Stockholm Convention on Persistent Organic Pollutants

Persistent Organic Pollutants Review Committee (POPRC)

DRAFT RISK MANAGEMENT EVALUATION

For

Commercial Pentabromodiphenyl Ether

Draft prepared by:

The ad hoc working group on commercial pentabromodiphenyl ether

May, 2007

<u>Draft Risk Management Evaluation for Commercial Pentabromodiphenyl Ether</u>

Note:

In accordance with the procedure laid down in Article 8 of the Stockholm Convention, this draft was prepared by the Persistent Organic Pollutants Review Committee (POPRC) during its inter-sessional work. Parties and observers to the Stockholm Convention are invited to provide technical and substantive comments on this draft. Comments received will be considered by the ad hoc working group and the revised draft will be made available for the third meeting of the POPRC (19-23 November in Geneva). Please submit your comments to the Secretariat of the Stockholm Convention preferably by e-mail before **<u>July 1, 2007</u>** to:

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Executive Summary

Background

Commercial Pentabromodiphenyl ether (C-PeBDE) is a mixture of brominated flame retardants (BFRs), mainly isomers of Pentabromodiphenyl ether (PeBDE) and Tetrabromdiphenyl ether (TeBDE). Brominated flame retardants are a group of brominated organic substances that inhibit or suppress combustion in organic material. They are or have 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 properties of PeBDE have lead to its wide -spread occurrence in the environment and in humans, and there is evidence of its toxicity, of this reason C-PeBDE causes 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 cheapest and most efficient. Today, it has become increasingly more 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. It has also become important to avoid the use of products containing flame retardants if this is not absolutely necessary on the basis of fire safety. Accordingly, some manufacturers have already replaced C-PeBDE with cost-competitive non-POPs alternatives in all uses, including PUR and electronics.

High levels of PeBDE are detected in the environment, the substance has severe toxic properties and has been shown to be persistent and bioaccumulative. It thus represents 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 PeBDE in several regions in the world. Since this is a global, transboundary problem, global actions to phase out C-PeBDE should be considered.

Conclusion and recommendation

Having evaluated the risk profile for commercial PeBDE (C-PeBDE), and having concluded that this chemical is likely, 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 that the Conference of the Parties to the Stockholm Convention consider listing of brominated diphenyl ethers with 4 or 5 bromines in Annex A, and specifying the related control measures.

1. Introduction

1.1 Chemical identity of the proposed substance

Background

In 2005 Norway nominated commercial Pentabromodiphenyl ether (C-PeBDE) to be listed as a persistent organic pollutant (POP) under Annex A of the Stockholm Convention. The convention is a global treaty to protect human health and the environment from POPs. Twelve substances (or groups of substances) are currently listed under the convention.[1] POPs are chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in living organisms and can cause harm to humans and the environment.

The POP Review Committee is considering a global ban on the production and use of C-PeBDE. As part of this consideration a questionnaire was sent to Parties and Observers to the Convention, asking for information about C-PeBDE as defined in Annex F of the Convention. Based on the information from the questionnaires and other sources, Norway has been responsible for the drafting of the present Risk Management Evaluation of a global ban on C-PeBDE.

PeBDE is a brominated flame retardant (BFR). Because of its chemical and toxic properties and wide spread occurrence in the environment and in humans PeBDE causes concern in many regions in the world. Brominated flame retardants are a group of brominated organic substances that inhibit or suppress combustion in organic material. They are or have 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 electric and electronic equipment (EE). To some extent they have also been used in specialized applications in textiles and in various other uses.

Chemical identity of the proposed substance

Commercial pentabromodiphenyl ether (C-PeBDE) 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 (HeBDE) species can also comprise a significant portion of C-PeBDE. The formulation of C-PeBDE used in North America and Europe contains 4-12% HeBDE.

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-PeBDE 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,

[1] Aldrin, cglordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, PCbs, dioxins and furans.

contain PeBDE 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 PeBDE 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 Data sources

The questionnaire

The questionnaire sent to the parties and observers of the convention contained requests for the following information:

- Data on production, use and release (additional Annex E information)
- Efficacy and efficiency of possible control measures in meeting risk reduction goals
- Alternatives (products and processes)
- Positive and/or negative impacts on society of implementing possible control measures
- Waste disposal implications (in particular obsolete stocks of pesticides and clean-up of contaminated sites)
- Access to information and public education
- Status of control and monitoring capacity
- Any national or regional control actions already taken, including information on alternatives, and other relevant risk management information.

As of 30. March 2007, the following Parties and Observers have returned the questionnaire:

- Bromine Science and Environmental Forum (BSEF)
- Canada
- Czech Republic
- European Community (EC) submitted by the United Kingdom
- Germany
- Environmental Health Fund on behalf of the International POPs Elimination Network (IPEN)
- Japan
- Monaco
- Norway
- Switzerland
- United States of America
- Zambia

In general, the information submitted from countries is limited. In particular, there is a lack of reliable data on production and consumption, and cost data of using alternatives. In addition, information concerning the positive and negative impacts on society of regulations is limited. Sufficient data on control actions already taken have been submitted, and some data on the use of control measures and on control and monitoring capacity in developed countries are available from some questionnaires.

Other data sources
Submissions with reference to more comprehensive studies like the risk reduction strategy study submitted by UK on behalf of the EC (EPA 2000) and the study of management options developed under the Convention on Long Range Transboundary Pollution submitted by Norway, have made it possible to do this risk management evaluation.
Information on national and regional regulations, or voluntary phase out of the use and production of C-PeBDE from developing countries are available, but information from developing countries is limited.
Most information on use and production patterns is from around 2000, when background material was gathered for management evaluations in the developed regions. This information has been updated in this document with complementing studies up to 2007. After 2000 production and new use of C-PeBDE has been phased out in most of the developed regions. There is no new information on use in US, where the production has been voluntarily phased out. Information was received about recent regulatory action in Australia and China.
The collected information would be inadequate for a quantitative analysis of the risks of phasing out production and use of C-PeBDE. However, the available data are sufficient to prepare a *qualitative* risk management evaluation consistent with the requirements of the Stockholm Convention.

1.4 Status of the chemical under international conventions

While C-PeBDE is being considered for listing under the Stockholm Convention, PeBDE is treated under several other international conventions. Below is a brief overview of the most important ones, based on UNEP (2006).

The OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) is guiding international cooperation on the protection of the marine environment of the North-East Atlantic. OSPAR's objective is to make every endeavour to move towards the cessation by the year 2020 of discharges, emissions and losses of hazardous substances which could reach the marine environment .
In 1998 the OSPAR Commission placed PBDEs on its "List of Chemicals for Priority Action". An OSPAR Commission background document on PBDEs was reviewed by Sweden in 2001. The next full review of this document is not planned before 2008. At the 4th North Sea Conference, it was decided to phase out the use of brominated flame retardants by 2020.

The UNECE Convention on Long-range Transboundary Air Pollution

United Nations Economic Commission for Europe (UNECE) works for sustainable economic growth among its 55 member countries. The UNECE Convention on Long-range Transboundary Air Pollution requires Parties to endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution. The Convention has been extended by eight protocols. The Protocol for POPs focuses on a list of 16 substances that have been singled out according to agreed risk criteria for total ban, elimination at a later stage or restrictive use. In 2005, C-PeBDE was nominated as a new POP to the Convention by Norway. In December 2005 PeBDE was considered by the Executive Body of the Convention to meet the screening criteria for POPs. In 2006 the management options C- PeBDE were assessed to give a basis for later negotiations on restrictions.

The Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is a multilateral environmental agreement designed to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals. It is an instrument to provide importers of products with the power to make informed decisions on which chemicals they want to receive and to exclude those they cannot manage safely.
The Convention entered into force in 2004 and today has more than 100 states as Parties. The EU notified PeBDE to the Convention in 2003. To become a candidate bans of the substance must be notified by two Parties. However it is not at this time a candidate for consideration to be added to Annex III of the convention (a list of pesticides and industrial chemicals that have been banned or severely restricted in countries or regions for health or environmental reasons)

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal

Should C-PeBDE be listed under the Stockholm Convention, and thus accepted as a POP, it will come under the aegis of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. The Basel Convention is the most comprehensive global environmental agreement on hazardous and other wastes. The Convention has 169 Parties and aims to protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes. The Basel Convention came into force in 1992. Under the Convention 5 guidelines on POP waste were developed and adopted in 2006.

Strategic Approach to International Chemicals Management (SAICM)
Should C-PeBDE be listed under the Stockholm Convention, and thus accepted as a POP, it will come under the aegis of the Strategic Approach to International Chemicals Management (SAICM), a policy framework for international action on chemical hazards that was adopted by the International Conference on Chemicals Management on 6 February 2006, in Dubai, United Arab Emirates. SAICM supports the achievement of a goal agreed at the 2002 Johannesburg World Summit on Sustainable Development, which was to ensure that by the year 2020 all chemicals are produced and used in ways that minimize adverse impacts on human health and the environment. SAICM includes substances with POPs characteristics as a class of chemicals to be prioritized for halting of production and use, and substitution by safer alternatives (SAICM Overarching Policy Strategy 2002).

1.5 Any national or regional control actions taken

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

- Australia: PeBDE 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 % PeBDE are classified as hazardous waste when they are discarded.
- US: the industry voluntarily ceased production 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 stopped voluntarily in 1990.

- Norway and Switzerland: both countries have banned production, import, export and marketing and use of PeBDE and mixtures containing 0.1 percent per weight or more of PeBDE. Products containing more than 0.25 % PeBDE are classified as hazardous waste when they are discarded. In Norway recycling and reuse of PeBDE and materials with PeBDE are not allowed.
- Canada: no production of PeBDE, regulations on use are in preparation. PeBDE was proposed to be added to the Virtual Elimination List in Canada in 2004.
- China: use of PeBDE in EE products was banned from 1. March 2007. There should currently be no production of C-PeBDE in China.

2. Production, use and release of PeBDE

2.1 Levels and trends of production and use

Overall demand and production

Based on the last available market information on C-PeBDE 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-PeBDE since 1970 was 100 000 t in 2001 according to BSEF.

Table 2.1 Total global demand of C-PeBDE 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)

The US EPA (2007) estimates that US production and import were between 4,500 and 23,000 tons in 2002. This indicates a somewhat larger US market in 2001/2002 than the number in Table 2.1. However, since there should be no current production of C-PeBDE in Europe, Japan, Canada and US, remaining production would be located in other parts of the world. According to BSEF there are some indications that since the late 1990s China may have produced C-PeBDE for the US market as well.
C-PeBDE 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 PeBDE 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-PeBDE produced in Europe and the US.

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

The last producer of C-PeBDE in the US, the Great Lakes Chemical Corporation (now Chemtura Corporation), voluntarily ended its production in 2004. In 2001 alone, almost 70,000 metric tons of polybrominated diphenyl ethers (PBDEs) were produced globally, almost half of which were used in products sold in the US and Canada. Before the phase-out in US the majority of PeBDE formulation produced globally were 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 commercial PeBDE formulation (Washington State 2006).

Production of C-PeBDE 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 tonnes in 2000 (used solely for PUR production) (EU 2000). The use of PeBDE was banned in the EU (25) in 2004. Use of PBDE in electrical and electronic appliances was phased out from 1 July 2006.

Results from a survey in Canada in 2000 indicated that approximately 1,300 tonnes of commercial products containing PBDE were imported into Canada. Based on quantities reported, C-PeBDE was imported in the greatest volume. PeBDE was proposed to be added to the Virtual Elimination List in Canada in 2004.

No information was found for Eastern European countries outside 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-PeBDE

Use of C-PeBDE as a flame retardant

Since 1999 the most common use (95-98%) of PeBDE has been in flexible polyurethane (PUR) foam. This foam contains between 10 and 18% of the commercial C-PeBDE formulation. Flame retarded, flexible PUR foam is used mainly for furniture, including upholstery in domestic furnishing, and in the automotive and aviation industries.

Other uses are in rigid polyurethane elastomers in instrument casings, in epoxy resins and phenol resins in electric and electronic appliances, and construction materials. C-PeBDE can also be used in small amounts in textiles, paints, lacquers, in rubber goods (conveyer belt, coating and floor panels) and in oil drilling fluids. Levels range from 5-30% by weight. Up to the early 1990s C-PeBDE was used in printed circuit boards, which was usual for FR2 laminates (phenol resins) in Asia. FR2 laminates are used in household electronics (television, radio, and video), vehicle electronics, and white goods (washing machines, kitchen appliances, etc.).

According to information from the BSEF member companies their sales for use of C-PeBDE in hydraulic fluid (in the form of a mixture) in petroleum drilling and mining stopped 10-20 years ago.

