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Part 1

**Overview Presentations,
Risk Assessment and Risk
Management**

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Brominated Flame Retardants – An Overview

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Current brominated flame retardants demand consumed 40% of worldwide bromine production, which is highly concentrated in the USA and Israel. The bulk of the balance is distributed between bromine used in the production of pesticides, petroleum additives, drilling fluids, water-treatment chemicals and rubber additives.

Bromine-based flame retardant formulations are applied annually to over 2.5 million tons of polymers. Plastics/elastomers parts, textiles, foams and coatings are their major end-uses. Electrical/electronics, furnitures/upholstery and building/transportation are their main applications.

The flame retardant characteristics required by industrial standards or regulations can be achieved by the use of high thermal stable polymer structures (PPS, PTFE, PAI, PEI...) or by polymers modified with flame retardant formulations which are chemically integrated into the polymer chain (FR reactives) or physically blended (FR additives).

Brominated flame retardants are considered highly efficient as main components in FR reactives or FR additives formulations. Non-halogenated alternatives can be based on metallic hydroxides (Al, Mg...) or on phosphorous, nitrogen based chemicals.

Approximately 70 brominated flame retardant chemicals (IPCS-EHC 192) account for a global consumption of over 300,000 tons and a business volume of 2 billion Euro. Over 3/4 of this worldwide market is concentrated in 3 brominated chemical types and 3 companies.

Brominated bisphenol A (TBBPA) and its derivatives are currently the most used (over 150,000 tpa) and are widely applied as FR reactive intermediates in the epoxy and vinyl ester resins production. TBBPA is also used as an intermediate in the production of FR additives for engineering thermoplastic polymers (TBBPA ethers, oligomers).

Brominated diphenyl, diphenyl ethers and diphenyl ethane, with nearly 100,000 tpa consumption, are the second largest brominated flame retardant chemical types currently used.

Decabromodiphenyl ether/oxide (DBDPO) remains the most important FR used in this group. The BSEF estimated world demand for 1999 at 54,800 tons. DBDPO is a general purpose FR additive, usually applied in combination with antimony trioxide in plastics, textiles and coating formulations.

Decabromodiphenyl ethane (82.3% bromine content) is commercialized as an alternative to DBDPO, "non-diphenyl oxide-based" FR additive.

The demand for pentabromodiphenyl ether (9,500 tons in 1999, according to the BSEF) is concentrated in the upholstery and furniture markets, where PBDPO is applied as a FR additive in textiles and polyurethane foam applications.

Octabromodiphenyl ether/oxide consumption (3,825 tons in 1999 - BSEF) is concentrated in FR-ABS formulations, which are also applied as FR additives in combination with antimony trioxide (OBDPO/Sb₂O₃, 4/1 ratio).

Brominated flame retardants with alicyclic structure currently account for an annual demand volume of 20,000 tons, covered mainly by the use of hexabromocyclododecane (HBCD) as a FR additive in polystyrene foams (exp. PS) applied as insulation building materials.

Amongst the other brominated chemicals used as flame retardants the predominant are:

- Polybrominated styrenics (BrPS), used as FR additives for engineering thermoplastics.
- Dibromoneopentyl glycol, as an aliphatic FR reactive, an esterification component of unsaturated polyester resins.
- Ethylenetetra-bromophthalimide, a derivative of the tetrabromophthalic anhydride (TBPA), used as an alternative to DBDPO in styrenics, elastomers and engineering polymers.
- Tribromophenol, mainly used as an intermediate in the production of FR additives (brominated allyl ethers, phenylene oxides, phenoxy-ethanes).

Brominated flame retardant producers develop and introduce several other chemicals or proprietary formulations, which are mainly used in commercial development volumes and/or for specific polymer applications, e.g. tris-tribromophenyl-cyanurate (Dead Sea Bromine Company Ltd.), polypropylene-dibromostyrene (Great Lakes Chemical Corp.) and Tetradecabromo diphenoxy benzene (Albemarle Corp.)

Addressing Human Health and Environmental Risk of BFRs, Particularly PBDEs: A Global Perspective

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Brominated flame retardants represent a specific group among this group of chemicals, the function of which is to ensure preventive flame protection. Bromine-based flame retardants can be divided into three classes: aromatic, aliphatic and cycloaliphatic. They are highly brominated compounds with a relative molecular mass ranging from 200 to that of large molecule polymers. On a weight basis, they usually contain 50-85% of bromine (IPCS, 1997). The highest volume brominated flame retardant in use is tetrabromobisphenol A (TBBPA), followed by decabromodiphenyl ether (DeBDE) and other polybrominated diphenyl ethers (PBDEs). All are aromatic compounds. Hexabromocyclododecane (HBCD) is a major cycloaliphatic flame retardant used primarily in polystyrene foam and flame-retard textiles. In addition to these compounds, flame retardants containing both bromine and phosphorus are also in use.

There is concern over the production of toxic products, particularly polybrominated dibenzofurans (PBDFs) and polybrominated dibenzo-p-dioxins (PBDDs) during manufacture, use and combustion of polybrominated flame retardants. The most likely sources for their production are PBDEs, polybrominated phenols, and polybrominated biphenyls (PBBs). If a chlorine source is present during pyrolysis, mixed halogen compounds will be predominantly produced.

The International Programme on Chemical Safety (IPCS) has evaluated risks to human health and the environment from exposure to a number of brominated flame retardants and their combustion products. Compounds evaluated include brominated diphenyl ethers (IPCS, 1994a) TBBPA and some of its derivatives (IPCS 1995a), Tris(2,3-dibromopropyl)phosphate and bis(2,3-dibromopropyl)phosphate (IPCS, 1995b), polybrominated biphenyls (IPCS, 1994b), and polybrominated dibenzo-p-dioxins and dibenzofurans (IPCS, 1998). A number of recommendations were made and research needs identified. These will be presented in detail. Exposure to PBDEs and most other brominated flame retardants require concerted international actions for various reasons. Firstly, most of these compounds are persistent, bioaccumulative chemicals. They may undergo transboundary transport, and represent

hazards to future generations. Risk management approaches should be put in place to ensure sound protection of human health and the environment now and in the future. This may require the application of precautionary measures. We need to learn from past experiences, identify data gaps, develop adequate risk assessment and management approaches and monitor the effectiveness of any intervention measures taken.

LPCS (1994a) Environmental Health Criteria 152: Polybrominated biphenyls. WHO, Geneva.

IPCS (1994b) Environmental Health Criteria 162: Brominated diphenyl ethers. WHO, Geneva.

IPCS (1995a) Environmental Health Criteria 172: Tetrabromobisphenol-A and derivatives. WHO, Geneva.

IPCS (1995b) Environmental Health Criteria 173: Tris(2,3-dibromopropyl)phosphate and bis(2,3-dibromopropyl)phosphate. WHO, Geneva.

IPCS (1994a) Environmental Health Criteria 192: Flame retardants: A general introduction. WHO, Geneva.

IPCS (1998) Environmental Health Criteria 205: Polybrominated dibenzo-p-dioxins and dibenzofurans. WHO, Geneva.

Brominated flame retardants (BFRs)

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A large number of polybrominated compounds are being, or has been, used as flame retardants. Any measures taken against one of these may result in an increased use of others, for which there may be less knowledge regarding the potential risk for environmental and human health effects. It is essential that we are aware of possible alternatives to be able to detect them early if they are released to the environment.

