serum of e-waste workers and the reference group of organic farmers and agriculturalists.**
- Concentration gradients of Dechlorane Plus, PBDD/Fs, PCDD/Fs and dl-PCBs, ndl-PCBs, HCB, PeCB, nBFRs and PBDEs were found in sediment and dust, and eventually soil samples. The pollution by these substances was the highest at the dumpsite with a substantial quantity of waste from electronic equipment and machineries, or right next to this dumpsite (and decreasing with distance from it). Also, concentrations of Dechlorane Plus, PBDD/Fs, HCB, PeCB, TB-

BPA, nBFRs and PBDEs were generally higher in the dust of working areas of households running an e-waste workshop when compared to resting and eating areas of these households.

Environmental contamination can be a source of POPs in humans. Ingestion of contaminated dust is considered one of the major pathways for human POPs exposure in e-waste recycling areas and elsewhere. Exposed workers in the Thai e-waste recycling communities and the control group from organic farms share similar dietary habits, but their local food contains different POP concentrations. Contamination of the local food chain in Khok Sa-ad is indicated by high concentrations of PCDD/Fs and PBDD/Fs in some of the sampled chicken eggs, exceeding European legal limits by one order of magnitude. However, these eggs are not primarily intended for human consumption. Therefore, dietary exposure may only partly explain the blood serum Dechlorane Plus and PBDE concentration differences between e-waste workers and the control group. It should be noted that the environmental and food samples were only partly paired with human blood samples, which leads to some uncertainties. Still, **the results of our study clearly link elevated Dechlorane Plus and PBDE levels in Thai e-waste workers with recycling activities in their communities.**

The one clear danger of the elevated Dechlorane Plus and PBDE levels found in e-waste workers is alteration in thyroid function. Because the thyroid hormone regulates human metabolism, anything that interferes with thyroid function increases the risk of a variety of symptoms, ranging from altered cognitive function and energy levels to weight and overall health. Hypothyroidism promotes obesity, tiredness, fatigue, dry skin, and reduced energy, while hyperthyroidism has the opposite effects. As thyroid is a hormone that affects almost every aspect of human physiology, there can be other organ-specific effects.

Based upon the results of the study, recommendations for Kalasin e-waste workers are suggested. Medical monitoring of e-waste workers and community members should include:

- Annual measurements of thyroid stimulating hormone (TSH) levels and both free and total triiodothyronine (T3) and thyroxine (T4)
- Fasting glucose levels

Personal protection measures for reducing e-waste workers' exposure to POPs include:

- Wearing respiratory protection while dismantling e-waste. Any kind of respiratory protection should be well fitting; i.e. medical masks are not recommended. In the case of using a simple cloth mask or any kind of reusable mask, it should be cleaned (washed) every time before it is put on.
- Hair and skin should be covered during work and/or washed afterwards.
- Work clothes have to be washed frequently.
- Eating and drinking should be avoided in areas with contaminated dust (i.e., working areas).
- E-waste dismantling and other working areas should frequently be cleaned of dust. Additional areas to be frequently cleaned include nearby areas where workers relax, and homes where e-waste workers may unintentionally introduce chemical contaminants from their clothes. Cleaning should be conducted on a wet - not dry - basis to avoid dust resuspension.
- Special attention must be paid to prevent toddlers from being exposed to contaminated dust due to their mouthing behaviour. Toddlers should especially be kept away from areas with contaminated dust (i.e., working areas).
- Although chicken eggs and meat are rarely consumed and samples of aquatic animals did not contain striking POP concentrations, for

safety reasons it is recommended to avoid the consumption and selling of locally-collected and produced foodstuffs of animal origin.

Measures to be adopted at the dumpsite are:

- Burning of waste at the dumpsite should be stopped immediately.
- No people should live, sleep or eat at the dumpsite or nearby.
- Workers whose jobs require them to be at the dumpsite for longer periods of time should wear additional respiratory protection (fine dust respirators).

It has to be emphasized that the formulated recommendations above are related to levels of substances that were studied and found in Khod Sa-ad. The study was designed in order to comprehensively screen a presumably problematic situation; however, it shall not be understood as sufficient for an exact determination of risks. For example, sampling of foodstuffs was not at all exhaustive. Also, **not all possible POPs were determined in the samples and numerous other pollutants are also of relevance for e-waste areas**. A prominent example of such a pollutant group are heavy metals. Including additional pollutants into the study would possibly lead to the formulation of additional recommendations for e-waste workers. It is also important to note that **the extent of health risks or prevalence of health impairments in an e-waste recycling population always arises from a complex mixture of various pollutants affecting this population and also factors not related to the e-waste business** (e.g., age, gender, diet, overall health condition, lifestyle, and other polluting activities such as domestic waste burning).

Policy recommendations for POPs include:

- To create a national system for e-waste management that reflects the principles of a toxic-free circular economy and extended producer's responsibility, as well as environmental and human rights.
- To implement a specific law for environmental restoration and compensation in Thailand.
- To set strict limits for POP content in waste under the Stockholm and Basel Conventions and ensure that waste containing POPs above such levels is not imported to Thailand or recycled in Thailand. POP content in waste must be destroyed or irreversibly transformed to avoid POP emissions into the environment and workers' exposures during e-waste dismantling and recycling.
- To review the need for exemptions from the global ban of PBDEs and Dechlorane Plus under the Stockholm Convention.
- To stop exempted uses of legacy POPs under the Stockholm Convention.
- To work towards a labelling system of products containing Dechlorane Plus under the Stockholm Convention to ensure easy identification of such products and to help Thailand separate dangerous products and wastes to reduce exposure and environmental contamination. This would also help to prevent ongoing exposures to Dechlorane Plus in workplaces, protecting health and promoting a non-toxic recycling system.

Results of this study illustrate that **pollution by POPs is a chronic problem that infringes on the rights to good environment and health of local communities in Thailand**. The fact that Khok Sa-ad subdistrict is located in Kalasin, a province that has been reported to have one of the highest poverty ratios in the Thai nation, exacerbates the socioeconomic dimension of this problem (UN DESA 2020). **The POPs in Khok Sa-ad are found in the blood of locals from a community that stands at the lower end of the socioeconomic gradient, but the e-waste from which those POPs originate likely comes from the more affluent sector of Thai society, and may have been imported from more developed countries.** Firstly, the mismanagement of e-waste is a function of more affluent societies pushing the burden of waste management and the associated pollutants to the poorer sectors. Secondly, it reflects the fact that **Thailand still severely lacks a national system for e-waste management that reflects the principles of a toxic-free circular economy and extended producer's responsibility, as well as environmental and human rights.**

The extensive contamination by POPs in the Khok Sa-ad area further reflects the conundrum of environmental restoration in Thailand. Currently, there is no clear example of successful restoration of a POPs-contaminated environment in Thailand. The **lack of a specific law for environmental restoration and compensation in Thailand's national legal milieu** is a big factor in this issue. It further highlights the **importance of restoration and restitution for POP contamination in developing countries within the context of the Stockholm Convention**.

In any case, the environment of the Khok Sa-ad site in the Kalasin province must receive restoration as soon as possible, to protect those people living in the locality and working in e-waste recycling operations. The responsibility of environmental restoration cannot be placed solely upon the local authorities, who are bound in capacity by limited resources. Therefore, we recommend that the central agencies of the Thai government explore options for environmental restoration of the Khok Sa-ad site, and take the lead in the initiative going forward.

References

Abou-Elwafa Abdallah, M. (2016). „Environmental occurrence, analysis and human exposure to the flame retardant tetrabromobisphenol-A (TBBP-A)-A review." Environment International **94**: 235-250.

Adu-Kumi, S., J. Petrlik, E. Akortia, M. Skalsky, J. Pulkrabova, J. Tomasko, L. Bell, J. N. Hogarh, D. Kalmykov and A. Arkenbout (2019). „Short-chain chlorinated paraffins (SCCPs) in eggs from six countries." Organohalogen Compounds **81**(2019): 337-339.

Agarwal, R., H. Kuncova, J. Petrlik, J. DiGangi, M. Skalsky and L. Maskova (2005). Contamination of chicken eggs near the Queen Mary's Hospital, Lucknow medical waste incinerator in Uttar Pradesh (India) by dioxins, PCBs and hexachlorobenzene. Keep the Promise, Eliminate POPs Reports.

Allen, J. G., S. Gale, R. T. Zoeller, J. D. Spengler, L. Birnbaum and E. McNeely (2016). „PBDE flame retardants, thyroid disease, and menopausal status in U.S. women." Environ Health **15**(1): 60.

Anh, H. Q., V. D. Nam, T. M. Tri, N. M. Ha, N. T. Ngoc, P. T. N. Mai, D. H. Anh, N. H. Minh, N. A. Tuan, T. B. Minh (2017). "Polybrominated diphenyl ethers in plastic products, indoor dust, sediment and fish from informal e-waste recycling sites in Vietnam: a comprehensive assessment of contamination, accumulation pattern, emissions, and human exposure." Environ Geochem Health **39**(4): 935-954.

Anh, H. Q., K. Tomioka, N. M. Tue, T. M. Tri, T. B. Minh and S. Takahashi (2018). „PBDEs and novel brominated flame retardants in road dust from northern Vietnam: Levels, congener profiles, emission sources and implications for human exposure." Chemosphere **197**: 389-398.

Anh, H. Q., K. Tomioka, N. M. Tue, L. H. Tuyen, N. K. Chi, T. B. Minh, P. H. Viet and S. Takahashi (2019). „A preliminary investigation of 942 organic micro-pollutants in the atmosphere in waste processing and urban areas, northern Vietnam: Levels, potential sources, and risk assessment." Ecotoxicology and Environmental Safety **167**: 354-364.

Arain, A. L. (2019). "Environmental Health Impacts of Informal Electronic Waste Recycling." Dissertation thesis, The University of Michigan. https://deepblue.lib.umich.edu/handle/2027.42/149875

Balmer, J. E., H. Hung, K. Vorkamp, R. J. Letcher and D. C. G. Muir (2019). „Hexachlorobutadiene (HCBD) contamination in the Arctic environment: A review." Emerging Contaminants **5**: 116-122.