Australia has reported use of C-PeBDE in manufacture of polyurethane foams for refrigerators, packaging and for use as potting agents, and in epoxy resin formulations supplied into aerospace market, laminating systems and adhesive systems. The US has reported use of C-PeBDE in the production of components for military airplanes. EU had an exemption for aircraft emergency evacuation systems that expired march of 2006.

A recent study, has indicated use of C-PeBDE in older computers (Betts 2006).

2.3 Global future demand for flame retardants

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. 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 (Fredonia Group, 2005).

As electronic circuits become smaller and more densely packed, and their plastic components are subjected to higher temperatures, the need for flame retardants increases. 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-PeBDE. In Asia more than 90% of electronic manufacturers already make products compliant with the EU ban on PeBDE. 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-PeBDE and products using C-PeBDE as input

PeBDE is synthesized from diphenyl ether by brominating it with bromine in the presence of a powdered iron/Friedel-Crafts catalyst. The producers of C-PeBDE have reported that the major routes of PeBDE release to the environment during production are filter waste and rejected material, both of which are disposed of in landfills. Waste water releases of PeBDE may also occur from spent scrubber solutions (RPA, 2000). The emissions to air from production of PeBDE is assumed to be none or negligible (RPA 2000, van der Gon *et al*. 2005).

According to RPA (2000) emissions from polyurethane production are assumed to occur prior to the foaming process when handling the additives (discharges to water) and during the curing (emissions to air). In the phase prior to foaming, releases to waste water are estimated at 0.1 kg/tonne handled PeBDE. Releases to air may also occur during the curing phase of the foam, when the temperature of the foam stays elevated for many hours depending on the production block size. Emissions to air at this phase are estimated to 1 kg/tonne PeBDE, but it is assumed that some of the volatilized PeBDE condenses in the production room ending up in the waste water. RPA (2000) concludes that 0.6 kg of PeBDE is released into waste water and 0.5 kg into air for each ton of C-PeBDE used in PUR production. Global annual production of PUR-foam in 2000 (containing 10-18% of C-PeBDE), has been estimated to be 150,000 tons (Alaee *et al.* 2003). Global annual releases of PeBDE from PUR-foam production are estimated in table 2.2.

Table 2.2 Global production and use of C-PeBDE in PUR-foam production and estimation of associated releases in 2000, PUR-foam containing 10-18% of C-PeBDE.

Production of PUR-foam	Use of C-PeBDE to PUR-foam production	Releases of PeBDE into waste water from PUR-foam production	Emissions of PeBDE into air from PUR-foam production
150,000 tons/year	15,000 – 27,000 tons/year	9,000 - 16,200 kg/year	7,500-13,500 kg/year

Source: Document developed under the Task Force on POPs; Exploration of management options for PeBDE (http://www.unece.org/env/popsxg/5thmeeting.htm)

There is limited information on emissions of PeBDE from manufacture of products other than PUR-foam, but emissions to air are assumed to be negligible. Major releases will be to waste water or solid waste. There is no information on the use of C-PeBDE in manufacturing processes from Eastern European countries outside the EU. Modeling indicates that emissions during manufacture of products containing C-PeBDE are minor in comparison to the consumption.

2.5 Emissions from use of C-PeBDE-containing products

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

Indoor equipment

PeBDE is a component in 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).

Several studies have detected PeBDE 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 PeBDE from PUR-foam, used in furniture (Wilford *et al.* 2005). Experimental data shows that TeBDE and PeBDE 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-PeBDE in older computers (Betts 2006).

PeBDE has been identified as an additive flame retardant in textiles in different national substance flow analyses in the ECE-region (Danish EPA 1999, Norwegian EPA 2003). In a Norwegian substance flow analysis manufacturers of furniture textile have stated that the textile contains 0.45 % PeBDE. Textiles used in the public sector, the transport sector and business sector in many countries have stringent rules for flammability.

C-PeBDE 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). The release of BFRs from products in use will depend on two factors:

- Release of BFRs from the surface
- Migration of BFRs in the polymer

When released from products, the BFRs 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. When the appliances are dismantled for reprocessing some of the dust will be released to the workplace air. Compared to an office environment the exposure from dismantling of the appliances may be several orders of magnitude higher (Danish EPA, 1999).

In RPA (2000) 3.9 % PeBDE of the amount of C-PeBDE present in products was estimated to be released annually through volatilization during their anticipated lifetime of 10 years, using a worst-case scenario. Global annual releases of PeBDE from new use of PUR-foam in articles are estimated in Table 2.3. Similar detailed information for other uses is not found in the literature.

Table 2.3 Global production and use of PeBDE in PUR-foam in products and estimated releases during their service life in 2000 (Metric ton/year).

Production of PUR-foam	**Content of C-PeBDE in PUR-foam**	**Releases of PeBDE during the lifetime of the products**
150,000	15,000 – 27,000	585 – 1,053

Source: Document developed under the Task Force on POPs; Exploration of management options for PeBDE (http://www.unece.org/env/popsxg/5thmeeting.htm)

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 PeBDE can be released to the environment from C-PeBDE-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%). The release can occur during the lifetime of the product (due to weathering, wear and tear etc.) and at waste disposal particularly when products are dismantled or subject to other mechanical processes. This can apply to the following outdoor applications of PVC (RPA, 2000):

- Car undercoating,
- Roofing material,
- Coil coating,
- Fabric coating,
- Cables and wires, and profiles,
- 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 PeBDE 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-PeBDE

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

Waste generated from production of C-PeBDE

In the production of C-PeBDE producers have stated that the major sources of waste release were filter waste and reject material. Waste water releases of PeBDE may also occur from spent scrubber solutions (RPA, 2000). C-PeBDE-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% PeBDE are classified and treated as hazardous waste. Waste from production of C-PeBDE is considered negligible.

Waste generated from manufacturing processes of products containing C-PeBDE

Blocks of PUR foam generally have to be cut into the required size/shape of the final product. This operation usually occurs after the blocks have cured and cooled. For some applications PUR foam can be produced in a mould of the desired shape, and then cutting is not required. 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 slabstock 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. C-PeBDE is no longer used for production of printed circuit boards in most producer countries. The information on the use of C-PeBDE in other manufacturing processes of EE-appliances is too limited to enable the drawing of conclusions about waste generation, but it is known that most of the waste ends up as solid waste. This waste is put into landfills or incinerated, as is waste generated from production of building materials, textiles and furniture.

When products containing C-PeBDE become waste

In the EU, wastes containing PeBDE 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 extrusion of metals the plastic fraction is disposed of or burned in municipal waste incinerators.
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 PeBDE is also put on landfills or incinerated when they end up as waste.

