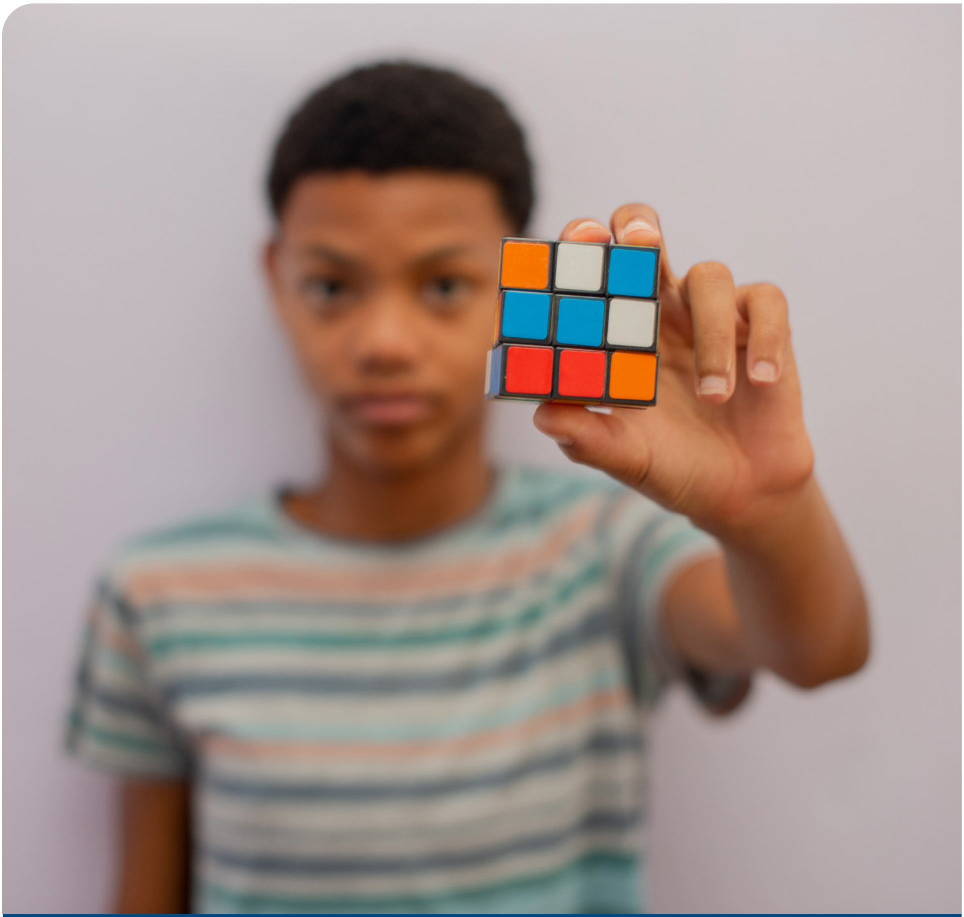

# HAZARDOUS CHEMICALS FOUND IN PLASTIC PRODUCTS IN AFRICA

## BROMINATED FLAME RETARDANTS IN CONSUMER PRODUCTS MADE OF RECYCLED PLASTIC FROM SEVEN AFRICAN COUNTRIES

June 2021

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**JUNE 2021**

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for a toxics-free future

**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.

**www.ipen.org**

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

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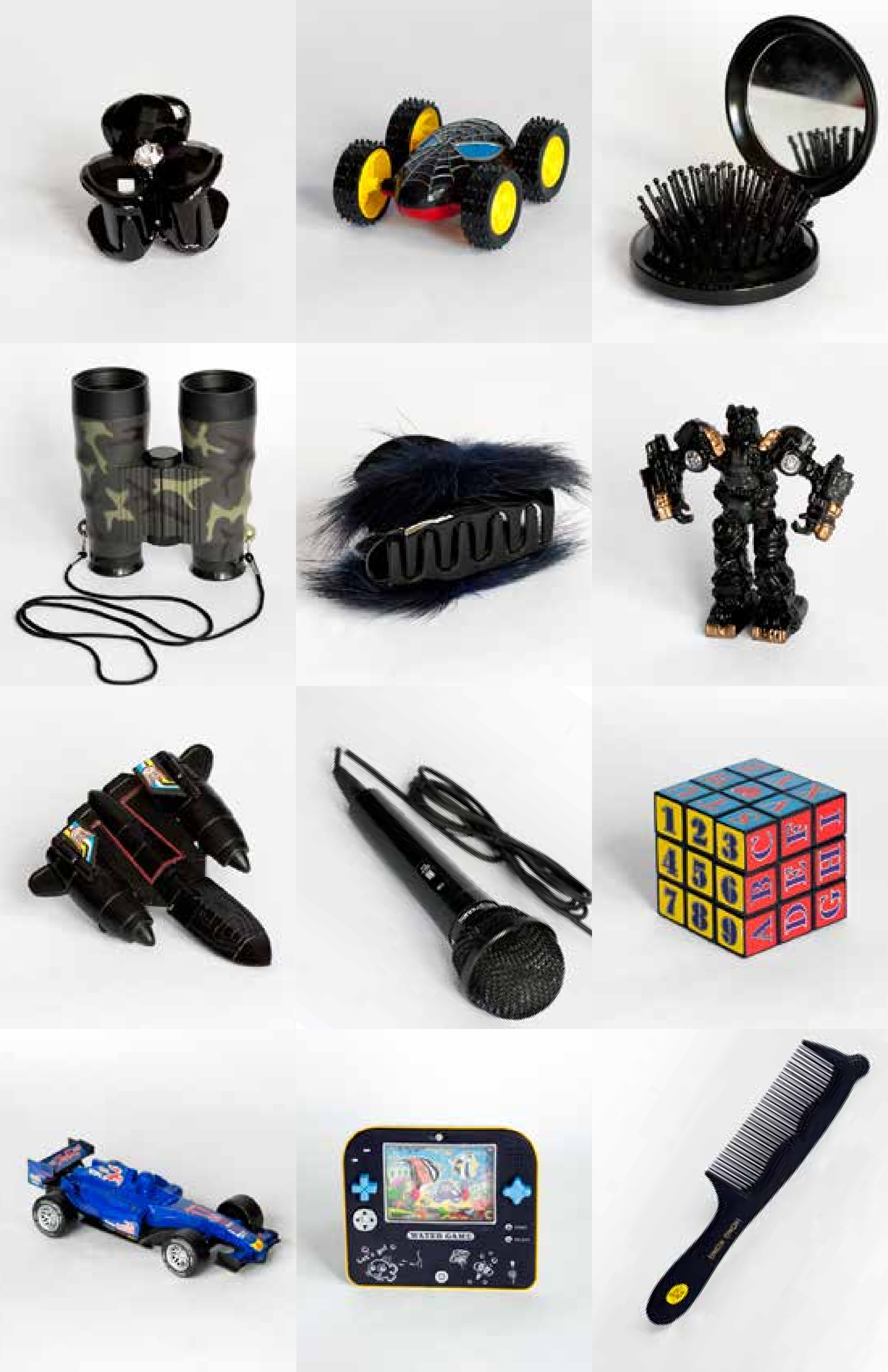
WATER GAME

# EXECUTIVE SUMMARY

Both the African environment and the human health of Africans suffer from toxic chemicals and imported wastes more than in developed countries. Africa has become the 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 markets.

Two hundred and forty-four samples of toys and other consumer products made of black plastic, from seven countries, were sampled for this study. Samples from Cameroon, Ethiopia, Gabon, Kenya, Morocco, Tanzania, and Tunisia were analyzed by X-ray fluorescence (XRF) and one-fifth of all 244 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).

Forty-seven samples, including 11 toys, 18 hair accessories, 10 kitchen utensils, 4 office supplies, and 4 other products were analyzed for eleven 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).

Only 8 of the 47 analyzed products contained levels of PBDEs below 50 ppm, which means that 39 products would be considered hazardous POPs waste in Africa when applying proposed, protective concentration limits defining when waste becomes hazardous waste under the Stockholm Convention, called the Low POPs Content Level (LPCL)[1]. That means that 16% out of all the 244 samples collected in seven African countries for this study would be considered hazardous waste.

1 98% of the 47 analyzed and 19% of the 244 collected samples.

