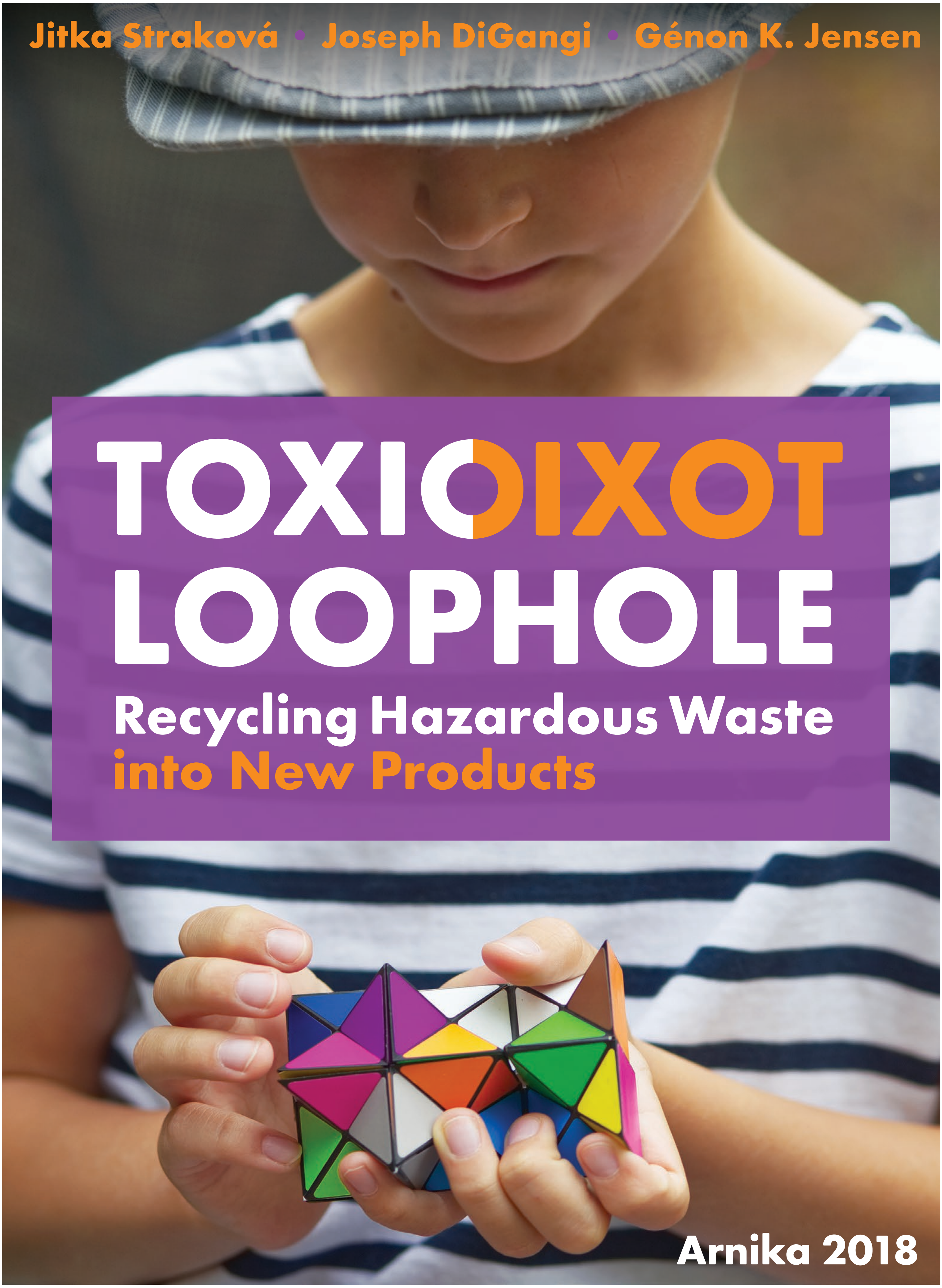
Jitka Straková • Joseph DiGangi • Génon K. Jensen

TOXIC LOOPHOLE

Recycling Hazardous Waste into New Products



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Arnika Association *is a Czech non-governmental organization established in 2001. Its mission is to protect nature and a healthy environment for future generations both at home and abroad. Since its beginnings, Arnika has worked on protection of consumers from chemically hazardous products. Lately, Arnika has been conducting its own research focusing on toxic chemicals in consumer products, mainly toys and child care products. Arnika serves as the Regional Hub for Central and Eastern Europe for IPEN.*
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The Health and Environment Alliance (HEAL) *is the leading not-for-profit organisation addressing how the environment affects human health in the European Union (EU) and beyond. HEAL works to shape laws and policies that promote planetary and human health and protect those most affected by pollution, and raise awareness on the benefits of environmental action for health. HEAL's EU Transparency Register Number: 00723343929-96*

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Established in 1998, **International POPs Elimination Network (IPEN)** *is currently comprised of over 500 Participating Organizations in 116 countries, primarily developing and transition countries. IPEN brings together leading environmental and public health groups around the world to establish and implement safe chemicals policies and practices that protect human health and the environment.IPEN's mission is a toxics-free future for all. IPEN's EU Transparency Register Number: 157269723532-97*

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Recycling Hazardous Waste into New Products

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LIST OF ABBREVIATIONS

ABS	*Acrylonitrile butadiene styrene*
BFRs	*brominated flame retardants*
BTBPE	*1,2-bis(2,4,6-tribromophenoxy) ethane*
COP	*Conference of Parties to the Stockholm Convention*
DBDPE	*Decabromodiphenyl ethane*
DecaBDE	*Decabromodiphenyl ether*
EDCs	*endocrine disrupting chemicals*
EEB	*European Environmental Bureau*
EU POPs regulation	*European Union´s Persistent Organic Pollutants Regulation*
EU RoHS directive	*EU Restriction of Hazardous Substances Directive (in electrical and electronic equipment)*
EU	*European Union*
E-waste	*electronic waste*
GPCR	*gas phase chemical reduction*
HBB	*Hexabromobenzene*
HBCD	*Hexabromocyclododecane*
HEAL	*Health and Environment Alliance*
HIPS	*high impact polystyrene*
IPEN	*International POPs Elimination Network*
LOD	*limit of detection*
LOQ	*limit of quantification*
LPCL	*low POPs content limit*
n	*number*
nBFRs	*new brominated flame retardants*
OBIND	*Octabromo-1,3,3-trimethylphenyl-1-indan*
OctaBDE	*Octabromodiphenyl ether*
POPs	*persistent organic pollutants*
PBDEs	*polybrominated diphenyl ethers*
PBEB	*2,3,4,5,6-pentabromoethylbenzene*
PBT	*Pentabromotoluene*
PC	*polycarbonate*
PCBs	*polychlorinated biphenyls*
PentaBDE	*Pentabromodiphenyl ether*
ppm	*parts per million*
REACH	*Registration Evaluation Authorization of Chemicals*
RMOA	*risk management option analysis*
SVHCs	*substances of very high concern*
SCWO	*super critical water oxidation*
UBA	*Umweltbundesamt (German Environment Agency)*
UPOPs	*unintentional persistent organic pollutants*
WEEE	*waste electrical and electronic equipment*
XRF	*X-ray fluorescence*
XRT	*X-ray transmission*
yr	*year*

CONTENTS

EXECUTIVE SUMMARY

This report found that consumer products, including toys, made from recycled electronic waste are contaminated with toxic chemicals. Product testing by Arnika, HEAL, IPEN and 17 other European organisations showed items on sale in Europe contained flame retardant chemicals, which are found in electronic waste and are restricted on health and environmental grounds. The report calls for closure of the loophole in EU legislation that allows products made from recycled waste to contain these contaminants. It outlines the changes in EU and international policy that would allow proper implementation of the Stockholm Convention to protect health and the environment by setting strict limit values for defining waste as being hazardous (POPs waste) and disallowing it there for export and toxic recycling.

The study

Between April and June 2018, 430 plastic items including toys, hair accessories, kitchen utensils and other consumer products were purchased in stores and markets in both European Union Member States (Austria, Belgium, Czechia, Denmark, France, Germany, Netherlands, Poland, Portugal, Spain, and Sweden) and surrounding Central and Eastern European countries (Albania, Armenia, Belarus, Bosnia and Herzegovina, Macedonia, Montenegro, Russia, and Serbia). All items were screened with a handheld XRF analyser showing that 109 samples (25%) had an elevated level of bromine and antimony indicating recycled plastic, most likely from e-waste.

E-waste contains bromine compounds that are used as flame retardants in electronic equipment. The compounds include polybrominated diphenyl ethers or 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 are permitted in consumer items made from recycled waste materials in the European Union.