Flame retardants are needed in the modern society, and there are a number of chemicals that fulfil this function. During the last decades we have realised that several of these substances are long lived in the environment and may cause adverse effects both there and in exposed humans. Presently risk reductions are being discussed for some chemicals used as flame retardants, and these may be substituted by other substances. It is difficult to obtain information on which compounds are being used, and it is therefore essential that those working with monitoring of chemicals in the environment are aware of as many possible alternatives as possible to be able to look for their possible appearance in the analysed samples. For the brominated compounds this is facilitated if the analytical method includes bromide ion detection with ECD-MS, as this method detect brominated substances with high sensitivity and selectivity.

Table 1 describes a number of brominated flame retardants and are mainly based on an IPCS document on flame retardants (WHO, 1997). It may give some ideas what to look for when a “new” signal appears in the analytical results. Ideally analytical laboratories working with environmental analysis should have a set of as many as possible of these substances and a knowledge how they perform in the used analytical scheme. There are probably additional brominated chemicals being used as flame retardants, and some of those given here have also other applications.

Table 1. Brominated chemicals, which are, or have been used, as flame retardants (from WHO, 1997).

Chemical	CAS	Use	Vol ^a	M ^b
Vinylbromide	593-60-2	Reactive FR	M	106
2,3-Dibromo-2-butene-1,4-diol	3234-02-04	Intermediate	M	244
2,4-Dibromophenol	615-58-7	Epoxy resins, phenolic resins, polyesters, polyolefins	H	250
Dibromoneopentylglycol	3296-90-0	Unsat polyesters, rigid PU foams, intermediate	H	260
Dibromopropylacrylate	19660-16-3	Acrylic fibres	-	270
2,4-Dibromophenylglycidyl ether	20217-01-0	Reactive	-	306
Tribromoneopentanol	36483-57-5	Reactive FR, PU, intermediate	M	322
2,4,6-Tribromoaniline	147-82-0	Reactive	-	327
2,4,6-Tribromophenol	118-79-6	Epoxy resins, phenolic resins, polyesters, polyolefins	H	328
Tribromophenylallyl ether	33278-89-5	EPS, foamed PS	L	368
5,6-Dibromohexahydro-2-phenyl-4,7-methano-1H-isoindole-1,3(2H)-dione	40703-79-5	PS	-	397
Tetrabromo-2,3-dimethylbutane		EPS, foamed PS	-	398
1,2-Dibromo-4-dibromomethylcyclohexane	3322-93-8	Expandable PS	L	410
Tetrabromoxylene	23488-38-2	PS, polyolefins, textiles	-	418
Tetrabromophthalic anhydride	632-79-1	Reactive FR, unsat polyesters, rigid PUF, reactive intermediate	H	460
Pentabromotoluene	87-83-2	Unsat polyesters, PE, PP, PS, textiles, rubbers, ABS	M	482
Pentabromophenol	608-71-9	Epoxy resins, phenolic resins, polyesters, polyolefins	H	484
Bis(2,3-dibromopropyl)phosphate	5412-25-9		-	494
Dibromochlordene	18300-04-4	PS	-	494
Pentabromoethylbenzene	85-22-3	Textiles, adhesives, PUF, coatings, unsat polyesters	-	496
Tetrabromodipentaerythritol	109678-33-3	Polyester, PU	-	502
Trichloromethyltetrabromobenzene		ABS, PS, polyester	-	506
Pentabromochlorocyclohexane	87-84-3	PS, PP	-	508
Tetrabromophthalic acid, sodium salt	25357-79-3	Unsat polyesters, rigid PUF, reactive FR	L	522
1-Pentabromophenoxy-2-propene	3555-11-01	Synergist	-	524
2,4,6-Tribromophenoxy-2,3-dibromopropane	35109-60-5	PP	-	526
Hexachlorocyclopentadienyl-dibromocyclooctane	51936-55-1	PS	-	536
Tetrabromobisphenol A	79-94-7	Intermediate	H	540
Hexabromobenzene	87-82-1	Paper, PA, PES, PP, PBT	-	546
Hexabromocyclohexane	1837-91-8	Styrene foams	-	552
Pentabromodiphenyl ether	32534-81-9	PU, textiles	H	560

Table 1 continued.

Chemical	CAS	Use	Vol ^a	M ^b
Tetrabromobisphenol S	39635-79-5	Intermediate	L	562
Bis(2,3-dibromo-1-propyl)phthalate	7415-86-3	Polyesters	-	562
Tetrabromobisphenol A, dimethyl ether	37853-61-5	Expandable PS	L	568
1,4-Bis(bromomethyl)tetrabromobenzene		Polyolefines	-	574
Bis(1,3-dichloro-2-propyl)(3-chloro-2,2-dibromomethylpropyl)phosphate	61090-89-9	Polyolefines	-	578
Pentabromophenylbenzoate		ABS, PS, polyester	-	588
Tetrabromobisphenol A, bis(2-hydroxyethyl ether)	4162-45-2	Intermediate	M	596
Tetrabromobisphenol A, bis(allyl ether)	25327-89-3	EPS, foamed PS	M	622
Hexabromobiphenyl	59536-65-1 67774-32-7	Thermoplastics	-	622
Tetrabromophthalic acid diol	20566-35-2	Wool, leather, PUF	M	624
Hexabromocyclododecane (HBCD)	25637-99-4 3194-55-6	Expandable PS, latex, textiles, adhesives, coatings, HIPS, unsat polyesters	H	636
Hexabromodiphenyl ether	61262-53-1 36483-60-0	PS, ABS, PC, unsat polyesters	-	638
Ethylene-bis(5,6-dibromonorbornane)-2,3-dicarboxamide	41291-34-3 52907-07-0	PP	M	668
1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	Thermoplastics, ABS, HIPS	L	682
1,2-Bis(tribromophenoxy)ethane		PS, PC, coatings	M	682
Tris(2,3-dibromopropyl)phosphate	126-42-7	Polyesters, urea, melamine, textiles	-	692
Tetrabromophthalic acid diesters, e.g. Br4DEHP	20566-35-2		H	706
1,3,5-Tris(2,3-dibromopropoxy)-2,4,6-triazine	52434-59-0	PP	L	723
Tetrabromobisphenol A, bis(2-ethyl ether acrylate)	66710-97-2		-	736
Octabromobiphenyl	61288-13-9	Thermoplastics	-	778
Octabromodiphenyl ether	32536-52-0	ABS	H	794
2,4-Dibromophenylphosphate	49690-63-3	Engineering thermoplastics	L	794
Decabromobiphenyl	13654-09-6	ABS, PS	-	934
Tetrabromobisphenol A, bis(2,3-dibromopropyl ether)	21850-44-2	Polyolefines	M	938
Ethylene-bistetabromophthalimide		PE, PP	M	944
N,N'-Ethylene-bis(tetrabromophthalimide)	32588-76-4	HIPS, PE, PP, thermoplastics, polyesters, PA, EPDM, PC, rubbers, textiles	M	944
Decabromodiphenyl ether	1163-19-5	PS, Polyester, PA, textiles	H	950
Decabromodiphenylethane	61262-53-1	HIPS, ABS, PP, PA, polyester/cotton	M	962
Tris(tribromoneopentyl)phosphate		Thermoplastics	L	1010
Tris(2,4,6-tribromophenyl)phosphate		Engineering thermoplastics	-	1028
Tetradecabromodiphenoxybenzene	58965-66-5	Engineering thermoplastics	M	1354

^a High (H), medium (M) or low (L) use volume, or not used today (-)

^b Based on the lightest stable isotopes ("molecular ion")

Reference

WHO, 1997, "IPCS, Environmental Health Criteria 192. Flame Retardants: A General Introduction". WHO, Geneva.

