HAZARDOUS CHEMICALS IN PLASTIC PRODUCTS

BROMINATED FLAME RETARDANTS IN CONSUMER PRODUCTS MADE OF RECYCLED PLASTIC FROM ELEVEN ARABIC AND AFRICAN COUNTRIES

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BROMINATED FLAME RETARDANTS IN CONSUMER PRODUCTS MADE OF RECYCLED PLASTIC FROM ELEVEN ARABIC AND AFRICAN COUNTRIES

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IPEN is a network of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

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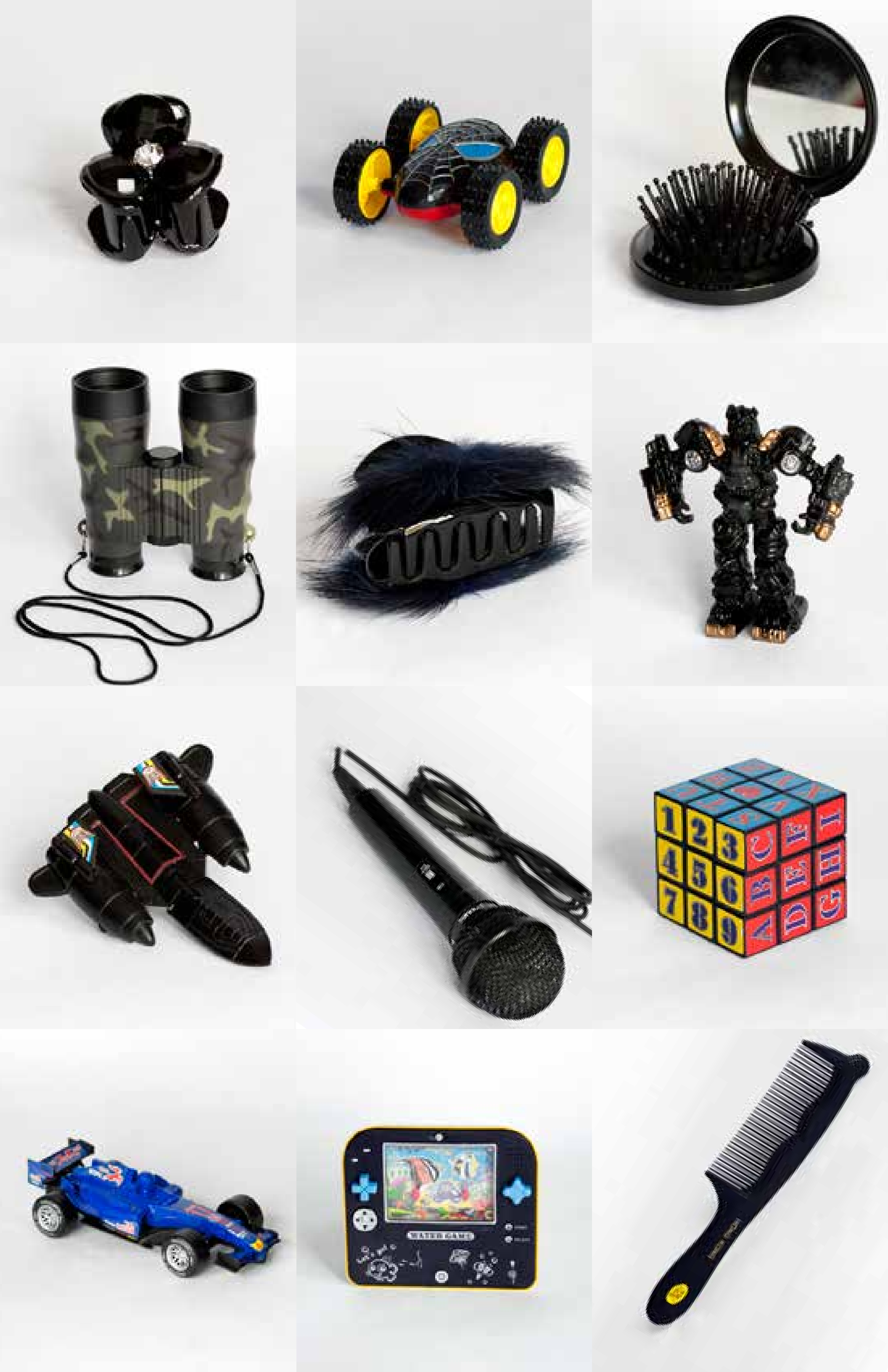
WATER GAME

EXECUTIVE SUMMARY

Both the environment in Africa and the Arabic region and the human health of Africans and people from Arabic countries suffer from toxic chemicals and imported wastes more than in developed countries. Africa has become a destination of illegal toxic waste exports and, as this study shows, toxic chemicals are also present in toys, kitchen utensils, and other consumer products sold at African and Arabic region markets.

Four hundred and thirty-four samples of toys and other consumer products made of black plastic, from eleven countries, were sampled for this study. Samples from Burkina Faso, Cameroon, Egypt, Ethiopia, Gabon, Jordan, Kenya, Morocco, Syria, Tanzania, and Tunisia were analyzed by X-ray fluorescence (XRF) and almost one fifth of all 434 samples were sent for special chemical analysis, based on the total content of bromine and antimony, because bromine and antimony content is an indication that black plastic may contain brominated flame retardants (BFRs); (Petreas, Gill *et al.* 2016).

Eighty-three samples including 22 toys, 27 hair accessories, 18 kitchen utensils, 11 office supplies, and 5 other products were analyzed for 11 common toxic BFRs, 16 congeners of polybrominated diphenyl ether (PBDE) standing for 3 commercial BDE mixtures, 3 isomers of hexabromocyclododecane (HBCD), listed as just HBCD, 6 novel BFRs (nBFRs), and tetrabromobisphenol A (TBBPA).

Out of the 83 analyzed products, only 22 had levels of PBDEs below 50 ppm, which means that 61 of them would be considered as POPs waste in Africa when applying the proposed protective concentration limits called the Low POPs Content Levels (LPCLs)[1], defining when waste becomes hazardous waste under the Stockholm Convention. That means that 14% out of all the 434 samples collected in eleven African and Arabic countries for this study would be considered hazardous waste.

The laboratory analysis showed that 79 out of the 83 samples contained OctaBDE at concentrations ranging from 2 to 176 ppm and 80 out of the 83 samples contained DecaBDE ranging from 4 to 296 ppm respectively. PentaBDE was measured in trace levels of 0.005 – 0.19 ppm only in 9 out of the 83 samples, all from Kenya. The highest measured concentrations

1 See Article 6 of the Stockholm Convention, which defines what is POPs waste (Stockholm Convention 2010). LPCL for each of the POPs listed under the Stockholm Convention is set in the General Technical Guidelines for POPs Waste, updated by the Basel Convention (Basel Convention 2017).

of PBDEs were found in children's toys, followed by office supplies, hair accessories, other consumer products, and kitchen utensils. The highest levels of HBCD were found in kitchen utensils followed by children's toys.

Looking at the total amount of PBDEs in the samples, in a toy-car from Jordan, in a cup for pens and pencils (office supply) from Tanzania, and a head dresser (hair accessory) from Morocco, these were detected at 390, 332 and 315 ppm respectively. The highest content of HBCD (49 ppm) was found in a knife handle from Tunisia. The highest levels of nBFRs measured, 689 and 441 ppm respectively, were detected in two toy samples bought in Jordan. The highest levels of TBBPA measured, 980, 458 and 243 ppm, were detected in two hair accessories samples (hair clip and hair headband) obtained in Kenya, and a toy pistol bought in Ethiopia respectively. The same two samples from Kenya having the highest levels of TBBPA also had the highest and third highest levels of the total sum of BFRs analyzed in this study at 1,347 and 1,149 ppm respectively, followed by two samples from Jordan, a toy car and a Rubik's-like cube, having the second and fifth highest total BFRs levels of 1,180 ppm and 880 ppm respectively, in which novel BFRs contributed to the total level substantially (689 and 441 ppm). It is necessary to note that only a limited number of BFRs was measured by the targeted chemical analysis used in this study, so the total levels of BFRs based on its results are very relative figures rather than reflecting the real content of all BFRs.

The results of this study show that BFRs regulated under the Stockholm Convention can be found in consumer products from markets in Africa and the Arabic region, similar to what has previously been shown in other countries. The concentration of the BFRs cannot be explained away as unintentional trace contamination (UTC); (DiGangi, Strakova *et al.* 2011, Rani, Shim *et al.* 2014, Puype, Samsonek *et al.* 2015, DiGangi, Strakova *et al.* 2017, Straková, DiGangi *et al.* 2018). It therefore raises the question why both regulated and unregulated toxic flame retardants were found at such high levels in products which do not need to be treated with these chemicals? The likely answer is that they are made of recycled plastic from plastic e-waste and end-of-life vehicles (ELVs) where BFRs were originally used.

This major problem of toxic BFRs contaminating toys and other consumer products arose when BFRs listed under the Stockholm Convention in 2009 were granted an exemption for recycling, promoted by developed countries such as the EU, Canada, Japan and others.

E-waste and ELVs plastic containing high levels of toxic flame retardants should be banned from entering the recycling chain.

The present study has shown that children's toys, hair accessories, office supplies and kitchen utensils found on the African and Arabic markets are affected by unregulated recycling of e-waste plastics that carry brominated flame retardants into new products. To stop this practice, stricter measures to control BFRs content in products and waste need to be set and enforced.

There were also high levels of nBFRs and TBBPA in the analyzed products. These substances are yet unregulated, but also pose significant health risks in the same way as the PBDEs and HBCD already listed under the Stockholm Convention. Only a class-based approach can address the practice of so-called regrettable substitution, where old toxic BFRs are replaced with new, likely also toxic but still unregulated BFRs. These continue to circulate in the waste and recycling streams in the same way as their regulated counterparts. It is clear that their levels in consumer products require immediate action. The most effective way would be to list these chemicals as a class under the Stockholm Convention, since listing this big group of toxic chemicals one by one as individual substances would take too long to protect consumers' health.

