April 2008

BROMINATED FLAME RETARDANTS: GUARDIAN ANGELS WITH A BAD STREAK?

Press Officer: Martin Ittershagen
Press Office: Anke Döpke, Dieter Leutert,
Fotini Mavromati, Theresa Pfeifer, Martin Stallmann
Adress: postcode 1406, 06813 Dessau-Roßlau
Telephone: +49-340 / 2103 -2122, -2827, -2250, -2318, -3927, -2507
E-Mail: pressestelle@uba.de
Internet: www.umweltbundesamt.de

Umwelt Bundes Amt
for our Environment

1 Summary

What are flame retardants and what are they used for?

Flame retardants delay the ignition of flammable materials such as plastic, textile and wood and retard the flame propagation. This either prevents a fire from breaking out in the first place, or gives people more time to escape. Materials treated with flame retardants will generally be destroyed in a full fledged fire, though. Numerous chemicals are used as flame retardants.

What are the special characteristics of brominated flame retardants?

Brominated flame retardants can be used in a broad range of plastics and are relatively inexpensive. However, many of the chemicals in this substance group are persistent, which means that they do not break down easily in the environment; and they bioaccumulate, which means that they are absorbed by living organisms. In the event of a fire or improper disposal, brominated flame retardants can form the highly toxic substance groups of dioxins and furans. However, not all brominated flame retardants have the same adverse environmental and human health effects. Flame retardants made of other chemicals such as chlorinated paraffins and certain halogenated phosphorus compounds can also harm the environment.

What are the major brominated flame retardants?

The most widely produced brominated flame retardants are decabromodiphenyl ether (DecaBDE), tetrabromobisphenol A (TBBPA) and hexabromocyclododecane (HBCD). DecaBDE is mainly used as a flame retardant for plastic casings of electrical and electronic equipment, as well as for textiles. TBBPA is mainly used for circuit boards, and (in minute quantities) for device casing plastics. HBCD is mainly used for expanded and extruded polystyrene insulation, for textiles, and to a lesser extent for plastic casings of electrical and electronic equipment.

What adverse environmental effects do brominated flame retardants have?

The extent to which various flame retardant input paths engender pollution is not fully understood. However, it is known that point source flame retardant emissions (i.e. emissions resulting from the processing of flame retardants in plastics and products) are of particular relevance, as are diffuse flame retardant emissions (i.e. emissions resulting from evaporation or runoff during product use and disposal). Owing to the persistence and bioaccumulation that characterize brominated flame retardants, they are also found in sediment and dust, as well as in numerous animals such as birds of prey and their eggs, as well as in polar bears, seals, and foxes. Moreover, global airstreams carry flame retardant emissions to distant areas such as the polar regions.

Which health risks are associated with flame retardants?

Low concentrations of DecaBDE, TBPPA and HBCD occur in breast milk and blood. According to European Union risk assessments these concentrations do not pose a direct health risk to humans. However, in accordance with the precautionary principle, breast milk should contain no flame retardants,[1] whose main route of entry is via the food chain but which can also be inhaled via house dust. Owing to the fact that flame retardant emissions accumulate in the food chain, it is important to rule out any potential long term indirect risk engendered by the summation (effect reinforcement) of low substance concentrations.

Which risks do the EU risk assessments identify?

The EU's chemical assessment regulations are currently in flux. The EU's Existing Substances Regulation, which mainly aims to reduce direct risks, was replaced on 1st June 2007 by the REACH Chemicals Regulation, which seeks to minimize both indirect and direct risks, in accordance with the precautionary principle.[2] REACH stipulates that continued use of PBTs (substances that are persistent, bioaccumulative and toxic) is subject to an authorization that defines specific conditions for use. EU experts have reached the following conclusions regarding the various flame retardants:

- Decabromodiphenyl ether (DecaBDE) is very persistent and accumulates in living organisms. Although it has not yet been classified as a hazardous substance, it is thought to have long term neurotoxic effects and to break down gradually into toxic lower brominated compounds. Although DecaBDE does not exceed the threshold for environmentally harmful concentrations, the competent EU panel of experts is considering the possibility of classifying DecaBDE as a PBT substance.

- Tetrabromobisphenol A (TBBPA) is also very persistent and accumulates in living organisms. It is toxic for aquatic organisms, and not for humans. TBBPA engenders local risks due to the fact that the environmental concentrations at specific production facilities exceed the threshold values for potential environmental harm.

- Hexabromocyclododecane (HBCD) is persistent, has a very high bioaccumulation potential and is toxic for aquatic organisms. The substance's high bioaccumulation potential is associated with a risk of long term adverse effects on ecosystems and human health. HBCD engenders local risks at specific production facilities as well as

[1] The reasons for the precautionary principle are explained in section 4.

[2] See section 4 for the demand of minimization specified by REACH.

indirect risks owing to the potential for accumulation in the food chain. The competent EU panel of experts has classified HBCD as a PBT substance.

Which EU decisions are pending with respect to flame retardants?

It is extremely likely that the EU will soon be imposing severe restrictions on the use of HBCD, to reduce the risks identified in the EU risk assessment of this substance. In 2008 as well, the European Commission will issue a proposed revision of the RoHS Directive[3] that may call for restrictions on the use of additional hazardous substances such as HBCD or TBBPA (in an additiv, non-bonded form) in electrical and electronic equipment. Decisions concerning authorization to use HBCD and DecaBDE under REACH will be made in 2009.

Not pending anymore is a decision of the European Court of Justice: On 1st April 2008 it ruled that electrical and electronic equipment put on the market for the first time is not allowed to contain DecaBDE anymore after 1st July 2008. The judgment is result of a lawsuit filed against the European Commission by Denmark and the European Parliament. The Commission had lifted the original ban of DecaBDE within the framework of the RoHS Directive. This action proved not to be legal on the grounds that adequate and more environmentally compatible alternatives were available.

What actions has the brominated flame retardant industry taken?

The brominated flame retardant industry recently established the VECAP (Voluntary Emission Control Action Plan) and SECURE (Self Enforced Control of Use to Reduce Emissions) programs in order to control and minimize industrial emissions of brominated flame retardants into the environment via technical measures. In this process, mass balances are elaborated and flame retardant manufacturers provide guidance on the handling of flame retardants to the processing companies, with a view to identifying and taking steps to minimize possible sources of uncontrolled emissions.

Which measures are advocated by the Federal Environment Agency (Umweltbundesamt)?

In keeping with the precautionary principle, the Federal Environment Agency regards as necessary that all emissions of persistent and/or bioaccumulative substances should be avoided. This includes chemicals whose emissions are not (yet) associated with any known toxicity, since such emissions cannot be eliminated neither from ecosystems nor the human body.