Releases from landfills and incineration

Polymer (foam) particles containing PeBDE 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 PeBDE put on landfill or incinerated in the EU is estimated to be 1,036 tonnes/year (RPA, 2000).
Given the physic-chemical properties of the substance (low water solubility, high octanol-water partition coefficient) it is considered very unlikely that significant amounts of PeBDE 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 PeBDE 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 PeBDE in both gaseous and particulate fractions in the air in the vicinity of the facility. The levels were above background levels of PeBDE (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-PeBDE (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-PeBDE-containing materials.

2.7 Emissions from recycling and dismantling activities

Electrical and Electronic (EE) waste recycling plants

The analyses of dismantled FR2 printed circuit boards in electrical scrap show that about 35% of the PBDE used consists of PeBDE. Based on market information it has been assumed that

25% of FR2 laminates in older appliances were treated with the commercial mixture of PeBDE (Swiss agency 2002).
Prevedouros *et al*. (2004) estimated production, consumption, and atmospheric emissions of PeBDE in Europe between 1970 and 2000 based on literature data. According to their study, the flow of PeBDE 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 PeBDE 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 PeBDE. 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 PeBDEs may be transferred into the environment. In plants with off-gas filtering, around 65% of the PeBDE will be collected (Morf *et al*. 2005).

Studies of the working conditions in recycling plants have detected levels of PeBDE in the indoor air, and indicate that PeBDE 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 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 PeBDE 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 PeBDE 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 Decabromodiphenyl ether (DeBDE) but also PeBDE and tetrabromobisphenol-A (TBBPA). The first step in the recycling of vehicles is fragmentation in a shredder, where the metals are separated from other materials. Plastics, rubber, paper, wood, dirt, etc. end up in several fractions of shredder residues. The plastic parts mainly end up in a fraction called "fluff".
It could be assumed that there are diffuse emissions from shredder plants, but these have not been estimated. The conditions for emissions can be assumed to be similar as for recycling plants of EE-appliances. For plants not equipped with an efficient air pollution control device a significant flow of dust-borne PBDEs may be transferred into the environment. In plants with off-gas filtering a large portion of PeBDE will end up in the collected fraction of the gas.

Dismantling of buildings and other constructions

In Switzerland, 5% of the PUR insulating foams produced in 1990was used in the building industry and contained 220 g/kg PeBDE (Swiss agency 2000).
Thermoplastic sheeting used to be treated with BFRs at concentrations between 1.3 and 5% by weight. According to a study for Denmark, 10 – 20 % of the plastic sheeting used in bridges and underground structures are possibly treated with flame retardants (Danish EPA 1999). There are indications of use of PeBDE in PVC plastic sheetings. There is no detailed information on the use of BFR. In the substance flow analysis made in Switzerland, 5% of products produced in 1990 with PVC plastic sheeting were assumed to contain PeBDE. The amount of PeBDE was estimated to be 49 g/kg PVC sheeting. Emissions of dust-borne PeBDE 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 Identification of possible control measures

There are in principle several control measures that could be implemented to reduce the use of C-PeBDE and/or reduce the environmental impacts associated with the use of the substance. The control measures are:

- *Voluntary commitments by industry* to reduce the environmental impacts associated with the use of C-PeBDE by reducing their production and/or use. Commitments have been successfully implemented in some countries, where industry voluntarily has phased out the production of PeBDE. It is likely that this measure works well when the actions needed are cheap, and/or it is obvious to the industry that it is facing a long term phase-out of the substance.

- *A ban/restriction on the use of C-PeBDE,* either as a whole or on a sectoral basis through both unilateral and multilateral fora. This could either be an outright ban on use in all sectors, in some products or restrictions on the concentrations in products. If agreed on by a sufficient number of countries this could be an effective measure if properly enforced. Some countries have already taken such actions.

- *Eco-labeling schemes*, which either requires that products containing PeBDE are labeled or more likely that products containing less harmful substances are given an eco-friendly label. This would inform users about the most environmental-friendly products, enabling them to choose these products if they want.

- *Economic instruments* like taxes on sales of C-PeBDE or taxes on sales of products containing the mixture. Alternatively trading of permits to buy and use C-PeBDE could be implemented. Both these instruments would give users economic incentives to reduce use of the substance.

- *A deposit-refund system for C-PeBDE,* implying that a deposit (tax) is paid by the buyer of a product containing C-PeBDE, which is wholly or partly refunded when the buyer returns the product to a certified waste treatment facility when it should be no longer used. This could be an effective measure to ensure proper waste handling and reduce release to the environment when a product ends up as waste, but would require identification of those wastes containing C-PeBDE. However, since national and regional bans already in place will reduce the amount of C-PeBDE entering the market, such a tax is unlikely to generate funds on the scale required for dealing with legacy problems.

- *Various control measures at the production or waste handling facilities* ensuring safe work environment 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-PeBDE, at the plants using C-PeBDE 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.

The properties of the different control measures are discussed below.

3.2 Efficacy and efficiency of possible control measures in meeting risk reduction goals

General considerations

Since the components of C-PeBDE of concern are released to the broader as well as the work environment during the manufacturing process of the mixture, when C-PeBDE is blended into products, during the lifetime use of the product and when the product ends up as waste, several control measures might have to be applied to reduce release of the components of C-PeBDE to the environment.

The choice of control measure for the remaining use of C-PeBDE and emissions of its components must take into account that most developed countries have phased out production of C-PeBDE, and that the ultimate long term goal is to phase out the global production and use of C-PeBDE and emissions of its components. 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.

Voluntary commitments and eco-labeling schemes can yield reductions in use of C-PeBDE and emissions of its components with rather low costs for producers at an early stage of a phase out process. They can stimulate reduced use of C-PeBDE in areas where costs are low, and voluntary schemes have been successfully used in several countries to reduce use of C-PeBDE. These measures could eventually also contribute to reductions in countries where so far few or no actions are taken to reduce the use of C-PeBDE. However, the global effectiveness of voluntary measures depends on the culture of the particular society, which is often influenced by experience, and these factors will be especially important when considering the adoption of measures in developing countries. The willingness among the affected industries to take necessary action to limit global use of C-PeBDE will also be important. Free riders tend to be a problem in many of the voluntary schemes that have been tried to curb emissions of various substances in the developed countries. Since the ultimate goal is to phase out C-PeBDE, other measures seem more likely to be effective at this stage.