Very high levels of brominated dioxins were measured in nine samples analyzed for this group of chemicals out of all samples in this study. The data showed that the sampled children's products and consumer products obtained in African and Arabic countries contained levels of brominated dioxins on a scale normally found in a variety of hazardous wastes, including in waste incineration processes. Their influence on toddlers has been studied in several examples of toys made from recycled black plastic. The conclusion of a recent study was that ingestion of pieces of plastic toys by children may represent an intake of dioxins up to a level that is 9 times higher than the recommended tolerable daily intake for dioxins of 0.28 pg TEQ/kg body weight/day. Brominated dioxins were found in the consumer products included in this study at much higher levels than in previous studies.

Stricter Low POPs Content Levels (LPCLs) should be applied to waste to stop the flow of e-waste and ELVs plastic into new products made of recycled plastic. Stricter LPCLs can also help to stop the import of POPs waste into African and Arabic countries. African and Arabic countries can then introduce stricter LPCLs and unintentional trace contamination (UTC) limits for BFRs in products into their national legislation and enforce it by using available separation techniques for border controls of incoming products and wastes. The demonstrated presence of brominated dioxins in products with relatively low levels of PBDEs underlines the need to apply stricter LPCLs.

ABBREVIATIONS

ABS	acrylonitrile butadiene styrene (a type of plastic used often in electronics casings)
BFRs	brominated flame retardants
Br	bromine
BTBPE	1,2-bis(2,4,6-tribromophenoxy)ethane, one of the nBFRs
DBDPE	decabromodiphenyl ethane, one of the nBFRs
DecaBDE	commercial mixture of Decabromodiphenyl ether
EFSA	the European Food Safety Authority
ELVs	end-of-life vehicles
EU	the European Union
e-waste	electronic waste
HBB	hexabromobenzene, one of the nBFRs
HBCD	hexabromocyclododecane
IARC	the International Agency for Research on Cancer
IPEN	the International Pollutants Elimination Network
LPCL	Low POPs Content Level
nBFRs	novel BFRs
OctaBDE	commercial mixture of Octabromodiphenyl ether (listed as hexabromodiphenyl ether and heptabromodiphenyl ether under the Stockholm Convention)
PBDD/Fs	polybrominated dibenzo-p-dioxins and furans, commonly called "brominated dioxins"
PBDEs	polybrominated diphenyl ethers
PCDD/Fs	polychlorinated dibenzo-p-dioxins and furans, usually called dioxins and/or chlorinated dioxins
PentaBDE	commercial mixture of Pentabromodiphenyl ether (listed as tetrabromodiphenyl ether and pentabromodiphenyl ether under the Stockholm Convention)
PFASs	per- and polyfluoroalkyl substances
POPs	persistent organic pollutants
TDI	tolerable daily intake
TEQ	toxic equivalent (established for calculation of dioxin toxicity levels)
UTC	unintentional trace contamination
XRF	X-ray fluorescence


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1. INTRODUCTION

Both the African environment and the human health of Africans suffer from toxic chemicals and imported wastes more than in developed countries. Situation is also similar in Arabic region, at least part of it. Africa has become a destination of illegal toxic waste exports and/or pesticides that are already banned in the countries of their origin. In 2006, Abidjan, the capital of the Ivory Coast, became the destination of 500 tons of a mixture of toxic waste that was dumped in different locations around the city. Seventeen people died. Tens of thousands had to seek medical treatment as a result of this disaster called "Probo Koala" after the ship that brought the toxic waste mixture to Africa (Amnesty International and Greenpeace 2012). Such accidents are only the tip of the iceberg of what is most likely a more common practice (Breivik, Gioia *et al.* 2011).

There is a long-standing history in Africa of places where imported electronics and end-of-life vehicles end up as a waste and are burnt. They contain dangerous chemicals such as heavy metals, toxic brominated flame retardants (BFRs), and other substances of concern, and their burning generates new, even more toxic chemicals, such as chlorinated and brominated dioxins or polyaromatic hydrocarbons. It is well documented how certain places and their inhabitants suffer from this practice, which is the result of loopholes in international legislation abused by companies and countries exporting e-waste and ELVs to Africa (Hogarh, Seike *et al.* 2012, Sindiku, Babayemi *et al.* 2015, Hogarh, Petrlik *et al.* 2019, Petrlik, Puckett *et al.* 2019, Oloruntoba, Sindiku *et al.* 2021). However, it is not only waste and the burning of it that can harm the African and Arabic population in relation to exposure to toxic chemicals. There is an increasing number of studies showing that products available on the African market also contain dangerous levels of toxic chemicals, including for example mercury (Uram, Bischofer *et al.* 2010), lead (Mathee 2014), short-chain chlorinated paraffins (Miller, DiGangi *et al.* 2017), and brominated dioxins (Sindiku, Babayemi *et al.* 2015, Petrlik, Brabcova *et al.* 2019).

Over 370 consumer products made from recycled plastic (including toys, puzzles including Rubik's cubes, kitchen utensils, office supplies, hair accessories, carpet padding, and other products) from 38 countries around the world have been analyzed to date. Banned BFRs such as polybrominated diphenyl ethers (PBDEs) or hexabromocyclododecane (HBCD) have been found in analyzed toys from Kenya, Nigeria, and South Africa in a previous IPEN and Arnika study (DiGangi, Strakova *et al.* 2017). However, no more complex analysis is available from Africa that focuses on toxic BFR content in products for groups more vulnerable to toxic chemicals such as children and women, similar to what was done for samples from European countries in 2018 (Straková, DiGangi *et al.* 2018). This report aims to fill that gap.

The current study aims to determine whether children's toys, hair accessories, office supplies, and kitchen utensils found on the African market contain BFRs. It is also a contribution to the discussion on setting appropriate standards and limits to improve the control of the circulation of harmful BFRs in consumer products and waste.

This is the first ever study focused specifically on countries of both African and Arabic region only, and also the second study that includes data about TBBPA levels measured in toys and other consumer products.

1.1 BRIEF INTRODUCTION TO BROMINATED FLAME RETARDANTS

Brominated flame retardants, BFRs, have been widely used in plastic and foam products for a long time, including in furniture upholstery, car seats and plastics, electronics, and building insulation (POP RC 2006, POP RC 2007, POP RC 2010). Their purpose is to increase the fire safety of the highly flammable plastic materials used. However, progress in scientific knowledge, efforts to protect consumers, as well as public pressure, have contributed to a gradual ban of the most toxic BFRs. PBDEs (Penta-, Octa-, and DecaBDE), and HBCD have been listed under the Stockholm Convention on Persistent Organic Pollutants (POPs) for global elimination. POPs, including PBDEs and HBCD, are not easily degraded in the environment, and are often able to travel far from the place of their release through water and air currents (Breivik, Wania *et al.* 2006, Segev, Kushmaro *et al.* 2009). PBDEs and HBCD are also known to disrupt the human hormonal, endocrine, immune and reproductive systems, and negatively affect the development of the nervous system and the intelligence in children (POP RC 2006, POP RC 2007, POP RC 2010, Sepúlveda, Schluep *et al.* 2010). Some of their substitutes, including decabromodiphenyl ethane (DBDPE) or 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) have been regrettable and have also been shown to be persistent, bioaccumulative, and able to travel long distances (EFSA CONTAM 2012, Vorkamp, Rigét *et al.* 2019). Tetrabromobisphenol A (TBBPA), an alternative to PBDEs and HBCD, and the largest-volume flame retardant used worldwide (Kodavanti and Loganathan 2019), is known to be endocrine-disrupting (Kitamura, Jinno *et al.* 2002).

The electrical and electronic engineering industry is one of the world's largest consumers of BFRs. Flame retardants are used in the production of plastic housings for consumer and office electronics, and for electronics containing heat sources, to decrease their flammability. Because BFRs are only added and not chemically bound to the plastic polymer, they are released from the material during the whole lifecycle of the product (Rauert and Harrad 2015), including disposal (Kim, Osako *et al.* 2006, Wong, Leung *et al.* 2008, Wu, Luo *et al.* 2008, Zhao, Qin *et al.* 2009).

In spite of the existing international and national legislation, a number of studies have shown the presence of PBDEs and HBCD in new products and household equipment (Turner and Filella 2017), including children's toys (Chen, Ma *et al.* 2009, Ionas, Dirtu *et al.* 2014, Guzzonato, Puype *et al.* 2017), thermo cups and kitchen utensils (Samsonek and Puype 2013, Puype, Samsonek *et al.* 2015, Guzzonato, Puype *et al.* 2017), and carpet padding (DiGangi, Strakova *et al.* 2011). Novel brominated flame retardants (nBFRs) have also been found to be present in products made of recycled plastics in significant concentrations (Straková, DiGangi *et al.* 2018). The studies concluded that these products were not intentionally treated with BFRs, but originated from the recycled plastic used to make them.

The findings of this study will be highly relevant for the ongoing global consultation processes on setting limit values for POPs in wastes and rules for plastic waste.

2. OBJECTIVES AND METHODS

The objective of this study was to assess whether brominated flame retardants found in e-waste are carried over into new consumer products available on the market as a result of plastic recycling. Specifically, this report aimed to determine whether children's toys, hair accessories, kitchen utensils, office supplies, and some other consumer products found on the market in Arabic and African regions are affected by unregulated recycling of e-waste plastics, which can carry brominated flame retardants into new products.

Based on previous peer-reviewed studies, it was assumed that black colored recycled plastic indicates e-waste as the likely recycling route (Turner and Filella 2017). For this reason, consumer products with black components and parts were prioritized for testing.