BAN (2018). Holes in the Circular Economy: WEEE Leakage from Europe. A Report of the e-Trash Transparency Project. http://wiki.ban.org/images/f/f4/Holes_in_the_Circular_Economy-_WEEE_Leakage_from_Europe.pdf. Seattle, USA, Basel Action Network**:** 120.

Behnisch, P. A., K. Hosoe and S.I. Sakai (2003). „Brominated dioxin-like compounds: in vitro assessment in comparison to classical dioxin-like compounds and other polyaromatic compounds." Environment International **29**(6): 861-877.

Birnbaum, L., D. Staskal and J. Diliberto (2003). „Health effects of polybrominated dibenzo-p-dioxins (PBDDs) and dibenzofurans (PBDFs)." Environment International **29**(6): 855-860.

Birnbaum, L. S. and D. F. Staskal (2004). „Brominated flame retardants: cause for concern?" Environ Health Perspectives **112**(1): 9-17.

Blake, A. (2005). The Next Generation of POPs: PBDEs and Lindane. Keep the Promise, Eliminate POPs Report, IPEN**:** 18.

Branchi, I., F. Capone, E. Alleva and L. G. Costa (2003). „Polybrominated diphenyl ethers: neurobehavioral effects following developmental exposure." Neurotoxicology **24**(3): 449-462.

Breivik, K., A. Sweetman, J. M. Pacyna and K. C. Jones (2002). „Towards a global historical emission inventory for selected PCB congeners — a mass balance approach: 1. Global production and consumption." Science of The Total Environment **290**(1): 181-198.

Brenner, K. S. and H. Knies (1990). „Formation of Polybrominated Dibenzofurans (PBDF's) and-Dioxins (PBDD's) During Extrusion Production of a Polybutyleneterephthalate (PBTP)/Glassfibre Resin Blended with Decabromodiphenylether (DBDPE)sb203; Product and Workplace Analysis." Organohalogen Compdounds **2**(1990): 319-324.

BRS (2017). „All POPs listed in the Stockholm Convention." Retrieved 07-03-2019, 2019, from http://www.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx.

Budin, C., J. Petrlik, J. Strakova, S. Hamm, B. Beeler, P. Behnisch, H. Besselink, B. van der Burg and A. Brouwer (2020). "Detection of high PBDD/Fs levels and dioxin-like activity in toys using a combination of GC-HRMS, rat-based and human-based DR CALUX® reporter gene assays." Chemosphere 251, 126579

Buser, H. (1986). „Polybrominated dibenzofurans and dibenzo-p-dioxins: thermal reaction products of polybrominated diphenyl ether flame retardants." Environmental Science & Technology **20**(4): 404-408.

Cai, K., Y. Liang, Q. Song (2020). „Biological exposure to PBDEs in e-waste areas: A review." Proceedings of the 15 th International Conference on Waste Management and Technology, June 28-30, 2020, 91-101.

Cai, K., Q. Song, W. Yuan, J. Ruan, H. Duan, Y. Li and J. Li (2020). „Human exposure to PBDEs in e-waste areas: A review." Environmental Pollution **267**: 115634.

Calonzo, M., J. Petrlik, J. DiGangi, IPEN Dioxin PCBs and Waste Working Group, Cavite Green Coalition, EcoWaste Coalition and Arnika Association (2005). Contamination of chicken eggs from Barangay Aguado in Philippines by dioxins, PCBs and hexachlorobenzene. Keep the Promise, Eliminate POPs Reports. Manila, Prague, IPEN, Arnika Association, EcoWaste Coalition**:** 30.

Chen, A., K. Yolton, S. A. Rauch, G. M. Webster, R. Hornung, A. Sjodin, K. N. Dietrich and B. P. Lanphear (2014). „Prenatal polybrominated diphenyl ether exposures and neurodevelopment in U.S. children through 5 years of age: the HOME study." Environ Health Perspectives **122**(8): 856-862.

Chen, X., Y. Chen, C. Huang, Q. Dong, C. Roper, R. L. Tanguay, Y. Zhu and Y. Zhang (2019). „Neurodevelopmental toxicity assessments of alkyl phenanthrene and Dechlorane Plus co-exposure in zebrafish." Ecotoxicol Environ Saf **180**: 762-769.

Chen, K., J. Zheng, X. Yan, L. Yu, X. Luo, X. Peng, Y. Yu, Z. Yang and B. Mai (2015). "Dechlorane Plus in paired hair and serum samples from e-waste workers: Correlation and differences." Chemosphere **123**: 43-47.

Chevrier, J., K. G. Harley, A. Bradman, M. Gharbi, A. Sjodin and B. Eskenazi (2010). „Polybrominated diphenyl ether (PBDE) flame retardants and thyroid hormone during pregnancy." Environ Health Perspectives **118**(10): 1444-1449.

Chu, I., D. C. Villeneuve, B. McDonald, V. E. Secours and V. & Valli (1987). "Pentachlorotoluene and pentabromotoluene: results of a subacute and a subchronic toxicity study in the rat." J Environ Sci Health B, **22**(3): 303-317. https://doi.org/10.1080/03601238709372559

Costa, L. and G. Giordano (2011). "Is decabromodiphenyl ether (BDE-209) a developmental neurotoxicant?" NeuroToxicology **32**: 9-24.

Covaci, A., S. Harrad, M. A. E. Abdallah, N. Ali, R. J. Law, D. Herzke and C. A. de Wit (2011). „Novel brominated flame retardants: A review of their analysis, environmental fate and behaviour." Environment International **37**(2): 532-556.

de Wit, C. A., A. Kierkegaard, N. Ricklund and U. Sellström (2010). "Emerging Brominated Flame Retardants in the Environment." In Brominated Flame Retardants (pp. 241-286). https://doi.org/10.1007/698_2010_73

DiGangi, J. and J. Petrlik (2005). The Egg Report - Contamination of chicken eggs from 17 countries by dioxins, PCBs and hexachlorobenzene. Available at: http://english.arnika.org/publications/the-egg-report.

Dishaw, L. V., L. J. Macaulay, S. C. Roberts and H. M. Stapleton (2014). „Exposures, mechanisms, and impacts of endocrine-active flame retardants." Curr Opin Pharmacol **19**: 125-133.

Dong M. and X. Li (2020). "The concentrations and temporal trend of Dechlorane Plus in human serum collected from a typical e-waste recycling area in China." Environmental Chemistry **39**: 2035-2043.

Dvorska, A., J. Strakova, S. Brosche, J. Petrlik, T. Boontongmai, N. Bubphachat, C. Thowsakul, A. Teebthaisong, P. Saetang and P. Jeungsmarn (2023). Environmental, food and human body burden of Dechlorane Plus in a waste recycling area in Thailand: No room for exemptions. IPEN, Arnika, and EARTH. 18p.

ECHA (2008). Risk Assessment of 2,2,6,6-tetrabromo-4,4isopropylidenediphenol(tetrabromobisphenol-A). Final Environmental Rar of February 2008**:** 425.

EFSA CONTAM (2012). „Scientific Opinion on Emerging and Novel Brominated Flame Retardants (BFRs) in Food." EFSA Journal **10**(10): 133.

Erkin-Cakmak, A., K. G. Harley, J. Chevrier, A. Bradman, K. Kogut, K. Huen and B. Eskenazi (2015). „In utero and childhood polybrominated diphenyl ether exposures and body mass at age 7 years: the CHAMACOS study." Environ Health Perspectives **123**(6): 636-642.

European Commission (2011). Commission Regulation (EU) No 1259/2011 of 2 December 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for dioxins, dioxin-like PCBs and non dioxin-like PCBs in foodstuffs. Official Journal of the European Union. **EC 1259/2011:** 18-23.

European Commission (2012). Commission Regulation (EU) No 252/2012 of 21 March 2012 laying down methods of sampling and analysis for the official control of levels of dioxins, dioxin-like PCBs and non-dioxin-like PCBs in certain foodstuffs and repealing Regulation (EC) No 1883/2006. Official Journal of the European Communities**:** L 84, 23.83.2012, p. 2011–2022.

European Commission (2014). Commission Regulation (EU) No 709/2014 of 20 June 2014 amending Regulation (EC) No 152/2009 as regards the determination of the levels of dioxins and polychlorinated biphenyls. Official Journal of the European Union: L 188/1, 27.6.2014.

European Commission (2016). Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. (OJ L 364, 20.12.2006, p. 5). Official Journal. **2006R1881 — EN — 01.04.2016 — 020.001:** 1-40..

Forti, V., C. P. Balde, R. Kuehr and G. Bel (2020). The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. Bonn/Geneva/Rotterdam, United Nations University

Fu, J., Y. Wang, A. Zhang, Q. Zhang, Z. Zhao, T. Wang and G. Jiang (2011). “Spatial distribution of polychlorinated biphenyls (PCBs) and polybrominated biphenyl ethers (PBDEs) in an e-waste dismantling region in Southeast China: Use of apple snail (*Ampullariidae*) as a bioindicator.” Chemosphere **82**: 648–655.

Gascon M, M. Vrijheid, D. Martinez, J. Forns, J. O. Grimalt et al. (2011). “Effects of pre and postnatal exposure to low levels of polybromodiphenyl ethers on neurodevelopment and thyroid hormone levels at 4 years of age.” Environment International **37**: 605-611.

Ghelli E., R. Cariou, G. Dervilly, G. Pagliuca and T. Gazzotti (2021). „Dechlorane Plus and Related Compounds in Food—A Review.“ International Journal of Environmental Research and Public Health **18**: 690-706.

Grosse, Y., D. Loomis, K. Z. Guyton, F. El Ghissassi, V. Bouvard, L. Benbrahim-Tallaa, H. Mattock and K. Straif (2016). „Carcinogenicity of some industrial chemicals.“ The Lancet Oncology **17**(4): 419-420.

Gullett, B. K., B. Wyrzykowska, E. Grandesso, A. Touati, D. G. Tabor and G. S. R. Ochoa (2010). „PCDD/F, PBDD/F, and PBDE Emissions from Open Burning of a Residential Waste Dump.“ Environmental Science & Technology **44**: 394–399.