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[3] Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Consequently, the Federal Environment Agency demands for precautionary reasons that DecaBDE, TBBPA and HBCD emissions should be minimized, since all three of these flame retardants are persistent and accumulate in living organisms. Moreover they are toxic to one degree or another and may engender long term health and ecological hazards. The hazardous effects of brominated flame retardants can be avoided by substituting dangerous substances with less dangerous substances, or by substantially reducing emissions through implementation of specific technical measures. In the view of the Federal Environment Agency the use of substitutes should be prioritized since this is the only reliable way to bring about a substantial reduction in flame retardant emissions.[4] However, far reaching technical measures to reduce emissions resulting from brominated flame retardants manufacture and processing should be implemented for as long as these substances remain in use. Inasmuch as substitutes that are safer for humans and the environment are available to varying extents and the three brominated flame retardants bond to plastics to varying degrees, we advocate a gradual phase out of the various brominated flame retardant application, as follows:

- As safe substitutes are available for DecaBDE, TBBPA and HBCD used for electrical and electronic equipment casings, the three brominated flame retardants for this application can and should be banned. Numerous vendors currently employ the substitute products, which as a rule are halogen free, organic phosphorus flame retardants.

- A sufficient number of safe substitutes for DecaBDE and HBCD in textile products such as curtains and fabrics for upholstery are readily available. Suitable in this regard are glass fibers, fibers made of flame resistant plastics, or fibers with embedded flame retardants. Here as well, the currently used hazardous chemicals could and should be completely dispensed with.

- So far no substitute is available for HBCD in polystyrene insulation; but for most applications other insulation materials than polystyrene can be used. In view of the environmental benefits of thermal insulation, the continued use of HBCD flame retardant for a limited period in such products is acceptable, providing that strict manufacturing/processing emission control measures are applied and suitable substitute chemicals are developed in the interim.

- Commercially viable substitutes for TBBPA in circuit boards are available, but unfortunately circuit board manufacturers use these products to a limited degree only. Efforts should be made to replace TBBPA in the medium term, and emission control measures should be implemented for all stages of the TBBPA product lifecycle.

[4] See section 6 for a discussion of the properties substitutes need to have.

2 Background

Brominated flame retardants are an environmental pollutant of long standing. During the 1990s, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) were the main focus of attention owing to their structural similarity to polychlorinated biphenyls (PCB) and dioxins and furans. The latter occurredas impurities in these flame retardants, of which they are also a combustion product under certain circumstances. Waste incineration techniques in Europe have since improved to the point where only minute amounts of dioxin and furan emissions are generated if regulated disposal methods are applied. This of course does not apply to fires or improper disposal scenarios. PBBs have been taken off the market since then owing to their hazardous properties, and the marketing of pentabrominated and octabrominated diphenyl ethers has been banned in the EU since 2004. However, a far more purified type of decabrominated diphenyl ether is still extensively used by various manufacturers.

The most commonly used brominated flame retardants in the world today are tetrabromobisphenol A (TBBPA), decabromodiphenyl ether (DecaBDE) and hexabromocyclododecane (HBCD). They are currently the subject of considerable scientific and political debate owing to the fact that the concentrations of these substances are on the rise in sediments and dust, as well as in many animals such as birds of prey (and their eggs), crustaceans, fish, polar bears, seals and foxes. Residues of these substances can also be absorbed by humans via the food chain, which could potentially have adverse effects on embryonic and infant development, both of which are particularly susceptible to such substances.

Numerous studies have been published in recent years on the environmental and health effects of these three brominated flame retardants and their propagation in the environment. The risk assessments for DecaBDE, TBBPA and HBCD in accordance with the European procedures for existing substances are available as initial drafts. The risks associated with these flame retardants cannot be accurately gauged using the standard tests due to the fact that their low solubility and the relatively large size of their molecules engender test problems in some cases. However, the high persistence and the accumulation in living organisms exhibited by these substances constitute sufficient cause for concern regarding their long term risk potential and have prompted calls by the European Commission for further environmental impact research regarding this type of pollution. For example, the potential effect of these substances on mammal endocrine systems is being investigated under the auspices of the EU's FIRE[5] research program.

HBCD meets the criteria for persistent, bioaccumulative and toxic substances (PBTs) pursuant to the EU chemicals regulation (REACH). In the case of DecaBDE the scientific jury is still out on the potential long term harmful effects and possible toxic degradation products, with the result that there is still controversy as to whether DecaBDE meets PBT

[5] FIRE: Flame Retardants Integrated Risk Assessment for endocrine Effects.

criteria. The Federal Environment Agency gauges that there is enough scientific evidence of the harmful environmental impact of DecaBDE to justify classifying this substance as a PBT. Under REACH, an authorization system for the use of PBTs will be phased in gradually from 1 June 2009. This means that PBT use will be subject to specific and rigorous regulations and will only be permissible until a substitute becomes available.

The use of DecaBDE in electrical and electronic equipment, which was originally banned by the RoHS Directive only to be re-legalized, was subject of a law suit before the European Court of Justice in the recent years. On 1st April 2008 the Court decided that new electrical and electronic equipment for the European market must not contain DecaBDE after 1st of July 2008.

The European Brominated Flame Retardant Industry Panel (EBFRIP) and its scientific arm the Bromine Science and Environmental Forum (BSEF), as well as numerous textile and plastic industry associations, recently responded to this situation by instituting the voluntary emission reduction programs known as "Voluntary Emission Control Action Plan" (VECAP) and "Self Enforced Control of Use to Reduce Emissions" (SECURE). This is expected to result in a substantial reduction of the DecaBDE, TBBPA and HBCD emissions generated by flame retardant production and industrial use by the participating companies in the EU. However, the situation in Germany is somewhat different: In 1986, the industry associations of the plastic manufacturers "VKE" and the manufacturers of textile finishing chemicals "TEGEWA" voluntarily discontinued use of all polybrominated diphenyl ethers. But this has not prevented companies that are not members of the aforementioned associations from continuing to use DecaBDE. Even though TEGEWA has since revoked its ban on DecaBDE to participate in VECAP, VKE is still adhering to its original self-imposed ban.

