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Report of the Persistent Organic Pollutants Review Committee on the work of its third meeting

Addendum

Risk management evaluation on commercial pentabromodiphenyl ether

At its third meeting, the Persistent Organic Pollutants Review Committee adopted the risk management evaluation on commercial pentabromodiphenyl ether, on the basis of the draft contained in document UNEP/POPS/POPRC.3/9. The text of the risk management evaluation, as amended, is set out below. It has not been formally edited.

COMMERCIAL PENTABROMODIPHENYL ETHER

RISK MANAGEMENT EVALUATION

Adopted by the Persistent Organic Pollutants Review Committee
at its third meeting

November 2007

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Executive Summary

Commercial Pentabromodiphenyl ether (C-PentaBDE) is a mixture of brominated flame retardants (BFRs), mainly isomers of Pentabromodiphenyl ether (PentaBDE) and Tetrabromodiphenyl ether (TetraBDE). Brominated flame retardants are a group of brominated organic substances that inhibit or suppress combustion in organic material. C-PentaBDE is or has been used almost exclusively in the manufacture of flexible polyurethane (PUR) foam for furniture and upholstery in homes and vehicles, packaging, and non-foamed PUR in casings and electronic equipment (EE). They are also used to some extent in specialized applications in textiles and in industry. The chemical and physical properties of TetraBDE and PentaBDE have led to their wide dispersal in the environment and in humans, and there is evidence of their toxicity. For these reasons the components of C-PentaBDE cause concern in many regions of the world.

There are national and international standards for fire safety for some product groups. This applies for example to electrical equipment, industrial packaging, upholstered furniture, curtains, electronic household appliances and electrical cables. These standards specify the flame-retarding properties that are required but not which flame retardants are to be used. Until now, brominated flame retardants have been considered to be the most efficient. Today, it has become common to replace these substances either with flame retardants without bromine or by changing the design of the product so that there is no need for the continued use of flame retardants.

High levels of the components of C-PentaBDE are detected in the environment. They have severe toxic properties and have been shown to be persistent and bioaccumulative. They thus represent a potential risk for future generations. Concentrations in wildlife and in humans have also increased significantly (RPA, 2000). Those findings have resulted in voluntary and regulatory phase-outs of C-PentaBDE in several regions in the world. Since this is a global, transboundary problem, global actions to phase out C-PentaBDE should be considered.

Several countries have reported that they would have problems regulating a commercial mixture of PentaBDE. Listing the individual congeners such as the major components, BDE-47 and BDE-99, or classes of tetrabrominated and pentabrominated diphenyl ethers (with specified membership of each class) would be consistent with existing national legislations for the congener PentaBDE and would facilitate the national monitoring and control of emissions, production and use. It has been suggested that consideration should also be given to listing HexaBDE, which constitutes a small proportion of the C-PentaBDE mixture. Since HexaBDE is a component of the C-OctaBDE, listing the HexaBDE would need to be considered when evaluating management options for OctaBDE.

Conclusion and recommendation

Having evaluated the risk profile for commercial PentaBDE (C-PentaBDE), and having concluded that components of this mixture are likely, due to the characteristics of its components, as a result of long-range environmental transport, to lead to significant adverse effects on human health and the environment, this risk management evaluation has been prepared, as specified in Annex F of the Convention.

In accordance with paragraph 9 of Article 8 of the Convention the Committee recommends to the Conference of the Parties to consider listing 2,2', 4,4'- tetrabromodiphenyl ether (BDE-47, CAS No. 40088-47-9) and 2,2',4,4',5-pentabromodiphenyl ether (BDE-99, CAS No. 32534-81-9) and other tetra- and pentabromodiphenyl ethers present in C-PentaBDE, using BDE-47 and BDE-99 as markers for enforcement purposes in Annex A of the Convention, as described above.

1. Introduction

1.1 Chemical identity of the proposed substance

Background

In 2005 Norway nominated commercial Pentabromodiphenyl ether (C-PentaBDE) to be listed as a persistent organic pollutant (POP) under Annex A of the Stockholm Convention, and Norway has been responsible for the drafting of the present Risk Management Evaluation (Annex F).

PentaBDE is a brominated flame retardant (BFR), one of a group of brominated organic substances that inhibit or suppress combustion in organic material. It has been used mainly in the manufacture of flexible polyurethane (PUR) foam for furniture and upholstery in homes and vehicles, packaging, and to a smaller extent non-foamed PUR in casings and electric and electronic equipment (EE). To some extent it has also been used in specialized applications in textiles and in various other uses. Because of the chemical and toxic properties of its main components, isomers of tetrabromodiphenyl ether (TetraBDE) and pentabromodiphenyl ether (PentaBDE), and their wide spread occurrence in the environment and in humans C-PentaBDE causes concern in many regions in the world.

Chemical identity of the proposed substance

Commercial pentabromodiphenyl ether (C-PentaBDE) refers to mixtures of bromodiphenyl ether congeners in which the main components are 2,2', 4,4'- tetrabromodiphenyl ether (BDE-47 CAS No. 40088-47-9) and 2,2',4,4',5-pentabromodiphenyl ether (BDE-99 CAS No. 32534-81-9), which have the highest concentration by weight with respect to the other components of the mixture. Hexabrominated diphenylethers (HexaBDE) species can also comprise a significant portion of C-PentaBDE. The formulation of C-PentaBDE used in North America and Europe contains 4-12% HexaBDE.

The numbering system for the PBDEs is the same as that used for polychlorobiphenyls (PCBs) (Ballschmiter *et al.* 1993). The acronym PBDE is used for the generic term polybromodiphenyl ether, covering all congeners of the family of brominated diphenyl ethers. It is sometimes abbreviated to BDE.

1.2 Conclusions of the Review Committee of Annex E information

Annex E of the Stockholm Convention requires a Risk Profile to be developed to evaluate whether the chemical is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and/or environmental effects, such that global action is warranted. A Risk Profile for C-PentaBDE was developed and accepted in 2006 (UNEP, 2006). The POP Review Committee concluded as follows:
“Pentabromodiphenyl ether (C-PentaBDE) is a synthetic mixture of anthropogenic origin with no known natural occurrence. It can be concluded therefore that the presence of components of C-PentaBDE in the environment is the result of anthropogenic activities. Long range transport must be responsible for its presence in areas such as the Arctic region, remote from sites of production and release. PentaBDE degrades slowly in the environment and can bioaccumulate and biomagnify in mammals and piscivorous birds. The phase out of C-PentaBDE production and use has led to a reduction in current use, but many materials in use, such as polyurethane foams and plastics in electronic equipment, contain PentaBDE which is slowly released to the environment. This release will be accelerated at end-of-life of such materials, especially during recovery and recycling operations. Although levels of PentaBDE in human blood and milk, and in other environmental species, are falling in Europe, they continue to increase in North America and the Arctic region.
Based on the information in this risk profile, C-PentaBDE, due to the characteristics of its components, is likely, as a result of long-range environmental transport and demonstrated toxicity in a range of non-human species, to cause significant adverse effects on human health and the environment, such that global action is warranted.”

1.3 Any national or regional control actions taken

Most developed countries have taken some actions to limit the production and use of PentaBDE.