All countries providing samples for the study are required to eliminate PBDEs from production and use. OctaBDE and DecaBDE and HBCD are listed in the Stockholm Convention on Persistent Organic Pollutants, a Convention which aims to eliminate or restrict the production and use of persistent organic pollutants (POPs). Only the European

Union, and 5 other countries around the globe have allowed recycling exemptions.

In order to support its toxic recycling policy, EU also uses and promotes higher limits for PBDEs and HBCD classification of material as POPs waste. So called Low POPs Content levels determine if material is classified as POPs waste and shall 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 from being exported from developed countries to Asian and African developing countries where environmentally sound waste disposable practices are quite rare.

Results

Of the original samples collected, 109 items were identified as likely to be containing flame retardants originating in recycled e-waste. **More detailed chemical analysis revealed that:**

- 94 samples (86%) contained OctaBDE at concentrations ranging from 1 to 161 ppm
- 50 sample (46%) exceeded the limit for OctaBDE concentrations of 10 ppm (EU Regulation on POPs for products that are made of new rather than recycled plastics)
- 100 samples (92%) contained DecaBDE at concentrations ranging from 1 to 3310 ppm
- The highest measured concentrations of PBDEs were found in children's toys, followed by hair accessories and kitchen utensils. A toy guitar from Portugal had the highest concentration of PBDEs (3318 ppm or 0.3% of product weight).

Health risks

Among the adverse impacts of PBDEs, endocrine disruption is a particular public health concern. PBDEs are known to disrupt human thyroid function affecting the developing brain and causing long-term neurological damage. Research shows PBDE exposure to be associated with poorer attention in children as well as hyperactivity.

Contamination of children's toys is especially worrying because children often put things in their mouths. It is unacceptable that toys, which are supposed to develop children's motor skills and intellectual capacity, such as plastic puzzles and Rubik's cubes, also expose them to toxic chemicals that have the very opposite, neurotoxic effects.

Food can be contaminated because PBDEs and HBCD can easily migrate from cooking items. PBDEs and HBCD in any product containing recycled plastics adds to all existing exposure paths, including via household dust.

Implications

The results indicate that toxic flame retardant chemicals are passed from e-waste into recycled consumer products on sale in the European Union and Central and Eastern European markets.

Ironically, if the products analysed in this study were made of virgin plastics instead of recycled materials, almost half (50 samples) would not meet the EU Regulation on POPs (OctaBDE concentrations must not exceeded the regulatory limit of 10 ppm). These different standards for PBDE content in virgin and recycled articles result from weak legislative thresholds for POPs waste and recycling exemptions in the Stockholm Convention listing of PentaBDE and OctaBDE. The legislative loopholes are motivated by recycling targets that ignore the consequences of contaminating new products during recycling, which continues the legacy of PBDE emissions and exposures.

The case of PBDEs illustrates an inconsistency in legislation on chemicals, products, and waste in the European Union. The study also reveals that consumer products made from recycled waste and containing toxic chemicals are not only on sale in the EU Member States, which make use of recycling exemptions for PBDEs, but are also on the market in Central and Eastern Europe. EU recycling goals are globalised through the international conventions – that means that hazardous e-waste is finding its way across state boundaries via recycling workshops back into recycled products. This loophole, hidden from public view, is threatening the health and lives of children, consumers, workers employed in recycling workshops and nearby residents as well as other vulnerable groups.

POLICY RECOMMENDATIONS

To close the toxic loophole, the following seven policy interventions are essential.

1. WITHDRAW THE RECYCLING EXEMPTIONS FOR MATERIALS THAT CONTAIN PentaBDE AND OctaBDE UNDER THE STOCKHOLM CONVENTION AND IN THE EU POPS REGULATION

During the Stockholm Convention, COP9, in 2019 the EU should withdraw its registration for the PentaBDE and OctaBDE recycling exemptions and encourage the small number of other Parties registered for those exemptions to do the same. The EU POPs regulation should be modified accordingly. This is an essential step to prevent contamination of new products with PBDEs and a key measure to achieve a truly circular economy, which must be non-toxic for the environment and for human health.

2. STOP UNDERMINING THE GLOBAL ELIMINATION AIMS OF THE STOCKHOLM CONVENTION IN THE EU

As the principle objective of the Stockholm Convention is to protect human health and the environment from POPs, the European Parliament should adopt a more protective standard of 10 ppm for DecaBDE content in articles made of recycled materials.

3. SET ENVIRONMENT- AND HEALTH-PROTECTIVE LIMITS FOR POPS WASTES UNDER THE BASEL CONVENTION AND EU POPS REGULATION

The EU should take the initiative to advocate for lowering the currently proposed hazardous waste limit of 1000 ppm for PBDEs and for HBCD to the scientifically and environmentally sound limits. These would be 50 ppm for PBDEs and 100 ppm for HBCD in the Basel and Stockholm Conventions and the EU POPs regulation. Only this low POPs content limit can help ensure separation of hazardous waste from the recycling stream. Protective low POPs content limits will also prevent waste export and waste disposal options, which cannot be considered environmentally sound.

4. STOP E-WASTE EXPORT FROM EUROPE TO DEVELOPING AND TRANSITION COUNTRIES UNDER BASEL CONVENTION PROVISIONS

E-waste must be clearly designated as hazardous. The EU should support modifications to the Basel Convention e-waste guidelines to prevent e-waste export to countries that lack regulatory infrastructure and technical and economic capacities for hazardous waste management.

5. STREAMLINE RESTRICTIONS FOR POPS, AVOID REGRETTABLE SUBSTITUTES, AND SPEED UP THE AUTHORISATION PROCESS UNDER THE REACH REGULATION

The entire group of halogenated flame retardants should be restricted under the REACH legislation to avoid replacement of PBDEs and other halogenated substances with regrettable substitutes. No exemptions, derogations, or transitional periods for restrictions or authorisations should be given for recycled materials or spare parts containing POPs.

6. IMPLEMENT SEPARATION TECHNIQUES TO REMOVE TOXIC CHEMICALS FROM WASTES AND NON-COMBUSTION TECHNOLOGIES FOR POPS DESTRUCTION

Until products are produced without toxic substances, separation techniques should be used to remove PBDEs and other toxic substances before recycling. The EU should implement non-combustion techniques for the destruction of POPs and advocate for their adoption in relevant Stockholm and Basel Convention working groups.

7. PUBLISH THE PROMISED NON-TOXIC ENVIRONMENT STRATEGY TO GUARANTEE A TRULY NON-TOXIC CIRCULAR ECONOMY AND BENEFITS FOR ENVIRONMENT AND HEALTH

To deliver on its commitment under the Seventh Environment Action Programme and progress on creating a circular economy, the EU in 2018 should publish a strategy for moving towards a non-toxic environment, including a clear commitment to keep chemicals of concern (e.g. flame retardants and other endocrine disruptors among others) out of products from the start due to their harmful impacts on vulnerable populations, such as infants, small children and pregnant women.

"Multinational chemical corporations have unleashed immense quantities of highly toxic and persistent chemicals that are harming the global environment and public health, including remote communities of the Arctic. Children are most vulnerable to the damage caused by the unconscionable practice of allowing these toxic chemicals to directly enter our homes, children's products, and foods. Governments of the world must take responsibility to do everything in their power to end the manufacturing and toxic recycling of POPs."

Pamela Miller,
IPEN / Alaska Community Action on Toxics

INTRODUCTION

Progress in scientific knowledge, efforts to protect consumers, as well as public pressure, is contributing to restrictions over the most toxic chemicals in consumer products. Mouthing toys for children, food contact materials, and kitchen utensils belong to products that are regulated. Nevertheless, there are huge legislative loopholes ignoring contamination of those critical items by persistent organic pollutants (POPs). The recycling of plastic casings of electric and electronic devices that contain POPs may lead to contamination of an unrecognizable variety of new products.[1]

The plastic casings of computers, televisions, electronic office equipment, and many other electrical and electronic items have been treated with brominated flame retardants (BFRs), toxic chemicals with POPs characteristics. The chemical industry marketed these chemicals to supposedly decrease the flammability of products, however, they do not work at the concentrations used in consumer products. Furthermore, the persistence, bioaccumulation, long-range transport and adverse health and environmental effects of polybrominated diphenyl ethers (PBDEs) raised global concerns and resulted in government agreement to eliminate commonly used flame retardants globally under the Stockholm Convention. This study asked whether brominated flame retardants found in e-waste are carried into new consumer products as a result of plastic recycling.