Economic instruments could ultimately lead to a phase out of the use of C-PeBDE if the tax or permit price are high enough to make switching to alternative solutions profitable Economic instruments have not proved effective in most developed countries when a total phase-out over short time is required, and have not been used for substances with the high level of concern of POPs. The experiences with their practical use are limited in most developing countries. It would therefore complicate things to introduce this measure. Since use of economic instruments is not at present allowed under the Stockholm Convention, further consideration should not be given to such measures.

Standards aiming at reducing the concentrations of C-PeBDE in products or for instance using additional additives would not be very effective, since concentrations have already been minimized to the degree possible to minimize costs (RPA, 2000). Besides, this measure would only target some parts of the value chain for C-PeBDE, leaving out important sources for

release to the outer and work environment. However, standards could be used to ensure environmentally benign waste handling.
It seems that in the current situation a global ban on production and use of C-PeBDE by listing the substance under the Stockholm Convention would be the most appropriate measure. Since suitable, more environmentally benign alternatives exist for all use of C-PeBDE (see below), a ban should cover all sectors. Eventually, some very special uses of C-PeBDE where alternatives are not efficient enough and/or very costly could be exempted for a time-limited transition period. However, it must be considered whether a ban could lead to substitution of C-PeBDE with other environmentally harmful substances and if this should warrant any action. A ban would eliminate emissions from the manufacturing of C-PeBDE, and also eliminate release from the production and use of C-PeBDE in new products. It would ensure that there would be no new production and use of C-PeBDE in the future. But it would not affect the emissions from C-PeBDE in products already in use. For most products the use of C-PeBDE as a flame retardant has already been replaced by other more environmentally friendly flame retardants, with some producers taking voluntary action ahead of regulation. Substitution has largely occurred in the developed countries. One country has reported need for an exemption for use of C-PeBDE in military aeroplanes, due to the lack of alternatives that meet the special demands for fire safety. Some time could be allowed for testing and technical modifications to develop alternatives and to be able to meet the special demands on fire safety in products with special needs. This would require a phase out plan for the use of these products, which would be warranted under Annex B of the Stockholm Convention, although listing in Annex A with time-limited exemptions would serve the same end.

Waste handling

A ban on production and use of C-PeBDE 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-PeBDE 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.
Article 6 clearly bans recycling of products and articles containing C-PeBDE if it results in new use of C-PeBDE as a constituent of new articles. Recycling and reuse of plastic material containing BFRs has been practiced but this would no longer be allowed if C-PeBDE were present in the new material at more than trace levels. This would be especially important for recycling of electronic articles containing C-PeBDE and for shredder plants with more diverse inputs, and so the consequences for this type of industry may need to be considered further.
A special challenge could be to separate C-PeBDE-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-PeBDE in the past and 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 national information about C-PeBDE content in different articles becoming waste.
Also, targets for phase out of the use of existing products containing C-PeBDE and the collection of these could be considered according to Annex B of the Convention.
Since there are substantial stocks of products containing C-PeBDE 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-PeBDE 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-PeBDE-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-PeBDE-containing articles, treat the various parts and the methods of environmentally sound treatment of the final C-PeBDE.

3.3 Information on alternatives (products and processes)

There are three ways to provide flame retardancy in products without using BFRs:

- substitute them with another flame retardant in a given material (i.e. plastic or foam);
- substitute them with another flame retardant in a different type of plastic or foam; or
- redesign the product so that there is no need for using flame retardants.

With the phasing out of C-PeBDE in important markets, manufacturers are actively identifying alternatives. Some companies, such as IKEA, have already phased out all C-PeBDEs 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.
The alternative flame retardants for C-PeBDE listed in Table 3.1 are mostly gathered from companies and all the chemicals listed are already in use. The human health or environmental impacts of these alternatives have not been investigated by the authors. For example, hexabromocyclododecane listed in Table 3.1 as an alternative for C-PeBDE 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, tri (2-chloroisopropyl) phosphate (TCPP) in particular, followed by phosphate esters, are relevant chemical alternatives to PeBDE. However, since that time other alternatives may have been developed and commercialized and should also be considered.

Table 3.1 Alternative flame retardants for C-PeBDE by substrate.

Substrate (material, or matrix, in which the flame retardant is used)	**Products in which the substrate is used in flame retardant quantity**	**Alternative flame retardants in commercial materials**	**Alternative materials: Non-flammable or containing halogen-free flame retardants**
Epoxy	• Printed circuit boards • Electronic component encapsulation • Technical laminates	•Reactive nitrogen and phosphorus constituents • Ammonium polyphosphate • Aluminium trihydroxide	• Polyphenylene sulphide
Unsaturated polyester	• Technical laminates • Plastic parts in Transportation	• Ammonium polyphosphate • Aluminium trihydroxide • Dibromostyrene •Tetrabromophthalic anhydride-based diol •Tetrabromophthalic anhydride •Bis (tribromophenoxy) ethane	None identified
Rigid polyurethane foam	• Insulation of cold storage plants/freezing rooms, pipes, etc.	• Ammonium polyphosphate • Red phosphorus • Tetrabromophthalate diol •Tetrabromophthalic anhydride-based diol • Bisphosphate	• Some applications: mineral wool or other technical solutions

Flexible polyurethane Foam	• Furniture • Components in Transportation	• Ammonium polyphosphate • Melamine • Reactive phosphorus polyols •Tetrabromophthalic anhydride derivative • Bromo-alkyl phosphates • Reofos NHP (halogen-free phosphorus flame retardant) • Bisphosphate	None identified
Laminates		• Triaryl phosphate isopropylated	None identified
Adhesives		• Tetrabromophthalate diol •Tetrabromophthalic anhydride based diol • Hexabromocyclododecane • Reomol® TOP • Bis (tribromophenoxy) ethane	None identified
Coatings		• Tetrabromophthalate Diol •Tetrabromophthalic anhydride based diol • Hexabromocyclododecane • Triaryl phosphate • Bis (tribromophenoxy) ethane	None identified

Source: Washington state (2006)

Alternatives to C-PeBDE in PUR foam

The US EPA Design for the Environment completed an assessment of alternatives to PeBDE 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 PeBDE 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 PeBDE in large-scale production of low-density flexible polyurethane foam, see Table 3.2. The US EPA assessed the hazards, potential exposures and tendency to bioaccumulate and to persist in the environment for the chemicals in each formulation. The alternatives are drop-in replacement chemicals for PeBDE. Existing storage and transfer equipment as well as foam production equipment can be used without significant modification. Alternatives compatible with existing process equipment at foam manufacturing facilities are the most cost effective, because they do not require the plants to modify their processes or purchase new equipment. The assessment looked into hazardous effects, persistence and bioaccumulation. The report did not assess the environmental impact of the use of those alternatives to the use of PeBDE, and was mainly focused on comparison of the impact of use in the production process of PUR-foam. The levels of bioaccumulation and persistence reported for the identified chemical formulations were low or moderate, with an exception for organic phosphate esters, which have high persistence, The assessment assigned high aquatic toxicity concern to most of the alternatives and low or moderate concern for human health effects.
Most of the commercial products were mixtures, and some information about constituents is included in Table 3.2.