- Australia: PentaBDE is effectively banned for use in new articles. Imports of articles containing BFRs are not regulated.
- EU: placing on the market and use in concentrations higher than 0.1 % by mass is banned from 2004 (EU-Directive 2003/11/EC). Use in electrical and electronic appliances was phased out from July 1st, 2006 under the EU’s Restriction of Hazardous Substances in electrical and electronic equipment. Products containing more than 0.25 % PentaBDE are classified as hazardous waste when they are discarded.
- US: the industry voluntarily ceased production of C-PentaBDE from 2005, and the use is forbidden in some states. USEPA requires notification and Agency review prior to restart of manufacture for any use (see rule at 40 CFR Part 721.10000).
- Japan: use of C-PentaBDE stopped voluntarily in 1990.
- Norway and Switzerland: both countries have banned production, import, export and marketing and use of PentaBDE and mixtures containing 0.1 percent per weight or more of PentaBDE. Products containing more than 0.25 % PentaBDE are classified as hazardous waste when they are discarded. In Norway recycling and reuse of PentaBDE and materials with PentaBDE are not allowed.
- Canada: no production of PentaBDE. Regulations on manufacture, use, sale and import were proposed in 2006. Canada will be implementing virtual elimination for the tetra-, penta- and hexa-BDE homologues contained in C-PentaBDE.
- China: use of PentaBDE in electric and electronic products was banned from 1 March 2007.
- The status of the chemical under international conventions is listed in UNEP/POPS/POPRC.3/INF/23.

2. Production, use and releases

2.1 Levels and trends of production and use that will require management

Overall demand and production

Based on the last available market information on C-PentaBDE from Bromine Science and Environmental Forum (BSEF), total global demand has decreased from 8,500 tons in 1999 to 7,500 tons in 2001. The estimated cumulative use of C-PentaBDE since 1970 was 100 000 t in 2001 according to BSEF.

Table 2.1 Total global demand of C-PentaBDE by region in 2001. Metric tons and percent.

	Americas	**Europe**	**Asia**	**Rest of the world**	**Total**	**Percent of total world usage of BFRs**
Penta-mix PBDE formulation	7,100	150	150	100	7,500	4 %

Source: BSEF (2001)

C-PentaBDE has been produced in Israel, Japan, US and the EU (Peltola et al., 2001 and TNO-report 2005). A patent on a technical mixture containing PentaBDE was issued for China in 1999. As produced in China, the technical mixture contained a different ratio of its constituents (that is, different proportions of congeners) than C-PentaBDE produced in Europe and the US.

The US EPA (2007) estimates that US production and import were between 4,500 and 23,000 tons in 2002, but specific figures are confidential to the industry. The last producer of C-PentaBDE in the US, the Great Lakes Chemical Corporation (now Chemtura Corporation), voluntarily ended its production in 2004. Before the phase-out in US the majority of the C-PentaBDE formulation produced globally was used in North America (>97%). At the end of 2004, approximately 7.5% of the more than 2.1 billion pounds of flexible polyurethane foam produced each year in the US contained the C-PentaBDE formulation (Washington State 2006).

Results from a survey in Canada in 2000 indicated that approximately 1,300 ton of commercial products containing PBDEs were imported into Canada. Based on quantities reported, C-PentaBDE was imported in the greatest volume.

Production of C-PentaBDE in the former EU (15) ceased in 1997 (EU 2000). Usage in the EU (15) declined during the second half of the 1990s and was estimated to be 300 metric ton in 2000 (used solely for PUR production) (EU 2000). The use of PentaBDE was banned in the EU (25) in 2004. Use of PBDEs in electrical and electronic appliances was phased out from 1 July 2006.

The major producer of BFR in Israel, the Dead Sea Bromine Group, declares in a public statement on its web site that its products do not contain C-PentaBDE. This is to comply with the ban in EU, which is an important market for the company.

Since there should be no current production of C-PentaBDE in Europe, Japan, Canada, Australia and the US, remaining production would be located in other parts of the world. There is no information reported on the status of the production in China.

No information was found for Eastern European countries outside the EU or for most countries in the Asia-Pacific region. No information was available from countries in Africa or Latin America.

2.2 Use of C-PentaBDE

Although production and use is essentially banned in developed countries, if C-PentaBDE is not listed as a POP, there is a possibility that developing countries could begin their own production and use. According to different national and regional surveys and national submissions under the LRTAP Convention C-PentaBDE is used/has been used in the following sectors (Swiss agency for the Environment 2002, Danish EPA 1999, EU 2000, Norwegian EPA 2003 and http://www.unece.org/env/popsxg/6thmeeting.htm):

• *Electrical and electronic appliances (EE appliances)*: computers (Betts, 2006; Hazrati and Harrad, 2006), home electronics, office equipment, household appliances and others, containing printed circuit laminates, plastic outer casings and internal plastic parts, such as various small run components with rigid PUR elastomer instrument casings.

• *Traffic and transport*: Cars, trains, aircraft and ships, containing textile and plastic interiors and electrical components.

• *Building materials*: foam fillers, insulation boards, foam insulation, pipes, wall and floor panels, plastic sheeting, resins, etc.

• *Furniture*: Upholstered furniture, furniture covers, mattresses, flexible foam components. C-PentaBDE c an also be found in PUR-foam based packaging.

• *Textile*s: curtains, carpets, foam sheeting under carpets, tent, tarpaulin, working clothes and protective clothing.

• *Packaging:* C-PentaBDE can also be found in PUR-foam based packaging.

2.3 Global future demand for flame retardants

If C-PentaBDE is not banned, there are indications that its production and use – together with other brominated flame retardants – could grow. According to a market analyst consultant company, global demand for flame retardants is expected to grow by 4.4 percent per year to 2.1 million metric tons in 2009, valued at USD 4.3 billion (Fredonia Group, 2005). Growth will largely be driven by demand in developing countries in Asia (China in particular), Latin America and Eastern Europe. The growth in demand is expected for most flame retardants. Globally, growth is expected to be largest for bromine compounds, mainly due to high growth rates in China. Demand for use in electrical and electronic applications is expected to grow fastest, as electronic circuits become smaller and more densely packed, and their plastic components are subjected to higher temperatures. Higher value products will continue to make inroads as substitutes for less environmentally friendly compounds, especially in Western Europe, and as chlorine compounds begin to be replaced in China by bromine- and phosphate-based and other flame retardants (Freedonia Group, 2005).

Construction markets are expected to be the second fastest growing market for flame retardants globally. An exception is China, where the second fastest growth will be from motor vehicles followed by textiles, both rapidly growing industries in that country. Plastics will continue to replace other materials such as metals and glass in a wide range of products in order to lower cost and weight and to improve design and production flexibility. Their usage is widespread and growing in transportation, building products and electrical and electronic products. Plastics must be made flame retardant for many applications. As a result, 75% of all flame retardants are used in plastics (Freedonia Group 2005).

Environmental restrictions vary by region. In Western Europe, Japan and to a lesser extent North America, such restrictions will especially limit growth of chlorinated compounds which might be considered as in-kind replacements for PBDEs. The ban on some brominated flame retardants in Western Europe is not expected to spread substantially to other regions (Freedonia Group 2005), but it drives the development of electrical and electronic equipment without the banned substances for sale on the world market. Dozens of Asian, European, and US companies announced in 2005 that they have developed or are developing electrical and electronic equipment that does not contain C-PentaBDE. In Asia more than 90% of electronic manufacturers already make products compliant with EU regulations. Officials from electronics companies and industry consultants consider that most electric and electronic equipment sold on the world market were in compliance with the ban in EU in 2005, due to the difficulties of keeping product streams separate ((Environmental International reporter 2006).