The laboratory analysis showed that 46 samples[2] contained OctaBDE and DecaBDE at concentrations ranging from 3 to 151 ppm, and from 4 to 296 ppm respectively. The highest measured concentrations of PBDEs were found in office supplies, followed by hair accessories, children's toys, 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, the highest levels were measured in a cup for pens and pencils (office supply) from Tanzania, and a head dresser (hair accessory) from Morocco (332 and 315 ppm respectively). The highest level of HBCD (49 ppm) was found in a knife handle from Tunisia and the highest TBBPA concentration (243 ppm) was detected in a toy pistol bought in Ethiopia. A hair clip from Morocco contained the highest total level for the sum of novel BFRs (434 ppm). The same sample also contained high levels of PBDEs and TBBPA and had the highest level of total sum of BFRs analyzed in this study, at 897 ppm.

The results of this study show that BFRs regulated under the Stockholm Convention can be found in consumer products from African markets, 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 market 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.

2 98% of the 47 analyzed and 19% of the 244 collected samples.

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.

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 countries. African 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.

# ABBREVIATIONS

| | |
|---|---|
| ABS | acrylonitrile butadiene styrene (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 (etablished for calculation of dioxin toxicity levels) |
| UTC | unintentional trace contamination |
| XRF | X-ray fluorescence |

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Commodore

# 1. INTRODUCTION

Both the African environment and the human health of Africans suffer from toxic chemicals and imported wastes more than in developed countries. 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 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 African countries only, and also the first 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 African market 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.

Two hundred and forty-four (244) samples of consumer products made of black plastic were obtained from markets and stores in seven African countries: Cameroon, Ethiopia, Gabon, Kenya, Morocco, 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. One-fifth of all 244 samples were sent for special chemical analysis to the University of Chemistry and Technology in Prague.

Forty-seven samples (including 11 toys, 18 hair accessories, 10 kitchen utensils, 4 office supplies, and 4 other products) out of the 244 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

The laboratory analysis of the 11 toys, 18 hair accessories, 10 kitchen utensils, 4 office supplies, and 4 other products from 7 countries found that 46 out of the 47 samples contained OctaBDE and DecaBDE at concentrations ranging from 3 to 151 ppm, and from 4 to 296 ppm respectively. The highest measured concentrations of PBDEs were found in office supplies, followed by hair accessories, children's toys, 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 47 samples presented in Annex 2 of this report.

**TABLE 1.** OVERVIEW OF THE ANALYTICAL RESULTS FOR THE ANALYZED BFRs BY CONSUMER PRODUCT GROUP, IN PPM (mg/kg)

| | Children's toys | Hair accessories | Kitchen utensils | Office supplies | Other products |
|---|---|---|---|---|---|
| Number of samples | 11 | 18 | 10 | 4 | 4 |
| OctaBDE | 6-60 | 13-151 | 3-15 | 9-83 | 0.16-33 |
| DecaBDE | 56-243 | 46-273 | 4-167 | 81-296 | 0.38-161 |
| ÐPBDEs | 82-269 | 75-315 | 11-182 | 87-332 | 0.54-194 |
| HBCD | <LOQ-11 | <LOQ-1.8 | <LOQ-49 | <LOQ-1.3 | <LOQ-0.4 |
| ÐnBFRs | 6-251 | 21-434 | 12-68 | 10-125 | 0.03-81 |
| TBBPA | 0.48-243 | 24-196 | 1.2-44 | 12-89 | 0.4-85 |
| ÐBFRs | 98-646 | 182-897 | 30-216 | 112-439 | 1-359 |
| **Total Br** | **456-13550** | **1045-16200** | **174-2298** | **626-8523** | **205-1309** |

**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 |
|---|---|---|---|---|---|---|
| Cameroon | 5 | <LOQ-1.5 | 49.5-210 | 19-225 | 19-113 | 112-495 |
| Ethiopia | 4 | <LOQ-2.5 | 35-149 | 25-187 | 1.2-243 | 72-646 |
| Gabon | 7 | <LOQ-4.7 | 0.54-209 | 0.03-125 | 0.4-89 | 1-424 |
| Kenya | 5 | <LOQ-1.1 | 90-269 | 10-154 | 0.5-50 | 111-318 |
| Morocco | 7 | <LOQ-3.1 | 37-315 | 6-434 | 10-196 | 98-897 |
| Tanzania | 10 | <LOQ-1.8 | 50-332 | 21-107 | 30-91 | 138-439 |
| Tunisia | 9 | <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 primar-