Table 3.2 Alternative Flame-Retardant Chemical Formulations

Albemarle Corporation	**Ameribrom, Inc. (ICL Industrial Products)**	**Great Lakes Chemical Corporation**	**Supresta (Akzo Nobel)**
SAYTEX® RX-8500 *Proprietary reactive brominated flame*	FR 513 *Tribromoneopentyl alcohol*	Firemaster® 550 *Proprietary halogenated aryl esters, proprietary*	Fyrol® FR-2 *Trs(1,3-dichloro-2-propyl) phosphate*

retardant, proprietary aryl phosphate, triphenyl phosphate CAS 115-86-6	*CAS 36483-57-5*	*triaryl phosphate isopropylated, triphenyl phosphate*	*CAS 13674-87-8*
SAYTEX® RZ-243 *Proprietary tetrabromophthalate, proprietary aryl phosphate, triphenyl phosphate*		Firemaster® 552 *Proprietary halogenated aryl esters, proprietary triaryl phosphate isopropylated, triphenyl phosphate*	AB053 *Tris(1,3-dichloro-2-propyl) phosphate*
ANTIBLAZE® 195 *Tris(1,3-dichloro-2-propyl) phosphate CAS 13674-87-8*			AC003 *Proprietary organic phosphate ester, triphenyl phosphate*
ANTIBLAZE ® 205 *Proprietary chloroalkyl phosphate, aryl phosphate and triphenyl phosphate*			AC073 *Proprietary aryl phosphates, triphenyl phosphate*
ANTIBLAZE® 180 *Tris(1,3-dichloro-propyl) phosphate CAS 13674-87-8*			
ANTIBLAZE® V-500 *Proprietary chloroalkyl phosphate, aryl phosphate and triphenyl phosphate*			
ANTIBLAZE® 182 *Proprietary chloroalkyl phosphate, aryl phosphate and triphenyl phosphate*			

Source: US EPA (2005)

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. Chemical companies and foam manufacturing facilities have experimented with their use in low-density flexible foams with moderate success. Generally the use of these chemicals either results in scorching of the foam (a discoloration and indication of localized overheating during production) or a negative effect on the physical properties of foam. Also, many formulations of these chemicals are available only as solids, making them less desirable as drop in substitutes for PeBDE. Since the commercial mixture PeBDE is liquid, addition of a solid flame retardant may require changes such as additional mixing steps and alteration of the process times. In some cases, these changes can have significant effects on foam quality or cost-effectiveness of production.

Three of the most commonly used chemicals that various reports have suggested may be viable alternatives to PeBDE are melamine, tris(1,3-dichloro-2-propyl) phosphate (TDCPP) (or TCPP) and ammonium polyphosphate (APP). There are numerous international manufacturers of melamine and its derivatives, which are non-halogenated flame retardants, typically supplied as a crystalline powders. 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. However, melamine and its derivatives display several toxic effects. These include changed electrolyte composition of urine, teratogenic effects in fertilized rainbow trout eggs, and reproductive effects in snails and houseflies (Daugherty 1982). Melamine also caused chronic injury to the male rat bladder due to stones formed during exposure to the chemical which correlated strongly with carcinoma (Danish EPA 1999).

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. TDCPP has been identified as having moderate hazard concerns for persistence, acute and chronic ecotoxicity, reproductive and developmental effects, genotoxicity and carcinogenicity (US EPA 2005).
APP is an additive flame retardant containing nitrogen and phosphorus, typically supplied in a crystalline form. It is currently used to provide flame retardancy in flexible and rigid polyurethane foams, as well as in intumescent laminations, molding resins, sealants and glues. APP does not accumulate in the food chain but metabolizes into ammonia and phosphate. It is not thought to be acutely toxic to humans (Leisewitz *et al*. 2000). However, chemical manufacturers and foam manufacturing trade groups do not consider it to be an alternative for PeBDE on a large scale. Reasons for this are that APP is typically incorporated as a solid, it has adverse effects on foam properties and processing and it is not considered to be as effective as a fire retardant compared to other alternatives.
White foam has become the industry standard for flame-retarded, low-density foam in the mattress and bedding industries, and in many upholstered furniture applications in the United States. While the colour of the foam, however, is not a determinant of its flame retardancy, manufactures seem to be reluctant to use discoloured/scorched foam for many applications because this is an indication of thermal stress on the foam which may lead to premature failure of the foam during its service life. Greater acceptance of discolored foams would allow manufacturers to choose from a wider variety of alternative flame retardants. Barrier fabrics are allowing mattress manufacturers to mask the colour.

Non-chemical alternatives to C-PeBDE in PUR foam

Non-chemical alternatives are also identified in 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 there is considerable interest in future applications of these technologies for the furniture industry as well.

In addition to the following technologies, 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. Flame-retardant barrier materials can be a primary defence in protecting padding for furniture and mattresses. Manufacturers can layer barrier materials to improve the flame retardancy of their products. This layering approach allows a product to maintain its fire resistance even if one layer is compromised. There are many types of barrier materials available, and some layers in the composites may be chemically treated to improve flame retardancy. Fabrics composed of natural fibres such as cotton may be chemically treated with phosphonitrilic chlorides, for example, but any hazards associated with these chemical treatments have not been assessed in this report.