Specifically, this report aimed to determine whether children's toys, hair accessories, and kitchen utensils found on the European market are affected by unregulated recycling of e-waste plastics which can carry brominated flame retardants into new products. The collection and release of the data under this report is intentionally scheduled during the review period of the POPs waste limits by the EU competent authorities and of the Recast of the EU POPs Regulation. The findings of this study will, 1) provide a basis for setting environmentally sound POPs waste limits in the EU and globally; 2) further justify a global ban on PBDEs without any exemptions; and 3) demonstrate how the case study of BFR recycling into new products provides important policy considerations for the EU Circular Economy. A circular economy free from toxic impacts on the environment and human health can only occur if toxic chemicals are eliminated from recycling streams. As the findings of this study are highly relevant for the ongoing consultation processes in Europe, policy recommendations resulting from this study will be widely communicated to the decision makers in the EU, Central and Eastern Europe, and the global level.

OBJECTIVES AND METHODS

This study asked whether brominated flame retardants found in e-waste are carried into new consumer products as a result of plastic recycling. Specifically, this report aimed to determine whether children's toys, hair accessories, and kitchen utensils found on the European market are affected by unregulated recycling of e-waste plastics which can carry brominated flame retardants into new products. Among the countries of sample collection, all are required to eliminate PBDEs from production and use, however, only the European Union makes use of recycling exemptions.

Four hundred thirty plastic items including toys, hair accessories, kitchen utensils and other consumer products were purchased in stores and markets in both European Union Member States (Austria, Belgium, Czechia, Denmark, France, Germany, Netherlands, Poland, Portugal, Spain, and Sweden) and surrounding Central and Eastern European countries (Albania, Armenia, Belarus, Bosnia and Herzegovina, Macedonia, Montenegro, Russia, and Serbia) between April and July 2018. European Union member states were chosen for this monitoring, because they make a use of recycling exemptions for waste containing PBDEs. The non-EU countries which took part in this survey are (as well as the EU) Parties to the Stockholm Convention. The non-EU countries were chosen to demonstrate global impact of the EU policy that push for toxic recycling outside of its territory.

Based on previous peer reviewed studies, we assumed that black colour of recycled plastic indicates e-waste as the likely recycling route.[2] For this reason, consumer products with black components and parts were prioritised for testing.

Mainly black parts of the products were screened using a handheld NITON XL3t 800 XRF analyser in order to identify samples with significant bromine and antimony levels (over 1000 ppm). X-ray florescence is useful for determining the presence of PBDEs in plastics.[3] Bromine is a key component of BFRs and antimony trioxide is a common BFR synergist.[4] If samples did not contain bromine and antimony levels over 1000 ppm, we analysed samples with bromine and antimony levels over 100 ppm. A minimum of three samples per country was sent for laboratory analysis to maintain geographic diversity among tested samples.

One hundred nine samples out of the 430 collected items (including 50 toys, 47 hair accessories, 7 kitchen utensils, and 5 other products) were analysed for PBDEs, HBCD, and nBFRs, i.e. 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), Decabromodiphenyl ethane (DBDPE), Hexabromobenzene (HBB), Octabromo-1,3,3-trimethylphenyl-1-indan (OBIND), 2,3,4,5,6-Pentabromoethylbenzene (PBEB), and Pentabromotoluene (PBT) in a laboratory at the University of Chemistry and Technology, Prague, Czech Republic. Targeted BFRs were isolated by extraction with n-hexane : dichloromethane (4:1, v/v). Identification and quantification of PBDEs and nBFRs were performed using gas chromatography coupled with mass spectrometry in negative ion chemical ionization mode (GC-MS-NICI). Identification and quantification of HBCD isomers were performed by liquid chromatography interfaced with tandem mass spectrometry with electrospray ionization in negative mode (UHPLC-MS/MS-ESI-). The limit of quantification ranged between 0.5–5 ppb for PBDEs, between 0.5-10 ppb for nBFRs, and was 10 ppb for HBCD.

For purposes of calculation, the components of the commercial OctaBDE mixtures include the following congeners: BDE 153, 154, 183, 196, 197, 203, 206, 207. The components of the commercial DecaBDE mixture are BDE 209, and HBCD includes 3 isomers; α-, β-, γ-HBCD.

"The countries in the Global South have been receiving tones of toxic waste for many years, contrary to the Convention's provisions. Instead of stopping the identified source and minimizing the toxic burden, another cycle adding more burden to the already affected countries is going to continue through consumer products that contain recycled flame retardants found in e-waste. It is, therefore, high time for the Parties of Stockholm Convention to amplify the issue and for the EU governments to play proactive role and stop exporting its E-waste to our countries."

Tadesse Amera,
IPEN / PAN-Ethiopia

RESULTS

Laboratory analysis of 50 toys, 47 hair accessories, 7 kitchen utensils, and 5 additional samples from 19 countries found 94 samples (86%) contained OctaBDE at concentrations ranging from 1 to 161 ppm. One hundred samples (92%) contained DecaBDE at concentrations ranging from 1 to 3310 ppm. The highest measured concentrations of PBDEs were found in children's toys, followed by hair accessories and kitchen utensils (Table 1). Ranges of PBDE concentrations per country are summarized in Table 2.

Forty five samples (41%) contained HBCD at concentrations ranging from 1 to 207 ppm, and 99 samples (91%) contained at least one representative of new BFRs. The detailed results per sample are reported in Annex 1.

Overall, the results indicate that toxic flame retardant chemicals found in e-waste are widely present in European and Central and Eastern European markets in consumer products made of recycled plastic. This includes three substances listed in the Stockholm Convention for global elimination (OctaBDE, DecaBDE, and HBCD).

Table 1: Ranges of PBDE concentration (ppm) in different types of consumer products

	EU threshold	Children's toys	Hair accessories	Kitchen utensils
OctaBDE	10/1000*	1-161	1-70	1-25
DecaBDE	Not set yet	3-3310	2-2491	1-195

*EU threshold is 10 ppm for articles made of virgin materials and 1000 ppm for articles made of recycled materials

Table 2: Ranges of PBDE concentration (ppm) in recycled plastic items compared to EU legislative thresholds

	Country	Number of samples	OctaBDE	DecaBDE	Sum of PBDEs
Measured ranges of concentrations (ppm)	**Albania**	4	2-57	34-1048	36-1105
	Armenia	4	4-36	28-594	33-630
	Austria	6	9-46	101-458	147-482
	Belarus	6	0-62	0-1533	0-1595
	Belgium	4	3-17	26-660	28-677
	Bosnia and Herzegovina	5	2-70	55-779	57-849
	Czechia	13	<LOQ-62	<LOQ-652	<LOQ-675
	Denmark	6	1-7	2-71	4-78
	France	6	1-34	2-1043	3-1077
	Germany	10	<LOQ-69	<LOQ-442	<LOQ-511
	Macedonia	5	4-27	80-770	84-790
	Montenegro	3	1-35	16-1770	17-1805
	Netherlands	3	0-25	<LOQ–569	0-593
	Poland	7	1-36	6-624	8-660
	Portugal	5	3-161	21-3310	25-3318
	Russia	5	6-65	14-534	37-574
	Serbia	5	7-119	89-1494	96-1550
	Spain	6	4-50	152-898	171-948
	Sweden	6	<LOQ-0	<LOQ-8	<LOQ-8
Legislative thresholds (ppm)	**EU POPs Regulation: Articles**		**10**	Not set yet	
	EU POPs Regulation: Recycled products		**1000**	Not set yet	
	Low POPs Content in Wastes for Stockholm Convention		**50 or 1000**	Not set yet	
	EU RoHS: Electronics				**1000**

LOQ=limit of quantification

"Because Serbia, as well as other Western Balkan countries, is in the process of European integration, its national legislation must be harmonized with EU regulations. As we do not want to have low quality recycled products with PBDEs imported into Balkan countries, implementation of legislation needs to be significantly improved, and a POPs monitoring system for the environment, products and food needs to be significantly improved. However, environmental policy is still not a priority of the governments from this region; a fact that is made clear through the lack of state financing in this area."

Jasminka Randjelovic,
Safer Chemicals Alternative (ALHem), Serbia

BACKGROUND TO THE STUDY

Legacy of Persistent Organic Pollutants: Of the thousands of chemicals that are already registered in the EU for industrial uses, persistent organic pollutants (POPs) are a special group of unmanageable substances of very high concern that require specific attention when designing strategies and measures to eliminate them from the environment. Closing material loops in a circular economy and establishing environmentally sound management for POPs wastes are essential steps to stop the legacy of hazardous emissions and exposures. Toxic recycling is especially damaging to a true circular economy as it continues the cycle of harm in new products. In addition, recycling workshops are often located in developing countries that do not use appropriate techniques for POPs destruction.[5] The dismantling of wastes containing POPs chemicals in the informal sector is a special problem due to the persistence, toxicity and long-range transport of the chemicals, and their ability to bioaccumulate and contaminate food chains.