A Survey of Tetrabromobisphenol A

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Background

Tetrabromobisphenol A (TBBPA) is the most abundant brominated flame retardant (BFR) currently in use. Over 120,000 tons are produced annually, which comprises 30% of all BFR usage.¹ TBBPA can serve as a reactive or additive flame retardant. About 90% of TBBPA use is for the production of reactive flame-retarded polymeric epoxy and polycarbonate resins, where they are generally used in printed circuit boards. The monomeric nature of TBBPA is lost in polymerization. The remainder of TBBPA is used as an additive flame retardant in acrylonitrile-butadiene-styrene (ABS) resins and in high-impact polystyrene, which are used in automotive parts, appliances, packaging, and consumer disposable products. TBBPA has a K_{ow} of 4.5-5.3, and is a weak acid with two phenolic hydroxyls ($pK_{a1} = 7.5$ and $pK_{a2} = 8.5$).

Environmental analyses

TBBPA can be readily extracted from products where it was used as an additive flame retardant,² and therefore, can also leach into the environment. When detected, TBBPA is usually found in soil, sediment, and sewage sludge. At a Swedish plant where electronic products were dismantled for recycling, TBBPA was among the highest BFRs detected in the air, i.e. 30 ng per cubic meter.³ The concentration of TBBPA in sediment near a plastics plant where TBBPA was used was found to be 34 ng TBBPA/g dry sediment, and 270 ng/g dry sediment downstream. The dimethoxy derivative was also found at concentrations of 24 and 1500 ng/g, respectively.² TBBPA has also been found in river sediment samples analyzed in Osaka, Japan⁴ and in Arkansas, USA,⁵ where TBBPA manufacturing and consumption is high. Sewage sludge from a treatment plant that received leachate water from a plastics industry, and from a plant where no known TBBPA users could be identified, both had similar levels of TBBPA, i.e. 56 and 31 ng/g, respectively.²

Reports of TBBPA and/or its derivatives in biota are rare. TBBPA was detected at the low ppb level (lipid weight) in each of 40 human blood samples analyzed for phenolic

organohalogenes.⁶ Relatively large fish samplings in 1987 and 1988 in Japan failed to detect any TBBPA at a limit of detection of 1 µg/ kg wet weight.^{7,8} Watanabe *et al.*⁹ have found the dimethoxy derivative but not TBBPA in mussels of Osaka Bay at 5 µg/ kg wet weight. Two of 19 marine fish and shellfish sampled at the same location contained dimethoxy TBBPA.¹⁰ It was not known whether methylation occurred in vivo or through microbial transformation. Only gram-positive bacteria, e.g. *Rhodococcus* sp., are known to O-methylate TBBPA.¹¹

Toxicology

The acute toxicity of TBBPA in laboratory animals appears to be low. The oral LD₅₀ for mice and rat is 10 and 5 g/kg body weight, respectively. Dermal application to rabbits produced no chloracne or systemic changes. No effect on body weight, serum chemistry, urin analysis, or histopathology was observed in inhalation studies conducted at 18 mg/L for 4h/day, 5 days/wk, for 2 weeks. TBBPA was not shown to be a sensitizer in either guinea pigs¹² or humans.¹³

In aquatic invertebrates, i.e. *Daphnia magna*, the 48h, acute LC₅₀ was 0.96 mg TBBPA/L, and at 0.056 mg/L, 5% of the organisms died.¹⁴ Continuous exposure of *Daphnia* for 21 days at up to 0.98 mg TBBPA/L resulted in no significant differences in survival when compared to controls, and only at the highest concentration were reproduction differences observed (21 offspring/treated female vs. 60 for control).¹⁵ In aquatic vertebrates, the 96h, acute LC₅₀ has been determined. For bluegill sunfish, rainbow trout, and fathead minnows the LC₅₀'s were 0.51, 0.40, and 0.54 mg/L, respectively. Continuous exposure of fathead minnows to TBBPA for 35 days at the highest concentration, i.e. 0.31 mg/L, resulted in significantly lower survival rates than controls (28% vs. 84%), but at lower concentrations no survival differences were observed. All fathead minnow larvae exposed to 0.31 mg/L died, but no differences with controls were observed at lower concentrations.¹⁵

In rats given an oral administration of TBBPA at gestation days 6-15, there was no difference between controls in number of viable fetuses, resorptions, or implantations at concentrations up to 3 g/kg.¹⁶ Another study which used doses up to 2.5 g/kg, demonstrated no toxic effects on the embryo or fetus, no skeletal abnormalities, and no abnormalities in postnatal development.¹⁷

Mutagenicity studies using *Salmonella typhimurium* and *Saccharomyces cerevisiae* with and without microsomal activation were all negative. Ames tests conducted with five bacterial strains also were negative.¹²

At 96h, growth of the marine algae, *Chlorella* sp. and the freshwater algae, *Selenastrum caricornutum*, were not inhibited at mg/L concentrations.^{18, 19} However, TBBPA was toxic for two other marine algae strains at an EC₅₀ of between 90-890 µg/L.

Metabolism

It was originally concluded that TBBPA was poorly absorbed in rats because 95% of a single oral dose was excreted in the feces as unchanged parent at 72h.²⁰ However, Hakk *et al.*²¹ have shown through the use of bile-duct cannulated rats that TBBPA is readily absorbed by rats. Metabolism to the glucuronic acid and sulfate ester conjugates in the liver was extensive. Elimination of these conjugates via the bile into the GI tract and subsequent deconjugation by gut microfloral resulted in the formation of parent in the fecal contents. Bluegill sunfish also demonstrated a rapid uptake of TBBPA when exposed to radiolabelled TBBPA in water at a concentration of 9.8 µg/L.²² The half-life of elimination of TBBPA was less than 1 day in rat and fish, and was estimated to be less than 5 days in oyster.

Degradation

TBBPA could be photodegraded by UV radiation when dissolved in water with a half-life that that decreased from winter (80.7 days), to autumn (25.9 days), to spring (10.2 days), and to summer (6.6 days).²³ Silica gel-bound TBBPA exposed to 254 nm radiation resulted in the formation of eight transformation products. The half-life under these *in vitro* conditions was very low, i.e. 0.12 days.

Degradation of TBBPA was tested in a variety of soil types under both aerobic and anaerobic conditions. The soils varied in their silt, sand and clay content. Biodegradation was observed in all soils, as measured by thin layer chromatography (TLC). However, mineralization to CO₂ represented less than 6% of the total metabolic activity. After 64 days, the soil with the highest clay content had the highest degradation activity towards TBBPA.²⁴ Under anaerobic conditions, only 0.5% of the TBBPA was mineralized, and degradation was lowest in soil with high silt content.²⁵ In sterile soil, no degradation of TBBPA was observed, implicating bacteria in the degradation process. Biodegradation of TBBPA (100 mg/liter) under sewage treatment conditions was not detected.