2.4 Emissions from production of C-PentaBDE and products using C-PentaBDE as input

The producers of C-PentaBDE have reported that the major routes of PentaBDE release to the environment during production are filter waste and material rejected because it does not meet specifications, both of which are disposed of in landfills. Waste water releases of PentaBDE may also occur from spent scrubber solutions (RPA, 2000). The emissions to air from production of C-PentaBDE is assumed to be none or negligible (RPA 2000, van der Gon et al. 2005). Modeling indicates that emissions during manufacture of products containing C-PentaBDE are minor in comparison to those associated with consumption.

2.5 Emissions from use of C-PentaBDE -containing products

TNO (2005) concludes that the major releases of PentaBDE to air stem from products and equipment which contain the substance as flame retardant.

Indoor equipment

PentaBDE has been in some studies of indoor dust, and several studies have examined the extent of human exposure (UNEP 2006). Indoor dust is considered to be one of the main sources of human exposure (UNEP 2006).
C-PentaBDE is used solely as an additive chemical. Although the vapor pressures of its constituents are low, some fraction can volatilize from the products during their whole life-cycle (RPA, 2000). When released, the PentaBDEs are likely to adsorb to particles. The particles (dust) may adhere to surfaces within the appliances, on other surfaces

in the indoor environment or be spread to the outdoor environment (Danish EPA, 1999). Physical breakdown of products can also contribute to the presence of PentaBDE in indoor dust.

Several studies have detected components of C-PentaBDE in indoor air and dust stemming from products like textiles, furniture and electronic devices (Shoeib et al., 2004, Stapleton et al. 2005, and Wilford et al., 2005). Controlled chamber experiments have detected volatilization of PentaBDE from PUR-foam, used in furniture (Wilford et al. 2005). However, the work of Hale et al. (2002) indicates that physical breakdown of foam may be the major release of PentaBDE from PUR-foam. Experimental data shows that TetraBDE and PentaBDE are released from electronic appliances, such as TV sets and computer monitors (Danish EPA, 1999). This is supported by a recent study, indicating use of C-PentaBDE in older computers (Betts 2006; Hazrati and Harrad 2006).

In RPA (2000) it was estimated that 3.9 % PentaBDE of the amount of C-PentaBDE present in products would be released annually through volatilization during their anticipated lifetime of 10 years, using a worst-case scenario. By 2000, the global annual releases of PentaBDE from new use of PUR-foam in articles are estimated to be 585 – 1,053 metric ton/year (see table 2.3 in UNEP/POPS/POPRC.3/INF/23).

Outdoor equipment

While material vaporized from outdoor equipment will be widely dispersed at low concentration in the air, particles of polymer (foam) products which contain C-PentaBDE can be released to the environment from C-PentaBDE-containing outdoor equipment. These particles are primarily released to the urban/industrial soil compartment (75%), but may also be released to surface waters (24.9%) or air (0.1%). PVC in which C-PentaBDE has been incorporated as flame retardant (RPA, 2000) may have been used in the following situations: car undercoating, roofing material, coil coating, fabric coating, cables and wires, and profiles and shoe soles. The emission factors for these releases are in RPA (2000) estimated to 2-10% over the lifetime of the product, with the higher factor being applied to products subject to high wear rates (such as car undercoating and shoe soles), and 2% during disposal operations. The releases in the EU region were in 2000 estimated to be 15.86 tonnes PentaBDE per year to industrial soil, 5.26 tonnes per year to surface water and 0.021 tonnes per year to air. No estimates of global releases are found in the literature.

According to information obtained from the bromine industry, historic uses of hydraulic fluid (in the form of a mixture) in petroleum drilling and mining can have resulted in excessive amounts released to the environment. No estimates of those releases are found in the literature.

2.6 Emissions from waste containing C-PentaBDE

Waste can be generated from production of C-PentaBDE, manufacturing processes of C-PentaBDE-containing products and when C-PentaBDE-containing products end up as waste. There is limited information in the literature concerning releases from C-PentaBDE- containing waste.

Waste generated from production of C-PentaBDE

In the production of C-PentaBDE producers have stated that the major sources of waste release were filter waste and reject material. Waste water releases of PentaBDE may also occur from spent scrubber solutions (RPA, 2000). C-PentaBDE-containing waste was put on landfill (RPA, 2000). In the US this waste is disposed of in landfills that are permitted to handle hazardous chemical waste. In the EU, wastes containing more than 0.25% PentaBDE are classified and treated as hazardous waste. Waste from production of C-PentaBDE is considered negligible.

Waste generated from manufacturing processes of products containing C-PentaBDE

The flame retardant lost during these processes will stay in the scrap foam. Foam scrap is often recycled into carpet underlay (rebond), particularly in the United States (EU has been an exporter of scrap foam (around 40,000 tonnes/year) to the United States for this use (RPA 2000)). Other uses for scrap foam such as regrinding and subsequent use as filler in a variety of applications (e.g. car seats, addition to virgin polyol in the manufacture of slab stock foam) have been reported. It is also possible that scrap foam is deposited on landfill or incinerated in many countries.

During the production of printed circuit boards a substantial part of the laminate is cut off and ends up in solid waste and this is also true of production of EE appliances. C-PentaBDE is no longer used for production of printed circuit boards in most producer countries. This solid waste is put into landfills or incinerated, as is waste generated from production of building materials, textiles and furniture.

When products containing C-PentaBDE become waste

In the EU, wastes containing PentaBDE are covered by regulations governing plastics containing BFRs. These plastics must be separated from EE-appliances prior to recovery and recycling by December 2006. After separation from metals, the plastic fraction is disposed of or burned in municipal waste incinerators, but technologies for separation of bromine-containing and non-bromine-containing plastics are emerging, thus aiding waste management and possible recycling.

Vehicle hulks are stored outdoors and then dismantled in shredder plants. In some countries regulations require that components containing hazardous substances are separated before shredding. This applies, obviously, for smaller components that are easy to dismantle. For most plastic and textile components this is not done, and flame retardants in those components end up in the waste fraction from the shredder plant that is put into landfills or sometimes incinerated.
Other products containing C-PentaBDE are also put on landfills or incinerated when they end up as waste.

Releases from landfills and incineration

Polymer (foam) particles containing C-PentaBDE could leach from landfills into soil, water or groundwater. However, it is not currently possible to assess the significance of this type of process. The amount of PentaBDE put on landfill or incinerated in the EU is estimated to be 1,036 ton/year (RPA, 2000). Given the physico-chemical properties of the substance (low water solubility, high octanol-water partition coefficient) it is considered very unlikely that significant amounts of PentaBDE will leach from landfills as the substance would be expected to adsorb strongly onto soils (RPA, 2000). However, Norwegian screening studies have measured concentrations of PentaBDE of concern in the leaching water from landfills (Fjeld et al. 2003 and 2004).

At the operating temperatures of municipal waste incinerators almost all flame retardants will be destroyed. However, based on experience with other organic compounds, trace amounts could pass through the combustion chamber (Danish EPA, 1999). Studies of municipal waste incineration facilities have detected levels of PentaBDE in both gaseous and particulate fractions in the air in the vicinity of the facility. The levels were above background levels of PentaBDE (Agrell et al. 2004, Law 2005, ter Shure et al. 2004).

Potentially toxic products such as brominated dibenzo-p-dioxins and dibenzofurans may be released during incineration of waste containing C-PentaBDE (Danish EPA, 1999), just as their chlorinated analogues may be produced during combustion of wastes containing chlorinated materials. While, the technologies used in modern well-run waste incinerators to manage chlorinated dioxins and dibenzofurans emissions are believed to be adequate for controlling emissions of brominated and mixed bromo/chloro species as well (OECD 2001), these substances could be released during open burning of C-PentaBDE-containing materials or some other combustion processes (EU 2000).