The Case of Brominated Flame Retardants

Brominated flame retardants (BFRs) are a group of chemicals that have been added to plastic and textile materials as a result of chemical industry marketing and lobbying that claims reduced flammability of products. Ironically, chemical flame retardants increase smoke toxicity more than they reduce fire growth rate.[6] The electrical and electronic products industry is one of the most important consumers of brominated flame retardants. BFRs are applied to plastic housings of consumer and office electronics, and electronics working with heat sources, in order to meet the safety standards – many of which resulted from industry lobbying and do not take into account environmental and health consequences.

The Case of POP-BFRs: PBDEs and HBCD

The indisputable toxicity and persistency of the main representatives of brominated flame retardants, i.e. polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD), resulted in governments listing them in the Stockholm Convention for global elimination. Scientists have raised serious concerns over substitutes for flame retardant chemicals, but they continue to be used without applying the precautionary principle or any restriction.[7]

PBDEs are of primary interest in this study due to the fact that these hazardous chemicals are allowed to be recycled from waste materials into new products despite their well-known adverse environmental and human health effects. This contradiction occurred in 2009 when PentaBDE and OctaBDE were listed in the Annex A of the Stockholm Convention with an intention to eliminate them globally from the environment.[8] At that time, governments agreed to an exemption that permits recycling of materials such as foam and plastics that contain these substances until 2030. Among countries making use of this recycling exemption is the European Union. HBCD and a few substitutes for PBDEs described as new 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.

Because BFRs are additives that are not chemically bound to the plastic polymer in question, they are released during the lifecycle of the product, including when it becomes waste. Serious concerns are raised by transboundary transport of wastes from the areas with the highest consumption of electronics per inhabitant to developing and transition countries that do not have the regulatory and technical infrastructure to deal with them safely.[9]

"Known or suspected effects of POPs in wildlife range from eggshell thinning in birds to reproductive disorders and malformations in fish and mammals. To ensure protection of wildlife and ecosystem health, the precautionary principle is clearly warranted. All man-made sources of POPs to the environment must be eliminated."

Andreas Prevodnik,
the Swedish Society for Nature Conservation

Inconsistency between Chemical, Product, and Waste Legislation

PBDEs may be used as a case study to illustrate the inconsistency between chemicals, products, and waste legislation that focuses on recycling targets but ignores the impacts of recycling toxic chemicals on human health and the environment. In countries where production of PBDEs has ended, these chemicals continue to expose humans and are released into the environment during material recycling,[10] use of consumer products,[11] and waste disposal.[12] PBDEs can easily migrate out of the treated or contaminated items and expose the human body through dermal contact,[13] inhaling dust,[14] or mouthing of children's toys.[15] Recycling of plastics containing PBDEs and other POPs substances and hazardous substances should be ended.

"The current recycling practices for plastics generated from e-waste poses serious threat of material chain contamination with BFR and we have consistently demanded recycling standards or appropriate disposal technology from the regulators to safeguard environment and human health."

Satish Sinha,
Toxics Link, India

Investigated Brominated Flame Retardants

Polybrominated diphenyl ethers (PBDEs) are a group of brominated flame retardants that include substances listed in the Stockholm Convention for global elimination such as PentaBDE, OctaBDE, and DecaBDE.[16] PBDEs are additives mixed into plastic polymers and are not chemically bound to the material; they therefore leach into the environment. These chemicals are known as endocrine disrupting chemicals (EDCs), and adversely impact the development of the nervous system and children's intelligence.[17]

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[18] of CRT television and computer casings and other office electronics made of acrylonitrile butadiene styrene (ABS) plastic. DecaBDE forms 7-20% of weight[19] of many different plastic materials, including high impact polystyrene (HIPS), polyvinylchloride (PVC), and polypropylene (PP) used in electronic appliances. As this study examines recycled consumer products made of plastic, OctaBDE and DecaBDE content was the main focus of our investigation.

"The recycling of toxic flame retardants into consumer products raises an alarm that should be translated into control actions in the European arena, including defining thresholds for POPs waste (so called Low POPs Content levels) and strategies for the circular economy, including the crucial interface of chemicals-products-waste legislation."

Jitka Straková, Arnika

RESTRICTIONS ON BROMINATED FLAME RETARDANTS

Restriction of PentaBDE and OctaBDE

Production and use of commercial mixtures of Penta- and OctaBDE are banned by the EC Regulation on persistent organic pollutants[20] in connection with their ban under the Stockholm Convention. The EU restriction exempts use of waste materials containing the two PBDE mixtures for recycling purposes. According to this legislation, products made of virgin materials are not allowed to exceed the impurity level of 10 ppm for the two mixtures of pollutants; however, the EU regulation inconsistently tolerates up to 1000 ppm of the same toxic chemicals in recycled items. This inconsistency allows weaker chemical safety standards for recycled products, undermines the credibility of recycling, and raises health concerns among consumers and workers in recycling facilities. An extra restriction applies at the EU level to electronics that are not allowed to contain over 1000 ppm of the sum of all PBDEs according to the RoHS directive.[21]

The Stockholm Convention requires that POPs wastes be treated so that POP content is destroyed or irreversibly transformed to the extent that they no longer exhibit POPs characteristics. The Convention sets low POPs content limits (LPCL) above which treatment is required. The current limits apply to commercial mixtures of Penta- and OctaBDE that were listed in the Annex A of the Stockholm Convention in 2009. As the result of a recent decision, Parties to the Convention (including the EU and other European countries) can choose between two thresholds for the sum of PentaBDE and OctaBDE – 50 ppm or 1000 ppm. All the wastes exceeding the chosen threshold (LPCL) are then considered and defined to be "POPs wastes" (a special category of hazardous waste). Wastes exceeding the LPCL cannot be freely exported or recycled, but must be treated according to rigorous requirements in the Stockholm Convention. The EU has proposed and consistently advocated for a combined PBDE LPCL of 1000 ppm. This weak hazardous waste limit would allow massive flows of PBDEs into consumer products and transboundary movement of wastes containing PBDEs, including e-waste, plastics, and foam. The flow of this contaminated material is likely to be from developed countries to developing countries where management costs are lower, but regulatory and technical infrastructure is weaker or even lacking.

The Stockholm Convention secretariat[22] notes that at least 50% of waste electrical and electronic equipment (WEEE) is collected outside of official take-back systems, part of which is then exported to developing countries as used equipment. Illegal shipments originate mainly from Europe, North America, Japan and Australia, with common destinations in Asia (including China, Hong Kong, India, Pakistan and Vietnam) and Africa (including Ghana, Nigeria, and Benin).

Restriction of DecaBDE

Commercial DecaBDE was listed in Annex A of the Stockholm Convention in 2017 for global elimination with a five-year phase-out period for use in textile products (excluding toys and clothing), plastic housing and parts of heating home appliances, irons, fans, immersion heaters (at concentrations lower than 10% by weight of that part), and polyurethane foam for building insulation. In addition, the EU successfully advocated for a specific exemption for auto spare parts at the request of the EU auto industry, and use of DecaBDE in aircraft at the request of the European aviation industry. The low POPs content limit for DecaBDE will be taken up at COP9 in 2019. One of the broadly discussed options is to express the limit as the sum of all three commercial mixtures of PBDEs listed in the Stockholm Convention (PentaBDE, OctaBDE, and DecaBDE).

DecaBDE will be restricted by REACH legislation in March 2019. The regulation should ban manufacturing and use and entirely ban recycling of DecaBDE into new products, since no exemption for recycling was included

Table 3: European Union legislative threshold for BFRs in products and wastes (ppm)

	POPs Regulation		RoHS	REACH	Low POPs Content
BFR	articles	recycled products	electronics	articles	wastes
Penta- and OctaBDE	10	1000			50 or 1000
DecaBDE*	Will be set in the POPs Regulation Recast in 2018			(1000) SVHC; Will be restricted in 2019	It is not set yet
Σ PentaBDE + OctaBDE + DecaBDE			1000		
HBCD	100			SVHC	100 or 1000

*DecaBDE was newly listed among substances for global elimination under the Stockholm Convention in 2017. The EU POPs Regulation will be updated according to this new entry. If this does not happen before March 2019, DecaBDE will be restricted under REACH legislation in concentrations over 1000 ppm.

in the Stockholm Convention listing. Until then, DecaBDE continues to contaminate waste streams and recycled products. Consumers have the right to ask for information about DecaBDE in products as it is part of the list of Substances of Very High Concern (SVHC) under the REACH legislation. For more information on legislative thresholds, please see Table 3.