Fabrics composed of synthetic fibres that are inherently flame retardant are also flame-retardant barrier materials. Plastic films derived from flame-retardant resins are also flame-retardant barrier materials. These materials are designed and manufactured to meet specific flammability standards. This also explains the large number of flame-retardant barrier materials that are available. Flame-retardant barrier materials can be characterized by cost, resulting in three primary groups. The first group of flame-retardant materials is the chemically treated, primarily boric acid treated, cotton-based materials. These materials are the least expensive flame-retardant barrier materials available. Mattress manufacturers that base their material decisions predominantly on cost prefer these flame retardants. Though estimates of exposure assume that use of boric acid-treated cotton will not significantly increase boron intake by the wearers, there is no information available on the release of boron in dust form consumer items (Leisewitz *et al*. 2000). The second group of flame-retardant materials is a blend of inexpensive natural fibres and expensive synthetic fibres. Synthetic fibres used in these blends include VISIL, Basofil, Polybenzimidazole, KEVLAR, NOMEX and fiberglass. Smaller manufacturers of furniture and mattresses in niche markets use these materials. These blends are commonly used in bus and airplane seating. The third group of flame-retardant materials is composed solely of expensive, high-performance synthetic fibres. They are generally used in industrial or high-performance applications such as firemen's coats and astronaut space suits.

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-PeBDE in EE-appliances

As of mid-November 2005, a number of big manufacturers were phasing out all PBDEs. Examples of alternative flame retardants processes currently being utilized include:

- Bromine-free circuit boards for TVs, VCRs and DVD players (Sony).
- Phosphorus-based flame retardants for printed circuit boards (Hitachi).
- Flame resistant plastic without deca-BDE (Toshiba).
- Halogen-free materials and low-voltage internal wires (Panasonic/Matsushita).

Manufacturing firms expects increased costs due to compliance with the EU ban on use of hazardous chemicals in EE-appliances, including PeBDE 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).
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-PeBDE in textiles

There are bromine-free flame retardant alternatives. Some of them are not environmentally sound, such as antimony trioxide and borax. There are also durable flame retardant materials, such as wool and polyester fibres. Some manufacturers claim that a ban on the use of C-PeBDE in textiles will give poorer quality and durability of the textile.
Table 3.3 Bromine-free flame retardant chemicals for textiles.

Textile	**Alternative flame retardants in commercial materials**
PVC, plastic coating of worker clothes	Antimony trioxide
Working clothes, Uniforms for off-shore, electricity plants, military sector, police, health sector	Tetrakishydroxymethyl phosphonium chloride (THPC)
	Phosphonitrilic chloride (PNC)
Cotton/polyester (bedclothes, clothing, worker clothes, protective clothing) used in public institutions, the off-shore sector, ship and hotels)	Pyrovatex (organic phosphorous compounds)
Cotton/polyester (worker clothes, protective clothing) used in the off-shore sector, ship and hotels	Proban (organic phosphorous compounds)
Carpets, textiles in the transport sector	Aluminium hydroxide
Tent, tarpaulin	Aluminium hydrate
Furniture textiles in the health sector, offices, industry and transport sector	Ammonium compounds
	Nitrogen phosphonic acid salt
	Zirconium acetate
Furniture for living room and bedroom	Borax
	Melamine

Source: Norwegian EPA (2003)

Table 3.4 Durable inherent flame retardant materials

Material	**Application**
PHD-cold foam	Mattresses and furniture
Flame retardant polyester fibre (Trevira CS)	Curtains, table clothes in public institutions, schools, vehicles, oil rigs
Wool	Furniture textiles for domestic use
Mixed fibres wool and cellulose	Bed clothes to baby carriages and beds

Source: Norwegian EPA (2003)

3.4 Summary of information on impacts on society of implementing possible control measures

Benefits of phasing out C-PeBDE

The most obvious benefits to the global society of phasing out C-PeBDE would be reduced releases to air, water and soil of the substance, as well as releases in workplace settings (UNEP, 2006). The major part of the releases of PeBDE ends up in soil and sediments, since in the environment the substance is bound to particles. PeBDE 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. Levels of PeBDE have been found in humans in all regions of the world (UNEP, 2006).

Most trend analyses show a rapid increase in concentrations of PeBDE in the environment and in humans from the early 1970s to the end of the 1990s. In the US, where PeBDE was in high use until recently and where it remains in such materials as polyurethane foam incorporated into consumer products, there has been a build-up in human tissue. Components found in C-PeBDE appear in a number of ecosystems and species, including several endangered species. Some individuals of these species show levels high enough to be of concern. The potential for the toxic effects in wild life, including mammals, is evident. Potential exposure of humans is through food, use of products containing C-PeBDE, and contact with indoor air and dust. PeBDE transfers from mothers to embryos and lactating infants. UNEP (2006), in its assessment, concludes that PeBDE 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.

When considering phasing out C-PeBDE, there is also a need to weigh the potential risk of further production and use of the substance against the potential risk of production and use of alternative substances. This is particularly the case when it comes to the use of PeBDE as flame retardant. Fire prevention is important to protect human safety and avoid social and economic losses due to fire. Thus, to the extent that the alternative substances are less efficient at preventing flames and fires, there would be a loss for society of replacing PeBDE with these less efficient substances. In addition, many toxic substances are released during fires; hence fire prevention can yield environmental benefits. Using less flame retardant substances could therefore yield an environmental loss if fires become more frequent. However, according to US EPA (2005), the available alternatives function as well as PeBDE. The discussion above leads to the conclusion that most of the alternatives are in themselves less hazardous to the environment than PeBDE. Indeed, few of the substitutes are classified as dangerous for the environment, though complete information is lacking in many cases. It is hard to find reliable assessments of the net environmental benefits of substituting PeBDE with other substances, because – among other reasons - of various properties of the substances and the increased amounts that will be needed to replace PeBDE. The criteria for assessing possible candidate substances have been published by the Danish EPA (1999)

Lack of data makes it impossible precisely to assess and quantify the overall net benefits of phasing out C-PeBDE. However, given the documented harm associated with PeBDE in the environment, its persistence and bioaccumulation, and given that most developed countries have already phased it out, there can be little doubt that the overall benefits are considered positive.

Costs of phasing out C-PeBDE

The incremental costs for *users* of C-PeBDE of replacing it with other substances in their products or re-designing the product itself to eliminate the need for additives would obviously have to be considered. Each affected plant would have its own suite of costs incurred by the phase out of C-PeBDE, so it is hard to make an overall assessment with any accuracy. Some producers 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-PeBDE. However, for some alternatives there may be an increase in costs associated with a need for higher loads (RPA, 2000).

Listing C-PeBDE 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-PeBDE. For those countries who have not yet adjusted their waste handling practices for C-PeBDE, 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. We have not seen reliable figures for the estimated costs of phasing out C-PeBDE, but most studies state that these cost are “low”. Allied to this economic analysis is the fact that most users in developed countries have phased out C-PeBDE seemingly without any great challenges.