ily 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 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 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, 39 out of the 47 analyzed products included in this study would be classified as POPs waste. That equals 16% out of all 244 samples collected in the seven African countries for this study. The wastes exceeding those levels should after implementation not be allowed to be freely imported to Africa, 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 cup for pens and pencils (office supply) from Tanzania, and a head dresser (hair accessory) from Morocco, at 332 and 315 ppm respectively. The highest content of HBCD (49 ppm) was found in a knife handle from Tunisia. The highest level of TBBPA measured, 243 ppm, was detected in a toy pistol bought in Ethiopia. A hair clip (sample ID MOR-HA-8A) from Morocco contained the highest level of the sum of novel BFRs at 434 ppm. The same sample had the highest level of the total sum of BFRs analyzed in this study (897 ppm), since it also contained high levels of PBDEs and TBBPA, 266 and 196 ppm respectively.

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 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 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 (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 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).

# 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 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 OctaBDE and DecaBDE. These two 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.3 So called Low POPs Content Levels (LPCLs) determine if a material is classified as hazardous POPs waste according to the Stockholm Convention4 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. Forty-six (98%) of them would not meet the UTC level for content of PBDEs in new virgin plastic products. Only one product, a can and beverage opener from Gabon, has 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 market? 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

3 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).

4 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 47 analyzed products, only 8 had levels of PBDEs below 50 ppm, which means that 39 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). 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 2018). 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 Statement5, 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.29*). 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 waste disposal, and disposal of POPs-containing waste in particular, in most African 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 contain-

5 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 the high levels of POPs in surrounding environment, including high levels of PBDD/Fs.** Photo: Martin Holzknech, Arnika, December 2018

ing BFRs 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 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 47 analyzed products in this study, only 8 had levels of PBDEs that were below 50 ppm, which means that 39 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 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 level of PBDEs at 50 ppm and more the total bromine (Br) content was not lower than 300 ppm and antimony (Sb) level was not lower than 70 ppm in 47 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 countries, and the


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

level of 300 ppm total Br 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).

SAMSUNG
ZANUSSI
HAPPY
Happy Plaza
SHARP

# 6. CONCLUSIONS AND RECOMMENDATIONS

The present study shows that children's toys, hair accessories, office supplies, and kitchen utensils found on the African market 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 countries. African 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.

# 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 FOR 47 ANALYZED SAMPLES OF TOYS AND CONSUMER PRODUCTS FROM SEVEN AFRICAN COUNTRIES