Haddow, J. E., G. E. Palomaki, W. C. Allan, J. R. Williams, G. J. Knight, J. Gagnon, C. E. O‘Heir, M. L. Mitchell, R. J. Hermos, S. E. Waisbren, J. D. Faix and R. Z. Klein (1999). „Maternal Thyroid Deficiency during Pregnancy and Subsequent Neuropsychological Development of the Child.“ New England Journal of Medicine **341**(8): 549-555.

Hallgren, S., T. Sinjari, H. Hakansson and P. O. Darnerud (2001). „Effects of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) on thyroid hormone and vitamin A levels in rats and mice.“ Arch Toxicol **75**(4): 200-208.

Haarr A., M. Nipen, E. B. Mwakalapa, A. R. Borgen, A. J. Mmochi and K. Borga (2023). “Chlorinated paraffins and Dechloranes in free-range chicken eggs and soil around waste disposal sites in Tanzania.” Chemosphere **329**: 138646.

Hogarh, J. N., J. Petrlik, S. Adu-Kumi, E. Akortia, G. Kuepouo, P. A. Behnisch, L. Bell, J. DiGangi, J. Rosmus and P. Fišar (2019). „Persistent organic pollutants in free-range chicken eggs in Ghana.“ Organohalogen Compounds **81**(2019): 507-510.

Hoh, E., L. Zhu and R. A. Hites (2005). „Novel Flame Retardants, 1,2-Bis(2,4,6-tribromophenoxy)ethane and 2,3,4,5,6-Pentabromoethylbenzene, in United States' Environmental Samples.“ Environmental Science & Technology **39**(8): 2472-2477.

Hoppe, A. A. and G. B. Carey (2007). „Polybrominated Diphenyl Ethers as Endocrine Disruptors of Adipocyte Metabolism.“ Obesity **15**(12): 2942-2950.

Huang, F., S. Wen, J. Li, Y. Zhong, Y. Zhao and Y. Wu (2014). "The human body burden of polybrominated diphenyl ethers and their relationships with thyroid hormones in the general population in Northern China." Science of The Total Environment **466-467**: 609-615.

IARC (2020). Agents Classified by the IARC Monographs, Volumes 1–127. Last update: 27th October 2020. Paris, International Agency for Cancer Researc**:** 39.

Ilyas, M., A. Sudaryanto, I. E. Setiawan, A. S. Riyadi, T. Isobe and S. Tanabe (2013). "Characterization of polychlorinated biphenyls and brominated flame retardants in sludge, sediment and fish from municipal dumpsite at Surabaya, Indonesia." Chemosphere **93:** 1500–1510.

Jacobson, M. H., D. B. Barr, M. Marcus, A. B. Muir, R. H. Lyles, P. P. Howards, L. Pardo and L. A. Darrow (2016). „Serum polybrominated diphenyl ether concentrations and thyroid function in young children.“ Environ Res **149**: 222-230.

Jayakumar, C., J. DiGangi, J. Petrlik, L. Maskova and H. Kuncova (2005). Contamination of chicken eggs from Eloor in Kerala, India, by dioxins, PCBs and hexachlorobenzene. Keep the Promise, Eliminate POPs Reports.

Kajiwara, N., Y. Noma and H. Takigami (2008). „Photolysis Studies of Technical Decabromodiphenyl Ether (DecaBDE) and Ethane (DeBDethane) in Plastics under Natural Sunlight.“ Environmental Science & Technology **42**(12): 4404-4409.

Kannan, K., C. Liao and H.-B. Moon (2012). Polybrominated dibenzo-p-dioxins and dibenzofurans. Dioxins and health Including Other Persistent Organic Pollutants and Endocrine Disruptors. Third Edition. A. Schecter. USA, Wiley**:** 255-302.

Kitamura, S., N. Jinno, S. Ohta, H. Kuroki and N. Fujimoto (2002). „Thyroid hormonal activity of the flame retardants tetrabromobisphenol A and tetrachlorobisphenol A.“ Biochemical and Biophysical Research Communications **293**(1): 554-559.

Kodavanti, P. R. S. and B. G. Loganathan (2019). Polychlorinated Biphenyls, Polybrominated Biphenyls, and Brominated Flame Retardants. Biomarkers in Toxicology**:** 501-518.

Kudryavtseva, A.D., A.A. Shelepchikov and E.S. Brodsky (2020). „Free-range chicken eggs as a bioindicator of dioxin contamination in Vietnam, including long-term Agent Orange impact.” Emerging Contaminants **6**: 114-123.

Kuriyama, S. N., C. E. Talsness, K. Grote and I. Chahoud (2005). „Developmental Exposure to Low-Dose PBDE-99: Effects on Male Fertility and Neurobehavior in Rat Offspring.“ Environmental Health Perspectives **113**(2): 149-154.

Labunska, I., S. Harrad, D. Santillo, P. Johnston and L. Yun (2013). „Domestic Duck Eggs: An Important Pathway of Human Exposure to PBDEs around E-Waste and Scrap Metal Processing Areas in Eastern China." Environmental Science & Technology **47**(16): 9258-9266.

Labunska, I., S. Harrad, M. Wang, D. Santillo and P. Johnston (2014). „Human Dietary Exposure to PBDEs Around E-Waste Recycling Sites in Eastern China." Environmental Science & Technology **48**(10): 5555-5564.

Lam, J., B. Lanphear, D. Bellinger, D. A. Axelrad, J. McPartland, P. Sutton, L. Davidson, N. Daniels, S. Sen and T. Woodruff (2017). „Developmental PBDE Exposure and IQ/ADHD in Childhood: A Systematic Review and Meta-analysis. (Suplemental Material)." Environmental Health Perspectives **125**(8): 198.

Langeland, A. (2016). "Heavy metal exposures from electronic waste recycling in a Thai community." International Institute Fellowships Poster Session (November 2016). Ann Arbor, MI.

Law, K., T. Halldorson, R. Danell, G. Stern, S. Gewurtz, M. Alaee, C. Marvin, M. Whittle and G. Tomy (2006). „Bioaccumulation and trophic transfer of some brominated flame retardants in a Lake Winnipeg (Canada) food web." Environmental Toxicology and Chemistry **25**(8): 2177-2186.

Law, R. J., C. R. Allchin, J. de Boer, A. Covaci, D. Herzke, P. Lepom, S. Morris, J. Tronczynski and C. A. de Wit (2006). „Levels and trends of brominated flame retardants in the European environment." Chemosphere **64**(2): 187-208.

Li N., X. W. Chen, W. J. Deng, J. P. Giesy and H. L. Zheng (2018). "PBDEs and Dechlorane Plus in the environment of Guiyu, Southeast China: A historical location for E-waste recycling (2004, 2014)." Chemosphere **199**: 603-611.

Li X, J. Liu, G. Zhou, Y. Sang, Y. Zhang, L. Jing, Z. Shi, X. Zho and Z. Sun (2021). "BDE-209 and DBDPE induce male reproductive toxicity through telomere-related cell senescence and apoptosis in SD rat." Environment International 146: 106307.

Liu, P. Y., G. D. Du, Y. X. Zhao, Y. S. Mu, A. Q. Zhang, Z. F. Qin, X. Y. Zhang, S. S. Yan, Y. Li, R. G. Wei, X. F. Qin and Y. J. Yang (2011). „Bioaccumulation, maternal transfer and elimination of polybrominated diphenyl ethers in wild frogs." Chemosphere **84**: 972–978

Liu, S., G. Zhao, J. Li, H. Zhao, Y. Wang, J. Chen and H. Zhao (2017). „Association of polybrominated diphenylethers (PBDEs) and hydroxylated metabolites (OH-PBDEs) serum levels with thyroid function in thyroid cancer patients." Environ Res **159**: 1-8.

Liu, J., S. Ma, M. Lin, J. Tang, C. Yue, Z. Zhang, Y. Yu and T. An (2020). "New Mixed Bromine/Chlorine Transformation Products of Tetrabromobisphenol A: Synthesis and Identification in Dust Samples from an E-waste Dismantling Site." Environmental Science & Technology **54**(19): 12235–12244

Luo, Y., X. J. Luo, Z. Lin, S. J. Chen, J. Liu, B. X. Mai and Z. Y. Yang (2009). „Polybrominated diphenyl ethers in road and farmland soils from an e-waste recycling region in Southern China: concentrations, source profiles, and potential dispersion and deposition." Science of the Total Environment **407**(3): 1105-1113.

Ma, Y., W. A. Stubbings, R. Cline-Cole and S. Harrad (2021). „Human exposure to halogenated and organophosphate flame retardants through informal e-waste handling activities - A critical review." Environmental Pollution **268**(Pt A): 115727.

Mach, V., J. Petrlík and J. Straková (2016). Aktuální znečištění a šíření kontaminace perzistentními organickými polutanty z areálu skladu nebezpečných odpadů ve Lhenicích (Levels of pollution by POPs and its spreading from the storage of hazardous waste in Lhenice, Czech Republic). Praha, Arnika - Toxické látky a odpady: 33.

Makey, C. M., M. D. McClean, L. E. Braverman, E. N. Pearce, X. M. He, A. Sjodin, J. M. Weinberg and T. F. Webster (2016). „Polybrominated Diphenyl Ether Exposure and Thyroid Function Tests in North American Adults." Environ Health Perspect **124**(4): 420-425.

Mason, G., M. Denomme, L. Safe and S. Safe (1987). „Polybrominated and chlorinated dibenzo-p-dioxins: synthesis biologic and toxic effects and structure-activity relationships." Chemosphere **16**(8-9): 1729-1731.

Matsukami, H., N. M. Tue, G. Suzuki, M. Someya, H. Tuyen le, P. H. Viet, S. Takahashi, S. Tanabe and H. Takigami (2015). „Flame retardant emission from e-waste recycling operation in northern Vietnam: environmental occurrence of emerging organophosphorus esters used as alternatives for PBDEs." Science of the Total Environment **514**: 492-499.

Meerts, I. A., R. J. Letcher, S. Hoving, G. Marsh, A. Bergman, J. G. Lemmen, B. v. d. Burg and A. Brouwer (2001). „In vitro estrogenicity of polybrominated diphenyl ethers, hydroxylated PDBEs, and polybrominated bisphenol A compounds." Environmental Health Perspectives **109**(4): 399-407.