2.7 Emissions from recycling and dismantling activities

Electrical and Electronic (EE) waste recycling plants

In EE waste recycling plants it is usually the metal that is recovered, sometimes plastic components, but never the PUR foam, which ends up in the waste fraction, that may be burned for energy recovery.
The analyses of dismantled FR2 printed circuit boards in electrical scrap show that about 35% of the PBDE used consists of C-PentaBDE. Based on market information it has been assumed that 25% of FR2 laminates in older appliances were treated with the commercial mixture of PentaBDE (Swiss Agency 2002).
Prevedouros *et al.* (2004) estimated production, consumption, and atmospheric emissions of PentaBDE in Europe between 1970 and 2000 based on literature data. According to their study, the flow of PentaBDE in disposed EE-appliances is estimated to be in the range of 17-60 metric tons per year within the time period 2000-2005. An experimental Swiss study on substance flow in a modern recycling plant showed a much higher flow of PentaBDE than expected from the literature study. The study revealed that the majority of producers and importers have insufficient information about the content of chemical compounds in the products they market (Swiss Agency, 2002).

In Morf *et al*. (2005), the average concentration in EE-appliances was estimated to 34 mg/kg PentaBDE. The highest amount was found in the plastic fraction of EE-appliances (125 mg/kg). If a recycling process is not equipped with an efficient air pollution control device as was used in the modern plant on which the experimental study was conducted, a significant flow of dust-borne PentaBDE may be transferred into the environment. In plants with off-gas filtering, around 65% of the PentaBDE will be collected (Morf *et al*. 2005).

Studies of the working conditions in recycling plants have detected levels of PentaBDE in the indoor air, and indicate that PentaBDE also can be spread as diffuse emissions from recycling plants. The authors of a national substance flow analysis carried out for Switzerland, covering the whole life cycle of Penta-, Octa-, and DecaBDE as well as tetrabromobisphenol-A (TBBPA), concluded that EE waste equipment accounts for the largest flow of the investigated BFRs compared to other waste fractions, such as, for example, automotive shredder residues and construction waste (Swiss Agency, 2002).

Dismantling of vehicles

In a substance flow analysis of BFR in Switzerland, the concentrations of PentaBDE in plastics were estimated to be 0.044 g/kg in road vehicles produced in 1998 and 0.089 g/kg in road vehicles produced in 1980. These concentrations refer to the amount of C-PentaBDE in the total weight of plastics in cars exclusive of EE plastic components. Up to the end of the 1980s, 100% of all unsaturated polyester (UP) resins was treated with BFR, primarily DecaBDE but also C-PentaBDE and TBBPA.

The first step in the recycling of vehicles is fragmentation in a shredder, where the metals are separated from other materials and recovered. The plastic parts mainly end up in a fraction called "fluff". The conditions for diffuse emissions can be assumed to be similar as for recycling plants of EE-appliances.

Dismantling of buildings and other constructions

In Switzerland, 5% of the PUR insulating foams produced in 1990 was used in the building industry and contained 220 g/ kg C-PentaBDE (Swiss Agency 2000).

There are indications of use of C-PentaBDE in PVC plastic sheeting. In the substance flow analysis made in Switzerland, 5% of products produced in 1990 with PVC plastic sheeting were assumed to contain C-PentaBDE. The amount of C-PentaBDE was estimated to be 49 g/kg PVC sheeting. Emissions of dust-borne PentaBDE can be assumed to be released during dismantling activities. The information is too limited to quantify those emissions.

3. Summary information relevant to the risk management evaluation

3.1 Possible control measures

There are in principle several control measures that could be implemented to reduce the use of C-PentaBDE and/or reduce the environmental impacts associated with the use of the substance, but many of these lie outside the scope of the Stockholm Convention. These include voluntary commitments by industry; eco-labeling schemes; economic instruments; and a deposit refund system.

A ban/restriction on the production and use of C-PentaBDE or key components of the commercial mixture would be an effective measure if properly enforced. Some countries have already taken such actions. Standards aiming at reducing the concentrations of bromodiphenyl ethers in products would be very effective.(RPA, 2000). Standards could be used to ensure environmentally benign waste handling. Risk management would be best achieved by a global ban on production and use of C-PentaBDE, brought about by listing the components of the mixture under the Stockholm Convention. Suitable, more environmentally benign alternatives exist for all use of C-PentaBDE so a ban could cover all sectors. A ban would eliminate emissions from the manufacturing of C-PentaBDE, and also eliminate release of bromodiphenyl ethers from the production and use of C-PentaBDE in new products. An important consideration is that a simple ban would not affect the emissions from C-PentaBDE in products already in use. One country has reported a need for an exemption for use of C-PentaBDE in military aeroplanes, due to the lack of alternatives that meet the special demands for fire safety.

Various control measures at the production or waste handling facilities would ensure safe work environments and good manufacturing practice, end-of-pipe controls reducing emissions to the environment, regulations on waste handling of products etc. These measures could be applied at the production plants for C-PentaBDE, at the plants using C-PentaBDE as input in their production and at the waste handling facilities. If properly designed and enforced this could be an effective tool to reduce releases from the sources in question.

Efficacy and efficiency of possible control measures

The choice of control measure for the remaining use and production of C-PentaBDE must take into account that most developed countries have phased out production of C-PentaBDE. However, action is still needed for the protection of human health and the environment from emissions and releases of the components of C-PentaBDE. Further risk reduction options should be examined against the following criteria (RPA, 2000):

- *Effectiveness*: the measure must be targeted at the significant hazardous effects and routes of exposure identified by the risk assessment. The measure must be capable of reducing the risks that need to be limited within and over a reasonable period of time.
- *Practicality*: the measure should be implementable, enforceable and as simple as possible to manage. Priority should be given to commonly used measures that could be carried out within the existing infrastructure.
- *Economic impact*: the impact of the measure on producers, processors, users and other parties should be as low as possible.
- *Monitorability*: monitoring should be possible to allow the success of risk reduction to be assessed.

Waste handling

A ban on production and use of C-PentaBDE would not in itself affect emissions of its components of concern from waste handling, where they can present a technical and legacy problem. However, listing a substance under the Stockholm Convention implies a ban on recycling and reuse of stockpiles of C-PentaBDE itself. Article 6 in the Convention requires that wastes and stockpiles are handled in a safe, efficient and environmentally sound manner, so that the content is destroyed or irreversibly transformed, taking into account international rules, standards and guidelines. The article also bans disposal operations that lead to recovery, recycling, reclamation, direct use or alternative use of POPs material.

A special challenge could be to separate C-PentaBDE-containing articles from those without the substance, since most articles are not labeled telling what they contain. However, there is information about articles that have contained C-PentaBDE in the past and about which articles it is used in today, like electronic articles, textiles and isolation material and casing materials. National authorities would have to make surveys to get more detailed information about C-PentaBDE content in different articles becoming waste. Technically the challenge would be the separation of bromine-containing and non-bromine-containing plastic components. Technologies on this field are emerging, thus aiding waste management and possible recycling, but they are expensive.