Four hundred and thirty-four (434) samples of consumer products made of black plastic were obtained from markets and stores in eleven countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Gabon, Jordan, Kenya, Morocco, Syria, Tanzania, and Tunisia. The samples were suspected to be made from recycled plastic. Children's toys, hair accessories, kitchen utensils, and office supplies were of primary interest.

As X-ray fluorescence is a useful technique for determining the presence of PBDEs in plastics (Gallen, Banks *et al.* 2014, Petreas, Gill *et al.* 2016), all samples were screened using a handheld NITON XL3t 800 XRF analyzer to guide the selection of samples for further laboratory analysis. As bromine is a key component of BFRs and antimony trioxide is a common BFR synergist (Petreas, Gill *et al.* 2016), the samples where the XRF indicated bromine and antimony levels over 1,000 ppm were then selected for a more detailed lab analysis. When a minimum of three samples representing different product categories (i.e., children's toys, hair accessories, kitchen utensils, office supplies, and other products) could not be identified among the collected samples, consumer goods down to 150 ppm of bromine and 40 ppm of antimony were selected instead and sent for lab analysis. Eighty three, almost one-fifth of all 434 samples were sent for special chemical analysis to the University of Chemistry and Technology in Prague.

Eighty-three samples (including 22 toys, 27 hair accessories, 18 kitchen utensils, 11 office supplies, and 5 other products) out of the 434 collected items were analyzed for 16 PBDE congeners. For the purpose of calculation, the components of the commercial PentaBDE mixtures include congeners BDE 28, 47, 49, 66, 85, 99, and 100, and for the OctaBDE mixtures include congeners BDE 153, 154, 183, 196, 197, 203, 206, and 207. The component of the commercial DecaBDE mixture is BDE 209.

Three isomers of HBCD (α-, β-, γ-HBCD), TBBPA, and six nBFRs, i.e., 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylpheny-1-indan (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT) were analyzed in the laboratory at the University of Chemistry and Technology in Prague, the Czech Republic. The targeted BFRs were isolated by extraction with n-hexane: dichloromethane (4:1, v/v). Identification and quantification of the PBDEs and nBFRs was performed using gas chromatography coupled with mass spectrometry in negative ion chemical ionization mode (GC-MS-NICI). Identification and quantification of the HBCD isomers was performed by liquid chromatography interfaced with tandem mass spectrometry with electrospray ionization in negative mode (UHPLC-MS/MS-ESI-). The limit of quantification was 5 ppb for BDE 209 and 0.5 ppb for the 15 other analyzed PBDE congeners, ranging between 0.5-5 ppb for the nBFRs, and was 0.5 ppb for HBCD and 5 ppb for TBBPA.

3. RESULTS

3.1 BROMINATED FLAME RETARDANTS

The laboratory analysis of the 22 toys, 27 hair accessories, 18 kitchen utensils, 11 office supplies, and 5 other products from 11 countries revealed that 79 out of the 83 samples contained OctaBDE at concentrations ranging from 2 to 176 ppm and 80 out of the 83 samples contained DecaBDE at concentrations ranging from 4 to 296 ppm respectively. PentaBDE was measured in trace levels of 0.005 – 0.19 ppm only in 9 out of 83 samples, all from Kenya. The highest measured concentrations of PBDEs were found in children's toys, followed by office supplies, hair accessories, other consumer products, and kitchen utensils. The highest levels of HBCD were found in kitchen utensils followed by children's toys. A summary of the results is presented in Table 1. The ranges of HBCD, PBDEs, nBFRs, and TBBPA, and the total sum of the analyzed BFR concentrations per country are summarized in Table 2. Detailed results for each of the analyzed samples can be found in the chart including the data for all 83 samples presented in Annex 2 of this report

TABLE 1. OVERVIEW OF THE ANALYTICAL RESULTS FOR THE ANALYZED BFRS ACCORDING TO THE GROUPS OF CONSUMER PRODUCTS, IN PPM (mg/kg)

	Children's toys	Hair accessories	Kitchen utensils	Office supplies	Other products
Number of samples	22	27	18	11	5
OctaBDE	2 - 176	7 - 151	0.4 - 35.6	9 - 83	0.16 - 33
DecaBDE	7 - 243	16 - 273	3 - 167	18 - 296	0.38 - 161
ΣPBDEs	9 - 390	29 - 315	3.9 - 182	50 - 332	0.54 - 194
HBCD	<LOQ - 12.5	<LOQ - 1.8	<LOQ - 49	<LOQ - 1.3	<LOQ - 0.4
ΣnBFRs	5 - 689	5 - 434	0.9 - 90.3	10 - 125	0.03 - 81
TBBPA	0.48 - 243	0.4 - 980	0.1 - 63	12 - 89	0.4 - 85
ΣBFRs	15 - 646	51 - 1,346	9.3 - 268.8	112 - 439	1 - 359
Total Br	**250 - 14,050**	**209 - 16,200**	**166 - 2,298**	**592 - 8,523**	**205 - 1,309**

TABLE 2. OVERVIEW OF THE ANALYTICAL RESULTS FOR THE ANALYZED BFRS, PER COUNTRY WHERE THE SAMPLES WERE OBTAINED

Measured ranges of concentrations (ppm)

Country	Number of samples	HBCD	ΣPBDEs	ΣnBFRs	TBBPA	ΣBFRs
Burkina Faso	5	<LOQ - 0.3	19 - 111	5.4 - 54	1.0 - 14	29 - 133
Cameroon	5	<LOQ - 1.5	50 - 210	19 - 225	19 - 113	112 - 495
Egypt	7	<LOQ - 12.5	17 - 267	5.5 - 103	0.4 - 84	58 - 418
Ethiopia	4	<LOQ - 2.5	35 - 149	25 - 187	1.2 - 243	72 - 646
Gabon	8	<LOQ - 4.7	0.54 - 209	0.03 - 125	0.4 - 89	1 - 424
Jordan	4	<LOQ - 1.2	30 - 390	20 - 689	7.3 - 186	57 - 1,180
Kenya	18	<LOQ - 1.1	0.2 - 279	0.3 - 412	0.5 - 980	0.6 - 1,347
Morocco	7	<LOQ - 3.1	37 - 315	6 - 434	10 - 196	98 - 897
Syria	4	0.004 - 0.2	3.9 - 194	0.9 - 69	0.2 - 64	5 - 214
Tanzania	11	<LOQ - 1.8	50 - 332	21 - 107	30 - 91	138 - 439
Tunisia	10	<LOQ - 49	11 - 308	12 - 325	3.5 - 151	30 - 608

The composition of BFRs differs among the individual samples and has no specific concentration patterns, suggesting that heterogeneous recycled materials were used. DecaBDE, followed by TBBA, were found at the highest concentrations in the samples. Moreover, novel BFRs (nBFRs) occur in significant concentrations in the sampled items. HBCD were found less frequently and at lower concentrations in the black plastic products analyzed in this study, probably because this flame retardant has primarily been used in polystyrene insulation, which is not recycled into any of the types of products included in this study. The kitchen utensil from Tunisia is the only exception among the analyzed samples, containing a substantial HBCD level. In comparison to former studies conducted by IPEN and Arnika (DiGangi, Strakova *et al.* 2017, Straková, DiGangi *et al.* 2018), the concentrations of HBCD in the recycled products seem to be decreasing. This trend could be a result of the global ban of HBCD in 2013 (Stockholm Convention 2013), and decreasing amounts of HBCD-treated products therefore entering the waste streams. HBCD has also been used in large volumes in polystyrene products, rather than in plastic casings for electronics, so it would also more probably be found in recycled polystyrene (Rani, Shim *et al.* 2014, Abdallah, Sharkey *et al.* 2018).

The average concentration of PBDEs in the samples of children's toys from Kenya remain at the same levels as in 2017 (DiGangi, Strakova *et al.* 2017). However, previously detected levels of PBDE in products from Nigeria (up to 1,174 and 672 ppm of OctaBDE and DecaBDE respectively) (DiGangi, Strakova *et al.* 2017) were significantly higher than the levels measured in the other African and Arabic countries in this study.

There are no official limit values for the content of BFRs in products or waste established in any legislation in the African and Arabic countries. However, the African region's representatives advocate for stricter limits for PBDEs in waste, to stop both the import of hazardous PBDE-containing e-waste into the region, and the recycling of this waste into new products. Stricter levels are proposed to be set – 50 ppm for the sum of PBDEs in total and 100 ppm for HBCD (Basel Convention 2017). The European Union uses and promotes less strict levels for PBDEs and HBCD at 1,000 ppm with the justification that it is not feasible for the recycling industry to meet stricter requirements than that. However, the EU is currently heading towards a reassessment of its limit values for POPs waste (Ramboll 2019).

After an implementation of the limit value of 50 ppm for the sum of PBDEs and 100 ppm for HBCD, 61 out of the 83 analyzed products included in this study would be classified as POPs waste. That equals 14% out of all 434 samples collected in the eleven countries for this study. Any wastes exceeding those levels should after implementation not be allowed to be freely imported to African and Arabic countries, or be recycled (see Article 6 of the Stockholm Convention), (Stockholm Convention 2010).

The highest total levels of the sum of PBDEs were detected in a toy car from Jordan, in a cup for pens and pencils (office supply) from Tanzania, and a head dresser (hair accessory) from Morocco, at 390, 332 and 315 ppm respectively. The highest content of HBCD (49 ppm) was found in a knife handle from Tunisia. The highest levels of nBFRs measured, 689 and 441 ppm respectively, were detected in two toy samples bought in Jordan. A hair headband (sample ID KE-H-16) from Kenya and a hair clip (sample ID MOR-HA-8A) from Morocco also contained high levels of the sum of novel BFRs at 434 and 412 ppm respectively. The highest levels of TBBPA measured, 980, 458 and 243 ppm, were detected in two hair accessories samples (hair clip and hair headband) obtained in Kenya and a toy pistol bought in Ethiopia, respectively. The same two samples from Kenya with the highest levels of TBBPA also had the highest and third highest levels of the total sum of BFRs analyzed in this study at 1,347 and 1,149 ppm respectively, followed by two samples from Jordan (a toy car and Rubik's-like cube) with the second and fifth highest total BFRs levels of 1,180 ppm and 880 ppm respectively, in which novel BFRs substantially contributed to the total level detected (with 689 and 441 ppm). The fourth highest level of total BFRs was measured in a hair clip sample from Morocco (sample ID MOR-HA-8A) (897 ppm), since it also contained high levels of PBDEs and TBBPA, 266 and 196 ppm respectively. It is necessary to note that only a limited number of BFRs was measured by targeted chemical analysis in this study, so the total levels of BFRs based on its results are very relative figures rather than reflecting the real content of all BFRs.