Meerts, I. A. T. M., J. J. van Zanden, E. A. C. Luijks, I. van Leeuwen-Bol, G. Marsh, E. Jakobsson, Å. Bergman and A. Brouwer (2000). „Potent Competitive Interactions of Some Brominated Flame Retardants and Related Compounds with Human Transthyretin in Vitro." Toxicological Sciences **56**(1): 95-104.

Miao, B., S. Yakubu, Q. Zhu, E. Issaka, Y. Zhang and M. Adams, M. (2023). "A Review on Tetrabromobisphenol A: Human Biomonitoring, Toxicity, Detection and Treatment in the Environment." Molecules, **28**(6). https://doi.org/10.3390/molecules28062505

Mohr, S., Á. García-Bermejo, L. Herrero, B. Gómara, I. H. Costabeber and M. J. González (2014). „Levels of brominated flame retardants (BFRs) in honey samples from different geographic regions." Science of The Total Environment **472**: 741-745.

Muenhor, D., S. Harrad, N. Ali and A. Covaci (2010). „Brominated flame retardants (BFRs) in air and dust from electronic waste storage facilities in Thailand." Environment International **36**(7): 690-698.

Munschy, C., K. Héas-Moisan, C. Tixier, L. Boulesteix and J. Morin (2011). „Classic and novel brominated flame retardants (BFRs) in common sole (Solea solea L.) from main nursery zones along the French coasts." Science of The Total Environment **409**(21): 4618-4627.

Muntean, N., M. Jermini, I. Small, D. Falzon, P. Furst, G. Migliorati, G. Scortichini, A. F. Forti, E. Anklam, C. von Holst, B. Niyazmatov, S. Bahkridinov, R. Aertgeerts, R. Bertollini, C. Tirado and A. Kolb (2003). „Assessment of dietary exposure to some persistent organic pollutants in the Republic of Karakalpakstan of Uzbekistan." Environ Health Perspectives **111**(10): 1306-1311.

Neeratanaphan, L., S. Khamma, R. Benchawattananon, P. Ruchuwararak, S. Appamaraka and S. Intamat (2017). "Heavy metal accumulation in rice (*Oryza sativa*) near electronic waste dumps and related human health risk assessment." Human and Ecological Risk Assessment: An International Journal **23**: 1086-1098.

Neitzel, R. L., S. K. Sayler, A. L. Arain and K. Nambunmee (2020). “Metal Levels, Genetic Instability, and Renal Markers in Electronic Waste Workers in Thailand.” The International Journal of Occupational and Environmental Medicine **11**(2): 72-84.

Nghiem, T.X., A. Q. Hoang, T. D. Nguyen, T. T. Nguyen, P. D. Tran, T. T. Nguyen and H. B. Tu (2022). “PCDD/Fs and Dioxin-like PCBs in Chicken Eggs and Soils in Dong Nai Province, Southern Vietnam: Impacts of Raising Methods and Nearby Pollution Sources.” Bull Environ Contam Toxicol **108**: 136-144.

NIEHS (2022). Dioxins. Retrieved 23-05-2023 from https://www.niehs.nih.gov/health/topics/agents/dioxins/index.cfm

Nishimura, C., G. Suzuki, H. Matsukami, T. Agusa, M. Takaoka, S. Takahashi, N. M. Tue, P. H. Viet, S. Tanabe, H. Takigami and T. Fujimori (2018). „Soil pollution by chlorobenzenes and polychlorinated biphenyls from an electronic waste recycling area in Northern Vietnam.“ International Journal of Environment and Pollution **63**(4): 283-297.

Nuasri, C., N. Kudthalang, C. Sombatyotha, W. Senajuk and S. Trisupakitti (2019). “Knowledge and Understanding of Hazardous Waste by Community Participation of Khoksa-ad sub-district Administrative Organization, Khongchai district, Kalasin Province.” UTK Research Journal **13**(1): 98-108.

OSPAR Commission (2011). Hazardous Substances Series: Background Document on Tetrabromobisphenol-A, OSPAR Commission**:** 50.

Oulhote, Y., J. Chevrier and M. F. Bouchard (2016). „Exposure to Polybrominated Diphenyl Ethers (PBDEs) and Hypothyroidism in Canadian Women.“ J Clin Endocrinol Metab **101**(2): 590-598.

PCD (2023). “Municipal Hazardous Waste Situation Annual Report 2022”. available: https://www.pcd.go.th/publication/29745. Pollution Control Department (PCD), Thailand

PCD-DIW (2021). Thailand: E-waste and Plastic Waste Management; available: https://www.env.go.jp/en/recycle/asian_net/Annual_Workshops/2021_PDF/Presentations/2_Country%20update%20and%20response%20to%20plastic%20amendment/Thailand.pdf. Asian Network 2021 online meeting, 10 - 11 November 2021, Pollution Control Department (PCD), Department of Industrial Works (DIW), Thailand.

Peshdary, V., G. Calzadilla, A. Landry, A. Sorisky and E. Atlas (2019). „Dechlorane Plus increases adipogenesis in 3T3-L1 and human primary preadipocytes independent of peroxisome proliferator-activated receptor gamma transcriptional activity.“ Int J Obes (Lond) **43**(3): 545-555.

Peshdary, V., G. Styles, M. Rigden, D. Caldwell, A. Kawata, A. Sorisky and E. Atlas (2020). „Exposure to Low Doses of Dechlorane Plus Promotes Adipose Tissue Dysfunction and Glucose Intolerance in Male Mice.“ Endocrinology **161**(8).

Petrlik, J. (2016). Persistent Organic Pollutants (POPs) in Chicken Eggs from Hot Spots in China (Updated version). Beijing-Gothenburg-Prague, Arnika - Toxics and Waste Programme, IPEN and Green Beagle**:** 25.

Petrlik, J., S. Adu-Kumi, J. N. Hogarh, E. Akortia, G. Kuepouo, P. Behnisch, L. Bell and J. DiGangi (2019). Persistent Organic Pollutants (POPs) in Eggs: Report from Africa. Accra - Yaounde - Gothenburg - Prague, IPEN, Arnika - Toxics and Waste Programme, CREPD - Centre de Recherche et d‘Education pour le Développement**:** 48.

Petrlik, J., L. Bell, B. Beeler, M. Møller, K. Brabcova, M. Carcamo, S. C. Chávez Arce, T. Dizon, Y. Ismawati Drwiega, M. Jopkova, G. Kuepouo, S. Mng'anya, G. Ochieng Ochola and M. Skalsky (2021). Plastic waste disposal leads to contamination of the food chain, International Pollutants Elimination Network (IPEN), Arnika - Toxics and Waste Programme.

Petrlik, J., L. Bell, J. DiGangi, S. M. Allo'o Allo'o, G. Kuepouo, G. Ochieng Ochola, V. Grechko, N. Jelinek, J. Strakova, M. Skalsky, Y. Ismawati Drwiega, J. N. Hogarh, E. Akortia, S. Adu-Kumi, A. Teebthaisong, M. Carcamo, B. Beeler, P. Behnisch, C. Baitinger, C. Herold and R. Weber (2022). „Monitoring Dioxins and PCBs in Eggs as Sensitive Indicators for Environmental Pollution and Global Contaminated Sites and Recommendations for Reducing and Controlling Releases and Exposure." Emerging Contaminants **8**(2022): 254-279.

Petrlik, J., T. Boontongmai, N. Bubphachat, C. Thowsakul, A. Teebthaisong, P. Saetang, N. Jelinek, J. Strakova, V. Grechko and P. Jeungsmarn (2022). „POPs in the surroundings of e-waste sites." Arnika - Toxics and Waste Programme, Ecological Alert and Recovery – Thailand (EARTH): Bangkok. p. 41.

Petrlik, J., J. DiGangi, L. Maskova (2005). Contamination of chicken eggs from Helwan in Egypt by dioxins, PCBs and hexachlorobenzene. Keep the Promise, Eliminate POPs Reports. Cairo, Prague, IPEN, Arnika Association, Day Hospital Institute: 30.

Petrlík, J., A. Dvorská, V. Mach, M. Šír, J. Straková, A. Teebthaisong, J. Tremlová, P. A. Behnisch, M. Bystrianský, A. Ritthichat and P. Saetang (2018). Toxic Hot Spots in Thailand. Research Reports based on sampling conducted in 2015–2017. Bangkok, Prague, Arnika - Toxics and Waste Programme, EARTH.

Petrlik, J., Y. Ismawati, P. Arisandi, L. Bell, B. Beeler, V. Grechko and S. Ozanova (2020). Toxic Hot Spots in Java and Persistent Organic Pollutants (POPs) in Eggs. Jakarta - Gresik - Gothenburg - Prague, IPEN, Arnika - Toxics and Waste Programme, Nexus3, Ecoton.

Petrlik, J., Y. Ismawati, L. Bell and B. Beeler (2022). „POPs Contamination Caused by Use of Plastic Waste as Fuel at Locations in Indonesia." Organohalogen Compounds **83**: 117-121.

Petrlik, J., P. Jeungsmarn, T. Boontongmai, P. Saetang, N. Jelinek, J. Strakova and V. Grechko (2022). Persistent organic pollutants (POPs) in surrounding of electronic waste recycling sites in Chachoengsao Province, Thailand. Bangkok, Prague, Arnika - Toxics and Waste Programme, EARTH.

Petrlík, J., D. Kalmykov, P. A. Behnisch and Z. Vachunova (2016). Chicken eggs as the indicator of the pollution of environment in Kazakhstan. Results of sampling conducted in 2013 – 2016 (Использование яиц кур свободного содержания в качестве индикатора загрязнения в Казахстане. Результаты опробования, проведенного в период в 2013 по 2016 гг.). Prague - Karaganda - Aktau, Arnika – Citizens Support Centre, EcoMuseum Karaganda, Eco Mangystau.

Petrlik, J., D. Kalmykov, L. Bell and R. Weber (2017). „Brominated flame retardants in eggs – data from Kazakhstan and Thailand." Organohalogen Compounds **79**(2017): 167-170.