Hexabromocyclododecane (HBCD)

HBCD is a brominated flame retardant primarily used in polystyrene building insulation. HBCD is an additive mixed into plastic polymers and is not chemically bound to the material; it may therefore leach into the environment. HBCD is highly toxic to aquatic organisms and has negative effects on reproduction, development, and behaviour in mammals, including transgenerational effects. HBCD is also found in packaging material, video cassette recorder housing, and electric equipment.

HBCD is listed in Annex A of the Stockholm Convention for global elimination with a five-year specific exemption for use in building insulation that should expire for most Parties in 2019.[23] This chemical is also included in the list of SVHC substances under the REACH legislation. For more information on legislative threshold, please see Table 3.

New Brominated Flame Retardants (nBFRs)

In addition to polybrominated diphenyl ethers (PBDEs), various alternative halogenated flame retardants have been used or recently introduced by the industry to replace PBDEs. Overall, toxic chemicals marketed as flame retardants lack adequate toxicity information. However, the information that is available has raised concerns. Some of the nBFRs are persistent, bio-accumulative and travel long distances. Despite these toxicological concerns and the lack of comprehensive information, nBFRs continue to be used as PBDEs substitutes.

1,2-Bis(2,4,6-tribromophenoxy) ethane (BTBPE)

BTBPE is one of the new flame retardants that replaced OctaBDE. It is used in the plastic casings of computers, TVs and mobile phones. Its metabolite, 2, 4, 6-tribomophenol, is a thyroid-disrupting chemical that has been found in umbilical cord blood. BTBPE has the potential to biomagnify in fish.[24]

Octabromo-1,3,3,-trimethylphenyl-1-indan (OBIND)

OBIND is another replacement for PBDEs that is used in different plastics of electronic products. OBIND has been found in bird eggs.[25] There is very little publicly known about its toxicity.

2,3,4,5,6-Pentabromoethylbenzene (PBEB)

PBEB is a flame retardant that was used mainly in the 1970s and 1980s under the name FR-105. It was used in polymers and has been poorly characterized toxicologically, but the substance is a brominated analogue of ethyl benzene, a carcinogen.

Pentabromotoluene (PBT)

PBT is used in polystyrene casings for electronics, ABS plastics and other plastic polymers, and sold under the name FR-105 or Flammex. Studies confirmed histologic changes on laboratory rats[26]; however, other than this fact, there is very little publicly known about this substance. A significant property of this substance is the ability to be transported for long distances.[27]

Hexabromobenzene (HBB)

HBB is a retardant mainly produced in Asia and applied to electronics. A significant property of this substance is the ability to travel long distances.[28]

Decabromodiphenylethane (DBDPE)

DBDPE is a commercially important alternative to DecaBDE used in plastic casings for televisions and other uses that previously incorporated DecaBDE. A significant property of this substance is the ability to be transported for long distances.[29]

DISCUSSION OF THE RESULTS

Comparison with Other Studies: This study is part of long-term monitoring efforts by IPEN and Arnika that started in 2011. Over 260 recycled consumer products including toys, puzzles including Rubik's cubes, kitchen utensils, hair accessories, and carpet padding from around the world have been laboratory analysed to date. Most of the samples (64%) came from the EU and Central and Eastern European countries. Concentration ranges of the main BFRs measured in consumer goods from the EU and Central and Eastern European countries in the past rounds of the monitoring are summarized in Table 4. The guitar toy from Portugal (PT-T-10A), which is reported in the present study, contained the highest concentration of PBDEs (3318 ppm or 0.3% of product weight) in consumer products analysed by IPEN and Arnika.

The results of monitoring products in this study are consistent with those found in a number of scientific studies that have measured PBDEs in new products made of recycled plastics, including children's toys,[30] hair accessories[31], food contact items,[32] carpet padding[33] and many other household items.[34] HBCD has been found in consumer products made of recycled polystyrene, including food packaging.[35]

Comparison with Legislative Thresholds

This study surveyed 109 consumer products for the presence of PBDEs and other BFRs. One hundred seven out of the 109 items (98%) contained measurable concentrations of PBDEs. If these products were made of virgin plastics rather than recycled materials, 50 of them (46%) would not meet the EU Regulation on POPs because OctaBDE concentrations exceeded the authorised limit of 10 ppm. If the products were electronics and the EU RoHS legislation was applied, 9 of them (8%) would exceed the regulatory limit because of high DecaBDE concentrations (over 1000 ppm). In addition, from 2019 onwards, these same products would violate the European legislation REACH because they exceeded the regulatory limit in consumer products. At the end of life of those products, the provisional POPs waste limit would be applied. Since the waste limit is currently defined by the Basel Convention as either 50 ppm or 1000 ppm, either none of the products or 11 products (10%) would qualify as POPs waste. The number of products which would fall into the POPs waste class depends on the final decision on the POPs waste limit for these substances. Governments are currently discussing setting this limit at 1000 or 50 ppm expressed as the sum of PentaBDE, OctaBDE, and DecaBDE.

The Stockholm Convention objective is to protect human health and the environment by eliminating POPs, including PentaBDE, OctaBDE, DecaBDE, and HBCD. However, to summarise, the EU is undermining that objective by applying different legislative thresholds for products made of virgin and recycled materials. As a result, POPs that should be eliminated are carried into new products via recycling, continuing exposure and threatening human health and the environment.

> "Articles made from recycled materials should be as safe as articles made from virgin materials. As this report shows, lowering the standards for toxic substances content in recycled materials puts consumers, and in particular children's, health at risk."
>
> *Dolores Romano,*
> *Ecologistas en Acción/EEB*

PBDEs in Recycled Plastic Consumer Goods: Impact of E-waste Recycling

In the context of this study, consumer products made of black plastic were chosen to be analysed because these plastics typically result from e-waste recycling.[36] The tested children's toys, hair accessories, and kitchen utensils do not require fire resistance but still contain BFRs due to recycling. And if they did require fire resistance, the measured concentrations of PBDEs (less than 0.3% of weight) in our tested products cannot supply the flame retardant function. Plastic casings of electronics usually require 7-20% of weight of one of the PBDE commercial mixtures to meet flammability standards.[37] The toxic recycling of plastics containing BFRs allows for contamination of the originally unaffected products and leads to the further exposure of consumers to PBDEs.

PBDEs in Material Recycling Processes and Their Pollution Victims

According to the San Antonio Statement, flame retardant chemicals are being found in all environmental matrices examined, including air, water, soil sediment, and sewage sludge.[38] The main sources of BFRs (including PBDEs) to the human body are mother's milk,[39]

Table 4: Levels of BFRs in children's toys, hair accessories, and kitchen utensils on the EU and Central and Eastern European market measured by IPEN and Arnika since 2015 (ppm)

Country of purchase	Rubik's/ puzzle cubes (n)	Toys (n)	Hair accessories (n)	Kitchen utensils (n)	OctaBDE	DecaBDE	HBCD	Data reported (yr)
Belarus	2				3-5	134-153	NA	2017
Czechia	6	12	14	1	0-513	2-2234	0-375	2015-17
Germany	2				1	3-4	0	2015
Hungary*	2				0-6	0-58	0/NA	2015
Netherlands		2			4-89	8-145	0-21	2017
Poland	4				0-51	0-79	0	2015
Russia	3				1-362	0-217	2-691	2017
Serbia	3				13-57	36-47	NA	2017
Slovakia	1		2		0-26	0-98	0	2015-17
Sweden	1				0	0	0	2015
United Kingdom	3				36-210	10-400	0-5	2017

*Analysis of one sample of recycled foam carpet padding purchased in Hungary in 2011 found elevated concentrations of PentaBDE (12 ppm). This initial monitoring did not include other foam products from Europe as carpet padding has been primarily used in North American countries.
n=number of analysed items; NA = not analysed

"The Stockholm Convention's expert committee confirmed that the recycling exemptions for PentaBDE and OctaBDE would result in more pollution and the loss of the long-term credibility of recycling. It's time for the EU to exert leadership and withdraw its registration for the recycling exemptions and encourage the small handful of Parties still registered for them to do the same."

Joseph DiGangi,
IPEN

diet,[40] and dust.[41] Ingestion and dermal contact with dust are understood as the main contributors to PBDE exposure,[42] followed by dietary ingestion of animal and dairy products, and infant consumption of human milk.[43] Recycling of e-waste and furniture foam containing PBDEs contaminates populations working and living in the surrounding area of e-waste recycling workshops.[44] The risk is generally higher for the population treating e-waste in developing countries, where the majority of European e-waste is processed.[45] The lack of health and safety guidelines, combined with improper recycling techniques - such as dumping, dismantling, inappropriate shredding, burning and acid leaching[46] - further increase the risk for workers.