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EU risk assessment of HBCDD

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Summary

Hexabromocyclododecane (HBCDD) is an additive BFR that is mainly used in different polystyrene resins and in textiles. HBCDD is not readily biodegradable, but the degree of persistency in the environment is not known. The bioconcentration factor in fish is very high, as is the toxicity to daphnia and algae. In mammals, HBCDD may cause liver toxicity and induce sensitisation. There is a need for additional information on effects, exposure, and environmental fate before concluding on needs for risk reduction.

Introduction

HBCDD is currently risk assessed within the EU existing substances regulation programme, with Sweden as rapporteur. In this process, data on toxicity, ecotoxicity, use, emissions, and exposure are compiled and assessed, eventually leading to conclusions on the need for risk reduction measures. A draft risk assessment report on HBCDD has been produced, containing the available information on toxicity, ecotoxicity and use (1). The process is currently in the stage of collecting additional information needed for concluding on the needs for risk reduction measures.

Effects

A high toxicity of HBCDD is observed in *Daphnia magna* (chronic exposure NOEC 3 ug/l) and marine alga (EC50 (72h) 11 ug/l), whereas the acute toxicity is very low in rodents (oral LD50 rat > 20g/kg). The dataset on repeated toxicity testing in rodents did not fulfill the requirements, and a 90 days oral study in rats is currently conducted by the industry. Based on the available studies, the liver seems to be the target organ (LOAEL 80 mg/kg/day). In a poor developmental toxicity study in rats, no evidence for developmental toxicity was observed. Still, there is a need for more information on reproductive toxicity. There are no indications on genotoxicity in the in vitro tests that have been performed. The available data indicate that HBCDD is a skin sensitiser.

Environmental fate

The degree of biodegradability of HBCDD is not resolved. The substance is not readily biodegradable by microorganisms (OECD TG 301D), but there is no data to indicate the degree of persistency of HBCDD. Monitoring data in sediment and air seem to support a rather long environmental half-life. QSAR modelling predicts a half-life in air of 1.8 days, indicating a potential for air transport of HBCDD. The lipophilicity of HBCDD (log Kow 5.6) indicates a potential for bioaccumulation. Two studies in fish have given biocentration factors of 9.000-18.000. HBCDD is present in biota at different trophic levels, but the degree of biomagnification has not been studied.

Use and exposure

The main use of HBCDD is as an additive flame retardant in different polystyrene resins and in textiles. As information on potential exposure of humans and of the environment is lacking, the exposure analyses was initially based on modelling (EUSES, EASE). The preliminary conclusions from the rapporteur included needs for risk reduction for workers due to risks of liver lesions, and to all human populations due to a risk for sensitisation. Real life exposure data is being produced by the industry, and until that information is available and analysed, the conclusions on needs for risk reduction are preliminary and subject to change.

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The commercial pentabromodiphenyl ether as a global POP

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Summary

Data on intrinsic properties of and monitoring results on pentabromodiphenyl ether (pentaBDE) have been reviewed in a Nordic project. According to the available data it can be concluded that pentaBDE fulfils the screening criteria set for the persistent organic pollutants (POPs) in the framework of the international UNECE LRTAP and UNEP Conventions.

Composition, adverse properties and fate

Persistent organic pollutants are described as chemicals which resist biodegradation, bioaccumulate, may be transported in the environment far from their sources and have potential to cause adverse effects to human health or the environment. In order to eliminate the pollution caused by chemicals recognized as POPs, two international legally binding instruments have recently been agreed on: the regional POP Protocol extending the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP) and the global UNEP Convention on POPs. The aim of this Nordic project is to contribute to listing of further POPs in these international agreements.

The congener compositions of typical polybrominated diphenylether (PBDE) products in use, pentaBDE, octaBDE and decaBDE are shown in Figure 1. The major congeners of commercial pentaBDE products are BDE-47 (up to ~40 %) and BDE-99 (up to ~40 %).

The atmospheric half-life of pentaBDE, indicating the potential for long-range transport, has been estimated to be ca. 12,6 days¹. It clearly exceeds the POP atmospheric half-life criterion of >2 days. Commercial pentaBDE is not readily biodegradable, and the major pentaBDE congeners are slowly if at all metabolised indicating even higher persistency than that of PCBs (i.a. 2, 3; major results summarised in 1). The half-lives of the commercial pentaBDE congeners in rat vary between 19 and 119 days⁴. The half-lives of pentaBDE in sediment, water and soil have not been reported, but the monitoring data from the aquatic environment

supports that its persistence exceeds the POP half-life criteria (> 2 or > 6 months in water or soil/sediment, respectively).

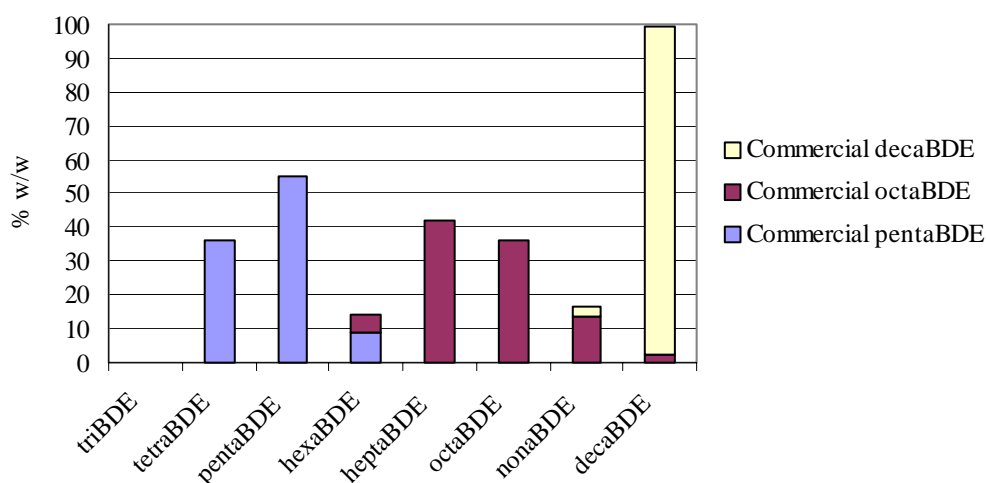


Figure 1. Congener composition of typical pentaBDE, octaBDE and decaBDE products¹.

The POP criterion for bioaccumulation (BCF > 5000) is evidently exceeded. The BCF for carp (*Cyprinus carpio*) of commercial pentaBDE has been estimated to be ca. 27 400¹. Bioaccumulation potential of the congeners BDE-47 and BDE-99 in mussels have been shown to be one order of magnitude higher than the bioaccumulation potential of the PCB congener CB-153 and other studied PCB congeners (CB-31, CB-52, CB-77, CB-118)⁵. Biomagnification potential of i.a. BDE-47, BDE-99 and BDE-100 has been reported for sprat, herring and salmon⁶.

Except the high acute toxicity for *Daphnia magna*, pentaBDE has been generally reported to have low acute toxicity (summarised in ¹ and ⁷). Nevertheless, thyroxin competing potential of hydroxylated metabolites⁸, ability to activate the Ah-receptor⁹ and possible ability to induce cancer (intragenic recombination)¹⁰ have been observed *in vitro*. *In vivo* rat studies indicate that liver is the main target organ affected by pentaBDE (summarised in¹) with a NOAEL of 1 mg kg⁻¹ d⁻¹. Other *in vivo* studies have found i.a. significantly increased EROD and MROD activities in fish¹¹ as well as developmental neurotoxicity¹² and immunotoxicity¹³ in mice for major congeners of pentaBDE.