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cameroon | CMR-0009-HA | hair-head-dress | H | 0 | 72,124 | 138,034 | 210,158 | 1,459 | 115,659 | 51,612 | 378,888 | 5,376 | 1,422 |  |
| 2 | Cameroon | CMR-0015-HA | hair-clip | H | 0 | 75,763 | 111,794 | 187,557 | 1,049 | 193,528 | 113,146 | 495,279 | 9,198 | 2,115 |  |
| 3 | Cameroon | CMR-0026-KU | kitchen-grater handle | K | 0 | 9,341 | 40,341 | 49,682 | 0 | 18,827 | 43,928 | 112,437 | 541 | 132 |  |
| 4 | Cameroon | CMR-002-CT | other-mobile frame | Ot | 0 | 23,432 | 127,986 | 151,418 | 407 | 58,797 | 19,218 | 229,840 | 841 | 213 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Cameroon | CMR-007-CT | toy-guitar | T | 0 | 48,024 | 69,090 | 117,115 | 744 | 224,950 | 63,793 | 406,601 | 7,529 | 1,756 |  |
| 6 | Ethiopia | Eth-H-03A | hair-head-dress | H | 0 | 21,518 | 127,124 | 148,642 | 66 | 25,104 | 24,421 | 198,233 | 1,045 | 282 |  |
| 7 | Ethiopia | Eth-H-07A | hair-clip | H | 0 | 76,827 | 89,235 | 166,062 | 1,637 | 187,200 | 107,123 | 462,022 | 8,380 | 2,211 |  |
| 8 | Ethiopia | Eth-K-02A | kitchen-pan-handle | K | 0 | 5,308 | 29,910 | 35,218 | 0 | 35,119 | 1,176 | 71,513 | 174 | 69 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | Ethiopia | Eth-T-01A | toy-pistol | T | 0 | 57,959 | 91,347 | 149,306 | 2,467 | 251,270 | 242,590 | 645,634 | 13,550 | 3,386 |  |
| 10 | Gabon | Ga-03-01 | kitchen-opener | K | 0 | 3,238 | 13,407 | 16,645 | 0 | 46,048 | 37,861 | 100,554 | 1,115 | 401 |  |
| 11 | Gabon | Ga-08-01 | kitchen-knife | K | 0 | 14,655 | 167,331 | 181,986 | 0 | 31,762 | 2,059 | 215,807 | 320 | 194 |  |
| 12 | Gabon | Ga-11-01 | office-stapler | Of | 0 | 83,336 | 125,636 | 208,972 | 415 | 125,029 | 89,418 | 423,835 | 7,305 | 1,781 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | Gabon | Ga-17-01 | toy-guitar | T | 0 | 12,382 | 177,809 | 190,191 | 4,738 | 22,939 | 21,758 | 239,627 | 1,289 | 303 |  |
| 14 | Gabon | Ga-28-01 | other-earrings | Ot | 0 | 7,065 | 39,996 | 47,060 | 151 | 56,415 | 15,818 | 119,445 | 205 | 124 |  |
| 15 | Gabon | Ga-29-01 | hair-lipstick | Ot | 0 | 32,804 | 160,832 | 193,635 | 0 | 81,252 | 84,517 | 359,404 | 1,309 | 330 |  |
| 16 | Gabon | Ga-30-01 | other-razor | Ot | 0 | 156 | 383 | 539 | 0 | 26 | 404 | 970 | 726 | 40 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | Kenya | KEN-H-4 | hair-clip | H | 0 | 46,198 | 68,690 | 114,888 | 201 | 153,953 | 33,224 | 302,265 | 4,392 | 1,296 |  |
| 18 | Kenya | KEN-H-6 | hair-clip | H | 0 | 41,155 | 64,468 | 105,623 | 1,132 | 79,754 | 49,876 | 236,385 | 4,214 | 1,582 |  |
| 19 | Kenya | KEN-H-7 | hair-head-dress | H | 0 | 59,739 | 85,324 | 145,063 | 0 | 82,279 | 48,384 | 275,726 | 3,754 | 908 |  |
| 20 | Kenya | KEN-O-1 | office-pen-holder | Of | 0 | 8,817 | 81,003 | 89,821 | 126 | 9,848 | 11,727 | 111,522 | 626 | 189 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Kenya | KEN-T-6 | toy-car | T | 0 | 26,412 | 242,580 | 268,991 | 0 | 48,407 | 477 | 317,875 | 456 | 288 |  |
| 22 | Morocco | MOR-HA-3A | hair-head-dress | H | 0 | 90,248 | 224,930 | 315,178 | 535 | 262,638 | 29,025 | 607,375 | 3,208 | 756 |  |
| 23 | Morocco | MOR-HA-5A | hair-brush | H | 0 | 39,394 | 273,026 | 312,420 | 0 | 61,143 | 59,307 | 432,869 | 2,069 | 752 |  |
| 24 | Morocco | MOR-HA-8A | hair-clip | H | 0 | 151,089 | 114,543 | 265,632 | 813 | 434,499 | 195,990 | 896,933 | 16,200 | 4,370 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Morocco | MOR-KU-7A | kitchen-milk handle | K | 0 | 7,600 | 29,212 | 36,811 | 0 | 37,872 | 29,552 | 104,236 | 578 | 121 |  |