There is a discrepancy between the total bromine content in the products and the total content of BFRs measured with the chemically specific targeted analyses (see Table 1 and Annex 2). This is a similar situation to the difference between measured PFAS chemicals levels with a targeted chemical analysis and the total organic fluorine content levels found when assessing PFAS content in various products (Strakova, Schneider *et al.* 2021). It shows that there are probably much more brominated chemicals contained in analyzed products, including unrecognized BFRs and their metabolites which were not on the list of targeted chemical analysis. There is a long list of other BFRs not analyzed in the products by targeted chemical analysis in this study (Örn and Bergman 2009, Guerra, Alaee *et al.* 2010).

Overall, the results in this study indicate that toxic flame retardant chemicals found in e-waste are widely present on African and Arabic markets in consumer products made of recycled plastic. This includes three substances listed under the Stockholm Convention for global elimination (OctaBDE, DecaBDE, and HBCD), as well as some other BFRs raising concerns, TBBPA and six novel BFRs in particular.

Many samples of black plastic consumer products contained significant levels of all the groups of BFRs analyzed in this study except HBCD, as demonstrated by the results from the hair clip from Morocco or toys from Jordan (see Annex 2). It shows that products made of recycled black plastic represent very varying mixtures of many BFRs, and their potential impact on human health must be assessed as a mixture. Therefore, the health impacts of black plastic products are proposed to be analyzed by using bioassay analyses such as for example various CALUX or EROD bioassays (Whyte, Jung *et al.* 2000, Hoogenboom, Traag *et al.* 2006, Behnisch 2013, Behnisch and Brouwer 2015, Ouyang, Froment *et al.* 2017) as it was demonstrated in one study for six toy samples including one from Nigeria (Budin, Petrlik *et al.* 2020). The DR CALUX bioassay analyses indicate the dioxin-like activity of the samples. We also measured the brominated dioxin content in some of the samples, as documented in the next subchapter.

3.2 BROMINATED DIOXINS

Nine samples included in this report, of consumer products made of recycled black plastic, were also analyzed for the contents of polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), or brominated dioxins in short. The results are summarized in Table 3 below.

TABLE 3. OVERVIEW OF THE ANALYTICAL RESULTS FOR THE ANALYZED PBDD/F CONGENERS IN NINE SAMPLES FROM SEVEN COUNTRIES.

The results for the sum of PBDEs and TBBPA in those samples are also given for comparison. The level of PBDD/Fs is expressed in total amounts as well as in toxic equivalents (TEQ).

Sample ID	Sample description	Country	TBBPA (ug/kg)	ΣPBDEs (mg/kg)	17 PBDD/F congeners (pg TEQ/g)	17 PBDD/F congeners (pg/g)
CMR-0009-HA	headdress	Cameroon	52	210	774	261,923
Ga-29-01	lipstick	Gabon	85	194	378	88,197
Ga-08-01	knife	Gabon	2	182	1,430	243,422
Jo-T-1N	toy car	Jordan	99	390	3,580	741,123
Jo-T-1C	Rubik's-like cube	Jordan	185	254	8,180	1,120,526
MOR-HA-3A	headdress	Morocco	29	315	885	173,957
KEN-T-6	toy car	Kenya	0.5	270	6,590	1,590,463
TZ-K-33A	spoon	Tanzania	33	52	210	28,751
TUN-T-18A	toy chess	Tunisia	36	195	513	176,370

Levels in the range of 210 – 8,180 pg TEQ/g were measured in the nine consumer products from African countries and Jordan. The highest levels were found in toys from Jordan and Kenya, while the lowest level of 210 pg TEQ/g of PBDD/Fs was measured in a spoon from Tanzania. The highest level of PBDD/Fs, 8,180 pg TEQ/g, which was measured in a Rubik's-like cube from Jordan in this report, is twice as much as the highest level of PBDD/Fs of 3,821 pg TEQ/g measured in black plastic consumer products so far, which was observed in a key fob obtained in Germany (Petrlík, Behnisch *et al.* 2018). The minimum levels of PBDD/Fs in the collection of samples investigated in this report are also several times higher than those measured in previous samples. 1,305 pg TEQ/g was the average level of PBDD/Fs measured in 13 samples from 11 various countries previously (Petrlik, Brabcova *et al.* 2019), and that equals approximately half the average level of 2,504 pg TEQ/g of PBDD/Fs in the samples from the current report. High levels of PBDD/Fs were measured in samples from African and Arabic countries despite the levels of the sum of PBDEs being below 500 ppm, which is the current UTC level set for recycled products in EU legislation.

PBDD/Fs have previously been found in plastics treated with a variety of BFRs (Schlummer, Brandl *et al.* 2004, Sindiku, Babayemi *et al.* 2015). It is well documented that PBDD/Fs are formed as unintentionally produced POPs during the production of different kinds of flame retardants (Hanari, Kannan *et al.* 2006, Ren, Peng *et al.* 2011). They can be also formed during further reprocessing when plastics containing brominated flame retardants experience thermal stress (Ebert and Bahadir 2003).

Brominated dioxins have been observed in the environment in various levels. They are not always expressed in TEQs, and thus hard to compare with the levels measured in TEQs in this study. For example, levels around 40 pg TEQ/g have been observed in dust in elementary schools in Taiwan (Gou, Que *et al.* 2016).

In total values, the levels of PBDD/Fs in consumer products in this study ranged from 28,751 – 1,590,463 pg/g. These levels are in most of cases higher than the PBDD/F levels measured in waste incineration bottom ash from Taiwan in a previous study (1,600 – 31,000 pg/g) (Tu, Wu *et al.* 2011). The levels observed in most of the toys and other consumer products in this study also exceeded those previously found in residues of pyrolyzed printed circuit boards (231–490 pg I-TEQ/g) (Lai, Lee *et al.* 2007) and in waste incineration ash after de novo synthesis expressed in total levels (7,200 pg/g PBDD/Fs) (Kawamoto 2009).

Taken together, the data demonstrates that the sampled children's products and consumer products included in this study, obtained in African and Arabic countries, contained significant levels of PBDD/Fs. The measured PBDD/F levels in this study were on a scale previously found in a variety of hazardous wastes, including waste incineration bag filter ash, waste incineration bottom ash, residues of burned printed circuit boards, and in waste incineration ash after de novo synthesis.

4. BACKGROUND OF THE REPORT

4.1 BROMINATED FLAME RETARDANTS AS LEGACY OF E-WASTE RECYCLING

BFRs regulated by the Stockholm Convention were found in consumer products from African and Arabic markets just as it has been in other countries in previous years at levels which are not possible to mark as unintentional trace contamination (UTC). It raises the question: Why have both regulated and unregulated toxic flame retardants been found at such high levels in products that do not need to be treated with these chemicals in the first place? Most of the products seem to be made of recycled black ABS plastic. Significant levels of lead were also found in some of the products analyzed. It could possibly originate from the original plastic material, or it could stem from the colorings used to make the recycled plastic look more consistent.

E-waste and end-of-life vehicle (ELVs) plastic usually contain bromine compounds that are used as flame retardants in electronic and car equipment. The compounds include PBDEs, such as PentaBDE, OctaBDE and DecaBDE. These three substances are of primary interest in this study because, although highly hazardous to health and the environment, they have been permitted in consumer items made from recycled plastic from waste materials in some countries. This avoidable practice started back in 2009 when the first two PBDEs were listed under the Stockholm Convention with recycling exemptions (Stockholm Convention 2009, Stockholm Convention 2009a) violating its basic principle. POPs are so dangerous that they should not be recycled, and although waste recycling is a good environmental practice it should not apply to waste containing toxic chemicals.

In order to support its toxic recycling policy, the EU also uses and promotes higher limits for PBDEs and HBCD in waste for its definition as hazardous POPs waste.[2] So called Low POPs Content Levels (LPCLs) determine if a material is classified as hazardous POPs waste according to the Stockholm Convention3 and should be decontaminated. Only low enough POPs content limits can ensure separation of hazardous waste from the recycling stream. A protective low POPs content limit will also prevent contaminated waste exports from developed countries to Asian and African developing countries, which do not have the capacity to deal with all the world's wastes contaminated with dangerous POPs substances.

It is not only the LPCLs that allow dangerous substances like banned BFRs to enter consumer products made of recycled plastic, but also a very high UTC level set in the European legislation (European Parliament and the Council of the European Union 2019). A special UTC level was set for products made of recycled waste upon request of European recyclers industry associations. The current level is 500 ppm of total PBDEs content in recycled products. The same level for new virgin products is set at 10 ppm for each individual PBDE listed under the Stockholm Convention. All products in this study are below the UTC level in recycled products as it is set in EU, including toys and kitchen utensils. Seventy-six (92%) of them would not meet the UTC level for content of PBDEs in new virgin plastic products. Only two products, a can and beverage opener from Gabon and a sponge from Kenya, have levels of BFRs below 1 ppm what can be considered a genuine UTC level.

Why is it that the European legislation and practice can influence products sold on the African and Arabic markets? It is because a large part of the products from recycled black plastic are made in China, but directed at the European market. That is why they are made to comply with EU rules and requirements. The EU is also a powerful player in international negotiations.