Evidence of long-range environmental transport from the measured exposure data

The BDE-47 has been observed in the vapour phase of air both indoors and outdoors^{14,15}. The persistence of pentaBDE adds also to the high potential for long-range transport. The long-range transport of pentaBDE by air can be confirmed from the scarce results (i.a. 15, 16) from remote areas, where BDE-47 was found in higher levels than the other PBDE congeners (followed by BDE-99 and BDE-100), and was in major part in the vapour phase. The sumPBDE concentration in air in these studies varied generally between ca. 1 and 10 pg m^{-3} .

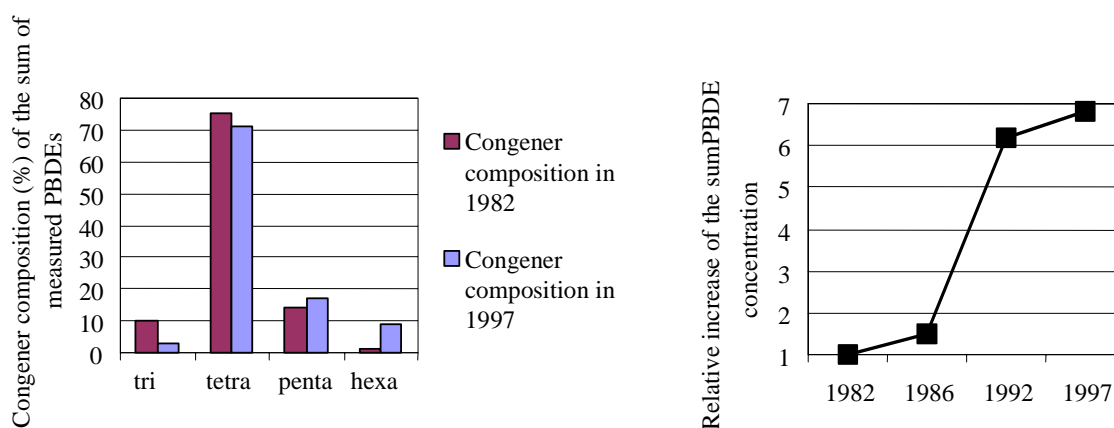


Figure 2a. Congener profiles in the Arctic beluga whale blubber in 1982 and 1997¹⁷.
Figure 2b. Increase of PBDE concentration in the Arctic beluga whale blubber¹⁷

The long-range transport of pentaBDE is confirmed also by biota samples from remote areas, i.a. 2, 16, 17, 18. In biota BDE-47 and BDE-99 are observed on even higher levels compared to other PBDEs than in the abiotic environment due to the preferential uptake of especially BDE-47 but also of BDE-99. Moreover, BDE-47 concentrations in Arctic marine mammals have been measured to even exceed the concentration of the most abundant PCB, CB-153¹⁶.

Data from remote areas are still scarce but indicate clearly increasing contamination by pentaBDE. Concentrations of the two major congeners in whales have been reported in the range of ca. 66 to 864 ng/g lipid (BDE-47) and 24 to 169 ng/g lipid (BDE-99)^{2, 17, 18}. The Figures 2a and 2b (based on ¹⁷) show a congener profile which represents probably a typical profile in the biota of remote areas and an increasing trend of pentaBDE in the Arctic beluga whales. An upward trend for the pentaBDE congeners has been observed also e.g. in the general human population in blood and milk with typical levels of few ng/g lipid^{19, 20}.

Conclusions

On the basis of the existing studies, the commercial pentaBDE fulfils the screening criteria set in the UNEP POP Convention and in the framework of the UN-ECE Protocol on POPs. The commercial pentaBDE and products containing it have already been proposed to be phased out in the European Union. Due to the wide use and occurrence in remote regions, wider regional and global risk reduction should be considered.

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Environmental Risk Assessment of Octa- and Decabromodiphenyl ether

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Summary

Comprehensive risk assessments have been agreed at EU level for the three commercial polybromodiphenyl ethers. The conclusions are that one will be banned, and a test programme is needed for the other two (octa- and decabromodiphenyl ethers) to characterise risks to sediment, soil and sewage treatment organisms, and to determine the likelihood of debromination to more toxic substances. There are no risks to surface water organisms, the atmosphere or top predators.

Abstract

Initial concerns about polybromodiphenyl ethers (PBDEs) were raised in the late 1980s, and subsequently the three commercial PBDE substances were prioritised for risk assessment under the EU Existing Substances Regulation (EC no. 793/93), with the UK responsible for the environment sections. The first stage of the environmental risk assessments was agreed by all EU member state technical experts in 1999 and the Commission's independent scientific advisory committee (CSTEE) in 2000: pentaBDE will be banned in the EU; octa- and decaBDE require further work.

The commercial PBDEs have between 4 and 10 bromine atoms/molecule. OctaBDE is a mixture of components with different degrees of bromination, whilst decaBDE is essentially pure. Both substances have low solubility in water (<1 microgram/l), low vapour pressure and a log octanol-water partition coefficient ($\log K_{ow}$) of ~6.2. They are persistent in water, sediment and soil systems, and are strongly adsorbed onto soil, sludge and sediment. They are much less bioaccumulative than would be predicted from the $\log K_{ow}$ alone (bioconcentration factors of <5, based on tests with fish).

Both substances are used as flame retardants: decaBDE is used in polymers (e.g. for TV cabinets and other electronic equipment) and textiles; octaBDE is used in polymers mainly for

office equipment. Total use of PBDEs in the EU is around 10,000-11,000 tonnes/year (based on data from the early 1990s) - decaBDE accounts for at least 75% and octaBDE ~15% (although this may have declined). Neither substance is produced in the EU.

Emission can occur from polymer processing sites, sites formulating or applying flame retardant treatments to textiles, volatile and leaching losses over the service life of polymers or textiles, and also particulate losses over their service life and at disposal. In practise it is expected that total emissions will be dominated by volatile losses from polymers over their service life (e.g. >91% of the total emission of octaBDE to air).

Predicted environmental concentrations (PECs) have been calculated using the methods in the EU Technical Guidance Document (available from <http://ecb.ei.jrc.it/>) and the EUSES model. These concentrations are likely to be realistic worst case levels, and are generally supported by the limited monitoring data available, although sediment levels may be underpredicted.

No effects have been seen in any aquatic toxicity test (unlike pentaBDE), so no predicted no effect concentration (PNEC) can be derived for surface water, sediment or soil organisms. Since exposure via direct ingestion of solid-bound substance is possible, toxicity tests with soil and sediment organisms are required. Neither substance is classified as Dangerous to the Environment in the EU classification and labelling scheme.

Potential risks for predators at the top of food chains are assessed by estimating whether substance levels in their food are likely to poison them ('secondary poisoning'), using data for laboratory mammals to derive the PNEC. This has only been done for octaBDE, since there is no evidence for bioaccumulation in biota for decaBDE. Overall, both substances appear to be less toxic and accumulative than pentaBDE.