Targets for phase out of the use of existing products containing C-PentaBDE and the collection of these could be considered according to Annex A or B of the Convention. Since there are substantial stocks of products containing C-PentaBDE in use, national authorities could consider some additional measures to limit releases. These measures could range from establishing collection points where people can deliver their used products to more actively promoting and encouraging people to deliver their waste products. A deposit-refund system does not seem appropriate since sales of new products containing C-PentaBDE would no longer be allowed and their presence has become a legacy problem. However, paying people a fee to deliver their products would be an option, although a source of funding for such an operation is not obvious.

A special challenge would be to ensure proper handling of C-PentaBDE-containing waste material/articles in developing countries. Since these countries have limited experience in handling this kind of waste, they would need practical help and information as well as financial help to ensure environmentally benign handling of this waste. The assistance could include how to dismantle C-PentaBDE-containing articles, treat the various parts and the methods of environmentally sound treatment of the final C-PentaBDE. If listed under the Stockholm Convention, guidelines on sound waste treatment of C-PentaBDE and articles containing C-PentaBDE will be developed under the Basel Convention (Article 6 para 2 of the Stockholm Convention).

3.2 Information on alternatives (products and processes)

With the phasing out of C-PentaBDE in important markets, manufacturers are actively identifying alternatives. Some companies, such as IKEA, have already phased out all C-PentaBDE globally. Another factor encouraging the development of alternatives is the fact that many governments and large corporations have developed green procurement guidelines that prohibit the use of PBDEs in electronic products.

Information on alternatives to C-PentaBDE already in use has been reported by companies, in a regional survey in US (Washington State 2006). The alternatives identified in this process are listed in Table 3.1 in UNEP/POPS/POPRC.3/INF/23. The human health or environmental impacts of these alternatives have not been investigated by the authors. For example, hexabromocyclododecane, an alternative for C-PentaBDE in coatings and adhesives, is not a preferable alternative. This compound already causes concern because of its chemical properties in several countries and regions. RPA (2000) suggests that only tetrabromobenzoate (TBBE) and chlorinated alkyl phosphate esters, tris (2-chloroisopropyl) phosphate (TCPP) in particular, followed by phosphate esters, are relevant chemical alternatives to PentaBDE. However, since that time other alternatives may have been developed and commercialized and should also be considered. Given the range of alternative flame retardants available, a wise course would be to examine the manufacturing processes, evaluate the use of synthetic materials, and give preference to those that pose least risk.

Alternatives to C-PentaBDE in PUR foam

The US EPA Design for the Environment completed an assessment of alternatives to C-PentaBDE in PUR which was released in September 2005 (US EPA, 2005). The agency has established a Furniture Flame Retardancy Partnership with a broad set of stakeholders to assess environmentally safer chemical alternatives to C-PentaBDE and to investigate other technologies for improving furniture fire safety. Leading US flame-retardant chemical manufacturers identified 14 chemical formulations that are viable substitutes for C-PentaBDE in large-scale production of low-density flexible polyurethane foam (see table 3.2 in UNEP/POPS/POPRC.3/INF/23). The identified alternatives are drop-in replacement chemicals for C-PentaBDE, compatible with existing process equipment at foam manufacturing facilities, and therefore cost-effective. Some chemicals other than these fourteen formulations are currently used for other types of foam and in niche markets for low-density polyurethane foam. The chemicals are used to flame retard high-density, flexible polyurethane foam.

Three of the most commonly used chemicals that various reports have suggested may be more environmental and viable alternatives to C-PentaBDE are melamine, tris (1,3-dichloro-2-propyl) phosphate (TDCPP) (or TCPP) and ammonium polyphosphate (APP). Flame retardants based on melamine are currently used in flexible polyurethane foams, intumescent coatings (those which swell on heating and thus provide some measure of flame retardancy), polyamides and thermoplastic polyurethanes. They are used effectively in Europe in high-density flexible polyurethane foams but require 30 to 40 percent melamine per weight of the polyol. TDCPP is a chlorinated phosphate ester that is often used in polyurethane foam formulations. It is used in high-density foam and has been used in low-density foams when light scorching (discoloration) is not a primary concern. APP, an additive flame retardant, is currently used to provide flame retardancy in flexible and rigid polyurethane foams, as well as in intumescent laminations, moulding resins, sealants and glues. However, chemical manufacturers and foam manufacturing trade groups do not consider it to be an alternative for C-PentaBDE on a large scale.

Non-chemical alternatives to C-PentaBDE in PUR foam

Non-chemical alternatives have also been identified by the US EPA (2005). Three currently available, alternative technologies for flame retarding furniture include barrier technologies, graphite impregnated foam and surface treatment. Graphite impregnated foam and surface treatments have limited commercial uses. Barrier technologies are predominantly used in mattress manufacturing rather than residential upholstered furniture, but may have further applications.

In addition, it should be noted that some furniture designs exclude the use of filling materials, and even fabric altogether. Design therefore, should be considered when evaluating alternative means for achieving flame retardancy in furniture.

Alternatives to C-PentaBDE in EE-appliances

As of mid-November 2005, a number of big manufacturers were phasing out all PBDEs. Manufacturing firms expects increased costs due to compliance with the EU ban on use of hazardous chemicals in EE-appliances, including C-PentaBDE among a range of other substances. Among the world producers of EE-appliances 35% expect the price of their products to increase by less than 5%, another 23% of the producers expect an increase between 5 and 10%; 6% of the producers expect prices to increase by more than 10% (Environmental International Reporter, 2006). Examples of alternative flame retardants processes currently being utilized include; bromine-free circuit boards (Sony), phosphorus-based flame retardants for printed circuit boards (Hitachi), flame resistant plastic (Toshiba), halogen-free materials and low-voltage internal wires (Panasonic/Matsushita) (Norwegian EPA, 2003). Leisewitz et al. (2000) says that no problems should arise from the use of zinc borate, magnesium hydroxide or expandable graphite as alternatives to the brominated flame retardants.

Alternatives for C-PentaBDE in textiles

There are bromine-free flame retardant alternatives for use in textiles (see table 3.3 in UNEP/POPS/POPRC.3/INF/23). Some of them, such as antimony trioxide and borax, are not environmentally sound. There are also durable flame retardant materials, such as wool and polyester fibres. Some manufacturers claim that a ban on the use of C-PentaBDE in textiles will give poorer quality and durability of the textile.

3.3 Impacts on society of implementing possible control measures

Benefits of phasing out C-PentaBDE

The most obvious benefits to the global society of phasing out C-PentaBDE would be the reduced risk to human health and the environment due to reduced releases to air, water and soil of the components considered to be POPS, as well as releases in workplace settings (UNEP, 2006). The major part of the releases of PentaBDE ends up in soil and sediments, since in the environment the substance is bound to particles. PentaBDE in soil or sediments is readily incorporated into the food chain and bioaccumulates in the fatty tissues of top predators, including humans. The substance is widespread in the global environment. There have been detected levels of concern in several endangered species.

Levels of PentaBDE have been found in humans in all regions of the world (UNEP, 2006). Potential exposure of humans is through food, use of products containing C-PentaBDE, and contact with indoor air and dust. PentaBDE transfers from mothers to embryos and breastfed infants. UNEP (2006), in its assessment, concludes that PentaBDE is likely to cause significant adverse effects on human health or the environment, such that global action is warranted (see chapter 1.2). Continued use will entail a potentially large cost.