This is also the reason why African countries want to protect their environment and the health of their citizens and push for the establishment of a stricter Low POPs Content Level of 50 ppm (mg/kg) for PBDEs as

2 The LPCL used in the EU is 1,000 ppm for PBDEs as well as for HBCD (European Parliament and the Council of the European Union 2011).

3 See Article 6 of the Stockholm Convention which defines what is POPs waste (Stockholm Convention 2010).

a sum under the Basel and Stockholm Conventions. This level is set as a provisional option for PBDEs in the General Technical Guidelines for POPs waste (Basel Convention 2017) based on the support from African negotiators. The higher LPCL of 1,000 ppm (mg/kg) is supported mainly by developed countries, including the EU, Japan and Canada.

Out of the 83 analyzed products, only 22 had levels of PBDEs below 50 ppm, which means that 61 of them would be considered as POPs waste in Africa when a LPCL of 50 ppm is applied.

This study shows that there is a much broader scale of BFRs present in products made of recycled e-waste and ELVs plastic. These include six nBFRs which have replaced PBDEs and HBCD in many applications, and TBBPA. These substances contribute to the content of all measured BFRs by more than half, as visible from results presented in Tables 1 and 2 as well as the more detailed results per each analyzed product in Annex 2. These flame retardants are not regulated under the international conventions, but that does not mean they are not harmful. At least some of them would definitely meet the criteria for definition of POPs as laid down in the Stockholm Convention. Decabromodiphenyl ethane (DBDPE), 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE), and hexabromobenzene (HBB) all bioaccumulate and have been found in different environmental compartments (EFSA CONTAM 2012) (Ricklund, Kierkegaard *et al.* 2009, Tlustos, Fernandes *et al.* 2010, EFSA CONTAM 2012, Shi, Zhang *et al.* 2016). TBBPA, an alternative to PBDEs and HBCD, and the largest-volume flame retardant used worldwide (Kodavanti and Loganathan 2019), is known to be a thyroid hormone-disrupting chemical (Kitamura, Jinno *et al.* 2002), and was classified as probably carcinogenic to humans by IARC recently (Grosse, Loomis *et al.* 2016, IARC 2020).

The characteristics and properties of all BFRs analyzed in this study can be found in Annex 1.

4.2 HEALTH ASPECTS

The brominated flame retardants found in the analyzed samples are known to migrate from the products (Rauert and Harrad 2015, Ionas, Ulevicus *et al.* 2016). They are related to negative impacts on the endocrine, immune and reproductive systems, and also negatively affect the nervous system development and intelligence in children (POP RC 2007, Sepúlveda, Schluep *et al.* 2010). Dermal exposure to PBDEs was in a recent study shown to also be a significant exposure route for adults, comparable to diet and dust ingestion (Liu, Yu *et al.* 2017).

4.2.1 PBDEs in children's toys and kitchen utensils: risks for consumers

It is well documented that BFRs migrate from consumer products made of plastic to household dust (Allen, McClean *et al.* 2008), and become available for human absorption. Sofas (Hammel, Hoffman *et al.* 2017) and electronics (Rauert and Harrad 2015) are important sources of PBDEs at home.

The appearance of kitchen utensils containing BFRs adds to the concern and scale of PBDEs intake by humans through food ingestion. Cooking experiments with kitchen utensils containing PBDEs demonstrated considerable transfer into the cooking oil (Kuang, Abdallah *et al.* 2018). When kitchen utensils containing PBDE are used, the transfer of PBDEs from the products is significantly intensified in comparison to the dermal contact with PBDE-contaminated products. In conclusion, cooking adds to the main routes of elevated transfer of BFRs from recycled consumer products into the human body.

Contamination of children's toys adds to the existing exposure paths, as children spend a significant amount of time on the ground in indoor areas having hand-to-mouth contact and playing with toys (Xue, Zartarian *et al.* 2007). According to a Belgian study (Ionas, Ulevicus *et al.* 2016), the PBDE exposure from mouthing toys was found to be higher than the exposure through diet or even dust. Young children are particularly sensitive to exposure due to toy mouthing and dust ingestion, as they play on the ground.

The findings of children's toys contaminated with PBDEs are alarming, because exposure occurs at the time of the children's development. Developmental neurotoxicity and endocrine disruption (Costa and Giordano 2007) are part of the PBDEs' properties that adversely affect children. PBDE exposure during prenatal and natal development is associated with poorer attention control in children, hyperactivity and behavioral problems

(Vuong, Yolton *et al.* 2018). It is contradictory for children to play with toys which are supposed to develop their motor skills and intellectual capacity, i.e., Rubik's cubes, toy guitars or games, while exposing them to toxic chemicals that have very opposite neurotoxic effects.

4.2.2 Potential health effects from the content of unintentional contaminants

Moreover, it can also be expected that there will be other harmful brominated substances such as brominated dioxins (PBDD/Fs) present in the analyzed products, as they accompany the BFRs in the original products (Sindiku, Babayemi *et al.* 2015, Petrlik, Brabcova *et al.* 2019). Their presence was analyzed and demonstrated in nine samples among the consumer products in this study at very high levels in the range of 210 – 8,180 pg TEQ/g. These substances exhibit similar health effects as chlorinated dioxins (PCDD/Fs), for which the tolerable daily intake (TDI) was recently lowered by the EFSA (EFSA CONTAM 2018a). Their influence on toddlers has been studied in several examples of toys made from recycled black plastic. The conclusion of a recent study was that ingestion of pieces of plastic toys by children may represent an intake of 2,3,7,8-TCDD equivalents up to a level that is "9 times higher than the recommended TDI for dioxins of 0.28 pg TEQ/kg body weight/day" (Budin, Petrlik *et al.* 2020).

4.2.3 Risks from the content of TBBPA in consumer products

TBBPA is a cytotoxicant, immunotoxicant, and thyroid hormone agonist with the potential to disrupt estrogen signaling (Kitamura, Jinno *et al.* 2002, Birnbaum and Staskal 2004). While earlier risk assessment studies concluded that there is no risk to human health associated with exposure to TBBPA (EFSA CONTAM 2011), 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. Toddlers are estimated to have a higher daily intake than adults. Dust ingestion constitutes for toddlers 90% of the overall exposure to TBBPA (Abdallah, Harrad *et al.* 2008). Furthermore, exposure to TBBPA may also occur prenatally and via breast milk. It is therefore important that women in childbearing age avoid exposure to TBBPA, including the usage of consumer products containing this chemical. From this point of view, the extremely high levels of TBBPA measured in the hair accessory samples from Morocco and Tunisia at 195 and 125 ppm respectively (e.g., hair clip sample MOR-HA-8A and hair dress sample TUN-HA-15A, see Annex 1) are of special concern in this study.

4.2.4 BFRs in hair accessories, kitchen utensils and office supplies pose a risk to women's health

Women are differently susceptible to BFR exposures and their associated health effects because of their physiology, different types of occupational exposures and different exposures to BFRs in household products (Mehta, Applebaum *et al.* 2020). For example, environmental toxicants including BFRs likely contribute to elevated rates of thyroid disease in women compared to men (Oulhote, Chevrier *et al.* 2016). This fact has important implications for women during their reproductive and post-menopausal ages. Post-menopausal women may be particularly vulnerable to PBDE induced thyroid effects, given low estrogen reserves. (Allen, Gale *et al.* 2016). Study focused on understudied population of low-income, overweight, pregnant women found that they may be uniquely vulnerable to environmental toxicants since their social positions, existing co-morbidities, and life stage may independently and synergistically amplify the adverse health effects of environmental toxicants (Mehta, Applebaum *et al.* 2020).

Hair beauty accessories, kitchen utensils, and to some extent also office supplies are typically used by women. Exposures to BFRs are in particular critical during pregnancy as PBDEs and TBBPA can cross the placental barrier to a developing fetus (Mitro, Johnson *et al.* 2015) and have been detected in breast milk (Tang and Zhai 2017). PBDEs exposures are associated with adverse health effects including pregnancy complications and neurological disorders in childhood including poorer concentration, attention, and reduced IQ (Herbstman, Sjodin *et al.* 2010, Gascon, Fort *et al.* 2012, Eskenazi, Chevrier *et al.* 2013, Zota, Linderholm *et al.* 2013, Wang, Padula *et al.* 2016).

4.2.5 FURTHER CONSEQUENCES WHEN THE PRODUCTS BECOME WASTE

According to the San Antonio Statement[4], flame retardant chemicals are being found in all environmental matrices examined including air, water, soil sediment, and sewage sludge (DiGangi, Blum *et al.* 2010, Daley RE 2011). The main sources of exposure to BFRs (including PBDEs) for the human body are mother's milk (Hooper and McDonald 2000), diet (Wu, Herrmann *et al.* 2007), and dust (Allen, McClean *et al.* 2008). Ingestion and dermal contact with dust are understood as the main contributors to PBDE exposure (Hammel, Hoffman *et al.* 2017), followed by dietary ingestion of animal and dairy products, and infant consumption of human milk (Jones-Otazo, Clarke *et al.* 2005).

Recycling of e-waste and furniture foam containing PBDEs contaminate populations working and living in the surroundings of e-waste recycling workshops (Liu, Zhou *et al.* 2008, Wang, Luo *et al.* 2011) and/or combined e-waste and ELVs scrapyards such as the one in Agbogbloshie, Ghana (Oteng-Ababio, Chama *et al.* 2014, Akortia, Olukunle *et al.* 2017). The risk is generally higher for the population treating e-waste in developing countries, where the majority of European and other developed countries' e-waste is processed (Stockholm Convention 2016). The lack of health and safety guidelines, combined with improper recycling techniques - such as dumping, dismantling, inappropriate shredding, burning and acid leaching (Sepúlveda, Schluep *et al.* 2010) further increase the risk for workers. A recent study by IPEN documented extremely high levels of POPs, including chlorinated and brominated dioxins, in the food chain of the population working and living at the e-waste scrap yard in Agbogbloshie (*see photo on p.31*). There, the highest level of brominated dioxins (300 pg TEQ/g fat) ever measured in chicken eggs was detected (Hogarh, Petrlik *et al.* 2019, Petrlik, Adu-Kumi *et al.* 2019), as well as one of the highest levels in soils from e-waste sites globally (Tue, Goto *et al.* 2016).