Risk characterisation involves the comparison of the PEC to the PNEC. If the ratio is above 1, there is a concern. Consequently, there is a low risk for surface water organisms, the atmosphere and top predators for both substances. A risk to sewage treatment plant, sediment and soil organisms can not be ruled out - toxicity testing is necessary. There are some other important issues for these substances:

- Can either substance degrade to more toxic and bioaccumulative lower congeners under environmental conditions not accounted for in the assessment (i.e. debromination by light or anaerobic microorganisms)? Testing is required to find out.
- How do these substances contribute to the formation of brominated dibenzo-*p*-dioxins and furans during burning and reprocessing?
- As pentaBDE is being banned, what contribution does commercial octaBDE make to levels of shared components in the environment?

The results of the test programme should be available during summer 2001. A revised risk assessment with final conclusions should be ready for discussion in the autumn, and hopefully final publication at the end of the year. In the meantime, the current risk assessment report (draft of August 1999) is available from the author, and may be published shortly by the European Commission.

Brominated Flame Retardants: Industry Testing and Research Programme

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Brominated flame retardants (BFRs) have been used by various industries for many years to protect consumer products and materials against fire hazards. About 75 different products are included in this group, and some of them have been alleged, mainly the PBDEs (Poly Brominated Diphenyl Ethers), to cause environmental and health concerns. This paper will describe the bromine industry's testing and research programme.

Brominated flame retardants are a group of about 75 chemicals, each different in their structure, physical chemical characteristics, toxicity profile and environmental fate. They are used in many consumer products to reduce flammability with an excellent proven record in saving life, property and reducing environmental impact from toxic gases released in fires. The European Commission has observed that "in the last 10 years a 20% reduction in fire deaths is a result in appropriate use of flame retardants"(1). The U.K. Government has concluded that "furniture complying with the furniture and furnishing regulations will not catch fire as non-compliant furniture, the actual number of lives saved could be as high as 1860 in the period from 1998 to 1997" (2). A Swedish fire testing institute has further found that "as many as 160 people may die in Europe each year as direct result of TV fires while there is no documented death due to the use of flame retardants" (3).

In recent years various publications have raised concerns about the use of BFRs due to environmental (4) and health concerns (5,6) and their behaviour at products' end-of-life. The bromine industry's practice has always been to place products on the market only after extensive testing programmes - from chemical physical characteristics, to toxicology, environmental fate and technical profiles. Some of the products that were placed on the market in the past, have been tested in recent years to upgrade their data base, including various elements of life cycle analysis, recycling and end of life programmes.

¹ This paper is on behalf of the Bromine Science and Environmental Forum, BSEF; Albemarle corporation, USA; Dead Sea Bromine Group, Israel and Great Lake Chemical corporation, USA,

The following activities are part of the bromine industry's programme to support the safe use of Brominated Flame Retardants:

- 1. Risk Assessment (RA) process, based on EEC 793/93 on the evaluation and control of the Risks of Existing Substances, for Deca, Octa, and Penta Bromo Diphenyl Ethers and HBCD, Hexabromocyclododecane.** This is the only official science-based evaluation about the risk of chemicals as used in various applications. The evaluation of Penta BDE has been completed and risk reduction measures are being recommended for this product by the EU. Deca and Octa are nearing the end of the evaluation process, and the last communication by the risk assessment authorities indicated no need for risk reduction measures for these two products. The bromine industry recently completed several studies to support the RA, among them: "Deca-BDE: A prolonged sediment toxicity test with *Lumbriculus Variegatus* using spiked sediment with 2% and 5% total organic carbon", "An oral prenatal developmental toxicity study of Deca-BDE in rats" and "Bacterial reverse mutation assay". The final RA study, a study on the potential for Deca-BDE to degrade in the environment, is near completion, and September 2001 is the target date of the RA authorities to finalize the Deca-BDE evaluation.

The risk assessment on HBCD is in progress and is being supported by an extensive testing programme, undertaken by both producers and users.

A Risk Assessment on TBBPA, Tetra Bromo Bisphenol A, is starting this quarter, with UK and Ireland being the responsible countries. As in the past, the industry will support this process with testing programmes in agreement with the regulatory authorities.

- 2. PBDEs in the Aquatic Environment.** *Research programmes under the leadership of Dr. J. de Boer, Netherlands Institute for Fisheries Research (RIVO), Ijmuden, The Netherlands.* This programme was initiated by the industry to investigate and understand the trends of PBDEs in the aquatic environment. Some of these studies will be reported separately in this meeting. A similar study has been launched by BFRIP, the bromine industry panel in the USA, to look into trends in North America.
- 3. Recycling of Plastics Containing BFRs.** Recycling will be the preferred option for consumer goods in the future. BSEF has completed studies which demonstrate that the

mechanical recycling of plastics with BFRs is safe and an environmentally sound process. Further, recycled plastics retain their fire-retardant properties, without any degradation in quality.

- 4. Bromine Recovery and Energy recovery from Electronic Waste.** One of the options for electrical and electronic equipment waste (WEEE) is energy recovery through combustion in municipal solid waste incinerators. BSEF and EBFRIIP initiated a programme to study the thermal process of bromine recovery from WEEE, as part of normal combustion process in municipal waste incinerators. A pilot trial was carried out in the TAMARA incinerator, including an analysis of the effects of high levels of bromine in the waste. No elevated levels of dioxins or furans were observed and the bromine can be recovered as bromine salt without any environmental or health concerns. Results will be reported in a separate paper at this conference.

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Fire prevention – more than brominated flame retardants

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When environmental and health scientist find and explain problems with brominated flame retardants actions are normally taken by health and environmental agencies. Fire prevention authorities also have a key role when there is a need for new fire safety systems. In this case there are alternatives to brominated flame retardants for most applications.

Fire prevention is much more than heavy use of chemicals in polymers – it is more like a concept. It is possible to use other materials and use different design methods. This is an area where fire safety authorities can help solving some environmental problems. Our knowledge from fire prevention in buildings (materials, fire load, fire enclosure, fire walls, detection and extinguishing systems etc) can be transformed and used for design of products. But also the use of the product in different surroundings can influence on the overall fire safety – you may need higher standards in public areas, in hotel beds and in hospitals.

Our Agency and our colleges around the world need to have a broad aspect on safety and need to regard all aspects when we decide on rules and write handbooks. There is also an obligation for us to follow the national Swedish environmental policy that states that we shall reduce the use of brominated flame retardants. At the same time fire safety is an important and in some cases essential safety factor.

After reading many studies and reports on the problems caused by brominated flame retardants the SRSA decided in 1997;

- To participate in the work to stop or reduce the use of polluting flame retardants. If facing out is planned the fire safety factor need to be tackled.
- By own research and in co-operation with other contribute to increased knowledge of the flame retardants effects on the environment at fires and other accidents.
- To help other agencies at their decisions in matter that can include the use of flame retarants and support the use of alternative fire prevention methods.

Brominated flame retardants are in focus and I think they can be replaced in most applications. An example¹ is electronic and electrical products where there are alternatives. One of the problems is that some of the new retardants are not fully investigated and may cause new or other problems.

To make these changes we need to act on an international stage together with colleges, scientists of several disciplines, producers, procurement agencies, labelling systems and standard organisations. Most rules and testing procedures are based on international standards that all producers have to fulfil. Studies² also show a need for more economic incentives to change to new and less toxic chemicals or methods. Product design can be a useful tool for some products³.