The Federal Environment Agency has been providing support for brominated flame retardant risk assessments for many years, and advocates the use of environmentally safe alternatives. In view of (a) the possibility that HBCD and DecaBDE will be subject to authorization requirements under the REACH Regulation; and (b) the legal dispute concerning the use of DecaBDE in electrical and electronic equipment under the RoHS Directive, the question which substitute chemicals are suitable takes on particular urgency. The Federal Environment Agency recommends minimizing the use of environmentally harmful flame retardants also beyond legal restrictions. Sometimes the use of flame retardants can be avoided at all, if an altered product design is employed. Toward this end, the Federal Environment Agency has elaborated scientific-based recommendations that should be included in eco-label requirements.[6]

3 Use of flame retardants

Flame retardants delay the ignition of flammable materials such as plastic, textile and wood and retard the flame propagation. This either prevents a fire from breaking out in the

[6] For details see section 6.

first place, or gives people more time to escape from a fire. Materials treated with flame retardants will generally be destroyed in a full fledged fire, though. In addition to flame retardant chemicals, fire safety can also be achieved through the use of (a) flame resistant or non-combustible materials such as glass, metal or flame resistant plastics; (b) a product design that meets the relevant fire safety criteria and integrates barrier layers or sufficiently great safe distances; or (c) general fire safety precautions via organizational measures or building structure modifications.

Quite a broad range of chemicals are used as flame retardants, and their mechanisms of action also vary greatly. Some flame retardants are based on a reactive mechanism, which means chemical bonding to the protected material, while other retardants are additives, which means that they are integrated into the material without the use of a chemical bond. 436,800 tons of flame retardants were used in Europe in 2005, 11 percent of which (50,000 tons) belonged to the group of brominated flame retardants (EFRA 2006). Figure 1 shows the relative amounts of the various types of flame retardants used in Europe.

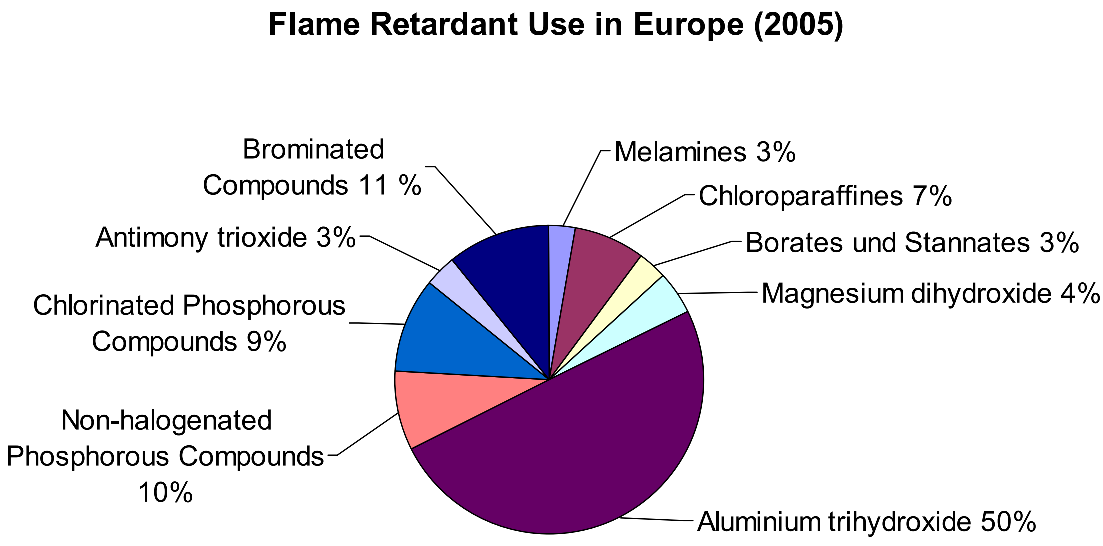

Figure 1: Flame retardant use in Europe2005, by weight percentage for the various types of flame retardants (source: EFRA 2006).

Flame retardants are mainly used in electrical and electronic equipment, ships, aircrafts, rail vehicles, construction materials, furniture and textiles. Each of these types of items is subject to specific test standards and fire safety requirements.

Brominated flame retardants are mainly used for electrical and electronic equipment, and to a lesser extent in construction materials and textiles. Most flame retardants used in transportation are halogen free (i.e. free of bromine or chlorine), in order to comply with the requirement that no corrosive fumes should be emitted in the event of a fire. Brominated flame retardants can be used for many different types of plastic and are relatively inexpensive. They exert their effect during the gas phase of a fire. In the heat of a fire brominated flame retardants disrupt a fire's normal chain reaction by releasing hydrogen bromide or free bromide. TBBPA, DecaBDE and HBCD are the most widely used brominated flame retardants.

4 Assessing the risks of chemicals

The identification and assessment of environmental and human health impacts and potential risks stemming from chemicals are governed by harmonized EU conventions. The EU is currently in the process of shifting the statutory basis for the assessment of industrial chemicals (to which flame retardants belong) from the current Existing Substances Regulation (793/93/EC) to the new REACH Chemicals Regulation (1907/2007/EC), which went into effect in June 2007. These two regulations and their technical guidance documents contain test procedures that help to identify the hazardous properties of chemicals, as well as standardized methods for quantitative assessments of the environmental and human health risks engendered by chemicals throughout their lifecycle.

A risk, within the meaning of the EU Existing Substances Regulation, is quantifiable in terms of a specific substance and situation, and relates to transparent cause and effect relationships that can be reproduced in the laboratory. These characteristics make the assessment procedure mainly suitable for the assessment of direct risks attributable to substance emissions that occur in a specific geographic region and within a specific timeframe. A **direct risk** is said to exist when the PEC (Predicted Environmental Concentration) of a chemical exceeds its PNEC (Predicted No Effect Concentration). If a risk assessment for a specific chemical fails to identify any risk, this only means that current uses of the chemical do not engender hazardous environmental concentrations, but does not necessarily mean that the substance is inherently safe.

An **indirect** or **systemic risk**, on the other hand, is defined as a risk that does not cause harmful effects as the result of direct contact with the chemical concerned (e.g. via inhalation), but instead indirectly provokes a risk through interactions within ecosystems (e.g. food chain accumulation). Inasmuch as the PNEC and PEC are indeterminable for these types of risks, there is a great deal of scientific uncertainty as to the long term environmental effects even of low concentrations of the relevant substances. Brominated flame retardants are suspected of engendering indirect risks owing to their high chemical stability and bioaccumulation properties.

Scientific uncertainty regarding environmental effects, risk assessment, and risk management tends to occur in connection with substances that have specific properties. Hence, REACH classifies the following substance properties as being of very high concern:

- PBTs: persistent, bioaccumulative and toxic substances.

  In order to be classified as a PBT, a substance must be concurrently persistent (not readily biodegradable in the environment) and bioaccumulative (accumulative in organisms) and toxic (toxic for humans, ecosystems, or organisms).

- vPvBs: very persistent and very bioaccumulative substances.

  Insofar as both high persistence and high bioaccumulation are demonstrated for a vPvB substance, toxicity needs not to be proven. Evidence of persistence and bioaccumulation demonstrate (apart from relevant laboratory test results) widespread evidence of a chemical in the environment, as well as in organisms that live in remote areas such as the Arctic.