Fire prevention is important to protect human safety, and to avoid social and economic losses due to fire, but also to prevent spread in the environment of toxic materials released in fires. Using less of the flame retardant substances, or less effective agents, could therefore cause losses if fires become more frequent, but according to US EPA (2005), the available alternatives function as well as C-PentaBDE. Most of the alternatives are in themselves less hazardous to the environment than C-PentaBDE. Just a few of the substitutes are classified as dangerous for the environment, though complete information is lacking in many cases. The criteria for assessing possible candidate substances have been published by the Danish EPA (1999)

An estimate should be made of the reduced cost to the society from reduced damage to ecosystems and to public health, when materials like C-PentaBDE are removed from the market. The value of reduced damage to environment and health is difficult to quantify, but several methods have been suggested. The Polluter Pays Principle, under which such costs should be internalized by the producer and/or the user, is seldom applied (at least without regulatory assistance), and so no good estimates are available of the potential cost of damage avoided.

Given the discussion above the overall net benefit of phasing out C-PentaBDE for human health and the environment, is most likely positive.

Costs of phasing out C-PentaBDE

According to submitted information, production of C-PentaBDE is already phased out or is being phased out in both developed and developing countries.

The incremental costs for users of C-PentaBDE of replacing it with other substances in their products or re-designing the product itself to eliminate the need for additives would have to be considered. Each affected plant would have its own suite of costs incurred by the phase out of C-PentaBDE, so it is hard to make an overall assessment with any accuracy. Some manufacturers may have to invest in new production equipment, but for most users this seems not to be necessary since there are available 'drop in' replacements. In general, the costs of buying many of the alternatives seem to be similar or slightly lower than buying C-PentaBDE. However, for some alternatives there may be an increase in costs associated with a need for higher loads (RPA, 2000). However these costs should be small considering that according to submitted information most manufacturers in developed and developing countries already ceased to use C-PentaBDE. Changes in market demand, because of existing regulatory bans in other regions, and phase out C-PentaBDE, will require adjustments like those already explained in Section 2.3 for the market of electrical and electronic equipment.

Listing C-PentaBDE or its components in the Stockholm Convention would oblige Parties to adopt measures or guidance, as specified in the Convention, for the handling of wastes contaminated with C-PentaBDE. For those countries who have not yet adjusted their waste handling practices for C-PentaBDE, adopting such measures will involve additional costs, in both developed and developing countries. In addition to containment technology and provisions for special handling, these measures could extend, for example, to the upgrading of waste treatment plants. No data are available on the costs experienced by countries that have adopted such measures. No reliable figures for the estimated costs of phasing out C-PentaBDE are available, but most studies state that these costs are “low”. Allied to this economic analysis is the fact that most users in developed countries have phased out C-PentaBDE seemingly without any great challenges.

Potential incremental costs of using alternative substances should be included in the analysis. Using less of the flame retardant substances, or less effective agents, could cause social and economic losses if fires become more frequent, but according to US EPA (2005), the available alternatives function as well as C-PentaBDE. It could be discussed whether the costs for *producers* of C-PentaBDE of closing the production and eventually switch to production of other substances should be included in a cost benefit analysis. These costs could be considered as part of an ordinary restructuring of production due to changes in market demand. No assessments of such restructuring costs for producers are found in the literature. However this cost should be small considering that most producers have already switched to production of other substances and the increased market demand of alternatives to C-PentaBDE, because of the phase-out in regions with the highest demands of the substance.

Costs incurred by national governments related to regulation, enforcement and compliance activities (including waste management) should be included in the assessment. Some data of this type have been compiled by Canada (Environment Canada 2006). Overall costs are likely to be low in developed countries where the systems for monitoring and control activities are already in place, but the costs could be considerable for developing countries without these systems. On the other hand implementation of the Stockholm Convention would require these systems to be established, the additional cost of listing C-PentaBDE would therefore be smaller.

In addition society may incur some specific costs when materials such as C-PentaBDE are removed from the market and when associated wastes and contaminated sites are addressed. The Polluter Pays Principle,[1] may be applied, but seldom is. Legacy problems such as that likely to be posed by the presence of PentaBDE in the environment often occur since the original 'polluter' in many cases cannot be identified or is no longer in business. The Polluter Pays Principle could however be an approach in those cases, but only where the original polluter can be identified and if the Party's regulatory framework permits such action.

Comparisons of costs and benefits

Given the conclusions of the Risk Profile (UNEP 2006) for C-PentaBDE, its widespread global occurrence in biota and in humans, action taken or underway to phase it out in developed and developing countries and the increased demand for alternatives to C-PentaBDE, the overall consequence of a full global phase-out is most likely to be positive. Overall, the cost for developed countries of a phase out of C-PentaBDE should be small, as discussed above. However, specialized waste management and disposal related to C-PentaBDE (stockpiles and articles) could be costly for some countries and financial and technical assistance to developing countries should be considered to address this aspect as required.

4. Synthesis of information

4.1 Summary of evaluation

Commercial pentabromodiphenyl ether (C-PentaBDE) has been used mainly in the manufacturing of flexible polyurethane (PUR) foam for furniture and upholstery in homes and vehicles, packaging, and to a small extent in (non-foamed) PUR in casings and electrical and electronic equipment (EEE). To some extent they have also been used in specialized applications in textiles and in various other uses. The risks it poses to human health and the environment have been explored in the Annex E Risk profile adopted by the POPRC in November 2006.

There are national and international standards for fire safety for some product groups. This applies for example to electrical material, industrial packaging, upholstered furniture, curtains, electronic household appliances and electrical cables. These standards specify the flame-retarding properties that are required. Traditionally brominated flame retardants have been considered to be the most cost-effective way of imparting ignition resistance to many types of articles. However, in some cases these are being replaced with flame retardants without bromine, or the design of the product is changed so that there is no need for the continued use of chemical flame retardants.

Suitable alternatives seem to exist for almost all uses of C-PentaBDE. However, some of the alternative substances are also hazardous, and the impacts of some have not been properly investigated. Still, overall benefits from phasing out the use of C-PentaBDE are assumed to be positive. Costs of phasing out C-PentaBDE are generally perceived to be “low” due to the fact that most developed countries have already phased out C-PentaBDE without meeting excessive challenges. Cost-competitive non-POP alternatives are available and have been taken up by companies as replacements for C-PentaBDE in PUR-foam and electronic equipment.

4.2 Elements of a risk management strategy

Since the dissemination of bromodiphenyl ethers into the environment is a global, transboundary problem, some global actions to phase out C-PentaBDE should be considered. Risk management would be best served by a global ban on production and use of C-PentaBDE covering all sectors. Listing components of C-PentaBDE under Annex A of the Stockholm Convention would be the most appropriate measure, given that most developed countries have already banned production. Eventually, some very special uses of C-PentaBDE (military airplanes, space suits etc.) where alternatives are not efficient enough and/or very costly could be exempted from the ban for a time-limited transition period. Developed countries have in place all monitoring and control capacities as well as legislative tools to enforce a ban. Thus, the main enforcement challenge would be for the developing countries to get sufficient capacities in place.

Several countries have reported that they would have problems regulating a commercial mixture containing unspecified bromodiphenyl ethers. Listing the individual congeners would be consistent with existing national legislation in several countries for components of C-PentaBDE and would facilitate the national monitoring and control of emissions, production and use. In addition, there is always the possibility that commercial routes might be found to one or other of the components of the mixture, thus avoiding any ban occasioned by listing C-PentaBDE.

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[1] Stockholm Convention Preamble: “Reaffirming Principle 16 of the Rio Declaration on Environment and Development which states that national authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.”