Petrlik, J., M. Khwaja, J. DiGangi and L. Mašková (2005). "Contamination of chicken eggs near the dump site on the edge of Peshawar, Pakistan by dioxins, PCBs and hexachlorobenzene." IPEN Dioxin PCBs and Waste Working Group, SDPI, Arnika Association. Keep the Promise, Eliminate POPs Reports.

Petrlík, J. and J. Straková (2018). Persistent Organic Pollutants (POPs) in Chicken Eggs from Alaverdi, Armenia. Results of sampling conducted in 2018. Yerevan - Prague, Arnika – Toxics and Waste Programme, Armenian Women for Health and Healthy Environment (AWHHE) and Ecolur**:** 25.

Petrlik, J., A. Teebthaisong, L. Bell, P. A. Behnisch, M. Da, P. Saetang, A. Ritthichat and D. Kalmykov (2018). „PCDD/Fs and PCBs in eggs – data from China, Kazakhstan and Thailand." Organohalogen Compounds **80**(2018): 794-798.

Phoonaploy, U., B. Tengjaroenkul and L. Neeratanaphan (2019). "Effects of electronic waste on cytogenetic and physiological changes in snakehead fish (*Channa striata*)". Environ Monit Assess **191**: 363

Phoonaploy, U., B. Tengjaroenkul and L. Neeratanaphan (2020). "Effect of heavy metals from an electronic waste open dumping area on the cytotoxicity of climbing perch (*Anabas testudineus*)." International Journal Of Environmental Studies **77**: 983-997.

Piachan, N. (2022). Environment crime: A case study of impact of electronic waste smuggling in Thailand. Masters Thesis, Chulalongkorn University.

Piskorska-Pliszczyńska, J. and S. Maszewski (2014). „Brominated dioxins: little-known new health hazards-a review." Bull Vet Inst Pulawy **58**: 327-335.

Pohl, H. R., P. R. McClure, M. Fay, J. Holler and C. T. De Rosa (2001). „Public health assessment of hexachlorobenzene." Chemosphere **43**(4): 903-908.

Polder, A., M. B. Müller, O. B. Brynildsrud, J. de Boer, T. Hamers, J. H. Kamstra, E. Lie, R. H. Mdegela, H. Moberg, H. E. Nonga, M. Sandvik, J. U. Skaare and J. L. Lyche (2016). „Dioxins, PCBs, chlorinated pesticides and brominated flame retardants in free-range chicken eggs from peri-urban areas in Arusha, Tanzania: Levels and implications for human health." Science of The Total Environment **551–552**: 656-667.

Poma, G., P. Volta, C. Roscioli, R. Bettinetti and L. Guzzella (2014). „Concentrations and trophic interactions of novel brominated flame retardants, HBCD, and PBDEs in zooplankton and fish from Lake Maggiore (Northern Italy)." Science of The Total Environment **481**: 401-408.

POP RC (2006). Risk profile on commercial pentabromodiphenyl ether, UNEP/POPS/POPRC.2/17/Add.1, Stockholm Convention POPs Review Committee.

POP RC (2007a). Risk profile on commercial octabromodiphenyl ether, UNEP/POPS/POPRC.3/20/Add.6, Stockholm Convention POPs Review Committee.

POP RC (2007b). Risk profile on pentachlorobenzene. UNEP/POPS/POPRC.3/20/Add.7, Stockholm Convention POPs Review Committee**:** 24.

POP RC (2008a). Risk management evaluation for commercial octabromodiphenyl ether, UNEP/POPS/POPRC.4/15/Add.1, Stockholm Convention POPs Review Committee.

POP RC (2008b). Risk management evaluation for pentachlorobenzene. UNEP/POPS/POPRC.4/15/Add.2, Stockholm Convention POPs Review Committee**:** 15.

POP RC (2010a). Report of the Persistent Organic Pollutants Review Committee on the work of its sixth meeting. Persistent Organic Pollutants Review Committee Sixth meeting. Geneva**:** 45.

POP RC (2010b). Risk profile on hexabromocyclododecane, UNEP/POPS/POPRC.6/13/Add.2, Stockholm Convention POPs Review Committee.

POP RC (2012a). Risk profile on hexachlorobutadiene. UNEP/POPS/POPRC.8/16/Add.2, Stockholm Convention POPs Review Committee**:** 24.

POP RC. (2012b). Risk profile on chlorinated naphthalenes, UNEP/POPS/POPRC.8/16/Add.1., Stockholm Convention POPs Review Committee.

POP RC (2014). Risk profile on decabromodiphenyl ether (commercial mixture, c-decaBDE), UNEP/POPS/POPRC.10/10/Add.2, Stockholm Convention POPs Review Committee**:** 58.

POP RC (2021). Draft risk profile: Dechlorane Plus. UNEP/POPS/POPRC.17/3. Stockholm Convention POPs Review Committee Seventeenth meeting, Geneva, 24–28 January 2022

Qin, X., Z. Qin, Y. Li, Y. Zhao, X. Xia, S. Yan, M. Tian, X. Zhao, X. Xu and Y. Yang (2011). „Polybrominated diphenyl ethers in chicken tissues and eggs from an electronic waste recycling area in southeast China.“ Journal of Environmental Sciences **23**(1): 133-138.

Quinn, L. P. (2010). Assessment of organic pollutants in selected wild and domesticated bird eggs from Gauteng, South Africa. Thesis. Potchefstroom Campus of the North-West University; 205 p.

Rauert, C., J. K. Schuster, A. Eng and T. Harner (2018). "Global Atmospheric Concentrations of Brominated and Chlorinated Flame Retardants and Organophosphate Esters." Environmental Science & Technology **52**: 2777–2789.

Reed, L., V. Büchner and P. B. Tchounwou (2007). „Environmental Toxicology and Health Effects Associated with Hexachlorobenzene Exposure.“ Reviews on Environmental Health **22**(3): 213.

Ren, M., H. Zeng, P.-A. Peng, H.-R. Li, C.-M. Tang and J.-F. Hu (2017). „Brominated dioxins/furans and hydroxylated polybrominated diphenyl ethers: Occurrences in commercial 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and 2,4,6-tribromophenol, and formation during synthesis of BTBPE.“ Environmental Pollution **226**: 394-403.

Ricklund, N., A. Kierkegaard and M. S. McLachlan (2010). „Levels and Potential Sources of Decabromodiphenyl Ethane (DBDPE) and Decabromodiphenyl Ether (DecaBDE) in Lake and Marine Sediments in Sweden.“ Environmental Science & Technology **44**(6): 1987-1991.

Roberts-Davis, T. L. and P. Saetang (2019). Trading Away Health and the Environment: The Toxic Business of Waste Imports into Thailand. Bangkok, EARTH, Arnika - Toxics and Waste Programme, **:** 61.

Saksasitorn, J. (2014). "Blood lead levels in children aged 0 - 5 years at Khongchai District, Kalasin Province." Mahasarakham Hospital Journal **11**(2): 6-15.

Sala, M., N. Ribas-Fitó, E. Cardo, M. E. de Muga, E. Marco, C. Mazón, A. Verdú, J. O. Grimalt and J. Sunyer (2001). „Levels of hexachlorobenzene and other organochlorine compounds in cord blood: exposure across placenta.“ Chemosphere **43**(4): 895-901.

Saetang, P., S. Rojanapraiwong, W. Mooksuwan, S. Prathumchat (2009). "Report on the initial study on the impacts of and seeking solutions for participatory waste management: a case study of Khok Sa-ad subdistrict, Khong Chai district, Kalasin province. Project to enhance citizen's participation in creating local governance". Available at: https://www.earththailand.org/th/new/document/163

Schecter, A. (2012). Dioxins and health Including Other Persistent Organic Pollutants and Endocrine Disruptors. Third Edition. USA, Wiley.

Schwarz, S., A. Rackstraw, P. A. Behnisch, A. Brouwer, H.-R. Köhler, A. Kotz, T. Kuballa, R. Malisch, F. Neugebauer, F. Schilling, D. Schmidt and K. Theo von der Trenck (2016). „Peregrine falcon egg pollutants." Toxicological & Environmental Chemistry **98**(8): 886-923.

Seith, R., A. L. Arain, K. Nambunmee, S. D. Adar, R. L. Neitzel (2019). "Self-Reported Health and Metal Body Burden in an Electronic Waste Recycling Community in Northeastern Thailand." Journal of Occupational and Environmental Medicine **61**(11), 905–909.

She, Y., Z., J. P. Wu, Y. Zhang, Y. Peng, L. Mo, X. J. Luo and B. X. Mai (2013). "Bioaccumulation of polybrominated diphenyl ethers and several alternative halogenated flame retardants in a small herbivorous food chain." Environmental Pollution **174**: 164-170.

Shen, H., R. Guan, G. Ding, Q. Chen, X. Lou, Z. Chen, L. Zhang, M. Xing, I. Han and Y. Wu (2017). „Polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in Zhejiang foods (2006–2015): Market basket and polluted areas." Science of The Total Environment **574**: 120-127.

Shi, Z., L. Zhang, J. Li, Y. Zhao, Z. Sun, X. Zhou and Y. Wu (2016). „Novel brominated flame retardants in food composites and human milk from the Chinese Total Diet Study in 2011: Concentrations and a dietary exposure assessment." Environment International **96**: 82-90.

Shkembi, A., K. Nambunmee, S. Jindaphong, D. Parra-Giordano, K. Yohannessen, P. Ruiz-Rudolph, R. L. Neitzel and A. Arain (2021). „Work Task Association with Lead Urine and Blood Concentrations in Informal Electronic Waste Recyclers in Thailand and Chile." Int J Environ Res Public Health **18**(20).

Siamrathonline (2018). "Kalasin province explains 320 tons of toxic waste", August 26, 2018. Available at: https://siamrath.co.th/n/44069. Retrieved on February 8, 2021

Sjödin, A., L. Hagmar, E. Klasson-Wehler, K. Kronholm-Diab, E. Jakobsson and A. Bergman (1999). „Flame retardant exposure: polybrominated diphenyl ethers in blood from Swedish workers." Environmental Health Perspectives **107**(8): 643-648.