- CMRs: carcinogenic, mutagenic or toxic to reproduction substances, i.e. substances that cause cancer, genetic mutations, or reproductive pathologies in mammals.

- Substances of equivalent high concern.

In accordance with the precautionary principle, REACH prohibits the manufacture, marketing and use of substances of very high concern, except in cases where the use can be justified for socio-economic reasons and no suitable alternatives are available. In such cases, the European Commission grants the substance manufacturer an authorization, subject to submission of an application which must demonstrate that the substance's emissions will be minimized as far as technically and practically possible.

The Federal Environment Agency has claimed criteria for a precautionary, sustainable substance policy that to some extent imposes more stringent regulations than those defined in REACH. The Federal Environment Agency urges that all environmental emissions of persistent and/or bioaccumulative substances should be avoided, including substances whose toxicity has not been demonstrated (yet). In view of the Federal Environment Agency, neither humans nor animals (including polar bears) should be exposed to persistent and bioaccumulative substances. Following are the five objectives of the Federal Environment Agency's program for a sustainable substance policy in accordance with the precautionary principle:

The Federal Environment Agency's five objectives for a sustainable substance policy in accordance with the precautionary principle:[7]

1. No irreversible emissions of persistent and/or bioaccumulative xenobiotics into the environment, irrespective of their toxicity.
2. No emissions of xenobiotics that are carcinogenic, mutagenic or toxic to reproduction into the environment.
3. No anthropogenic release of natural substances that exhibit the properties mentioned in items 1 and 2 into the environment, if such release increases the natural background burden.
4. Reduce emissions of other toxic or ecotoxic substances to the technically feasible minimum.
5. Minimize the emissions of substances whose potential effects are unknown, if these substances cannot be removed from the environment.

5 DecaBDE, TBBPA and HBCD substance evaluations

The flame retardants decabromodiphenyl ether (DecaBDE), tetrabromobisphenol A (TBBPA) and hexabromocyclododecane (HBCD) are widely dispersed in the environment and have been detected at the top of the food chain and in polar regions; this is indicative of the persistence and bioaccumulative potential of these substances. In view of this fact, the Federal Environment Agency regards as necessary that environmental emissions of these three brominated flame retardants should be banned, or lacking that, minimized. These flame retardants have some properties in common, but also differ from each other in terms of their substance properties, toxicity, and chemical decomposition products in the wake of a fire. The application domains of these three substances overlap in some areas, whereas in others only one of the three substances is used.

The applications, toxicological profiles, results of European risk assessments, and current risk management measures for these three flame retardants will now be described.

5.1 Decabromodiphenylether (DecaBDE)

Application domain: DecaBDE is the brominated flame retardant with the second-highest worldwide production volume, amounting to some 56,400 tons annually, approximately 8300 tons of which is used in Europe. DecaBDE is mainly used as a flame retardant in the plastic casings of electrical and electronic equipment. Its second most common use is for textiles.

[7] Federal Environment Agency (2001): Action Areas and Criteria for a precautionary, sustainable Substance Policy using the example of PVC. Erich Schmidt Verlag.

Exposure and toxicity: DecaBDE is very persistent, accumulative in living organisms and highly mobile. Elevated concentrations are found in sediments near several factories, at the top of the food chain, and in remote regions. DecaBDE has been detected in foxes, seals, falcon eggs and breast milk. Although DecaBDE is not classified as toxic either to humans or the environment, the scientific data concerning its potential neurotoxicity and endocrine effects in the low dose range are inconclusive. There is also evidence that DecaBDE biodegrades gradually into lower brominated, relatively toxic and bioaccumulative substances such as PentaBDE and OctaBDE, which have been banned in Europe. Consequently the rising environmental concentrations of these substances and increased human exposure to them via fatty foods as well as products in home environments are of concern. However, only partial data on the scope and significance of the various routes of entry and distribution paths of DecaBDE is available. In the event of a fire or improper disposal, DecaBDE forms dioxins and furans, both of which are highly toxic.

Table 1: Proofs of DecaBDE in the European environment.[8]

Proofs of DecaBDE in the European environment		
Presence in environmental media[a]		
Surface water (fresh water)	-	µg / l
Sediment (fresh water)	<0.25 - 1,293 (174,000)	µg / kg DW
Soil	<0.02 - 330 (2,200)	µg / kg DW
Sewage sludge	<0.1 - 7,963 (18,039)	µg / kg DW
Presence in selected organisms[b]		
Sparrow hawk eggs, UK	< 2 - 36	µg / kg fat
Gull eggs, Norway, study 1	< 2.7 - 52.5	µg / kg fat
Gull eggs, Norway, study 2	< 0.5 - 4.3	µg / kg fat
Gull liver, Norway	<1- 2,586	µg / kg fat
Fish, estuary of the Schelde River, Wadden Sea (eels, flounder, sole, herring)	1.9 - 17	µg / kg fat
Opposum shrimp, estuary of the Schelde River	269 - 600	µg / kg fat
Mussels, Norway	0.04 - 0.46	µg / kg WW
Cod liver, Norway	0.4 - 3.0	µg / kg WW
Seals, Norway	0.02	µg / kg fat

[8] The data are from the European risk assessment: European Chemicals Bureau: Update of the Risk Assessment of Bis(pentabromophenyl) ether (Decabromodiphenyl ether). August 2007.

Polar bears, fatty tissue, Norway	0.09	µg / kg fat
Fox liver, Belgium	< 9.1- 760	µg / kg fat
Birds of prey, blood, Belgium	< 2 - 58	µg / kg fat
Presence in humans		
Blood	< 1 - 273 (2,400)	µg / kg fat
Breast milk	< 0.1 - 6.8	µg / kg fat
DW: dry weight; WW: wet weight; ( ): extremely elevated value a: The highest concentrations stem from the immediate environs of factories. b: The concentrations in fat are higher than that of the total fresh weight due to the fact that DecaBDE bioaccumulates in fat. The differences between the proportion of fat found in organs and organisms make it impossible to determine a general conversion factor.		

Results of the EU risk assessment: The 2005 risk assessment did not indicate immediate need to enact risk reduction regulations for DecaBDE. The European Commission instructed the relevant industries to investigate the key pending issues by 2014. Environmental and human monitoring programs which will expire in 2010 (environment) and 2014 (humans) respectively are started then to fill in some of the missing information regarding bioaccumulation and substance degradation into lower brominated, toxic and persistent substances. A European Chemicals Bureau[9] panel of experts is currently considering the possibility of asserting DecaBDE as a PBT owing to its potential long term toxicity. As PBT-Substance, DecaBDE could become subject to the authorization procedure under REACH.