| 26 | Morocco | MOR-OA-3A | office-paper punch | Of | 0 | 32,048 | 55,010 | 87,058 | 1,285 | 47,661 | 36,092 | 172,097 | 8,523 | 2,552 |  |
| 27 | Morocco | MOR-T-2A | toy-play ground | T | 0 | 15,296 | 76,599 | 91,895 | 3,095 | 43,626 | 41,231 | 179,848 | 4,739 | 1,226 |  |
| 28 | Morocco | MOR-T-5A | toy-car | T | 0 | 5,908 | 75,952 | 81,860 | 0 | 6,088 | 10,021 | 97,969 | 817 | 437 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Tunisia | TUN-HA-15A | hair-head-dress | H | 0 | 99,940 | 57,942 | 157,882 | 598 | 324,861 | 125,087 | 608,427 | 13,450 | 3,364 |  |
| 30 | Tunisia | TUN-HA-17A | hair-clip | H | 0 | 48,320 | 259,939 | 308,259 | 0 | 118,906 | 38,087 | 465,251 | 2,386 | 677 |  |
| 31 | Tunisia | TUN-HA-1A | hair-clip | H | 0 | 76,950 | 88,821 | 165,770 | 868 | 232,553 | 72,455 | 471,647 | 9,651 | 2,597 |  |
| 32 | Tunisia | TUN-KU-6A | kitchen-knife | K | 0 | 6,680 | 25,540 | 32,220 | 48,890 | 18,705 | 3,517 | 103,333 | 821 | 235 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Tunisia | TUN-KU-7A | kitchen-potato-masher | K | 0 | 7,150 | 3,713 | 10,863 | 0 | 11,953 | 7,619 | 30,435 | 2,298 | 1,084 |  |
| 34 | Tunisia | TUN-T-15A | toy-chess, black side | T | 0 | 45,693 | 110,391 | 156,085 | 823 | 112,314 | 18,643 | 287,865 | 10,850 | 2,858 |  |
| 35 | Tunisia | TUN-T-17A | toy-game coin | T | 0 | 33,223 | 62,323 | 95,545 | 530 | 61,517 | 16,072 | 173,664 | 4,018 | 881 |  |
| 36 | Tunisia | TUN-T-18A | toy-chess | T | 0 | 45,766 | 149,570 | 195,335 | 10,508 | 115,840 | 36,414 | 358,098 | 1,915 | 477 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Tunisia | TUN-T-21A | toy-sun-glasses | T | 0 | 59,573 | 55,939 | 115,512 | 0 | 157,750 | 151,004 | 424,266 | 4,164 | 1,278 |  |
| 38 | Tanzania | TZ-A-21A | office-stand | Of | 0 | 35,545 | 296,241 | 331,786 | 0 | 64,475 | 42,695 | 438,956 | 1,970 | 723 |  |
| 39 | Tanzania | TZ-H-11A | hair-clip | H | 0 | 13,927 | 151,820 | 165,747 | 175 | 36,708 | 63,902 | 266,532 | 4,927 | 1,210 |  |
| 40 | Tanzania | TZ-H-12A | hair-clip | H | 0 | 13,120 | 61,541 | 74,661 | 0 | 20,902 | 86,446 | 182,009 | 2,611 | 646 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41 | Tanzania | TZ-H-16A | hair-head-dress | H | 0 | 59,554 | 131,069 | 190,624 | 564 | 94,918 | 90,086 | 376,191 | 7,501 | 1,824 |  |
| 42 | Tanzania | TZ-H-17A | hair-head-dress | H | 0 | 56,522 | 46,228 | 102,751 | 1,785 | 92,206 | 90,993 | 287,735 | 9,269 | 2,456 |  |
| 43 | Tanzania | TZ-H-20A | hair-clip | H | 0 | 45,866 | 79,659 | 125,525 | 1,817 | 107,294 | 78,914 | 313,550 | 4,203 | 1,285 |  |
| 44 | Tanzania | TZ-K-32A | kitchen spatula | K | 0 | 7,830 | 49,681 | 57,512 | 0 | 68,180 | 30,195 | 155,886 | 452 | 110 |  |

| Number | Country | Sample ID | Item | Group | pentaBDE µg/kg | oktaBDE µg/kg | PBDE 209 µg/kg | Sum of PBDEs µg/kg | Sum of HBCD µg/kg | Sum of nBFRs µg/kg | TBBPA µg/kg | Total BFRs µg/kg | Br (mean)ppm | Sb (mean)ppm | Photo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | Tanzania | TZ-K-33A | kitchen-strainer-spoon | K | 0 | 9,329 | 42,774 | 52,103 | 0 | 56,635 | 32,964 | 141,703 | 388 | 97 |  |
| 46 | Tanzania | TZ-K-34A | kitchen-spatula | K | 0 | 9,047 | 41,141 | 50,188 | 0 | 52,045 | 35,489 | 137,721 | 401 | 72 |  |
| 47 | Tanzania | TZ-T-7A | toy-Rubik's-cube | T | 0 | 55,343 | 88,824 | 144,167 | 1,119 | 93,723 | 76,434 | 315,443 | 5,470 | 1,213 |  |

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