Stockholm Convention (2009a). Listing of tetrabromodiphenyl ether and pentabromodiphenyl ether. Decision SC 4/18. Geneva.

Stockholm Convention (2009b). Listing of hexabromodiphenyl ether and heptabromodiphenyl ether. Decision SC 4/14. Geneva.

Stockholm Convention (2010). Stockholm Convention on Persistent Organic Pollutants (POPs) as amended in 2009. Text and Annexes. Geneva**:** 64.

Stockholm Convention (2013a). Listing of hexabromocyclododecane. Decision SC-6/13. Geneva.

Stockholm Convention (2013b). An amendment to Annex A adopted by the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants at its sixth meeting (Decision SC-6/13). Geneva.

Stockholm Convention (2016). Report for the evaluation and review of brominated diphenyl ethers listed in Annex A to the Convention. UNEP/POPS/COP.8/INF/12. Geneva**:** 76.

Stockholm Convention (2017a). Listing of decabromodiphenyl ether. Decision SC-8/10. Geneva

Stockholm Convention (2017b). The 16 New POPs. An introduction to the chemicals added to the Stockholm Convention as Persistent Organic Pollutants by the Conference of the Parties. Geneva**:** 13.

Stockholm Convention. (2019a). „The 12 initial POPs under the Stockholm Convention." Retrieved 15/12/2021, 2021, from http://www.pops.int/TheConvention/ThePOPs/The12InitialPOPs/tabid/296/Default.aspx.

Stockholm Convention. (2019b). „All POPs listed in the Stockholm Convention." from http://www.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx.

Stockholm Convention (2022). Listing of perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds. Decision SC 10/13., (2022).

Stockholm Convention (2023a). Decision SC-11/[--]: Listing of Dechlorane Plus. Geneva.

Stockholm Convention (2023b). Decision SC-11/[--]: Listing of UV-328. Geneva.

Straková, J., J. DiGangi, G. K. Jensen, J. Petrlik and L. Bell (2018). Toxic Loophole - Recycling Hazardous Waste into New Products. Arnika/IPEN/HEAL, 40.

Sun, Y., Y. Wang, B. Liang, T. Chen, D. Zheng, X. Zhao, L. Jing, X. Zhou, Z. Sun and Z. Shi (2020). „Hepatotoxicity of decabromodiphenyl ethane (DBDPE) and decabromodiphenyl ether (BDE-209) in 28-day exposed Sprague-Dawley rats." Science of the Total Environment **705**: 135783.

Tanee, T., A. Chaveerach, R. Sudmoon, J. Teanma, A. Ragsasilp and P. Sirikhansaeng (2018). „Heavy Metal Accumulation and DNA Changes in Plants Around an Electronic Waste Dumpsite Suggested Environmental Management Plan." Environmental Claims Journal 30(2): 131-141.

Teebthaisong, A., J. Petrlik, A. Ritthichat, P. Saetang and J. Strakova (2018). „POPs contamination at 'recycling' and metallurgical site in Thailand." Organohalogen Compounds **80**: 373-376.

Teebthaisong, A., P. Saetang, J. Petrlik, L. Bell, B. Beeler, M. Jopkova, Y. Ismawati, G. Kuepouo, G. Ochieng Ochola and E. Akortia (2021). „Brominated dioxins (PBDD/Fs) in free range chicken eggs from sites affected by plastic waste." Organohalogen Compounds **82**(2021): 199-202.

Thanomsangad, P., B. Tengjaroenkul, M. Sriuttha and L. Neeratanaphan (2019). "Heavy metal accumulation in frogs surrounding an e-waste dump site and human health risk assessment." Human And Ecological Risk Assessment: An International Journal **26**(5): 1313-1328.

The Epoch Times (2005). "Taiwan Environmental Protection Agency announced the results of cross-border investigation." Retrieved 17-12-2005; Available from: http://www.epochtimes.com/b5/5/12/17/n1156901.htm.

The Isaan Record (2019). „Kalasin's burning e-waste dump needs a legal fix." Published on September 23, 2019, accessed December 7, 2022. https://theisaanrecord.co/2019/09/23/kalasin-e-waste-burning-legal-fix/

Tiseo, I. (2022). „Global E-Waste - Statistics." Retrieved 13/11/2022 from https://www.statista.com/topics/3409/electronic-waste-worldwide/#topicHeader__wrapper.

Tlustos, C., A. Fernandes and M. Rose (2010). „The emerging BFRs-Hexabromobenzene (HBB), BIS(246-tribromophenoxy)ethane (BTBPE) and decabromodiphenylethane (DBDPE)- in Irish foods." Organohalogen Compounds **72**: 1577-1579.

Toft, G., V. Lenters, R. Vermeulen, D. Heederik, C. Thomsen, G. Becher, A. Giwercman, D. Bizzaro, G. C. Manicardi, M. Spano, L. Rylander, H. S. Pedersen, P. Strucinski, V. Zviezdai and J. P. Bonde (2014). "Exposure to polybrominated diphenyl ethers and male reproductive function in Greenland, Poland and Ukraine." Reprod Toxicol **43**: 1-7

Traag, W.A., T. T. Hoang, T. Murk and L. Hoogenboom (2012). "Dioxins in free range consumption eggs from Vietnam: levels and health risks." Organohalogen Compounds **74**: 1373-1376.

Tue, N. M., S. Takahashi, G. Suzuki, T. Isobe, P. H. Viet, Y. Kobara, N. Seike, G. Zhang, A. Sudaryanto and S. Tanabe (2013). „Contamination of indoor dust and air by polychlorinated biphenyls and brominated flame retardants and relevance of non-dietary exposure in Vietnamese informal e-waste recycling sites." Environment International **51**: 160-167.

UN DESA (2020)."Kalasin Happiness Model: Leaving no one behind's report. Improving fundamental quality of life for the poor". United Nations Department of Economic and Social Affairs. Available at: https://publicadministration.un.org/unpsa/Portals/0/UNPSA_Submitted_Docs/2019/c93a5a98-c611-4642-995e 6b531d1881ba/2020%20UNPSA_Kalasin%20Happiness%20Model%20 Evaluation%20Report_25112019_055044_0404103a-de71-4bb7-92ef-afecc4bdfe82.pdf?ver=2019-11-25-055044-533

van den Berg, M., L. S. Birnbaum, M. Denison, M. De Vito, W. Farland, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker and R. E. Peterson (2006). „The 2005 World Health Organization reevaluation of human and Mammalian toxic equivalency factors for dioxins and dioxin-like compounds." Toxicological Sciences **93**(2): 223-241.

van den Berg, M., M. S. Denison, L. S. Birnbaum, M. DeVito, H. Fiedler, J. Falandysz, M. Rose, D. Schrenk, S. Safe, C. Tohyama, A. Tritscher, M. Tysklind and R. E. Peterson (2013). „Polybrominated Dibenzo-p-dioxins (PBDDs), Dibenzofurans (PBDFs) and Biphenyls (PBBs) - Inclusion in the Toxicity Equivalency Factor Concept for Dioxin-like Compounds." Toxicological Sciences **133**(2):197-208

Vorkamp, K., R. Bossi, F. F. Rigét, H. Skov, C. Sonne and R. Dietz (2015). „Novel brominated flame retardants and dechlorane plus in Greenland air and biota." Environmental Pollution **196**: 284-291.

Viberg, H., A. Fredriksson and P. Eriksson (2003). „Neonatal exposure to polybrominated diphenyl ether (PBDE 153) disrupts spontaneous behaviour, impairs learning and memory, and decreases hippocampal cholinergic receptors in adult mice." Toxicology and Applied Pharmacology **192**(2): 95-106..

Vuong, A. M., G. M. Webster, M. E. Romano, J. M. Braun, R. T. Zoeller, A. N. Hoofnagle, A. Sjodin, K. Yolton, B. P. Lanphear and A. Chen (2015). „Maternal Polybrominated Diphenyl Ether (PBDE) Exposure and Thyroid Hormones in Maternal and Cord Sera: The HOME Study, Cincinnati, USA." Environ Health Perspectives **123**(10): 1079-1085.

Waiyarat S., S. K. Boontanon, N. Boontanon, S. Fujii, S. Harrad, D. S. Drage and M. Abou-Elwafa Abdallah (2022). Exposure, risk and predictors of hexabromocyclododecane and Tetrabromobisphenol-A in house dust from urban, rural and E-waste dismantling sites in Thailand. Chemosphere **302**: 134730.

Wang, J., M. Tian, S. J. Chen, J. Zheng, X. J. Luo, T. C. An and B. X. Mai (2011). "Dechlorane Plus in house dust from e-waste recycling and urban areas in South China: Sources, degradation, and human exposure." Environmental Toxicology and Chemistry **30**: 1965–1972

Wang, S., K. A. Romanak, M. Hendryx, A. Salamova and M. Venier (2020). „Association between Thyroid Function and Exposures to Brominated and Organophosphate Flame Retardants in Rural Central Appalachia.“ Environmental Science & Technology **54**(1): 325-334.

Wang, C., L. Zeng, Y. Li, C. Shi, Y. Peng, R. Pan, M. Huang, S. Wang, J. Zhang and H. Li (2022). „Decabromodiphenyl ethane induces locomotion neurotoxicity and potential Alzheimer‘s disease risks through intensifying amyloid-beta deposition by inhibiting transthyretin/transthyretin-like proteins.“ Environment International **168**: 107482.

Watanabe, I. and S.I. Sakai (2003). „Environmental release and behavior of brominated flame retardants.“ Environment International **29**(6): 665-682.

Watkins, D., J., M. D. McClean, A. J. Fraser, J. Weinberg, H. M. Stapleton, A. Sjödin and T. F. Webster (2011). Exposure to PBDEs in the Office Environment: Evaluating the Relationships Between Dust, Handwipes, and Serum. Environmental Health Perspectives **119**(9): 1247-1252.