Additional measures: Sweden and Norway have both banned the use of DecaBDE. The OSPAR and Helsinki conventions for the protection of the marine environment call for reduction of DecaBDE emissions to zero in the medium term. In addition, from 1st July 2008 DecaBDE is banned in electrical and electronic equipment placed at the European market for the first time, as a result of a recent decision of the European Court of Justice. The judgment followed a claim of the European Parliament and Denmark against the European Commission and renewed the originally imposed ban of the flame retardant DecaBDE within the "RoHS-Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment"(2002/95/EC). In the interest of controlling the use of DecaBDE, in 2004 the European flame retardant industry established the VECAP project, which calls for voluntary control of emissions resulting from the use of DecaBDE in plastics and textiles. In 1986, Germany's plastics industry association "Verband der

[9] The European Chemicals Bureau coordinates all European chemical assessment activities for the European Commission. A panel of industry and government experts is currently considering whether authorization procedures should be required for the use of more than 100 known, problematic substances. The panel is also considering whether current PBT and vPvB substance authorization criteria are suitable (see Annex XIII of REACH).

Kunststofferzeugenden Industrie – VKE" (now known as Plastics Europe Deutschland) voluntarily imposed a ban on the use of DecaBDE in plastics.

The Federal Environment Agency's position: In view of the fact that DecaBDE is used as an additive flame retardant and less hazardous DecaBDE substitutes are readily available for both plastics and textile applications, the Federal Environment Agency regards a complete stop on the use of DecaBDE as feasible and necessary. However, EU flame retardant industry favors voluntary emission reduction measures. Although such measures can reduce DecaBDE emissions occasioned by DecaBDE manufacture and processing within the EU, they will not affect the emissions during product use and improper disposal and during manufacture and processing at productions sites outside the EU. These emissions can only be avoided through the use of DecaBDE substitutes. Emission control measures that solely target manufacture and processing will inevitably fall short of the mark unless reliable data regarding the main routes of entry is available.

5.2 Tetrabromobisphenol A (TBBPA)

Application domain: With 145,000 tons manufactured annually, TBBPA is the brominated flame retardant with the highest production volume worldwide. Some 7000 tons of the chemical are used in the EU each year, approximately 90 percent of it as a reactive flame retardant in electronic circuit boards. Lesser amounts are used as an additive flame retardant in phenolic resins, as well as in ABS[10] plastics for casings of electrical and electronic equipment.

Exposure and toxicity: TBBPA is classified as toxic for aquatic organisms, but not for humans. The substance is highly persistent and is found in low concentrations in organisms at the top of the food chain such as (in Europe) falcon tissue and bird of prey eggs from Greenland, as well as in human breast milk. In addition, in a fire and in cases of improper disposal, when catalyzed by circuit board copper the bromine in TBBPA can promote the formation of dioxin and furan, although not to the same degree as with DecaBDE.

[10] ABS: acrylonitrile-butadiene-styrol

Table 2: Proofs of TBBPA in the European environment.[11]

Proofs of TBBPA in the European environment		
Presence in environmental media[a]		
Surface water (fresh water)	< 0.001 - 0.020	µg / l
Sediments (fresh water)	< 0.1 - 270 (9,752)	µg / kg DW
Soil	< 0.1	µg / kg DW
Sewage sludge	< 0.1 - 192 (600)	µg / kg DW
Presence in selected organisms[b]		
Freshwater eel, Berlin	0.045 - 0.10	µg / kg WW
Fish, Lake Mjøsa, Norway	0.01 - 0.18	µg / kg WW
Cod, liver, Norway	0.35 - 1.73	µg / kg WW
Whitefish, filet, North Sea	97 -245	µg / kg fat
Starfish, estuary, UK	4,5	µg / kg WW
Hermit crab, North Sea	< 1 - 35	µg / kg fat
Common porpoise, blubber, UK	6 -35	µg / kg WW
Cormorant, liver, UK	0.07-10.9	µg / kg WW
Birds of prey, eggs, Norway	< 0.004 - 0.013	µg / kg WW
Presence in humans		
Blood	< 0.1 - 10	µg / kg fat
Breast milk	< 0.01 - 11	µg / kg fat

DW: dry weight; WW: wet weight; ( ): extremely elevated value
a: The highest concentrations stem from the immediate environs of factories.
b: The concentrations in fat are higher than that of the total fresh weight due to the fact that TBBPA bioaccumulates in fat The differences between the proportion of fat found in organs and organisms make it impossible to determine a general conversion factor.

Results of the EU risk assessment: As with DecaBDE, the EU risk assessment of TBBPA found that the available data is insufficient for a certain determination of current exposure levels (environmental concentrations). Nonetheless, the study identified risks for surface water, soil and sediment in the immediate environs of factories (point sources) as well as systemic risks. The indirect, long term risks arising from TBBPA are attributable to diffuse soil immissions, as well as possible breakdown into bisphenol A and TBBPA bis(methyl

[11] The data are from the European risk assessment: European Chemicals Bureau: Risk Assessment of 2,2',6,6'-tetrabromo-4,4'-isopropylidene diphenol (tetrabromobisphenol-A). June 2006.

ether), the latter being a candidate for classification as a PBT. As a consequence of the foregoing, in the interest of reducing point source risks, in November 2007 the EU recommended emission reduction measures and regulations within the framework of Directives 96/61/EC[12] (water policy) and 2000/60/EC[13] (industrial plants). TBBPA does not meet REACH's current PBT criteria because its bioconcentration factor and toxicity are lower than the critical threshold value.

Additional measures: The OSPAR and Helsinki conventions call for reduction of TBBPA emissions to zero in the medium term. The European Parliament has proposed TBBPA as a priority substance for the Water Framework Directive. The brominated flame retardant industry has included TBBPA in the voluntary emission reduction program known as VECAP, and is gathering more precise TBBPA emission data. There is currently no way of telling if this initiative will be sufficient to reduce the identified risks of TBBPA emissions.

The Federal Environment Agency's position: As TBBPA is very persistent and widely dispersed in the environment, the avoidance of TBBPA should take priority over TBBPA emission reduction measures. Substitutes that could be used at short notice are readily available for additive TBBPA applications (see section 6). For reactive applications in printed circuit boards with epoxy resin as a carrier material the producers also have developed alternative substances, but the market share of these products remains relatively small. Environmentally safer alternatives should be used for this application in the medium term, insofar as TBBPA manufacturers and processers can't demonstrate that emissions can be avoided in all phases of the product lifecycle.

5.3 Hexabromocyclododecane (HBCD)

Application domain: Approximately 22,000 tons of HBCD are used annually worldwide, making this substance the third most commonly used brominated flame retardant. Approximately 9600 tons of HBCD are used in the EU annually, chiefly in polystyrene insulation, but also in textiles and in electrical and electronic equipment components.