PBDEs in Children's Toys and Kitchen Utensils: Risks for Consumers

It is well documented that brominated flame retardants migrate from consumer products made of plastic to household dust,[47] and therefore are present for human absorption. Sofas[48] and electronics[49] are important sources of PBDEs at home.

The appearance of kitchen utensils with BFR-content adds to the concern and scale of PBDE intake by the human body through food ingestion. Cooking experiments with kitchen utensils containing PBDEs demonstrated considerable transfer of the POP-chemicals into the cooking oil.[50] 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.[51] According to a Belgian survey,[52] PBDE exposure (similar to the REACH thresholds) from mouthing toys was found to be higher than the exposure through diet or even dust. Infants are particularly sensitive to exposure due to toy mouthing and dust ingestion, as they play on the ground.[53]

Our findings of children's toys contaminated with PBDEs are alarming, because exposure occurs at the time of children's development. Developmental neurotoxicity and endocrine disruption[54] are part of PBDEs' properties that adversely affect children. PBDE exposure during prenatal and natal development is associated with poorer attention control in children, hyperactivity and behavioural problems.[55] It is contradictory for children to play with toys that are supposed to develop their motor and intellectual capacity, i.e. tested puzzle and Rubik's cubes, while exposing them to toxic chemicals that have the very opposite neurotoxic effects.

"It is a sad irony that children's health in Europe is at risk from recycling. The study reveals that over 10% of toys, hair clips and brushes, and kitchen utensils tested contain a highly toxic and banned chemical. This is happening because of a loophole in EU legislation and global treaties that allow companies to re-use recycled materials in new consumer products without cleaning them up first. Urgent action is needed to close this gap because the chemicals identified, brominated flame retardants, affect thyroid function in children resulting in disrupted brain development and attention deficits."

Génon K. Jensen,
Health and Environment Alliance (HEAL)

LEGISLATIVE CHALLENGES AND SOLUTIONS

Recycling materials containing toxic chemicals can contaminate the resulting products, leading to a legacy of hazardous emissions and exposures. Toxic recycling is an obstacle to a truly circular economy. In the case of POPs chemicals, their persistence, toxicity, ability to contaminate food chains and to travel long distances are particular challenges.

Withdraw the Recycling Exemptions for PentaBDE and OctaBDE (Stockholm Convention, EU POPs Regulation)

In 2009, the Conference of Parties to the Stockholm Convention (COP4) listed commercial mixtures of PentaBDE and OctaBDE in Annex A of the treaty for global elimination.[56] At that time, the EU and other governments also agreed on an exemption for the recycling of plastics, foam, and other materials containing commercial PentaBDE and OctaBDE until 2030. However, concerns raised by the recycling exemption prompted governments to request the treaty's expert committee to examine the issue. At the following Conference of the Parties (COP5) the expert committee (known as the POPs Review Committee) recommended acting to "… eliminate brominated diphenyl ethers from the recycling streams as swiftly as possible."[57] The Committee noted that, "Failure to do so will inevitably result in wider human and environmental contamination and the dispersal of brominated diphenyl ethers into matrices from which recovery is not technically or economically feasible and in the loss of the long-term credibility of recycling." The results of our study confirm the predictions of the Stockholm Convention expert committee, as PBDEs contaminate children's toys, hair accessories, kitchen utensils, and other food contact items as a result of recycling.

The Stockholm Convention recycling exemption for PentaBDE and OctaBDE has only been registered by a small number of Parties. Five Parties have registered for the PentaBDE recycling exemption: Brazil, Canada, EU, Japan, and Turkey. Six Parties have

> *"We need to make it obligatory for the chemical content in products to be made available on the packaging, starting with toys and other products for children."*
>
> ***Claus Jørgensen,***
> *Danish Consumer Council*

registered for the OctaBDE recycling exemption: Brazil, Cambodia, Canada, EU, Japan, and Turkey. At the next Conference of Parties in 2019, the EU should withdraw its recycling exemptions for PentaBDE and OctaBDE and encourage the small number of Parties registered for these exemptions to also withdraw them.

Set Environmentally Sound Limits for POPs Wastes (Basel and Stockholm Conventions, EU POPs Regulation)

The last Conference of Parties to the Basel and Stockholm Conventions in May 2017 suggested using either a 50 ppm or 1000 ppm limit for POPs waste containing PBDEs.[58] The EU advocated for the weaker value of 1000 ppm to fulfil its own recycling targets. With this level, all wastes containing less than 1000 ppm of PBDEs will be considered "clean" and they will be allowed to be exported out of Europe for recycling or disposal. Weak hazardous waste limits also have the consequence of decreasing demand for superior POPs waste disposal technologies that are able to destroy all the POPs content of the waste, thus making innovative and protective techniques marginalized and economically non-viable.

Ironically, the lack of effectiveness of the 1000 ppm low POPs content level for PBDEs is clearly illustrated by a study performed by the EU's own consultants, ESWI/BiPro,[59] which finds that for a limit of 1000 ppm, a negligible proportion of waste containing POP-PBDEs would be actually classified as POPs waste. This runs counter to the objectives of the Stockholm Convention – to protect human health and the environment by eliminating POPs.

The provisional low POPs content level for PBDEs of 1000 ppm also raises concerns because PBDEs are very similar in structure and toxicological profiles to polychlorinated biphenyls (PCBs),[60] and therefore exhibit similar hazards and concerns as PCBs. The low POPs content level for PCBs was set at 50 ppm. However, a true health-based standard would be even more stringent, considering the fact that PCBs exhibit carcinogenic properties and there is a risk with any level of exposure.[61] Substances such as PBDEs that resemble PCBs should not have a weak low POPs content limit of 1000 ppm.

Stop E-waste Export into Developing Countries (Basel Convention)

The largest use of commercial OctaBDE and DecaBDE has been for the treatment of plastic casings of electronics. The EU restricted PentaBDE and OctaBDE in 2004[62] and most of the remaining European countries did so after 2009, when PentaBDE and OctaBDE were listed in Annex A of the Stockholm Convention for global elimination and European Parties to the Convention started to implement the restriction into the national legislation. Assuming that the lifespan of such equipment is 10 to 15 years, the majority of articles containing PBDEs in the EU reached the end-of-life limit four years ago. Those stores of POP-PBDEs in e-waste are essentially hazardous waste stockpiles. E-waste must be clearly branded as hazardous and provisions taken to prevent export to countries lacking regulatory infrastructure and technical and economic capacities for hazardous waste management.

An e-waste guidance document will be adopted at the next Conference of Parties to the Basel Convention in 2019. The current wording of paragraph 31 of the "E-waste Guidelines" document[63] allows traders to export consumer electronics with non-functional parts that are waste upon arrival by making a claim of "export for repair." As e-waste is hazardous waste containing PBDEs and other hazardous substances, this paragraph must be modified to require tests of the exported devices. If the tests show that the equipment is not functional or if it contains POPs over the low POPs content limit, than the items have to be considered waste, which is subject to the control procedures of the Basel Convention. Otherwise, POPs and other toxic substances will continue to poison the Global South.

Streamline Restrictions for POPs, Avoid Regrettable Substitution, and Speed-up the Authorization Process under REACH

Although REACH is supposed to evaluate existing and new chemicals entering the EU market, the process is lengthy and burdensome for public authorities. The use of fast-track restrictions under Art 68.2 of REACH should be considered for POPs.[64] It is not acceptable to wait for a minimum of 10 years for the restriction of POPs. The process needs to be simplified and accelerated. Restrictions of groupings of POPs – rather than individual substances – should be considered, in order to avoid regrettable substitutions. No exemptions, derogations, or transitional periods for restrictions or authorisations should be given for recycled materials or spare parts containing POPs.

What is particularly worrying is that new flame retardants are being introduced to the market much faster than they are being evaluated for their health and environmental impacts. This results in an accumulation of potentially problematic chemicals worldwide.

The Candidate List is a key feature of REACH and has become a worldwide reference for encouraging substitution. The entire group of halogenated flame retardants should be quickly added to the REACH Candidate List without being slowed down due to risk management option analysis (RMOA) - which introduces an additional screening process that puts yet another burden on Member States.[65]

Disclose Full Information on Chemicals in Products

Insufficient information on chemicals in products, waste streams and recycled materials hampers monitoring of compliance of recycled materials and articles produced within existing legislation. If the information on chemical content in the products were available, consumers would have the ability to make more informed decisions about their purchases. Additionally, the recycling industry would be able to separate undesired items out of the waste streams and control bodies would have clues about how chemical legislation is performing in real life. Setting full materials disclosure goals should be a key priority for European governments.