Most national regulations concern specific compounds. It will therefore be more practical, rather than listing the commercial mixture C-PentaBDE under the Convention, to list major components of the mixtures (BDE-47 and BDE-99) or to list all brominated diphenylethers with 4 or 5 bromines. All mixtures with one of the isomers of tetrabromodiphenyl ether (TetraBDE) or pentabromodiphenyl ether (PentaBDE) will then be covered by the conditions in the Convention, except when they occur as trace. The Convention could set lower limits for these listed substances, so that mixtures containing concentrations below these levels (traces, for example) would not be covered.

A particular reason for listing by bromination level rather than listing the commercial mixture is that the production of low brominated PBDE mixtures apart from PentaBDE, which was discontinued as a voluntary measure by the industry, could be restarted. For example, the commercial mixture “Tetrabromodiphenyl ether” which was previously used in Japan, would not be covered by the C-PentaBDE prohibition, should a manufacturer decide to produce it, but listing of specified congeners would cover the case.

At present C-OctaBDE and Deca-BDE do not contain TetraBDE or PentaBDE so there will be no consequences of the proposed listing of brominated flame retardants with 4 to 5 bromines (Guardia *et al.* 2006 and EU 2002).

The C-PentaBDE contains up to 12% of HexaBDE. A global risk profile for C-OctaBDE, which also contains appreciable amounts of the HexaBDE, is under consideration by the Committee. If HexaBDE is considered a POP, one option for C-PentaBDE could be listing brominated flame retardants with 4 to 6 bromines. But this would also have consequences for C-OctaBDE which has yet to undergo a risk management evaluation by the POPRC.

The provision of guidance on criteria for the selection of alternatives to C-PentaBDE should be part of the risk management strategy for the elimination of this substance. It will be important to discourage the replacement of C-PentaBDE with other environmentally harmful substances.

A ban would eliminate emissions from the manufacture of C-PentaBDE and products containing it. It would not affect the emissions from C-PentaBDE in products already in use. Recycling and reuse of products containing C-PentaBDE would not be allowed, if it results in new use of the isomers of TetraBDE or PentaBDE as constituents of new products, since these activities are banned under Article 6 of the Convention. Recycling and recovery can occur, but only if the new product does not contain the specified isomers of TetraBDE and PentaBDE. Additional regulations might need to be considered when products are treated to recover the valuable materials such as metals that are contained in them, and the components of C-PentaBDE is inadvertently released to the environment. This would especially be important for recycling of electronic articles containing C-PentaBDE and for shredder plants handling these and other products, like vehicles. Some components in the waste fraction can be sorted out, but for most EE appliances this will not be practical. Thus, new regulations might require installation of air pollution control devices on some incinerators and plants, and that would be costly for them. However, most developed countries already have other restrictions that require off-gas filtering of the emissions from recycling and shredder plants.

Consideration was given to listing of brominated diphenylethers with four or five bromines in Annex B, with targets to be set for the phase out of the use of specific existing products containing C-PentaBDE. However, collection of such products would be a major task and the likely complexity of such schemes militated against such a recommendation. However, a paragraph on endeavours to achieve this could be added for countries with management systems in place. The general rules on waste handling in the Stockholm Convention will, of course, apply to C-PentaBDE once brominated diphenylethers with 4 or 5 bromines are listed.

Waste fractions containing C-PentaBDE should be handled as hazardous waste. This is already done in large parts of the UN ECE region. This could impose extra costs on some countries and sectors. The solutions for waste handling should to a large extent depend on local conditions and be designed to fit into existing systems and traditions, taking the general rules of the Stockholm Convention into consideration, including the general guideline on waste handling in the Basel Convention, which includes in Annex VIII such substances as PCBs and polybromobiphenyls and 'other polybrominated analogues'.

Concluding statement

This risk management statement has been prepared in accordance with the content specified in Annex F of the Convention, and builds on the Risk Profile adopted by the POPRC in 2006 (UNEP 2006).

The available information on commercial pentaBDE includes laboratory studies conducted either with commercial mixtures or specific congeners and monitoring data for different combinations of congeners. In addition to the information summarized in the Risk Profile, the scientific literature offers a significant number of reviews presenting the overall toxicity of this chemical family.

The current level of information covers some of the tetra and pentaBDE congeners and seems to be consistent with a generic assessment (e.g., Canton et al., 2006; Huwe et al., 2007), since the properties that define POP characteristics and its associated risks are similar for those congeners investigated. Therefore, considering that:

- Existing national legislators have reported difficulties with the control of commercial mixtures and the enforcement of the regulations;
- Some studies cover all components in the mixture;
- Monitoring and bioaccumulation studies have demonstrated the presence of unknown pentaBDEs (e.g. Burreau et al., 2006);
- There is no information indicating that some congeners within the family do not share the POP characteristics observed for congeners or mixtures for which information is available; and
- The level of potential risk identified in the risk profile indicates that the concern cannot be restricted to the main components in the mixture, and therefore, listing BDE-47 and BDE-99 alone would be insufficient,

the Committee proposes that the best approach for listing the chemicals substances reviewed under the risk profile of commercial pentaBDE is to cover all polybrominated diphenyl ethers with four or five bromines. It should be noted that this proposal is based on a specific review of the characteristics of this particular group of chemicals, and that this approach should not be generically extrapolated to other chemical families in which large differences among the properties of closely related homologues, congeners or isomers have been found.

In accordance with paragraph 9 of Article 8 of the Convention the Committee recommends to the Conference of the Parties to consider listing 2,2', 4,4'- tetrabromodiphenyl ether (BDE-47, CAS No. 40088-47-9) and 2,2',4,4',5-pentabromodiphenyl ether (BDE-99, CAS No. 32534-81-9) and other tetra- and pentabromodiphenyl ethers present in C-PentaBDE, using BDE-47 and BDE-99 as markers for enforcement purposes. in Annex A of the Convention, as described above.

References

Agrell, C., A. F. H. ter Schure, J. Sveder, A. Bokenstrand, P. Larsson and B. N. Zegers (2004). Polybrominated diphenyl ethers (PBDEs) at a solid waste incineration plant. I: atmospheric concentrations. Atmos. Environ. 38, 5139-5148.

Alaee, M., P. Arias, A. Sjødin and Å. Bergman (2003). An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possible modes of releases. Env. Inter. 29, 683-689.

Ballschmiter, K., A. Mennel and J. Buyten (1993). Long-chain Alkyl Polysiloxanes as Non-Polar Stationary Phases in Capillary Gas Chromatography, Fresenius' J. Anal. Chem. 346: 396-402.

Betts, K. (2006). PBDEs and PCBs in computers, cars, and homes. Environ. Sci. Technol. 40: 7452.

BSEF (2007). Annex F Questionnaire Responses Submitted by the Bromine Science and Environmenl Forum (BSEF).

BSEF (2001). Major brominated flame retardants volume estimates. Total market demand by region 2001. Bromine Science and Environment Forum 21 January 2001. www.bsef.com.

Burreau S, Zebühr Y, Broman D, Ishaq R. 2006. Biomagnification of PBDEs and PCBs in food webs from the Baltic Sea and the northern Atlantic Ocean. Sci Total Environ. 366:659-72.

Cantón RF, Sanderson JT, Nijmeijer S, Bergman A, Letcher RJ, van den Berg M. 2006. In vitro effects of brominated flame retardants and metabolites on CYP17 catalytic activity: a novel mechanism of action? Toxicol Appl Pharmacol. 216:274-81.