During the last two years a new system was presented on the 8th of May this year. It is a voluntary system for simultaneous judgement of fire- environment and health quality. The system has been planned during two years and will be open for different kind of products sold on an international market. The system will create incentives for manufacturers who design products that perform better than standards. They can, via the system, get an assessment of their products. The proposal is the result from a co-operation between Swedish Rescue Services Agency (SRSA), Swedish National Chemical Inspectorate, Swedish Environmental Protection Agency and National Association of State Fire Marshals (US) and corresponding US environmental agencies.

The system, which has no name so far, will make it easier for producers to phase out certain “dangerous” flame retardants. Fire safety can also be achieved by design, selection of materials or in bedded alarm- or extinguishing systems. The project group has also come to the conclusion that the environmental concerns can be managed without changing the rules for fire precautions.

About SRSA

The Swedish Rescue Services Agency (SRSA) is a governmental agency with around 900 employees. The Agency supervises fire-brigades and other rescue services according to the Rescue Act. The SRSA advice and educate fire personal, handle rules for transport of dangerous goods and civil defence. The Rescue Act also deal with fire prevention and fire safety, which locally is inspected by around 250 local administrated fire-brigades. Fire officers also do some fire investigations which all are collected by SRSA.

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**Product Design to Reduce Restricted Substances –
Experience with Brominated Flame Retardants in Vehicle Design**

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This paper is the result of a Master's thesis, developed in cooperation with the Swedish National Chemicals Inspectorate (KemI) and the International Institute for Industrial Environmental Economics (IIIEE) at Lund University.

Abstract

Vehicle producers are recognising the need to reduce the hazardous substances and materials used in vehicles. To do this, some focus on early decision-making in the vehicle design process. This paper investigates the vehicle design chain to reveal how restricted substances, specifically brominated flame retardants, are being addressed and what main factors influence this. Results show that restricted brominated flame retardants are still used vehicles, and the situation is similar for many other restricted substances. Results are based on information gathered from interviews with a range of actors in the industry and in the field

Extended Abstract

Vehicle producers are recognising the need to reduce the hazardous substances and materials used in vehicles. To do this, some producers are addressing these issues early in the vehicle design process. This is largely in response to existing and coming substance oriented regulations, product-focused policies and a subsequent pressure from actors along the vehicle design chain.

This paper investigates the vehicle design chain to reveal how restricted brominated flame retardants are being addressed and the main factors influencing this. The specific case of brominated flame retardant use in vehicles is examined. Information is from interviews with a range of actors.

Overall, this paper concludes that the restricted brominated flame retardants are not yet removed from vehicles. In part, this is because the industry is not able to apply suitable alternative solutions for all applications in vehicles and components. Also, it is partly because

vehicle producers and suppliers of components, such as electronics and textiles, do not know all cases where brominated flame retardants are used. Likewise, they do not know which flame retardants are used in many cases. The situation is similarly unclear for many other restricted substances.

A list of substances targeted for restrictions is currently the most common mechanism to address the use of brominated flame retardants and other restricted substances. While lists have brought profile to the issue, they alone are not enough to integrate restricted substance considerations into vehicle design decisions and thus, may not adequately address the issue. In practice, substance lists lead to substitution of one substance with another. The mindset associated with substitution is to include restricted substance considerations in vehicle design when there is no disruption to the existing design process and minimal change to the vehicle. However, the problem with restricted substance use is not confined to a fixed number of chemicals with a negative impact. The problem is the use of a large number of poorly understood substances. Thus, substitution of one substance with another may not actually constitute a solution.

Changing the current mindset to actually integrate restricted substance considerations into vehicle design decisions increases possibilities to reduce the use of these substances. Integration can also lead to changes in the design process and the product that bring performance and business improvements. The paper exemplifies the potential for this improvement.

However, the vehicle design process is geared to respond to continual time and cost pressures placed on the industry. Therefore, it is also key to recognise that integration into this process may still not adequately address brominated flame retardant use.

Based on these conclusions, suggestions include a step-back approach when faced with a brominated flame retardant in a design. Before looking for an alternative substance, there are benefits to first consider the necessity for the flame retardant and its intended function.

Further suggestions include requiring suppliers to work with restricted substances in a similar way in their product design.

There are constraints to such an approach. As anticipated, these include behaviour of actors and a lack of incentives along the vehicle design chain. Among specific constraints to reducing the use of brominated flame retardants is the current method for testing materials for fire safety in the vehicle industry. The paper analyses a range of opinions on the test method and reveals opportunity to overcome such constraints.

Risk Assessment of Three Commercial PBDEs: Probabilistic Analysis of Chronic Daily Intakes from Different Sources and Comparison with European Commission Results

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Summary

A human health risk assessment was performed to predict theoretical chronic daily intakes (CDIs) of penta-, octa- and deca- brominated diphenyl ethers (PeDBE, ODBE, and DBDE, respectively) for five different age groups: 0-2 years, 2-6 years, 6-12 years, 12-18 years, and 18-70 years associated with eight exposure pathways. In addition to a deterministic analysis using default exposure assumptions, a probabilistic analysis also was performed to quantify distribution frequencies for pathway and aggregate exposures for each age group. Results were compared to CDIs calculated by the European Commission Existing Substances Programme (ECESP)^{1,2,3}.

Introduction

Several environmental monitoring programs indicate increasing levels of PBDEs in the environment and in wildlife, particularly in nordic countries where this trend sharply contrasts with a general decrease in the occurrence of dioxins, PCBs and some chlorinated pesticides in mammals and aquatic wildlife^{4,5}. Furthermore, there is sufficient evidence indicating that the concentrations of PBDEs in human breast milk and adipose tissues have increased sharply over the same period⁶.

At present, the ECESP, in accordance with Council Regulation EEC 793/93 on the evaluation and control of the risks to human health and the environment of existing substances, is the only regulatory organization that has undertaken risk assessment of PBDEs^{1,2,3}. Draft reports for PeDBE, ODBE, and DBDE were completed last year, and will likely influence the course of future regulations in the Europe Union and elsewhere concerning commercial uses of these substances. The ECESP results demonstrate that our understanding of environmental fate and potential health effects associated with exposure to PBDEs is limited. Several important data gaps remain unaddressed such as (a) the relationship between dietary levels and adverse

health effects in children; (b) relevant toxicity endpoints and likely effects-thresholds in humans and wildlife; and, (c) environmental fate and pathways of exposure to these compounds. This study represents a first step towards addressing these and other concerns using probabilistic risk assessment. The results are compared to lifetime CDIs calculated by ECESP^{1,2,3}.

Risk Assessment Methods

Exposure Pathways and Assumptions. Eight exposure pathways were evaluated for each age group, including fish ingestion, ingestion of human breast milk (at 0-1 years only), ingestion of drinking water from all household sources, ingestion of dairy products, ingestion of meat products, ingestion of below ground vegetables, ingestion of above ground vegetables and fruits, and inhalation of ambient urban air. Exposure equations were adopted from USEPA⁷. Exposure assumptions and their default point estimates and probability density functions (PDFs) were derived from USEPA⁸ and Finley et al.⁹. Body weights and inhalation rates were assumed to be normally distributed in the population. PDFs for ingestion rates were assumed to be lognormally distributed; standard deviations from mean point estimates were used to define the boundaries of input values randomly selected in Monte Carlo simulations. Oral bioavailability of PeDBE, ODBE, and DBDE was assumed to be 90%, 50%, and 6%, respectively^{6,7,8}. Bioavailability through inhalation was assumed to be 75% for each congener group¹⁰. Elimination rates were not incorporated into the assessment because the few available human data contradict results observed in animal studies¹⁰.