The products analyzed in this study containing high levels of BFRs might create additional problems when they too become waste. As there is not sufficient capacity for safe disposal of POPs-containing waste in particular, in most African and Arabic countries, products made of black plastic can end up at an unsecured dumpsite. Open burning is a common practice at these dumpsites, often intentionally, as people want to make more space for additional incoming waste. Burning plastics containing BFRs

4 The San Antonio Statement on Brominated and Chlorinated Flame Retardants1 is a consensus statement that documents health and environmental harm and, in some applications such as furniture foam, the lack of fire safety benefit from the use of brominated and chlorinated flame retardant chemicals (BFRs and CFRs). This statement, signed by more than 220 scientists and physicians from 30 countries, was published in the December 2010 Environmental Health Perspectives (DiGangi, Blum *et al.* 2010, Daley RE 2011).

Burning of e-waste plastics at scrapyard in Agbogbloshie, Ghana, leads to high levels of POPs in surrounding environment, including high levels of PBDD/Fs.
Photo: Martin Holzknech, Arnika, December 2018

leads to the formation of PBDD/Fs and brominated polycyclic hydrocarbons which then contaminate the local food chain (Gullett, Wyrzykowska *et al.* 2010, Nishimura, Horii *et al.* 2017, Petrlik, Bell *et al.* 2021). 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).

Brominated dioxins in free-range chicken eggs sampled in the areas of three dump sites or landfill sites in Libreville (Gabon), Pugu Kinyamwezi (Tanzania), and Yaoundé (Cameroon) were measured in a recent study by IPEN and Arnika (Petrlik, Bell *et al.* 2021). The levels of PBDD/Fs in two of these samples contributed to the total dioxin toxicity of the eggs by one tenth, which is a quite substantial level. It clearly shows the already existing problem with brominated compounds present in the wastes ending up in African dumpsites and landfills.

5. HOW TO FIX THE PROBLEM?

5.1 HALT THE ENTRY OF PLASTIC TREATED WITH BFRs TO BE RECYCLED INTO TOYS AND OTHER CONSUMER GOODS

A major problem arose when BFRs listed under the Stockholm Convention were granted exemptions for being recycled from wastes. E-waste and ELVs plastic containing high levels of toxic flame retardants should be halted from entering the recycling chain. This requires improvement of international rules in the first place, and better sorting of plastics at the sites where the recycling occur.

Also, the loophole allowing exports of nonfunctional electronics under the guise of repair in the Basel Convention's Technical Guidelines needs to be closed and stricter standards for the definition of hazardous wastes must be established under both the Basel and Stockholm Conventions.

African and Arabic countries also need to improve their national legislations to require better control of entering waste and products, in particular with regards to POPs content (see chapters 5.2 – 5.4 discussing this topic further).

5.2 NEED FOR SETTING STRICTER LIMITS

The potential human exposures to PBDEs and related harmful chemicals in products, including PBDD/Fs in waste, call for setting strict limit values for POP BFRs in products. The LPCLs for waste that defines POPs waste according to Article 6 of the Stockholm Convention also needs to be stricter. This should be established at a level of 50 ppm as proposed by the African region, and accompanied with setting an UTC level at 10 ppm, the same level as is applied in the EU for products from virgin plastics (European Parliament and the Council of the European Union 2019).

Out of the 83 analyzed products in this study, only 22 had levels of PBDEs that were below 50 ppm, which means that 61[5] of them would be considered as POPs waste when a LPCL of 50 ppm is applied. This level should be enforced in practice and introduced into the national legislation of each of the African countries. This raises the question of whether setting stricter limits than they are used in EU is manageable? Practically, it is mainly a question of using separation techniques for waste containing

5 14% of the total 434 samples collected in eleven African and Arabic countries for this study.

higher levels of BFRs and also techniques available for custom control of products entering the market.

5.3 SEPARATION TECHNIQUES

Gas chromatography and mass spectrometry are usually used for laboratory quantification of brominated flame retardants in different matrices including plastics. Typical bromine concentrations in plastics used in electric and electronic appliances are: 6-10% in high impact polystyrene (HIPS), 4-5% in polycarbonate (PC), and 6.8-9.6% in acrylonitrile butadiene styrene (ABS); (Weil and Levchik 2009). These known concentrations indicate what kind of plastics should be separated from the materials destined for recycling.

In recycling workshops and plants, methods based on the total concentration of bromine are applied to identify BFR-treated plastic and separate it out of the waste stream. For example X-ray fluorescence (XRF) and X-ray transmission (XRT) are operated on the industrial scale (UNEP 2017).

In the informal plastic recycling sector in India, a simple sink-and-float method is used for BFR plastic separation (UNEP 2017). Identical plastic materials are first shredded and then placed into a bath. This method is based on the different densities of BFR plastic (which is significantly more dense), which sinks, and its non-flame retardant counterpart, which floats on the surface of the bath.

For the level of PBDEs at 50 ppm and more, the total bromine (Br) content was not lower than 300 ppm and the antimony (Sb) level was not lower than 70 ppm in 83 out of the total number of products analyzed in this study.

The methods described above can also be used for border control of the consumer products and/or waste entering the African and Arabic countries, and the level of 300 ppm of total bromine content in combination with 50 ppm of antimony measured by XRF can be used as a threshold level.

5.4 REGULATION OF BFRs OTHER THAN PBDEs AND HBCD

No limit values are currently set for nBFRs and/or TBBPA in consumer products or wastes. The elevated levels of POP-PBDE and new BFRs in some consumer products reported in this study and the known and unknown adverse effects of these chemicals require a class-based approach to restriction of BFRs. The same approach is currently being discussed for PFASs in the EU (ECHA 2020).

EcoWaste Coalition, participating organization of IPEN uses handheld-XRF successfully for analyses of large variety of products.
Photo: EcoWaste Coalition


SAMSUNG
ZANUSSI
HAPPY
Happy Plaza
SHARP
The Pirates
super weapon

6. CONCLUSIONS AND RECOMMENDATIONS

The present study shows that children's toys, hair accessories, office supplies, and kitchen utensils found on the African and Arabic markets are affected by unregulated recycling of e-waste plastics which carry brominated flame retardants into new products. To stop this practice, stricter measures to control BFRs in products and waste need to be set and enforced.

Also, high levels of novel BFRs (nBFRs) and tetrabromobisphenol A (TBBPA) were detected in the analyzed products. These substances are unregulated yet but pose significant health risks, as well as PBDEs and HBCD which are already listed under the Stockholm Convention and regulated to a certain level. Only a class-based approach can address the regrettable substitutes and likely toxic new BFRs that are currently used without any regulation and which will continue to circulate in the waste streams, just as their persistent counterparts. Listing these chemicals under the Stockholm Convention as individual substances would also take much longer. Their levels in consumer products require immediate action.

Stricter Low POPs Content Limits (LPCLs) which define POPs wastes according to Article 6 of the Stockholm Convention should be applied in order to stop the flow of e-waste and ELVs plastic into recycled plastic and the products made of it. Stricter LPCLs can also help to stop the continuing import of POPs waste into African and Asian countries. African and Asian countries can introduce stricter LPCLs and UTC limits for BFRs in products into their national legislations and enforce them by using available separation techniques for border controls of incoming products and wastes.

Very high levels of brominated dioxins were measured in nine analyzed samples in this study. The presence of brominated dioxins in products with relatively low levels of PBDEs underlines the urgent need to apply stricter LPCLs.

ANNEX 1:
BROMINATED FLAME RETARDANTS (BFRs)

Brominated flame retardants such as polybrominated diphenyl ethers (PBDEs) are known as endocrine-disrupting chemicals (EDCs) and adversely impact the development of the nervous system and of children's intelligence (POP RC 2006, POP RC 2007, POP RC 2014).

The indisputable toxicity and persistency of the main representatives of brominated flame retardants, i.e., PBDEs and HBCD, resulted in governments listing them under the Stockholm Convention for global elimination. Scientists have raised serious concerns over substitutes for flame retardant chemicals, but they continue to be used without precautions or restrictions (DiGangi, Blum *et al.* 2010).

PBDEs are of primary interest for this study because these hazardous chemicals have been and still are used in many plastic products, including recycled plastics. PBDEs have been allowed to be recycled from waste materials into new products despite of their well-known adverse environmental and human health effects. HBCD and a few substitutes for PBDEs, described as novel brominated flame retardants (nBFRs), are also investigated in this study. The new flame retardants are being introduced to the market much faster than they are being evaluated, so there is an accumulating worldwide inventory of potentially problematic chemicals.

Only limited information is available on the current global market volume, but approximately 390,000 tons of brominated flame retardants were sold in 2011. This represents 19.7% of the flame retardants market (Townsend Solutions Estimate 2016).

POLYBROMINATED DIPHENYL ETHERS (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are a group of brominated flame retardants that include substances listed under the Stockholm Convention for global elimination such as PentaBDE (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 already have been identified in breast milk in Indonesia in research from more than a decade ago, and "the levels were in the same order as those in Japan and some European countries, but were one or two orders lower than North America" (Sudaryanto, Kajiwara *et al.* 2008).

PBDEs have adverse effects on reproductive health as well as developmental and neurotoxic effects (POP RC 2006, POP RC 2007, 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.

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 2010). 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 2013). This chemical also belongs among the SVHC substances under the REACH legislation.