Danish EPA (1999). Brominated flame retardants. Substance flow analysis and assessment of alternatives. www2.mst.dk/udgiv/Publications/1999/87-7909-416-3/html/kap04_eng.htm

Daugherty, M.L. (1982). Chemical hazard information profile draft report: Melamine CAS No. 108-78-1. Office of Toxic Substances, US EAP.

Environment Canada (2006). Regulatory Impact Analysis Statement for proposed Polybrominated Diphenyl Ether Regulations. www.ec.gc.ca/CEPA/Registry/regulations/Detail/Reg.cfm?intReg=108.

Environmental International Reporter (2006). Electronics firms worldwide pledge to meet EU Directive banning use of some chemicals. Vol. 29, No 5.

European Union (2000). Risk Assessment of Diphenyl Ether, Pentabromo derivative (Pentabromodiphenyl ether). CAS Number: 32534-81-9, EINECS Number: 251-084-2. Final report of Augsut 2000, Commissioner of the European Communities. Rapporteur: United Kingdom.

European Union (2002). Risk Assessment. Report of bis(pentabromophenyl)ether. CAS Number: 1163-19-5, EINECS Number: 214-604-9. Final report. European Chemical Bureau. Volume 17. Appendix G.

Fjeld, E., M. Schlabach, J. A. Berge, T. Eggen, P. Snilsberg, G. Källberg, S. Rognerud, A. Borgen and H. Gundersen (2003). Screening of selected new organic contaminants - brominated flame retardants, chlorinated paraffins, bisphenol A and triclosan. SFT-report 4809/2004.

Fjeld, E., M. Schlabach, J. A. Berge, N. Green, T. Eggen, P. Snilsberg, C. Vogelsang, S. Rognerud, G. Kjellberg, E. K. Enge, C. A. Dye and H. Gundersen (2004). Screening of selected new organic contaminants 2004. Brominated flame retardants, alkylated substances, irganol, diuron, BHT and dicofol. SFT-report 927/2005.
Freedonia Group Inc. (2005): World flame retardants. R154-1365. http://www.mindbranch.com

Hale, R. C., M.J. La Guardia, E. Harvey and T.M. Mainor (2002). Potential role of fire retardant-treated polyurethane foam as a source of brominated diphenyl ethers to the US environment. Chemosphere 46: 729-735.

Hazrati, S. and S. Harrad (2006). Causes of Variability in Concentrations of Polychlorinated Biphenyls and Polybrominated Diphenyl Ethers in Indoor Air. Environ. Sci. Technol. 40: 7584-7589.

Law, R.J., C. R. Allchin, J. de Boer, A. Covaci, D. Herzke, P. Lepom, S. Morris, J. Tronczynski and C. A. de Wit (2005). Levels and Trends of Brominated Flame Retardants in European and Greenland Environments. Chemosphere 64: 187 – 208.

Huwe J, Hakk H, Lorentzsen M. 2007. Bioavailability and mass balance studies of a commercial pentabromodiphenyl ether mixture in male Sprague-Dawley rats. Chemosphere. 66:259-66.

La Guardia, M.J., Hale R.C. and Harvey, E. (2006) Detailed Polybrominated Diphenyl Ether (PBDE) Congener Composition of the widely used Penta-, Octa- and Deca-PBDE Technical Flame-Retardant Mixtures. Environ. Sci. Technol. 40(20) : 6247-6254.

Leisewitz, A., H. Kruse and E. Schramm (2000). German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Substituting Environmentally Relevant Flame Retardants: Assessment Fundamentals. Research report 204 08 642 or 207 44 542.

Morf, L.S., J. Tremp, R. Gloor, Y. Huber, M. Stengele and M. Zenegg (2005). Brominated flame retardants in waste electrical and electronic equipment: Substance flow in a recycling plant. Environ. Sci. Technol, 39, 8691-8699.

Norwegian EPA (2003). Bruken av bromerte flammehemmere i produkter.
Materialstrømsanalyse. (The use of brominated flame retardants in products. A material flow analysis) TA-1947/2003. (In Norwegian only).

OECD (2001): Report on Incineration of Products Containing Brominated Flame Retardants.
http://www.olis.oecd.org/olis/1997doc.nsf/LinkTo/env-epoc-wmp(97)4-REV3

Peltola, J. and Yla-Mononen, L. (2001). Pentabromodiphenyl ether as a global POP. TemaNord 2001, vol. 579. Copenhagen: Nordic Council of Ministres; ISBN 92-893-0690-4: 78 pp.

Prevedouros, K., K. C. Jones and A. J. Sweetman (2004). Estimation of the production, consumption, and atmospheric emissions of pentabrominated diphenyl ether in Europe between 1970 and 2000. Environ. Sci. Technol, 38, 3224-3231.

Prevedouros, K., Jones, K.C., and Sweetman, A.J. (2004). Estimation of the Production, Consumption and Atmospheric Emissions of Pentabrominated Diphenyl Ethers in Europe Between 1970 and 2000. Environ. Sci. Technol. 38: 3224-3231.
RPA (2000). Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Pentabromodiphenyl Ether. Stage 4 Report. Risk & Policy Analysis Limited, London.
SAICM Overarching Policy Strategy 14d, Global Plan of Action Activity 54, 55 (2002).
www.chem.unep.ch/saicm%20texts/SAICM%20documents.htm.

Shoeib, M., Harner, T., Ikonomou, M. and Kannan, K. (2004). Indoor and Outdoor Concentrations and Phase Partitioning of Perfluoroalkyl Sulfonamides and Polybrominated Diphenyl Ethers. Environ. Sci. Technol. 38: 1313-1320.

Stapleton, H.M., Dodder, N.G., Offenberg, J.H., Schantz, M.M. and Wise, S.A. 2005. Polybrominated Diphenyl Ethers in House Dust and Clothes Dryer Lint. Environ. Sci. Technol. 39: 925-931.

Swiss Agency (2002). Environmentally hazardous substances: Selected polybrominated flame retardants, PBDE and TBBPA – Substance flow analysis. Environmental series No. 338.

ter Schure, A.F.H., C. Agrell, A. Bokenstrand, J. Sveder, P. Larsson and B. N. Zegers (2004). Polybrominated diphenyl ethers at a solid waste incineration plant II: atmospheric deposition. Atmos. Environ. 38, 5149-5155.

TNO (2005). Study of the effectiveness of the UNECE Persistent organic pollutants protocol and cost of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the POP protocol. R 2005/194.

UNEP (2006). Risk profile: pentabromodiphenyl ether. Stockholm Convention on Persistent Organic Pollutants: Persistent Organic Pollutants Review Committee, Second Meeting, Geneva 6-10 November, 2006. UNEP/POPS/POPRC.2/17, Addendum 1.

US EPA (2005). Future Flame Retardant Partnership: Environment Profiles of Chemical Flame-retardant Alternatives for Low Density Polyurethane Foam. Chemical Hazard Reviews, Vols. 1&2. www.epa.gov/dfe/pubs/flameret/ffr-alt.htm.

Van der Goon, D., M. van het Bolscher, A.J.H. Visschedijk and P.Y.J. Zandveld (2005). Study of the effectiveness of the UNECE persistent organic pollutants protocol and cost of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the POP protocol. TNO-report 2005/194.

Washington State (2006). Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Draft Final Plan, December 1, 2005.

Wilford, B.H., M. Shoeib, T. Harner, J. Zhu and Jones, K.C. (2005). Polybrominated Diphenyl Ethers in Indoor Dust in Ottawa, Canada: Implications for Sources and Exposure. Environ. Sci. Technol. 39(18): 7027-7035.