Keep Chemicals of Concern Out of Products

If chemicals of health and environmental concern are kept out of products, the problem of toxic recycling will never be repeated in the future. The precautionary principle should be applied when there are new chemical substances entering the market. If there is limited knowledge about new substances or uncertainty about the chemical properties of new substances, they should never be allowed to be used in products. In this sense, the EU should publish a strategy towards a non-toxic environment by 2018, including a clear commitment to keep chemicals of concern (e.g. endocrine disruptors and flame retardants, among others) out of products from the start, due to their harmful impacts on vulnerable populations, general public and environmental ecosystems. Only with this commitment may the EU guarantee a truly non-toxic circular economy.

TECHNICAL SOLUTIONS

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).[66] These known concentrations indicate

> "Weak limits for POPs waste that are promoted by the EU permit the use of POPs waste disposal options that cannot truly be considered environmentally sound. Such disposal options result in significant new releases of POPs to the environment, which are harmful to human health and ecosystems."
>
> *Jindřich Petrlík,*
> *Arnika / IPEN Dioxin, PCBs, and Wastes Working Group*

"Not in vain, REACH legislation includes mechanisms like authorisation and fast track restriction for preventive regulatory action on hazardous chemicals. However, we should finally start to focus on entire groups of related substances, especially in recycled and recyclable plastic materials. Grouping is crucial to avoid regrettable substitution. It also encourages sustainable product design and clean recycling."

Manuel Fernandez,
BUND

what plastics should be separated from the materials destined for recycling.

In recycling workshops and plants, methods based on the total concentration of bromine are an option to identify BFR-treated plastic and separate it out of the waste stream. In Europe, X-ray fluorescence (XRF) and X-ray transmission (XRT) are operated on the industrial scale.[67]

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

Destruction Technologies

If we want to move rapidly to a circular economy that does not generate or recirculate toxic chemicals such as persistent organic pollutants (POPs), we must adopt techniques to destroy POPs waste that do not, in turn, generate unintentional POPs (UPOPs) as part of the process. Source categories for unintentional POPs in Annex C of the Stockholm Convention include waste incinerators (including co-incinerators of municipal, hazardous or medical waste or of sewage sludge), cement kilns firing hazardous waste, production of pulp using elemental chlorine or chemicals generating elemental chlorine for bleaching, and thermal processes in the metallurgical industry. Incineration or burning of PBDE-containing wastes generates brominated dioxins,[68] effectively creating more toxic substances.

Various technically feasible and available techniques can destroy POPs. For brominated POPs such as PBDEs these techniques include Super Critical Water Oxidation (SCWO) and a process known as Creasolv,[69] which can separate brominated POPs such as HBCD from the polymer matrix of polystyrene, allowing the polymer to be recycled without POPs. Another technique is Gas Phase Chemical Reduction (GPCR),[70] a process using hydrogen under pressure to reduce POPs by molecular dechlorination to compounds such as methane and water. More recently, mechanochemical processes such as high-energy ball milling using a reactant have been found capable of destroying brominated POPs and even creating useful commercial compounds out of the residual materials of the process.

Alternatives to BFRs

Chemical industry marketing pushes flame retardant chemicals into electrical and electronic products, including by lobbying for fire safety standards that require their products. The current standards need to be reviewed and updated to ensure they adequately measure fire safety and take adverse environmental and health impacts[71] into account.

Stockholm Convention guidance materials[72] show that alternative, less hazardous, chemical and non-chemical flame retardants are commercially available for both POP-PBDEs. The German Environment Agency (UBA) suggests the adoption of design measures into the products, e.g. use of flame-resistant materials and integration of barrier layers, as the top methodology for maintaining flame retardancy based on ecological priorities.[73] Chemical alternatives to halogenated and toxic flame retardants also include inorganic flame retardants (aluminium or magnesium hydroxides).

"The alternatives to incineration of PBDEs are available, commercialised and avoid the creation of UPOPs. If we are to break the cycle of UPOPs creation we must adopt these technologies on a much broader basis."

Lee Bell,
IPEN

POPS RECYCLING CONTAMINATES CHILDREN'S TOYS

Recycling e-waste that contains toxic flame retardants contaminates new products, continues exposure, and undermines the credibility of recycling.

CHILDREN

Brominated flame retardants are distributed from recycled e-waste plastics into children's toys. These chemicals are known to disrupt human hormone systems, adversely impacting the development of the nervous system and children's intelligence.

FAMILIES

OctaBDE, DecaBDE, and HBCD have been used as flame retardants in a variety of electronic products for many years. These chemicals were recognized as POPs of global concern that need to be eliminated just like other POPs listed in the Stockholm Convention.

WORKERS

E-waste recycling is spreading poisons in insecured recycling sites and exposed workers' bodies.

LOW INCOME COUNTRIES

E-waste is often trafficked to low and middle income countries that do not have capacities to deal with them.

The POPs Treaty needs to stop recycling exemptions and establish strict hazardous waste limits to discontinue use and global distribution of POPs.

CONCLUSIONS

This study confirms the transfer of brominated flame retardants found in e-waste into new consumer products as a result of plastic recycling. Specifically, this report determined that children's toys, hair accessories, and kitchen utensils found on the European market are affected by the unregulated recycling of e-waste plastics.

The case of PBDEs illustrates the inconsistency between chemicals, products, and waste legislation in the European Union. However, our study reveals consumer products with toxic chemicals not only in the EU Member States that make use of recycling exemptions for PBDEs, but also on the markets in Central and Eastern Europe. As the EU recycling goals are globalized through the international conventions, hazardous e-waste finds its way through state boundaries into recycling workshops and back into recycled products.

The guitar toy from Portugal contained the highest concentration of PBDEs (3318 ppm or 0.3% of product weight) among the consumer products IPEN and Arnika have analysed over the last 3 years. The finding of contamination in children's toys is particularly alarming, because PBDEs affect children during development. The appearance of kitchen utensils containing these chemicals adds to the concern of PBDE intake by the human body through food ingestion.

If the tested products were made of virgin plastics instead of recycled materials, 50 of them (46%) would not meet the provisions of the EU Regulation on POPs that limits the concentration of PBDEs to 10 ppm. This discrepancy undermines the circular economy and urgently needs to be corrected to ensure sound chemical standards for products made of virgin as well as recycled materials and to ensure the credibility of recycling.

The weak legislative thresholds for POPs waste in the EU and the Stockholm Convention recycling exemptions also contribute to unequal standards for PBDE content in virgin and recycled articles. Those legislative loopholes are motivated by blind recycling targets that ignore the contamination of new products by persistent organic pollutants and other toxic chemicals and continue the legacy of PBDE emissions and exposures. The lesson has to be immediately learned and acted upon to avoid the same failings during the POPs Regulation Recast, POPs waste thresholds updates, and the chemicals, products, and waste legislation interface framing in the context of the circular economy.

ANNEX I

LOD=limit of detection; LOQ=limit of quantification

Tables with analytic results (ppm) per country

EU COUNTRIES

Austria

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Gun**	AT-T-01	1 747	459	9	359	368	6	24
Toy	**Gun**	AT-T-3	3 921	955	18	147	166	8	31
Toy	**Fidget spinner**	AT-T-5	2 411	544	14	307	321	0	59
Hair	**Hair clip**	AT-H-3	3 337	885	16	132	147	0	48
Hair	**Hair clip**	AT-H-5	7 908	1 952	24	458	482	2	73
Hair	**Hair brush**	AT-H-7	2 114	706	46	101	147	0	23

Belgium

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Telescope**	BE-T-6	5 785	1 515	17	660	677	1	42
Hair	**Hair brush**	BE-H-3	1 772	682	6	57	64	0	20
Hair	**Hair clip**	BE-H-6	1 778	490	3	26	28	0	25
Hair	**Hair brush**	BE-H-4	1 970	661	9	86	95	0	30

Czechia

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Gun**	CZ-T-15A	10 700	2 479	22	511	533	2	19
Toy	**Kitchen set**	CZ-T-16A	615	176	0	24	24	1	6
Hair	**Comb**	CZ-H-7A	1 782	510	15	26	42	0	16
Food con-tact	**Pastry brush set**	CZ-H-4B	625	4 922	1	24	26	0	26
Food contact	**Knife**	CZ-K-12	587	501	2	9	11	<LOQ	2
Food contact	**Fork**	CZ-K-13	1 056	494	5	144	148	<LOQ	0