Exposure Point Concentrations. Exposure point concentrations in different environmental compartments were adopted from the results of regional scale environmental modeling performed by ECESP^{6,7,8}. The average concentration of PeDBE in human breast milk was adopted from Darnerud et al.¹¹; quantitative data for ODBE and DBDE were not found in the literature. Mean concentrations in air reflect measurements reported in two ambient urban air samples collected by Sjodin et al.¹². PDFs for PeDBE, ODBE, and DBDE in different environment compartments were represented as triangular distributions in Monte Carlo simulations. As a first approximation of the wide variability in the available data, concentrations were assumed to vary $\pm 50\%$ from point estimates calculated by ECESP^{6,7,8}. For human breast milk, minimum and maximum concentrations represented the range reported in nursing Swedish women by Darnerud et al.¹¹.

Results and Discussion

Frequency distributions from the Monte Carlo analysis describing the theoretical cumulative CDIs of PeDBE, ODBE, and DBDE over an average human lifetime are shown in Figure 1. The point estimate from the deterministic assessment, mean and 95th percentiles from the probabilistic analysis, and the point estimate calculated by ECESP^{1,2,3} also are indicated. Mean theoretical lifetime CDI was highest for DBDE (4.27×10^{-3}), followed by PeDBE (1.54×10^{-3}) and ODBE (1.23×10^{-4}). Results at the 95th percentile were nearly equivalent for PeDBE and DBDE (2.67×10^{-3} and 2.64×10^{-3} , respectively). Theoretical CDIs at the 95th percentile in the five different age groups are summarized in Table 1. CDIs associated with the different exposure pathways were highest in the 0-2, 2-6, and 6-12 years age groups, suggesting children may be exposed to PeBDEs, ODBE, and DBDE at significantly higher levels than other ages. Theoretical CDIs associated with consumption of below ground vegetables, meat and dairy products, and fish (PeDBE only) were generally one to three orders of magnitude greater than for other exposure pathways.

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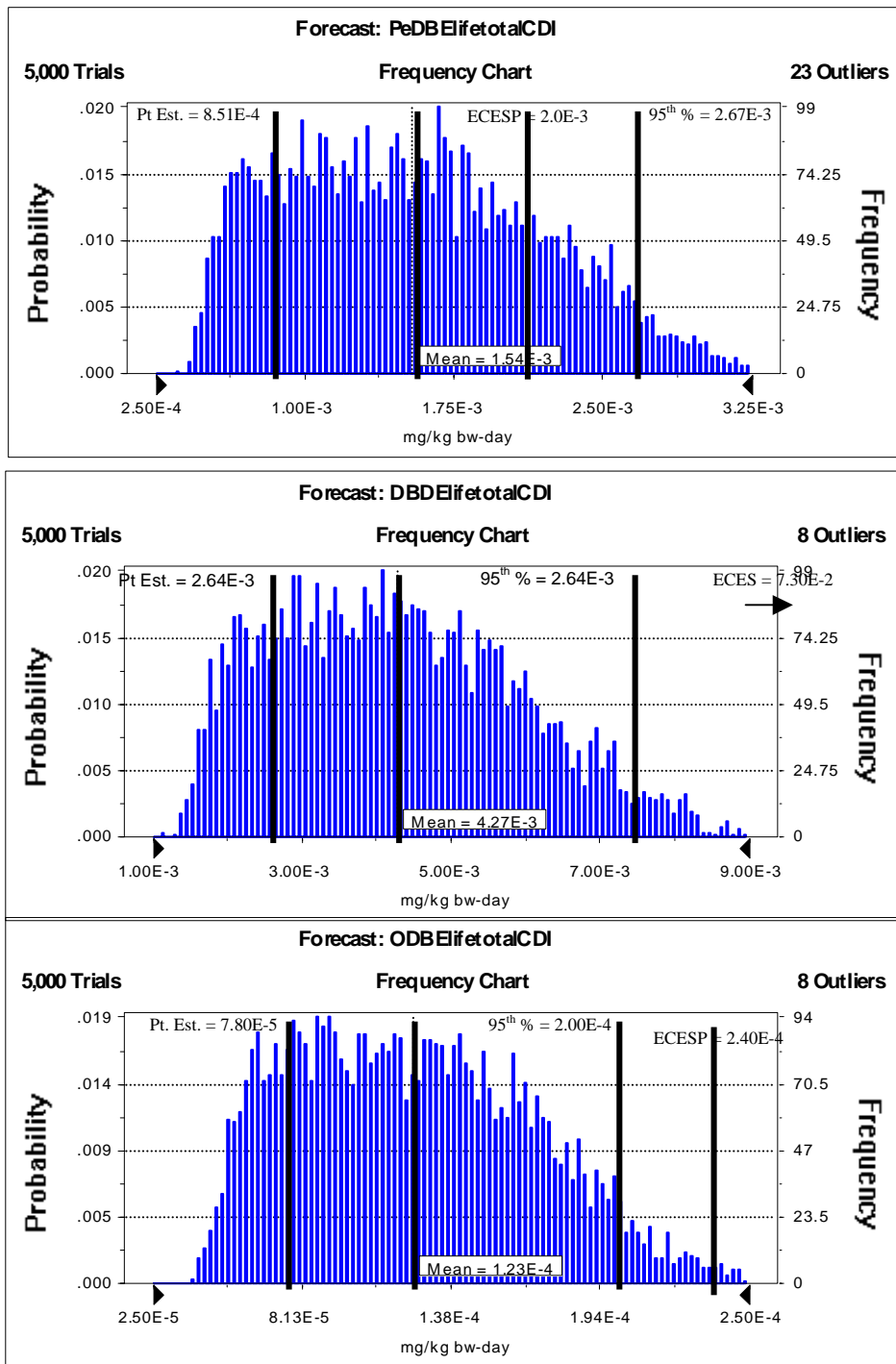


Figure 1. Frequency distributions from a Monte Carlo analysis describing the theoretical cumulative lifetime chronic daily intake of PeDBE, ODBE, and DBDE. Point estimates calculated in this study and by ECESP^{1,2,3} and the mean and 95th percentile from the Monte Carlo analysis after 5,000 iterations are indicated.

Table 1. Total Chronic Daily Intake (mg/kg bw-day) of PeDBE, ODBE, and DBDE by Different Age Groups at the 95th Percentile of Cumulative Exposure through Inhalation and Ingestion of Fish, Drinking Water, Meat and Dairy Products, and Above and Below Ground Vegetables. Exposure to PeDBE Through Ingestion of Breast Milk at 0 - 1 years was included only in the 0 - 2 year age group.

Chemical	Age Group				
	0-2 Years	2-6 Years	6-12 Years	12-18 Years	18-70 Years
PeDBE	8.41E-04	6.29E-04	4.43E-04	4.19E-04	3.45E-04
ODBE	6.27E-05	4.91E-05	3.42E-05	3.08E-05	2.45E-05
DBDE	2.25E-03	1.73E-03	1.21E-03	1.12E-03	8.88E-04