Exposure and toxicity: HBCD is toxic for aquatic organisms. It has been widely detected in marine animals and also in human breast milk. The human health hazards of HBCD arising from its presence in breast milk, as well as its potential to engender reprotoxicity or neurotoxic development pathologies have not been scientifically proven. HBCD, which is persistent and highly bioaccumulative, is found at the top of the aquatic (birds' eggs, seals, polar bears) and terrestrial (birds' eggs) food chains, as well as in inhabited and uninhabited regions (e.g. polar regions). HBCD pollution is clearly on the increase. When

[12] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.

[13] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

combusted using an inadequate combustion technique or in an uncontrolled fire, HBCD forms polybrominated furans and dioxins, albeit not to the same degree as DecaBDE.

Table 3: Proofs of HBCD in the European environment.[14]

Proofs of HBCD in the European environment		
Presence in environmental media[a]		
Surface water (fresh water)	< 0.02 - 1.5	µg / l
Sediments (fresh water)	< 0.1 -11,000	µg / kg DW
Soil	0.14 - 90	µg / kg DW
Sewage sludge	< 0.3 - 9,120	µg / kg DW
Presence in selected organisms[b]		
Fresh water fish (e.g. eel and trout)	< 0.03 - 9,432 (27,705)	µg / kg WW (fat)
Moss, Norway	< 1.5 - 11,114	µg / kg WW
Peregrine falcon, eggs (in Greenland, Sweden and elsewhere)	< 0.002 - 160 (590)	µg / kg WW (fat)
Crustacea (e.g. mussels and shrimp)	< 0.5 - 329 (17,337)	µg / kg WW (fat)
Ocean fish, muscle (e.g. perch, eel, gudgeon;)	< 0.001 - 49 (1,113)	µg / kg WW (fat)
Ocean fish, liver (cod, sole, etc.)	< 0.3 - 89	µg / kg WW
Aquatic mammals (seals, common porpoise, dolphins)	0.5 - 6,400 (21,345)	µg / kg WW (fat)
Polar bears	5 - 45	µg / kg WW
Sea birds	0.5 - 100	µg / kg FG
Presence in humans		
Blood, The Netherlands	< 80 -360	µg / kg fat
Breast milk, Sweden	< 0.2 ˉ 2.4	µg / kg fat

[14] The environmental data are from the draft of the EU environmental risk assessment – environmental part: KEMI – Swedish Chemicals Agency (2006): Risk assessment Hexabromocyclododecane. Draft October 2006 (not published). For data on human risk, see: Covaci, A.; Gerecke, A. C.; Law, R. J.; Voorspoels, S.; Kohler, M.; Heeb, N. V.; Leslie, H.; Allchin, C. R.; de Boer, J. (2006): Hexabromocyclododecanes (HBCDs) in the Environment and Humans: A Review. Environmental Science & Technology, Bd. 40, S. 3679 – 3688.

DW: dry weight; WW: wet weight; ( ): extremely elevated value
a: The highest concentrations stem from the immediate environs of factories.
b: The concentrations in fat are higher than that of the total fresh weight due to the fact that HBCD bioaccumulates in fat The differences between the proportion of fat found in organs and organisms make it impossible to determine a general conversion factor.

Results of the EU risk assessment: The risk assessment identified direct risks as well as a potential systemic risk. HBCD use engenders considerable local risks for humans and the environment (surface water and sediments). The critical point sources comprise plants that manufacture expanded and extruded polystyrene (EBS and XPS) and coat textiles. The exposure scenarios analyzed for the risk assessment identified occupational health risk resulting from inhalation of HBCD as particulate matter. High bioaccumulation also engenders indirect risks via all food chains, particularly for aquatic mammals, attributable to emissions from all key HBCD application domains. As with the two other flame retardants, great uncertainty exists in respect to the relevant data (particularly environmental pathways quantification), prompting the risk assessment authors to recommend that the data situation should be improved via additional testing and data based on environmental monitoring. In view of the considerable need for action, in September 2007 the member state (Sweden) responsible for the HBCD risk assessment put forward risk reduction recommendations. Sweden advocates a ban on all applications except thermal insulation, for which a transitional period is proposed. HBCD also fulfills the criteria for the authorization procedure under REACH. If HBCD use would become subject to a REACH authorization procedure, the authorization would be granted (if at all) for a limited time only and the use conditions would be tightly restricted.

Additional measures: Apart from Sweden's far-reaching recommendations for EU risk reduction measures, HBCD is subject to other regulations. The international accords for the protection of the marine environment, OSPAR and Helsinki convention, call for reduction of HBCD emissions to zero in the medium term. The flame retardant industry has included HBCD in the VECAP emission reduction program. In addition, in 2007 the European Brominated Flame Retardant Industry Panel (EBFRIP) established an EU-wide HBCD monitoring program known as SECURE which aims to gather data on HBCD current exposure levels as well as future trends in this regard.

The Federal Environment Agency's position: HBCD is an additive flame retardant with a strong tendency towards bioaccumulation, and whose long term human toxicity has yet to be fully described. The substance is also persistent, and is toxic for aquatic organisms. In view of these facts, the waiving of HBCD should be prioritized over selected emission reduction measures. Sufficient numbers of safer substitutes for HBCD in the domains of textile coating and plastics for electrical and electronic equipment casings are available to allow for near-term phasing out of HBCD use for such applications. However, no viable substitute is currently available for polystyrene insulation. Research should be conducted in this area to develop and test a suitable alternative substance. Insofar as polystyrene insulation manufacturers still use HBCD, efficient emission reduction measures must be carried out for all phases of the product lifecycle. The Federal Environment Agency also advocates, insofar as technically feasible, the use ofother, environmentally safe thermal insulation materials until an alternative flame retardant for polystyrene insulation has been developed.

5.4 Overview of the substance evaluations

Table 4 provides an overview of the hazard characteristics and risk assessments for the three brominated flame retardants decabromodiphenyl ether (DecaBDE), tetrabromobisphenol A (TBBPA) and hexabromocyclododecane (HBCD).

Table 4: Overview of the hazard and risk characteristics of DecaBDE, TBBPA, and HBCD.