Weber, R., C. Herold, H. Hollert, J. Kamphues, L. Ungemach, M. Blepp and K. Ballschmiter (2018). „Life cycle of PCBs and contamination of the environment and of food products from animal origin.“ Environmental Science and Pollution Research **25**(17): 16325-16343

White, S. S. and L. S. Birnbaum (2009). „An Overview of the Effects of Dioxins and Dioxin-Like Compounds on Vertebrates, as Documented in Human and Ecological Epidemiology.“ Journal of Environmental Science and Health, Part C **27**(4): 197-211.

Windal, I., M. S. Denison, L. S. Birnbaum, N. Van Wouwe, W. Baeyens and L. Goeyens (2005). „Chemically Activated Luciferase Gene Expression (CALUX) Cell Bioassay Analysis for the Estimation of Dioxin-Like Activity: Critical Parameters of the CALUX Procedure that Impact Assay Results.“ Environmental Science & Technology **39**(19): 7357–7364.

Wu, J.-P., Y.-T. Guan, Y. Zhang, X.-J. Luo, H. Zhi, S.-J. Chen and B.-X. Mai (2011). „Several current-use, non-PBDE brominated flame retardants are highly bioaccumulative: Evidence from field determined bioaccumulation factors.“ Environment International **37**(1): 210-215.

Xiong, P., X. Yan, Q. Zhu, G. Qu, J. Shi, C. Liao and G. Jiang, G. (2019). “A Review of Environmental Occurrence, Fate, and Toxicity of Novel Brominated Flame Retardants.” Environmental Science & Technology **53**(23): 13551-13569.

Xu, P., X. Lou, G. Ding, H. Shen, L. Wu, Z. Chen, J. Han and X. Wang (2015). „Effects of PCBs and PBDEs on thyroid hormone, lymphocyte proliferation, hematology and kidney injury markers in residents of an e-waste dismantling area in Zhejiang, China.“ Science of the Total Environment **536**: 215-222.

Yamaguchi, Y., M. Kawano, R. Tatsukawa and S. Moriwaki (1988). „Hexabromobenzene and its debrominated compounds in human adipose tissues of Japan.“ Chemosphere **17**(4): 703-707.

Yan X., J. Zheng, K. H. Chen, J. Yang, X. J. Luo, L. H. Yu, S. J. Chen, B. X. Mai and Z. Y. Yang (2012). “Dechlorane Plus in serum from e-waste recycling workers: Influence of gender and potential isomer-specific metabolism.” Environment International **49**: 31–37.

Yanagisawa, R., E. Koike, T. T. Win-Shwe and H. Takano (2019). „Decabromodiphenyl ether exacerbates hyperglycemia in diet-induced obese mice.“ Toxicology **412**: 12-18.

Yin J. F., J. F. T. Li, X. H. Li, Y. L. Yang and Z. F. Qin (2020). “Bioaccumulation and transfer characteristics of Dechlorane Plus in human adipose tissue and blood stream and the underlying mechanisms.” Science of the Total Environment **700**: 134391.

Yogui, G. T. and J. L. Sericano (2009). „Levels and pattern of polybrominated diphenyl ethers in eggs of Antarctic seabirds: Endemic versus migratory species.“ Environmental Pollution **157**(3): 975-980.

Zeng, Y.-H., X.-J. Luo, B. Tang and B.-X. Mai (2016). „Habitat- and species-dependent accumulation of organohalogen pollutants in home-produced eggs from an electronic waste recycling site in South China: Levels, profiles, and human dietary exposure.“ Environmental Pollution **216**: 64-70.

Zeng, Y., C. Huang, X. Luo, Y. Liu, Z. Ren and B. Mai (2018). „Polychlorinated biphenyls and chlorinated paraffins in home-produced eggs from an e-waste polluted area in South China: Occurrence and human dietary exposure.“ Environment International **116**: 52-59.

Zhan, F., H. Zhang, R. Cao, Y. Fan, P. Xu and J. Chen (2019). „Release and Transformation of BTBPE During the Thermal Treatment of Flame Retardant ABS Plastics.“ Environmental Science & Technology **53**(1): 185-193.

Zhang, M., J. Shi, Y. Meng, W. Guo, H. Li, X. Liu, Y. Zhang, H. Ge, M. Yao and Q. Hu (2019). „Occupational exposure characteristics and health risk of PBDEs at different domestic e-waste recycling workshops in China.“ Ecotoxicology and Environmenal Safety **174**: 532-539.

Zhang, H. D., P. Wang, Y. M. Li, H. T. Shang, Y. W. Wang, T. Wang, Q. H. Zhang and G. B. Jiang (2013). “Assessment on the occupational exposure of manufacturing workers to Dechlorane Plus through blood and hair analysis.” Environmental Science & Technology **47**: 10567–10573.

Zhao, X. R., Z. F. Qin, Z. Z. Yang, Q. Zhao, Y. X. Zhao, X. F. Qin, Y. C. Zhang, X. L. Ruan, Y. F. Zhang and X. B. Xu (2010). „Dual body burdens of polychlorinated biphenyls and polybrominated diphenyl ethers among local residents in an e-waste recycling region in Southeast China.“ Chemosphere **78**(6): 659-666.

Zheng X. B., J. P. Wu, X. J. Luo, Y. H. Zeng, Y. Z. She and B. X. Mai (2012). “Halogenated flame retardants in home-produced eggs from an electronic waste recycling region in South China: Levels, composition profiles, and human dietary exposure assessment.” Environment International **45**: 122–128.

Zheng, X., F. Xu, K. Chen, Y. Zeng, X. Luo, S. Chen, B. Mai and A. Covaci (2015). „Flame retardants and organochlorines in indoor dust from several e-waste recycling sites in South China: composition variations and implications for human exposure.“ Environment International **78**: 1-7.

Zhou, T., D. G. Ross, M. J. DeVito and K. M. Crofton (2001). „Effects of Short-Term in Vivo Exposure to Polybrominated Diphenyl Ethers on Thyroid Hormones and Hepatic Enzyme Activities in Weanling Rats.“ Toxicological Sciences **61**(1): 76-82.

Zhu, J., L. Zhao and L. Guo (2022). „Dechloranes exhibit binding potency and activity to thyroid hormone receptors.“ J Environ Sci (China) **112**: 16-24.

Annex A

Informed Consent form signed by each blood donor participating in the study

Logo

Organization
Address
Contact

Sample code (to be completed by an Authorized Employee): ____-__/____/____

Informed Consent

I have been clearly informed of the purpose of the study and I agree to participate in the study.

I agree to fill in a short questionnaire, which contains questions related to the monitored substances in the blood.

I agree to provide my blood for analysis and I give a consent for the handling of the obtained data for the purposes of this study.

I have been assured that the information obtained in the study will be confidential and any misuse will be ruled out. The samples are provided with a code and the anonymity of personal data and results is guaranteed. The data will be handled in accordance with **Thailand's Personal Data Protection Act (PDPA)**.

My **participation is voluntary**, and I am free to terminate my participation at any time without giving a reason.

- **I agree with the long-term storage** of a blood sample for further research (analyses for other harmful and beneficial substances).

YES / NO (circle appropriate answer)

Place: ________________________ Date: ________________

Name of the Blood donor: ____________________________

Signature: ______________________

Name of the Authorized Employee: _____________________

Date: ______________

Signature: _____________________

Annex B

Certificate of Approval by the Institutional Review Board (IRB) Ethic Committee for Human Research, Kalasin Provincial Public Health Office

	คณะกรรมการจริยธรรมการวิจัยในมนุษย์ สำนักงานสาธารณสุขจังหวัดกาฬสินธุ์
	หนังสือรับรองการพิจารณาจริยธรรมโครงการวิจัย (Certificate of Approval)
หมายเลขโครงการวิจัย KLS.REC47/2565 .ชื่อโครงการวิจัย โครงการติดตามสุขภาพของผู้ปฏิบัติงานในพื้นที่จัดการขยะอิเล็กทรอนิกส์ ในประเทศไทย Health monitoring system of E-Waste dismantling workers in Thailand.	
ชื่อผู้วิจัย นายสุรเชษฐ์ ภูลวรรณ นายแพทย์เชี่ยวชาญ(ด้านเวชกรรมป้องกัน)	สังกัด โรงพยาบาลฆ้องชัย สำนักงานสาธารณสุขจังหวัดกาฬสินธุ์

วิธีการทบทวน (Reviewed Method): การพิจารณาโดยคณะกรรมการที่ได้รับมอบหมาย (Expedited review)

เอกสารข้อมูลสำหรับผู้วิจัย :

1 แบบยื่นขอรับการพิจารณาจริยธรรมการวิจัย (Submission form for Ethical Review)
2 แบบฟอร์มการประเมินโดยผู้วิจัย (Self-Assessment Form for Principle Investigator)
3 โครงร่างงานวิจัย (Proposal)

อื่นๆ :

คณะกรรมการจริยธรรมการวิจัยในมนุษย์ สำนักงานสาธารณสุขจังหวัดกาฬสินธุ์ ให้การรับรองการยกเว้นพิจารณาจริยธรรมโครงการวิจัย ตามแนวทางหลักจริยธรรมการวิจัยในคนที่เป็นมาตรฐานสากล ได้แก่ ประกาศเฮลซิงกิ แนวทางการปฏิบัติการวิจัยทางคลินิกที่ดีและรายงานเบลมองต์

Kalasin Provincial Public Health Office Research Ethics Committee has exempted the above research protocol which has been reviewed and approved based on international guidelines for human research projection including the Declaration of Helsinki, International Conference on Harmonization in Good Clinical Practice (ICH-GCP) and The Belmont Report.

ลงนาม..