Food contact	**Scissors**	CZ-K-9	178	48	0	1	1	<LOQ	2
Food contact	**Scissors - handle**	CZ-K-14A/1	285	102	0	4	4	<LOQ	1
Food contact	**Scissors - rivet**	CZ-K-14A/2	187	89	<LOQ	<LOQ	<LOQ	29	0
Food contact	**Knife**	CZ-K-15	225	134	25	195	220	<LOQ	3
Other	**Eye-glasses**	CZ-O-8	358	51	0	1	1	<LOQ	1
Other	**Coat hanger**	CZ-H-5A	2 917	1 127	62	302	365	15	208
Other	**Stapler**	CZ-O-6	5 812	1 286	23	652	675	2	42

Denmark

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Magic cube star**	DK-T-4A	5 777	2 167	1	4	4	<LOQ	2
Toy	**Fidget cube**	DK-T-3A	535	156	2	16	18	0	10
Toy	**Revolver**	DK-T-8A	1 746	746	1	3	4	0	1
Toy	**Police gun set**	DK-T-6A	8 144	3 389	3	33	36	2	24
Hair	**Diadem**	DK-H-3A	507	178	4	2	6	<LOQ	18
Hair	**Hair clip**	DK-H-6A	932	276	7	71	78	0	24

France

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Revolver gun**	F-T-3	5 944	1 804	34	1 043	1 077	1	89
Toy	**Musical mobile phone**	F-T-6	1 444	288	5	21	26	0	16
Toy	**Water gun**	F-T-12	2 369	497	4	322	327	1	32
Hair	**Diadem**	F-H-1	3 121	860	13	293	306	1	38
Hair	**Hair clip**	F-H-4	5 141	1 441	26	718	744	1	45
Hair	**Diadem**	F-H-5	905	360	1	2	3	<LOQ	1

Germany

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Formula 1**	D-T01	279	111	3	33	35	0	9
Toy	**Magic cube**	D-T03	318	171	1	25	26	<LOQ	5
Toy	**Pistol super police**	D-T06	4 924	1 364	15	247	262	2	51
Toy	**Key fob with magic cube**	D-T07	8 015	2 497	69	442	511	2	40
Hair	**Hair brush**	D-A10	1 929	836	12	93	106	1	39
Hair	**Comb**	D-A13	516	74	4	17	21	0	9
Hair	**Mini hair claws**	D-A14	424	<LOD	<LOQ	<LOQ	<LOQ	207	<LOQ
Hair	**Hair brush**	D-A9	2 431	652	5	30	35	7	18
Other	**Massage roller**	DE-KU-56a	4 383	1 540	42	178	221	<LOQ	160
Other	**Waste bin**	DE-KU-63a	437	172	13	165	178	<LOQ	77

Netherlands

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Cameta water gun**	NE-T-3	2 483	722	0	<LOQ	0	<LOQ	<LOQ
Hair	**Diadem**	NE-H-3	1 322	351	5	20	25	<LOQ	9
Hair	**Hair clip**	NE-H-11	4 222	1 427	25	569	593	6	87

Poland

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Car**	PL-TC-11A	1 216	262	3	118	122	0	18
Toy	**IQ cube**	PL-IC-10A	5 344	1 735	36	624	660	10	68
Hair	**Diadem**	PL-HBH-9A	522	223	1	84	85	1	5
Hair	**Hair clip**	PL-HC-1A	1 409	402	6	97	103	0	32
Hair	**Diadem**	PL-HB-3A	814	208	1	6	8	<LOQ	8
Hair	**Hair brush**	PL-HBWM-5A	872	225	4	25	29	0	9
Hair	**Hair brush**	PL-HBII-6A	1 964	511	3	25	29	0	9

Portugal

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Chess tray**	PT-T-8A	15 070	4 716	161	1 494	1 654	25	1 076
Toy	**Small guitar**	PT-T-10A	3 208	1 115	9	3 310	3 318	2	16
Hair	**Comb**	PT-H-7A	564	228	10	37	47	0	15
Hair	**Comb**	PT-H-8A	468	150	3	21	25	0	9
Hair	**Diadem**	PT-H-10A	8 322	2 032	34	2 491	2 526	3	33

Spain

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Rubik's cube	SP-T-3	4 517	1 328	19	152	171	4	46
Toy	Cowboy gun	SP-T-5	995	177	4	598	603	0	25
Toy	Water game	SP-T-9	4 053	870	15	571	586	2	34
Hair	Hair clip	SP-H-1	8 936	2 131	46	853	899	1	31
Hair	Hair clip	SP-H-6	18 794	4 882	43	764	807	5	161
Hair	Diadem	SP-H-10	10 696	3 164	50	898	948	2	86

Sweden

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	**Jokes squirt cam-era**	SWE-T-1B	6 900	1 218	0	<LOQ	0	<LOQ	<LOQ
Toy	**Pixle pals, harley quinn**	SWE-T-1J	100	<LOD	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Hair	**Diadem**	SWE-HA-1A	307	80	0	<LOQ	0	<LOQ	1
Hair	**Pocket comb**	SWE-HA-1B	6 919	4 514	0	<LOQ	0	<LOQ	<LOQ
Hair	**Diadem**	SWE-HA-1E	601	97	0	8	8	<LOQ	2
Hair	**Comb**	SWE-HA-1G	563	99	0	2	2	<LOQ	1

NON-EU COUNTRIES

Albania

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Hair	Comb	AL-H-1A	195	820	2	34	36	<LOQ	13
Hair	Claws clamps	AL-H-1F	5 877	2 307	37	396	433	0	48
Hair	Claws clamps	AL-H-1J	6 340	2 272	57	1 048	1 105	0	112
Hair	Banana clip	AL-H-1L	1 319	366	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Armenia

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Rail car	AM_3	746	239	9	41	50	0	16
Toy	Car	AM_4	961	296	5	28	33	<LOQ	11
Hair	Hair clip	AM_1	12 781	3 233	36	594	630	4	68
Hair	Diadem	AM_2	1 124	280	4	81	85	0	21

Belarus

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Racing car	BY-T-3A	1 198	193	2	4	6	<LOQ	16
Toy	Infinity developing toy	BY-T-5A	1 933	318	4	21	25	0	31
Toy	Camera	BY-T-6A	15 763	4 041	62	1 533	1 595	5	70
Hair	Hair clip	BY-H-8A	1 268	443	14	96	110	0	35
Hair	Hair clip	BY-H-9A	2 637	797	23	736	759	2	126
Hair	Banana clip	BY-H-10A	5 100	<LOD	0	0	0	<LOQ	0

Bosnia and Hercegovina

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Police truck	BN-T-4A	4 467	2 081	11	65	76	<LOQ	50
Toy	Rubik's cube	BN-T-5A	6 267	1 838	67	535	603	0	322
Toy	Spiderman car	BN-T-8A	1 216	425	2	55	57	1	<LOQ
Hair	Hair clip	BN-H-8A	17 414	5 856	70	779	849	5	193
Hair	Hair clip	BN-H-9A	1 408	430	9	185	194	94	33

Macedonia

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Jeep	MK-T-1A	591	242	11	143	154	<LOQ	22
Toy	Gun shooter	MK-T-1B	3 413	820	27	629	656	8	57
Toy	Machine gun	MK-T-1C	2 579	593	13	619	632	1	27
Toy	Bow, arrows, and sword	MK-T-1AD	608	354	4	80	84	<LOQ	17
Hair	Hair wreaths set	MK-H-1D	16 208	4 398	20	770	790	2	117

Montenegro

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Police car	MN-T-1	942	273	1	16	17	0	3
Toy	Car shooter play set	MN-T-7	3 114	849	10	189	199	10	30
Toy	Car	MN-T-9	4 798	1 211	35	1 770	1 805	2	119

Russia

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Robot	RU-T3	8 273	2 790	65	14	79	0	11
Toy	Car	RU-T4	749	198	6	31	37	0	12
Toy	Rail car	RU-T5	2 724	702	12	199	211	1	80
Toy	Chess	RU-T7	3 906	594	40	534	574	0	79
Hair	Comb	RU-T8	1 151	340	12	98	110	1	33

Serbia

Sample type	Sample	Sample ID	Bromine	Antimony	octaBDE	decaBDE	ΣPBDEs	HBCD	ΣnBFRs
Toy	Transformers fighting plane	SR-T-4A	18 712	5 306	119	1 161	1 279	14	1 211
Toy	Audio FM Scan radio	SR-T-5A	947	260	11	684	695	0	20
Toy	Microphone	SR-T-7A	25 683	6 620	7	89	96	0	37
Toy	Binoculars	SR-T-9A	1 128	238	9	104	113	0	28
Hair	Hair clip	SR-H-8A	15 550	4 995	55	1 494	1 550	4	289

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