Flame retardant	DecaBDE	TBBPA	HBCD
Hazard characteristic (classification and labelling)	-	R 50/53	R 50/53, R 33, R 64 (proposed)
Direct risks (PEC/PNEC assessment)			
Local environmental risks engendered by point sources (aquatic environments, soil, sludge, and sediment)	no	yes	yes
Health risks (workplace safety, product use)	?	no	yes (workplace safety)
Indirect risks (PBT assessment)			
Persistence Half life> 60 days in water Half life> 120 days in soil / fresh-water sediment	yes (very persistent)	yes (very persistent)	yes (persistent)
Bioaccumulation BCF greater than 2000	? (test problems)	yes (below threshold value)	yes (very bioaccumulative)
Accumulates in the food chain (based on monitoring findings)	yes	yes	yes
Detected in polar regions (potential for remote transport)	yes	yes	yes
Long term toxicity (CMR properties, endocrine effects, neurotoxicity)	? (endocrine effects, neurotoxicity)	no	?
Long term ecotoxicity (0.1 mg/l in chronic tests for aquatic organisms)	?	yes (below threshold value)	yes
Toxic and/or persistent degradation products	yes	yes	yes

BCF: bioconcentration factor. PEC: Predicted Environmental Concentration. PNEC: Predicted No Effect Concentration. PBT: persistent, bioaccumulative and toxic. CMR: carcinogenic, mutagenic or toxic to reproduction. R50/53: very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment. R33: danger of cumulative effects. R64: may cause harm to breastfed babies.

6 Reduction of brominated flame retardant emissions into the environment

6.1 Emission reduction via emission control or substitution

Brominated flame retardant emissions can be reduced by two different routes: (a) by implementing technical emission control measures; (b) by substituting the flame retardants either by safer ones or by completely new materials or fire protection methods. Technical measures chiefly aim to reduce point source emissions attributable to the production process or specific waste treatment measures. On the other hand, diffuse emissions engendered by flame retardant use or improper disposal can only be eliminated via flame retardant substitution. Brominated flame retardants contaminate the environment via all routes of entry.

In the coming years, risk reduction measures will also be influenced by the results of REACH risk assessments. Flame retardant users normally are free to decide whether to substitute dangerous substances with less dangerous substances or to implement technical emission reduction measures. However, the use of substances that meet the REACH criteria for persistent, bioaccumulative and toxic substances (PBTs) will be allowed during a transitional period only, afterwards these substances will be banned in accordance with the precautionary principle. Any further use of PBTs will be subject to an authorization process, for which the user will need to demonstrate that no safer alternative is available, the use of the substances can be justified for socioeconomic reasons, and the emissions can be adequately controlled during the whole lifecycle. The European Chemicals Bureau has recommended classifying the flame retardant HBCD as a PBT and is considering this for DecaBDE as well. If both of these substances are officially assessed as PBTs, current available substitutes and the effectiveness of emission control measures will be the determining criteria for future decisions on authorization of these substances.

It is the Federal Environment Agency's position that stringent emission control measures and/or substitution requirements should be imposed for all three brominated flame retardants, even if these substances are not classified as PBTs in accordance with the REACH PBT criteria. Even in cases where these flame retardants do not meet all of the three PBT criteria, some of their values fall just short of the prescribed threshold values, or existing scientific evidence of harmful impacts has yet to be definitively disproven (see table 4). Moreover, in view of the fact that the PBT identification criteria in Annex XIII of REACH are not yet accurate enough to identify such substances reliably, REACH stipulates that the European Commission is to assess the adequacy of these criteria by 1 December 2008. The three brominated flame retardants DecaBDE, HBCD and TBBPA meet Federal Environment Agency's criteria for the implementation of precautionary measures (see box in section 4). Scientific data about their presence in environmental media and at the top of food chains worldwide prove that these flame retardants are in fact persistent, highly mobile and accumulative in living organisms.

The brominated flame retardant industry has voluntarily agreed to control emissions of these substances via the VECAP and SECURE programs, which apply to industry associations, as well as flame retardant processors. Under these programs, mass balances are elaborated and manufacturers provide guidance on the handling and processing of flame retardants, with a view to identify and then minimize sources of uncontrolled emissions. Calculations realized by DecaBDE vendors show that emissions could potentially be reduced at numerous plants that make or use flame retardants. Such reductions would be a step in the right direction. However, such measures would not be sufficient to reduce pollution to acceptable levels, particularly pollution of the world's oceans.

The Federal Environment Agency regards as necessary that diffuse product emissions, as well as the harmful byproducts of fires and improper disposal, must be reduced by substituting less dangerous substances for all three of the brominated flame retardants. The broad use of alternative substances or products would also reduce brominated flame retardant emissions from non-EU manufacturing or processing plants, as well as those within the EU that are not part of the VECAP and SECURE emission reduction programs.

Table 5 lists the Federal Environment Agency's ecological priorities for the use of various flame retardants in products. In general the Federal Environment Agency regards the use of halogen-free, reactively bonded flame retardants or the use of alternative materials and equipment designs as being more ecologically beneficial than halogenated flame retardants.[15] Reactively bonded flame retardants are also preferable since they have far less of a tendency to migrate or leech out of the products into which they are integrated. Prior to use, the environmental and health impacts of all halogenated and halogen-free flame retardants have to be adequately investigated, and the products should be manufactured and disposed of in such a way as to avoid any environmental or health risks. In certain cases, the implementation of organizational and technical measures may allow for rearrangement of the ecological priorities defined in table 5. The Federal Environment Agency strongly recommends that product manufacturers only use flame retardants that meet the criteria set forth in the following table.

[15] Virtually all flame retardants that are currently identified as critical are halogenated flame retardants. Especially brominated substances tend to be persistent and bioaccumulative. Therefore brominated flame retardants are unsuitable alternatives, especially if and their molecular structure differs only slightly from that of known problematic substances. Halogenated phosphorous compounds exhibit harmful toxic properties. Moreover, in fires and when not disposed of properly, all highly halogenated chemicals have a strong tendency to form corrosive fumes, as well as dioxins and furans.

Table 5: Ecological priorities for the use of flame retardants in products

Ecological priorities for the use of flame retardants in products
1. Design measures aimed at reducing the use of flame retardants (e.g. use of flame resistant materials; integration of barrier layers; adjusting flame retardant use to device voltage)
2. Inorganic flame retardants (aluminum hydroxide, magnesium hydroxide, red phosphorus (micro-encapsulated), ammonium polyphosphate)
3. Reactively bonded, halogen-free organic nitrogen and phosphorus compounds
4. Additive halogen-free organic nitrogen and phosphorous compounds that are not persistent or bioaccumulative and that are not toxic to humans or the environment in the long term.
5. Reactively bonded, halogenated flame retardants
6. Additive halogenated flame retardants that are not persistent or bioaccumulative and that are not toxic to humans and the environment in the long term.
The aforementioned priorities are subject to the following preconditions: ▪ The relevant properties of all flame retardants used must be investigated adequately. ▪ Proper product manufacture and disposal are not to give rise to any environmental or health risks. ▪ In certain cases, the implementation of organizational and technical measures may allow for rearrangement of the ecological priorities defined above.

6.2 Substitution of DecaBDE, TBBPA and HBCD

There are differences in the extent to which alternatives to DecaBDE, TBBPA and HBCD have been developed and evaluated. The present section provides an overview of the current status of technically suitable halogen-free alternatives for the relevant application domains. However, this section does not evaluate in detail the health and environmental effects of these substitutes.