Potential incremental costs of using alternative substances should be included in the analysis. In addition, an estimate might be made, albeit with great difficulty, of the reduced cost of damage to ecosystems and to public health when materials like C-PeBDE are removed from the market. 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. Legacy problems such as that likely to be posed by the presence of PeBDE in the environment do not lend themselves to management under the terms of the Polluter Pays Principle since the original 'polluter' often cannot be identified or is no longer in business.

It could be discussed whether the costs for *producers* of C-PeBDE 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.

Costs incurred by national governments related to regulation, enforcement and compliance activities should be included in the assessment. No such cost figures are found, but overall costs are likely to be low in developed countries where the systems for monitoring and control activities are in place. However, the costs could be considerable for developing countries without these systems. On the other hand the implementation of the Stockholm Convention will require these systems to be established, and cannot be considered a cost for listing C-PeBDE. It could however be extra costs for the waste handling of products and materials containing C-PeBDE .

3.5 Other considerations

All Parties to the Convention would be responsible for the monitoring and enforcement of a worldwide ban on the production and use of C-PeBDE if it were to be listed as a POP. It should be relatively simply to control the production, export and imports of C-PeBDE,, but the same cannot be said about production, export and import of products and materials that contain PeBDE (RPA, 2000). Most developed countries have the required systems to deal with those problems, but it could be an extra cost for developing countries, if C-PeBDE is listed. The treaty does not ban products already in use, but poses an obligation on proper waste handling. This could also imply extra costs for developing countries. It could be extremely difficult and expensive to quantify the chemicals in products. But because of national and international standards for fire safety for some product groups, the industry already have the obligation to have this knowledge. There is also an expanding amount of knowledge about use in products, from surveys in the developed world. The threat of infringers being excluded from the world market should discourage producers from placing such products on the market. Most of the alternatives are less-than or as expensive as C-PeBDE, and there should therefore be less economic incentives to produce new products containing C-PeBDE. For electric articles it has been found to be impractical and costly to divide the product streams, to apply with the ban in EU. The market is therefore already phasing out use of banned BFR in electric articles globally. National authorities would have to make surveys to get more detailed national information about C-PeBDE content in different articles becoming waste. Monitoring and control with the ban could be done through spot tests, aiming on distributors and producers. But the development of more appropriate methodologies for determining the chemical species present in new flame retarded consumer goods and other products would facilitate a ban.

According to the Bromine Science and Environment Forum, all developed countries have in place monitoring and control capacities as well as legislative tools to restrict the use of C-PeBDE. Thus, the main challenge in this area would be for the developing countries to get sufficient capacities in place.

4. Synthesis of information

4.1 Summary of evaluation

Pentabromodiphenyl ether (PeBDE) is a brominated flame retardant (BFR). BFRs are a group of brominated organic substances that inhibit or suppress combustion in organic material. They have been used almost exclusively in the manufacturing of flexible polyurethane (PUR) foam for furniture and upholstery in homes and vehicles, packaging, (non-foamed) PUR in casings and electronic equipment (EEE). To some extent they have also been used in specialized applications in textiles and in various other uses.

Because of its chemical and toxic properties and wide spread occurrence in the environment and in humans, PeBDEs causes concern in many regions of the world. The substance has shown to be persistent and bioaccumulative, and thus a potential risk for future generations. Concentrations in wildlife and in humans have also increased significantly. Those findings have resulted in voluntary and regulatory phase-outs of this compound in several regions of the world. Most developed countries have either banned the production and use of PeBDE or put restrictions on use.

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. Until now, brominated flame retardants have been the cheapest and therefore considered to be the most efficient in cost-effectiveness terms. However, it has become increasingly common to replace these substances either with flame retardants without bromine, or to change the design of the product so that there is no need for the continued use of chemical flame retardants. It has also become important to avoid the use of products containing flame retardants if such is not absolutely necessary on the basis of fire safety.

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

4.2 Elements to a risk management strategy

Since the dissemination of PeBDE into the environment is a global, transboundary problem, global actions to phase out C-PeBDE should be considered. A global ban on production and use of C-PeBDE covering all sectors, to be achieved by listing C-PeBDE 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-PeBDE (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 of PeBDE. Most national regulations concern compounds. It will therefore be more practical, rather than listing C-PeBDE under the Convention, as was earlier envisaged by the POPRC, to **list brominated diphenylethers with 4 or 5 bromines**. All mixtures with one of the isomers of Tetrabromodiphenyl or Pentabromodiphenyl ether 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. Complete coverage of the components of the C-PeBDE would require also the listing of Hexabromodiphenyl ether, with the same lower limit, since it can comprise up to 12% of the commercial product. This could be an issue for the listing of commercial Octabromodiphenyl ether, which also contains appreciable amounts of the HeBDE.

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

A ban would eliminate emissions from the manufacture of C-PeBDE and products containing it. It would not affect the emissions from C-PeBDE in products already in use. Recycling and reuse of products containing C-PeBDE would not be allowed, if it results in new use of the isomers of TeBDE or PeBDE as a constituent 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 isomers of TeBDE and PeBDE. 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-PeBDE is inadvertently released to the environment. This would especially be important for recycling of electronic articles containing C-PeBDE 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. These source categories could be added to Annex C.

Consideration was given to listing of brominated diphenylethers with 4 or 5 bromines in Annex B, with targets to be set for the phase out of the use of specific existing products containing C-PeBDE. However, collection of such products would be a major task and the likely complexity of such schemes militated against such a recommendation. The general rules on waste handling in the Stockholm Convention will, of course, apply to C-PeBDE once brominated diphenylethers with 4 or 5 bromines is listed.

Waste fractions containing C-PeBDE 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. Ways to ensure collection of articles containing C-PeBDE, and the setting of targets, should therefore be left to each country.

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 Convention into consideration, including the general guideline on waste handling for POPs in the Basel Convention. The listing under the Stockholm Convention will imply the development of a guideline for waste containing the isomers of TeBDE and PeBDE under the entity of Basel, that have to be considered as well.

5. Concluding statement

Having evaluated the risk profile for C-PeBDE, and having concluded that this chemical is likely, as a result of long-range environmental transport, to lead to significant adverse effects on human health and the environment, such that global action is warranted, this risk management statement has been prepared in accordance with the content specified in Annex F of the Convention.

In order to ensure that listing under the Convention achieves the aim of preventing the use of the hazardous components of the C-PeBDE mixtures, the Committee recommends to the Conference of the Parties to the Stockholm Convention that, in accordance with paragraph 9 of Article 8 of the Convention and specifying the related control measures, brominated diphenylethers with 4 or 5 bromines be listed in Annex A.

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