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

2008, Abou-Elwafa Abdallah 2016). ABS resins are used in automotive parts, pipes and fittings, refrigerators, business machines, and telephones. The main applications where plastic containing tetrabromobisphenol A 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 signaling (Kitamura, Jinno *et al.* 2002, Birnbaum and Staskal 2004). TBBPA is 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).

While earlier risk assessment studies concluded that there is no risk to human health associated with exposure to TBBPA (EFSA CONTAM 2011), recent studies have identified this chemical as "probably carcinogenic to humans" (Grosse, Loomis *et al.* 2016, IARC 2020).

TBBPA has been detected in almost all environmental compartments all over the world, rendering it a ubiquitous contaminant (Abou-Elwafa Abdallah 2016). It has been found to bioaccumulate, e.g., in peregrine falcon eggs (Schwarz, Rackstraw *et al.* 2016).

Human exposure studies have revealed dust ingestion and diet as the major pathways of TBBPA exposure in the general population.

Toddlers are estimated to have a higher daily intake than adults. Dust ingestion constitutes 90% of the overall exposure to TBBPA for toddlers (Abdallah, Harrad *et al.* 2008). Furthermore, exposure to TBBPA may occur prenatally and via breast milk. It is therefore important that women of childbearing age should avoid exposure to TBBPA including the usage of consumer products containing this chemical.

TBBPA was also measured in a soil sample from Agbogbloshie e-waste scrap yard at a level of 149 ng g-1 dw which was higher than the levels of nBFRs but lower than the level of PBDEs measured in the same sample. It was not found to accumulate in the eggs from that site (Petrlik, Adu-Kumi *et al.* 2019).

Very little is known about any occupational exposure at TBBPA production sites and the exposure of the general population living in the vicinity of these production facilities. In addition, more information is required about the fate of this chemical in the waste stream. More research is also required to evaluate the risk associated with potential degradation/debromination of TBBPA to produce the hazardous chemical bisphenol A (BPA) under various environmental conditions (Abou-Elwafa Abdallah 2016).

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

NOVEL BFRS (nBFRs)

Novel BFRs (nBFRs) are a group of chemicals that in many cases have replaced already restricted BFRs. Different sources list different chemicals among this group, but only a few of them are measured in the environment. Recent studies have also shown that nBFRs are becoming widespread in the environment, including in food (Shi, Zhang *et al.* 2016, McGrath, Morrison *et al.* 2017).

The scientific panel of the EFSA evaluated 17 "emerging"[6] and 10 "novel"[7] BFRs in 2012 and suggested that: "There is convincing evidence that tris(2,3-dibromopropyl) phosphate (TDBPP) and dibromoneopentyl glycol (DBNPG) are genotoxic and carcinogenic, warranting further surveillance of their occurrence in the environment and in food. 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). EFSA's panel also stated that for most evaluated BFRs, there were not sufficient data about their presence in the environment to draw meaningful conclusions.

1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) 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 (with a log Kow of 11.1); (Covaci, Harrad *et al.* 2011). DBDPE has been identified in sewage sludge (De la Torre, Concejero *et al.* 2012), indoor dust (Julander, Westberg *et al.* 2005, Ali, Harrad *et al.* 2011) outdoor dust (Muenhor, Harrad *et al.* 2010, Anh, Tomioka *et al.* 2018), chicken eggs (Tlustos, Fernandes *et al.* 2010), honey (Mohr, García-Bermejo *et al.* 2014), food in general (Tlustos, Fernandes *et al.* 2010, Shi, Zhang *et al.* 2016), and in sediments and peregrine falcon eggs (Ricklund, Kierkegaard *et al.* 2009, Ricklund, Kierkegaard *et al.* 2010).

BTBPE was first produced in the 1970s and is used as a replacement for OctaBDEs (Hoh, Zhu *et al.* 2005). It has been identified in various abiotic media (dust, atmosphere, sediment, water) and biotic media (zooplankton, mussel, fish, aquatic bird eggs, honey, chicken eggs or food in general)

6 The group of emerging BFRs included: BEH-TEBP - Bis(2-ethylhexyl)tetrabromophthalate, BTBPE - 1,2-Bis(2,4,6-tribromophenoxy)ethane, DBDPE - Decabromodiphenyl ethane, DBE-DBCH - 4-(1,2-Dibromoethyl)-1,2-dibromocyclohexane, DBHCTD - 5,6-Dibromo-1,10,11,12,13,13-hexachloro-11-tricyclo[8.2.1.02,9]tridecene, EH-TBB - 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate, HBB - 1,2,3,4,5,6-Hexabromobenzene, HCTBPH - 1,2,3,4,7,7-Hexachloro-5-(2,3,4,5-tetra-bromophenyl)-bicyclo[2.2.1]hept-2-ene, OBTMPI - Octabromotrimethylphenyl indane (OBIND in this study), PBB-Acr - Pentabromobenzyl acrylate, PBEB – Pentabromoethylbenzene, PBT – Pentabromotoluene, TBNPA - Tribromoneopentyl alcohol, TDBP-TAZTO - 1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6-trione, TBCO - 1,2,5,6-Tetrabromocyclooctane, TBX - 1,2,4,5-Tetrabromo-3,6-dimethylbenzene, and TDBPP Tris(2,3-dibromopropyl) phosphate.

7 The group of novel BFRs included: BDBP-TAZTO - 1,3-Bis(2,3-dibromopropyl)-5-allyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBNPG - Dibromoneopentyl glycol, DBP-TAZTO - 1-(2,3-Dibromopropyl)-3,5-diallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBS – Dibromostyrene, EBTEBPI - N,N'-Ethylenebis(tetrabromophthalimide), HBCYD – Hexabromocyclododecane (HBCD or HBCDD are other abbreviations used for this chemical, already listed in Annex A to the Stockholm Convention), HEEHP-TEBP - 2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate, 4'-PeBPO-BDE208 - Tetradecabromo-1,4-diphenoxybenzene, TTBNPP - Tris(tribromoneopentyl) phosphate, and TTBP-TAZ - Tris(2,4,6-tribromophenoxy)-s-triazine.

(Hoh, Zhu *et al.* 2005, Julander, Westberg *et al.* 2005, Ali, Harrad *et al.* 2011, Wu, Guan *et al.* 2011, Mohr, García-Bermejo *et al.* 2014, Poma, Volta *et al.* 2014, Petrlik 2016, Petrlik, Kalmykov *et al.* 2017, Anh, Tomioka *et al.* 2018).

This compound 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 has been 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).

HBB has commonly been used for the manufacture of paper, woods, textiles, plastics, and electronic goods (Yamaguchi, Kawano *et al.* 1988, Watanabe and Sakai 2003). Thermal degradation of the DecaBDE technical mixture and polymeric PBDEs pyrolysis could also be sources of the HBB found in the environment (Thoma and Hutzinger 1987, Gouteux, Alaee *et al.* 2008).

The laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology inPrague routinely measures six nBFRs in environmental and consumer product samples, including plastic products for this study: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylpheny-1-indane (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT).

ANNEX 2:

DETAILED DATA ON 83 ANALYZED SAMPLES OF TOYS AND CONSUMER PRODUCTS FROM ELEVEN AFRICAN COUNTRIES

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
1	Burkina Faso	hair-head-dress [BF-29-01]	H	257	80		3,597	15,827	19,424	0	14,073	17,721	51,218	
2	Burkina Faso	peeler handle [BF-12-01]	K	173	126		8,597	36,660	45,258	0	963	26,213	72,434	
3	Burkina Faso	potato mash-er handle [BF-13-01]	K	166	91		1,725	20,687	22,412	13	1,101	5,359	29,155	
4	Burkina Faso	can opener handle [BF-10-01]	K	453	178		5,145	105,380	110,525	0	4,265	18,006	132,796	
5	Burkina Faso	tank [SID]BF-24-01	T	342	440		3,799	42,775	46,574	0	4,561	53,625	104,760	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
6	Cameroon	hair-head-dress [CMR-0009-HA]	H	5,376	1,422	0	72,124	138,034	210,158	1,459	51,612	115,659	378,888	
7	Cameroon	hair-clip [CMR-0015-HA]	H	9,198	2,115	0	75,763	111,794	187,557	1,049	113,146	193,528	495,279	
8	Cameroon	kitchen-grater handle [CMR-0026-KU]	K	541	132	0	9,341	40,341	49,682	0	43,928	18,827	112,437	
9	Cameroon	mobile frame [CMR-002-CT]	Ot	841	213	0	23,432	127,986	151,418	407	19,218	58,797	229,840	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
10	Cameroon	toy-guitar [CMR-007-CT]	T	7,529	1,756	0	48,024	69,090	117,115	744	63,793	224,950	406,601	
11	Egypt	brush [EG-HA-3]	H	690	208		14,564	44,988	59,552	0	366	5,536	65,454	
12	Egypt	hair headband [EG-HA-6]	H	2,275	583		7,382	259,162	266,544	258	84,019	67,124	417,945	
13	Egypt	tape holder [EG-OA-1]	O	4,392	1,114		18,460	31,753	50,213	850	23,697	68,990	143,750	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
14	Egypt	calculator [EG-OA-4]	O	3,255	1,148		37,920	85,925	123,845	170	40,049	102,999	267,062	
15	Egypt	billiard´s ball [EGY-T-1H]	T	250			2,074	14,830	16,903	12,534	4,215	24,722	58,374	
16	Egypt	chessboard [EG-T-5/1]	T	2,067	805		11,645	61,055	72,700	433	9,801	18,184	101,119	
17	Egypt	chess piece [EG-T-5/2]	T	810	266		8,338	101,019	109,357	363	2,673	59,587	171,981	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
18	Ethiopia	hair-head-dress [Eth-H-03A]	H	1,045	282	0	21,518	127,124	148,642	66	24,421	25,104	198,233	
19	Ethiopia	hair-clip [Eth-H-07A]	H	8,380	2,211	0	76,827	89,235	166,062	1,637	107,123	187,200	462,022	
20	Ethiopia	dish handle [Eth-K-02A]	K	174	69	0	5,308	29,910	35,218	0	1,176	35,119	71,513	
21	Ethiopia	toy-pistol [Eth-T-01A]	T	13,550	3,386	0	57,959	91,347	149,306	2,467	242,590	251,270	645,634	
22	Gabon	opener [Ga-03-01]	K	1,115	401	0	3,238	13,407	16,645	0	37,861	46,048	100,554	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
23	Gabon	knife handle [Ga-08-01]	K	320	194	0	14,655	167,331	181,986	0	2,059	31,762	215,807	
24	Gabon	stapler [Ga-11-01]	Of	7,305	1,781	0	83,336	125,636	208,972	415	89,418	125,029	423,835	
25	Gabon	earring [Ga-28-01]	Ot	205	124	0	7,065	39,996	47,060	151	15,818	56,415	119,445	
26	Gabon	lipstick [Ga-29-01]	Ot	1,309	330	0	32,804	160,832	193,635	0	84,517	81,252	359,404	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
27	Gabon	razor holder [Ga-30-01]	Ot	726	40	0	156	383	539	0	404	26	970	
28	Gabon	toy-guitar [Ga-17-01]	T	1,289	303	0	12,382	177,809	190,191	4,738	21,758	22,939	239,627	
29	Gabon	building kits [Ga-22-01]	T	512	155		3,057	15,530	18,587	0	15,988	35,151	69,726	
30	Jordan	hair clip [Jo-H-1H]	H	209	72		10,207	19,422	29,628	0	7,336	20,372	57,336	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
31	Jordan	office scissors [Jo-O-1B]	O	592	202		7,174	34,673	41,846	0	27,461	33,774	103,081	
32	Jordan	Rubik's like cube [Jo-T-1C]	T	6,434	1,845		110,409	143,508	253,917	0	185,466	440,590	879,972	
33	Jordan	toy-car [Jo-T-1N]	T	14,050	2,468		175,870	214,618	390,488	1,168	99,072	688,789	1,179,518	
34	Kenya	hair-clip [KEN-H-4]	H	4,392	1,296	0	46,198	68,690	114,888	201	33,224	153,953	302,265	
35	Kenya	hair-clip [KEN-H-6]	H	4,214	1,582	0	41,155	64,468	105,623	1,132	49,876	79,754	236,385	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
36	Kenya	hair-head-dress [KEN-H-7]	H	3,754	908	0	59,739	85,324	145,063	0	48,384	82,279	275,726	
37	Kenya	hair headband [KE-H-03]	H	3,703	955	189	78,653	143,836	222,678	0	75,117	94,894	392,689	
38	Kenya	hair headband [KE-H-16]	H	14,200	4,454	167	148,908	129,807	278,882	907	457,959	411,535	1,149,284	
39	Kenya	hair clip [KE-H-12]	H	12,850	3,542	190	101,494	56,811	158,495	448	980,197	207,781	1,346,921	
40	Kenya	hair headband [KE-H-02]	H	1,556	428	5	23,425	71,831	95,261	288	24,150	29,305	149,004	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
41	Kenya	knife handle [KE-K-10]	K	317	311	119	13,223	51,815	65,156	0	712	16,973	82,841	
42	Kenya	spoon handle [KE-K-25]	K	212	74	26	1,842	6,476	8,344	0	132	860	9,336	
43	Kenya	beer opener [KE-K-15]	K	583	193	128	35,573	79,723	115,424	36	63,097	90,259	268,815	
44	Kenya	pen [KEN-O-5]	O	252	91	0	0	16	16	0	7,186	203	7,405	
45	Kenya	pencil holder [KE-O-17]	O	1,237	289	6	5,327	78,317	83,651	136	16,033	21,850	121,669	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
46	Kenya	sponge (of-fice) [KE-O-15]	O	234	177	0	0	233	233	0	38	318	589	
47	Kenya	office-pen [KEN-O-1]	O	626	189	0	8,817	81,003	89,821	126	11,727	9,848	111,522	
48	Kenya	toy-car [KEN-T-6]	T	456	288	0	26,412	242,580	268,991	0	477	48,407	317,875	
49	Kenya	car toy [KE-T-16]	T	357	154	54	12,063	119,425	131,542	47	18,255	29,979	179,823	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
50	Kenya	car toy [KE-T-01]	T	447	152	0	16,826	136,566	153,392	0	10,098	18,885	182,375	
51	Kenya	toy "Minnie Mouse" [KE-T-04]	T	378	104	0	1,913	7,356	9,269	113	1,034	5,561	15,977	
52	Morocco	hair-head-dress [MOR-HA-3A]	H	3,208	756	0	90,248	224,930	315,178	535	29,025	262,638	607,375	
53	Morocco	hair-brush [MOR-HA-5A]	H	2,069	752	0	39,394	273,026	312,420	0	59,307	61,143	432,869	
54	Morocco	hair-clip [MOR-HA-8A]	H	16,200	4,370	0	151,089	114,543	265,632	813	195,990	434,499	896,933	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
55	Morocco	milk handle [MOR-KU-7A]	K	578	121	0	7,600	29,212	36,811	0	29,552	37,872	104,236	
56	Morocco	office-paper punch [MOR-OA-3A]	O	8,523	2,552	0	32,048	55,010	87,058	1,285	36,092	47,661	172,097	
57	Morocco	toy-play ground [MOR-T-2A]	T	4,739	1,226	0	15,296	76,599	91,895	3,095	41,231	43,626	179,848	
58	Morocco	toy-car [MOR-T-5A]	T	817	437	0	5,908	75,952	81,860	0	10,021	6,088	97,969	
59	Syria	hair clip [SY-H-A4]	H	5	1		27,230	39,448	66,678	180	63,653	69,011	199,522	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
60	Syria	hair-head-dress [SY-H-A3]	H	674	218		12,428	181,322	193,750	36	4,832	15,533	214,151	
61	Syria	soup spoon [SY-kit-U2a]	K	1	560		361	3,540	3,902	4	193	928	5,026	
62	Syria	soup spoon (handle) [SY-kit-U2b]	K	2	1		1,508	28,734	30,242	5	170	2,698	33,115	
63	Tanzania	hair-clip [TZ-H-11A]	H	4,927	1,210	0	13,927	151,820	165,747	175	63,902	36,708	266,532	
64	Tanzania	hair-clip [TZ-H-12A]	H	2,611	646	0	13,120	61,541	74,661	0	86,446	20,902	182,009	
65	Tanzania	hair-head-dress [TZ-H-16A]	H	7,501	1,824	0	59,554	131,069	190,624	564	90,086	94,918	376,191	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
66	Tanzania	hair-head-dress [TZ-H-17A]	H	9,269	2,456	0	56,522	46,228	102,751	1,785	90,993	92,206	287,735	
67	Tanzania	hair-clip [TZ-H-20A]	H	4,203	1,285	0	45,866	79,659	125,525	1,817	78,914	107,294	313,550	
68	Tanzania	kitchen turner [TZ-K-32A]	K	452	110	0	7,830	49,681	57,512	0	30,195	68,180	155,886	
69	Tanzania	noodle scoop [TZ-K-33A]	K	388	97	0	9,329	42,774	52,103	0	32,964	56,635	141,703	
70	Tanzania	kitchen turner [TZ-K-34A]	K	401	72	0	9,047	41,141	50,188	0	35,489	52,045	137,721	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
71	Tanzania	office stand [TZ-A-21A]	O	1,970	723	0	35,545	296,241	331,786	0	42,695	64,475	438,956	
72	Tanzania	Rubik's like cube [TZ-T-7A]	T	5,470	1,213	0	55,343	88,824	144,167	1,119	76,434	93,723	315,443	
73	Tanzania	pistol toy [TZ-T-9A]	T	467	105		8,482	51,796	60,278	17	4,489	64,534	129,318	
74	Tunisia	hair-head-dress [TUN-HA-15A]	H	13,450	3,364	0	99,940	57,942	157,882	598	125,087	324,861	608,427	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
75	Tunisia	hair-clip [TUN-HA-17A]	H	2,386	677	0	48,320	259,939	308,259	0	38,087	118,906	465,251	
76	Tunisia	hair-clip [TUN-HA-1A]	H	9,651	2,597	0	76,950	88,821	165,770	868	72,455	232,553	471,647	
77	Tunisia	knife handle [TUN-KU-6A]	K	821	235	0	6,680	25,540	32,220	48,890	3,517	18,705	103,333	
78	Tunisia	mashed potatoes [TUN-KU-7A]	K	2,298	1,084	0	7,150	3,713	10,863	0	7,619	11,953	30,435	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
79	Tunisia	hanger [TUN-KU-5A]	O	362	136		8,974	71,360	80,334	0	58	561	80,953	
80	Tunisia	chessboard-black part [TUN-T-15A]	T	10,850	2,858	0	45,693	110,391	156,085	823	18,643	112,314	287,865	
81	Tunisia	toy-game coin [TUN-T-17A]	T	4,018	881	0	33,223	62,323	95,545	530	16,072	61,517	173,664	
82	Tunisia	toy-automatic game [TUN-T-18A]	T	1,915	477	0	45,766	149,570	195,335	10,508	36,414	115,840	358,098	

Number	Country	Item [Sample ID]	Group	Br (mean)ppm	Sb (mean)ppm	pentaBDE µg/kg	oktaBDE µg/kg	PBDE 209 µg/kg	Sum of PBDEs µg/kg	Sum of HBCD µg/kg	TBBPA µg/kg	Total BFRs µg/kg	Total BFRs	Photo
83	Tunisia	glasses [TUN-T-21A]	Ot	4,164	1,278	0	59,573	55,939	115,512	0	151,004	157,750	424,266	

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