Substitutes for DecaBDE, TBBPA and HBCD in plastics for electrical and electronic equipment: Numerous investigations and use cases are available for alternatives to brominated flame retardants that are used in the casings and small components of electrical and electronic equipment.[16] Under most circumstances, halogen-free, organic phosphorus compounds are substituted for brominated flame retardants in casing plastics. This necessitates replacing low cost ABS (acrylonitrile-butadiene-styrol) and HIPS (high impact polystyrene) plastics with somewhat more expensive, less flammable mixtures of the latter plastics with PE (polycarbonate) or PPE (polyphenyl ether). Substances such as

[16] On overview give for example: Döring, Manfred; Diederichs, Jan (Eds.) (2007): Halogen-free flame retardants in E&E applications – A growing toolbox of materials is becoming available. Karlsruhe Research Center.

magnesium hydroxide, microencapsulated red phosphorus, melamine, and organic phosphinates are suitable substitutes for the polyester (PBT, PET) or polyamide (PA) plastics used in small electrical and electronic equipment components. The amount of flame retardants used in low voltage devices can often be reduced, since oftentimes it exceeds the amount stipulated by fire safety standards. In addition, the advantages and disadvantages of increasing external ignition flame retardant requirements for electrical and electronic equipment should be discussed more widely by experts as well as the general public. Thus far, this issue has been considered solely from a technical standpoint by the designated panels of fire protection.

Substitutes for DecaBDE and HBCD in textiles include the following: long-term impregnation of cellulose fibers with reactive phosphorus based flame retardants; flame resistant polyester fibers with integrated phosphorus based flame retardant compounds; fibers made of flame resistant fiber materials such as polyaramide; non-combustible glass fibers; optimized intumescence systems that expand during a fire, thus forming a barrier layer. Fabric and upholstery structure and thickness are also key flame retardant parameters.

Alternatives to TBBPA in printed circuit boards: Considerable progress has been made in recent years in terms of developing bromine free printed circuit boards.[17] As a result, many vendors now offer alternative products, primarily phosphorus based like DOPO (dihydrooxaphosphaphenantrene), polymer phosphonates, and metal phosphinates, which in some cases are combined with inorganic compounds such as aluminum hydroxide or silica dioxide. Epoxy resins remain the most commonly used carrier material as in classic printed circuit boards. Recent research findings show that thermoplastic printed circuit boards made of flame resistant carrier polymers such as PEI (polyetherimide) or PES (polyethersulfone) may also be a suitable substitute.

Alternatives to HBCD in insulation: Although no substitute for HBCD in polystyrene insulation is currently available, rock wool is a highly suitable substitute for flame retardant polystyrene insulation, except for perimeter insulation applications. Modern rock wool insulation is completely safe for use in buildings, but standard work safety precautions must be taken during the installation process. Owing to global warming, thermal insulation in today's buildings must meet considerably higher standards than in the past. This prompted Sweden (the EU member state in charge of risk reduction measures) to "to consider the need for time limited exemptions for certain uses of HBCDD in EPS and XPS under the Limitations directive" on the grounds that the use of flame retarded polystyrene thermal insulation should be allowed for a brief transitional period.

Table 6 lists the main, halogen-free substitutes that are technically feasible for the relevant application domains. Although a detailed assessment of the environmental and

[17] See footnote 16.

health effects of these alternative substances and materials has not been provided here, all of those listed below meet the requirements set forth in table 5.

Table 6: Halogen-free substitutes for the brominated flame retardants DecaBDE, TBBPA and HBCD (examples)

Application domain	Brominated flame retardants (use in plastics/fibers)	Examples of technically suitable alternative substances or materials
Casings of electrical and electronic equipment	DecaBDE (ABS, HIPS) HBCD (HIPS) Additive TBBPA (ABS)	Phosphorous based halogen-free flame retardants: RDP, BDP (PC, PC/ABS, PPE/HIPS)
Small components in electrical and electronic equipment	DecaBDE (PBT, PET, PA)	Microencapsulated red phosphorus, magnesium hydroxide, melamine, metal phosphinate (PA) Metal phosphinate (PBT, PET)
Printed Circuit boards	Reactive TBBPA (epoxy resin) Additive TBBPA (phenol resin)	Phosphorus based halogen free flame retardants: DOPO/aluminum hydroxide (epoxy resin) Metal phosphinate/DOPO/silica dioxide (epoxy resin) Polymer phosphonate (epoxy resin) Flame resistant thermosets Flame resistant thermoplastics (under development)
Textile coatings	DecaBDE (various fibers) HBCD (various fibers)	Inherently flame resistant synthetic fibers with integrated flame retardants (PP, PE) Flame resistant synthetic fibers (polyaramide); glass fibers Long term integration of phosphonium compounds (cellulose) Intumescence systems (various fibers)
Polystyrene insulation	HBCD (EPS, XPS)	Rock wool (except perimeter insulation)

ABS: acrylonitrile-butadiene-styrol
BDP: bisphenol A-bis(diphenylphosphate
DOPO: dihydrooxaphosphaphenantrene
EPS: expanded polystyrene
HIPS: high impact polystyrene
PC: polycarbonate
PET: polyethylene terephthalate
PP: polypropylene
PPE: polyphenyl ether
RDP: resorcinol-bis(diphenylphosphate)
XPS: extruded polystyrene

7 Comprehensive action and research recommendations

The Federal Environment Agency opines that further comprehensive research and practical measures are needed in the following areas:

The **PBT criteria** defined by REACH are not flexible enough to encompass reliably all relevant environmental chemicals, since these criteria are mainly based on lab tests, many of which are unsuitable for such chemicals. Hence in identifying PBTs, the EU should take greater account of the results of monitoring studies of chemical residues in the environment.

Moreover, the fact that persistent and bioaccumulative substances are not satisfactorily classified and labelled makes it difficult for non-specialists to take the necessary precautionary measures in production settings. Broadening the scope of **classification and labelling** requirements would also go a long way towards promoting the development of products that are safer for the environment and human health, since product developers could identify critical substances more easily and use safer products in their stead.

Evaluations of alternative substances are crucially important both for the assessment of authorization applications under REACH, as well as for voluntary substitution measures. The ongoing progress of technological development will necessitate continuous and maybe even institutionalized assessments of alternative substances and products, in order to formulate viable recommendations in this domain.

At last it is necessary to look beyond the environmental implications of the three brominated flame retardants discussed in the present report. This means that researchers should be devoting greater efforts to the **detection of other brominated and non-brominated flame retardants in the environment,** insofar as there is evidence that these substances may be hazardous.