(นายแพทย์พรพัฒน์ ภูนากลม)
นายแพทย์เชี่ยวชาญ(ด้านเวชกรรมป้องกัน)
ประธานคณะกรรมการจริยธรรมการวิจัยในมนุษย์

วันที่รับรองการพิจารณาจริยธรรม: วันที่ 23 กันยายน 2565
Date of approval: 23 September 2022

วันหมดอายุ:วันที่ 22 กันยายน 2566
Date of expiration: 22 September 2023

Annex C-1

Questionnaire completed by each blood donor

Questionnaire for e-waste workers

Ecological Alert and Recovery - Thailand (EARTH)
211/2 Ngamwongwan Rd. Soi 31, Bangkhen,
Muang, Nonthaburi 11000
mobile: +66(0) 909816336 Tel. +66(0) 2 952 5061

Sample code (to be completed by an Authorized Employee): ____-__/____/____

Sampling date: ____/____/____ (DD/MM/YY)

Questionnaire for the collection of blood samples

Name and Surname: ______________________________ **Male** / **Female** (circle appropriate)

Birth Date: ____/____/____ (DD/MM/YY) **Age**: __________

Weight: ________ **Height**: ________

Years spent working in an e-waste dismantling workshop: ______________

Circle appropriate and fill in the additional information, please:

Smoker: YES / NO

Former smoker: YES / NO Has not smoked for _____ months

Passive smoking (smoking at home or in the workplace): YES / NO

Regular use of drugs: YES / NO

Type of drugs used (e.g., sedatives, high blood pressure drugs, etc.): ________________

Use of hormonal preparations (e.g., contraception, etc.): YES / NO

If so, **the period of use**: _____ years

Use of food supplements (vitamins, minerals, etc.): YES / NO

If so, **frequency of use**: _____ times per week

Viral diseases in the last 3 months: YES / NO

Vaccinations in the last 3 months: YES / NO

If so, **what type of vaccination**: ____________

X-ray examination in the last 3 months: YES / NO

Any other health problems: ____

Circle appropriate and fill in the additional information about your daily job, please:

How long do you work in e-waste processing field? ____ years

How far do you live from the workshop you work in? ____ m / km

How many hours do you usually work? ____ per day

What type of work do you do?

E-waste dismantling: YES / NO

If so, average **length of the dismantling** is ____ hours per day, ____ times per week/month

E-waste shredding: YES / NO

If so, average **length of the shredding** is ____ hours per day, ____ times per week/month

E-waste burning: YES / NO

If so, average **length of the burning** is ____ hours per day, ____ times per week/month

Any other type of work with e-waste: ____________

If so, average **length of the work** is ____ hours per day, ____ times per week/month

Describe activities and their length during your ordinary working day (for example yesterday):

____
____
____
____
____
____

Circle appropriate and fill in the additional information about your daily diet, please:

What do you usually eat for (for example yesterday):

breakfast? ____

lunch? ____

dinner? ____

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How many hours do you sleep per day? ______ hours

Do you drink alcohol? YES / NO

If so, average **amount** of wine/beer/spirit is ____ ml per day/week/month

Do you drink coffee? YES / NO

If so, average **amount** of coffee is ____ ml per day/week/month

Do you drink black/green tea? YES / NO

If so, average **amount** of tea is ____ ml per day/week/month

Do you take drugs of abuse (i.e., LSD, cocaine, heroin, marijuana, ketamine, ecstasy, methamphetamine etc.)?

If so, average frequency of ______ use is ____ times per week/month

If so, average frequency of ______ use is ____ times per week/month

Annex C-2

Questionnaire completed by each blood donor

Questionnaire for the control group

Ecological Alert and Recovery - Thailand (EARTH)
211/2 Ngamwongwan Rd. Soi 31, Bangkhen,
Muang, Nonthaburi 11000
mobile: +66(0) 909816336 Tel. +66(0) 2 952 5061

Sample code (to be completed by an Authorized Employee): ____-__/____/____

Sampling date: ____/____/____ (DD/MM/YY)

Questionnaire for the collection of blood samples

Name and Surname: ____________________________ **Male** / **Female** (circle appropriate)

Birth Date: ____/____/____ (DD/MM/YY) **Age**: _________

Weight: _______ **Height**: _______

Have you ever worked at e-waste processing industry?: YES / NO

What is your job? __________________

Circle appropriate and fill in the additional information, please:

Smoker: YES / NO

Former smoker: YES / NO Has not smoked for _____ months

Passive smoking (smoking at home or in the workplace): YES / NO

Regular use of drugs: YES / NO

Type of drugs used (e.g., sedatives, high blood pressure drugs, etc.): _______________

Use of hormonal preparations (e.g., contraception, etc.): YES / NO

If so, **the period of use**: _____ years

Use of food supplements (vitamins, minerals, etc.): YES / NO

If so, **frequency of use**: _____ times per week

Viral diseases in the last 3 months: YES / NO

Vaccinations in the last 3 months: YES / NO

If so, **what type of vaccination**: ___________

If so, **what part of the body**: ___________

Any other health problems: ____

Circle appropriate and fill in the additional information about your daily job, please:

How many hours do you usually work? ____ per day

Describe activities and their length during your ordinary working day (for example yesterday):

____
____
____
____
____
____

Circle appropriate and fill in the additional information about your daily diet, please:

What do you usually eat for (for example yesterday):

breakfast? ____

lunch? ____

dinner? ____

snacks? ____

How much water do you drink per day? ______ litres per day

How many hours do you sleep per day? ______ hours

Do you drink alcohol? YES / NO

If so, average **amount** of wine/beer/spirit is ____ ml per day/week/month

Do you drink coffee? YES / NO

If so, average **amount** of coffee is ____ ml per day/week/month

Do you drink black/green tea? YES / NO

If so, average **amount** of tea is ____ ml per day/week/month

Do you take drugs of abuse (i.e., LSD, cocaine, heroin, marijuana, ketamine, ecstasy, methamphetamine etc.)?

Health Monitoring System of e-waste dismantling workers in Thailand

2022 – 2023

If so, average frequency of ______ use is ____ times per week/month

If so, average frequency of ______ use is ____ times per week/month

July 10th, 2022

Dear *Participant's name*

On behalf of the Ecological Alert and Recovery – Thailand (EARTH), Arnika association Czech Republic (Europe), The Khok Sa-ad subdistrict authority, and the Khong Chai hospital, we would like to **thank you** for taking part in the Study of the Health Monitoring System of the e-waste dismantling workers in Thailand, which is part of the EU-funded project: Public participation through citizen science and EIA system enhancement.

The blood of each person contains thousands and thousands of different chemical substances, which is normal, but our main goal was to find out if there are higher levels of specific chemicals in your blood as a result of working in the e-waste industry. By being a participant, you provided information that could help the community learn if and to what extent the e-waste dismantling workers may be affected by these chemicals.

We are writing to report the results we received from analyzing your blood samples for toxicants present in e-waste. Your blood was tested for **16 different polybrominated diphenyl ethers (PBDEs), dechlorane plus (anti-DP, syn-DP), hexabromococyclododecanes (HBCDs), several new brominated flame retardants (new BFRs), tetrabromobisphenol A (TBBPA), pentachlorobenzene (PeCB), hexachlorobenzene (HCB), and chlorinated paraffins (SCCP, MCCP)**.

At this point there are no official rules from world health authorities on what are dangerous levels of any of these toxicants. But a good way to understand these is to compare your results to the results of other people in this study, and to people who do not work in the e-waste dismantling industry and do not even live in the vicinity of areas where this activity is carried out (the so-called Reference group). On the following page there is a graph showing how your values differ from the representative values of people in the Reference group aged 48-68 living in Thailand, who have never worked in the e-waste industry. In this graph you can also find the comparison of your results with the median values of e-waste workers living and/or working in the Kalasin area. Based on the results, we found that:

Your total **PBDEs content** was: **YY ng/g**
XX times Lower – at the same level – higher than Reference group
XX times Lower – at the same level – higher than E-waste workers median values

Your total **DP content** was: **YY ng/g**
XX times Lower – at the same level – higher than Reference group
XX times Lower – at the same level – higher than E-waste workers median values

Your total **PeCB content** was: **YY ng/g**
XX times Lower – at the same level – higher than Reference group
XX times Lower – at the same level – higher than E-waste workers median values

Your **HCB content** was: **YY ng/g**
XX times Lower – at the same level – higher than Reference group
XX times Lower – at the same level – higher than E-waste workers median values

Your total **SCCP and MCCP content** was: **YY ng/g**

EU – European Union
EIA – Environmental Impact Assessment

Annex D

Example of letter for blood donors

XX times Lower – at the same level – higher than Reference group
XX times Lower – at the same level – higher than E-waste workers median values

At the same time, your ***new BFRs, HBCD and TBBPA*** *concentration in your blood serum was* ***under the LOQ (limit of quantification).***

According to scientists, higher blood levels of these substances can disrupt a person's hormonal and immune system, and even cause cancer. Nevertheless, potential disease outbreaks or any health problems are not only a result of chemical concentration in blood, but a result of a mix of various factors (age, lifestyle, overall health condition and others). Thus, as a prevention, we recommend You visit a doctor and have measurements of thyroid stimulating hormone (TSH) levels and both free and total triiodothyronine (T3) and thyroxine (T4) done. We also recommend monitoring of fasting glucose levels. In cooperation with doctors and toxicology experts, in order to reduce exposure to toxic substances during your work, we would like to recommend You to:

- **Use protective equipment** such as respiratory protection, gloves, long sleeved clothing;
- **Avoid eating and drinking in working area** and areas nearby, where dust from working area is transmitted;
- **Do not burn plastic parts** of the e-waste;
- **Separate your workspace** from the area where you prepare food and from the space where you spend your free time;
- **Clean frequently the area where e-waste is being dismantled**, near-by areas where you relax, and areas in your homes where you carry and change your working clothes.
- **Avoid the consumption and selling of locally produced foodstuffs of animal origin**.

Graph 1. Your PBDEs/DPs/PeCBs/HCB/SCCP+MCCP blood content results (blue) compared to Reference group median values (green) and median values of e-waste workers living/working in Kalasin area (orange).

Again, on behalf of the Ecological Alert and Recovery – Thailand (EARTH) and the Arnika org. Czech Republic, thank You for participating in this study.

Your sincerely,

Penchom Saetang

Director of EARTH, on behalf of the research team

Arnika is a Czech non-governmental organization established in 2001. Its mission is to protect nature and a healthy environment for future generations both at home and abroad.

www.english.arnika.org

EARTH is an independent non-governmental organization striving for social and environmental sustainability and justice in Thai society and promoting climate justice, good governance and accountability of governmental and international agencies. EARTH focuses on the impacts of hazardous substances on ecosystems, local communities, and workers' health.

www.earththailand.org/en

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