Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan:

Interim Plan

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Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: *Interim Plan*

by
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Executive Summary

This "Interim Chemical Action Plan for PBDEs" identifies actions the state may take to reduce the threat of PBDEs (polybrominated diphenyl ethers) in the environment. In his Executive Order of January 2004, Governor Gary Locke directed the Department of Ecology (Ecology), in consultation with the Department of Health (DOH), to develop a plan to reduce the threat of PBDEs in the environment.

The most current scientific information about the environmental and human health risks of PBDEs has been thoughtfully reviewed in the development of this plan, as have the experiences of other states and Europe where policies to reduce PBDEs have been crafted. After many months of study, after consulting with some of the leading researchers in the field, and after hearing from hundreds of concerned residents and groups, Ecology and DOH have outlined steps contained within this plan that will reduce the impact of PBDEs on human health and the environment.

This Interim Plan includes revisions to the Draft Chemical Action Plan released in October 2004. Changes were based on comments received during the public comment period and from the External Advisory Committee that has guided Ecology and Health throughout the development of this document. Ecology and DOH will release the final PBDE Chemical Action Plan in December 2005.

Definition and Use

PBDEs are members of a broader class of brominated chemicals used as flame retardants. They are often added to plastics, upholstery fabrics and foams in products as common as computers, TVs, furniture and carpet pads. There are three main types of PBDEs used in consumer products: Penta-BDE, Octa-BDE and Deca-BDE. Each of these types of PBDEs has different uses and different toxicity. Manufacturers of Penta-BDE and Octa-BDE have agreed to voluntarily stop producing these two forms of PBDEs by the end of 2004. Deca-BDE is not part of this agreement and currently makes up 80 percent of overall PBDE use in the US.

Flame retardants like PBDEs are added to products so that they will not catch on fire or burn so easily if exposed to flame or high heat. Fires are a leading cause of death and injury in the U.S. Most plastic and foam are petroleum based and catch fire easily. Strict fire safety regulations in the U.S. require manufacturers to take steps to reduce the flammability of their products. Actions proposed by Ecology and Health with respect to limiting the use of PBDEs were considered within the context of ensuring adequate levels of fire protection.

Human Health and the Environment

In recent years PBDE flame retardants have been found in the environment, in foods and in people. PBDEs have been measured in blood, fat and breast milk in people around the world. The highest levels of PBDEs in people have been found in Canada and in the U.S., which are the largest producers and consumers of PBDE products. The components of the Penta and Octa-BDE formulations are those most often found in food and people while Deca-BDE is more prevalent in sediment and indoor dust. Although PBDEs have been detected in everything from food to indoor air and dust, exactly how people are exposed to PBDEs is an area of ongoing study. PBDEs build up in the body because they reside and persist in fatty tissue.

Concern about the human health risks from exposure to PBDEs comes from studies of animals in laboratory settings. The health effects of PBDEs have not been studied in humans. Results of studies with laboratory animals suggest that exposure to PBDEs in the womb can disrupt neurological development. This kind of damage causes altered behavior, learning and memory. Decreases in thyroid hormone and reproductive problems are also seen in laboratory animals. Most of these studies point to the components of Penta- and Octa-BDE formulations as being of primary concern with respect to human health. Deca-BDE is the least toxic of the three forms but may degrade into the more toxic Penta-BDE or Octa-BDE components.

It is important to understand that the mere presence of chemicals does not necessarily represent a health risk. Although PBDEs are present in people and many foods, these levels have not yet reached those shown to be toxic in lab animals and do not pose an immediate health threat. If PBDE levels continue to rise, however, real health risks can be expected, particularly for our children. Therefore, Ecology and DOH propose the following recommendations to reduce the impact of PBDEs on both human health and the environment.

Recommendations

Recommendations for reducing PBDEs in the environment and for protecting human health are detailed in the body of this plan. Many of the policy options that were considered are also presented and the rationale for the policies recommended is provided. Key recommendations are summarized as follows.

- The Washington State Legislature should prohibit the manufacture, distribution (but not transshipment) or sale of new products containing Penta-BDE and Octa-BDE in Washington state by July 2006. The ban may include an exemption for new products that contain recycled material from products that contained Penta-BDE and Octa-BDE, pending further review.

- Ecology and DOH, in consultation with stakeholders, should develop a proposal for a ban on appropriate products containing Deca-BDE, with recommendations by December 2005. Twelve months time would allow the agencies to determine how to ban Deca-BDE in a way that does not jeopardize fire safety, unnecessarily burden Washington businesses, or prompt the use of alternative flame retardants that might be equally or more harmful.

- Ecology should establish, by July 2006, appropriate disposal and recycling practices for products containing PBDE flame retardants.

Interim Plan

- Ecology and DOH should work with other states and interested parties in a dialogue toward improving U.S. chemical policy. Current U.S. chemical policy has resulted in only minimal testing of many chemicals currently in use.

- The state's purchase of PBDE products should be restricted in appropriate contracts, consistent with Executive Order 04-01.

- Health should develop methods and materials for education on how the public can minimize exposure to PBDEs. This will include information on the benefits of breastfeeding and advice about eating fish as part of a healthy diet. DOH continues to recommend breastfeeding as the best choice for feeding infants and encourages Washingtonians to eat a variety of fish as a good source of protein and beneficial fatty acids.

- The state Department of Labor and Industries (L&I) should develop and communicate ways for employers and employees at large to minimize exposure to PBDE-containing dust using standard industrial hygiene controls.

- DOH and L&I should continue to investigate the feasibility of implementing a workplace exposure study in collaboration with the federal Centers for Disease Control and Prevention.

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Acronyms and Abbreviations

ABS	acrylonitrile butadiene styrene
BDE	brominated diphenyl ether
BFR	brominated flame retardant
CEPA	Canadian Environmental Protection Act
CPSC	Consumer Product Safety Commission
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EIA	Electronic Industries Alliance
EICTA	European Industry Association for Information Systems, Communication Technologies and Consumer Electronics
EPDM	ethylene-propylene terpolymer
HIPS	high-impact polystyrene
IWGFM	Interagency Working Group on Fire and Materials
JGPSSI	Japanese Green Procurement Survey Standardization Initiative
L&I	Washington State Department of Labor and Industries
LDPE	low-density polyethene
PBDE	polybrominated diphenyl ether
PBDF	polybrominated dibenzofuran
PBT	persistent bioaccumulative toxin
POP	persistent organic pollutants
PSAMP	Puget Sound Ambient Monitoring Program
RFP	requests for proposal
RoHS	Restriction on Hazardous Substances
SNUR	Significant New Use Rule
TERT	Toxics Exposure Reporting and Tracking Review
THF	tetrahydrofuran
WEEL	Workplace Environmental Exposure Level

I. Introduction

The Draft PBDE Chemical Action Plan (CAP) is a joint document of the Washington State Department of Ecology (Ecology) and Department of Health (DOH). This is the second chemical action plan developed as part of Ecology's Persistent, Bioaccumulative Toxin (PBT) Initiative. The purpose of this document is to identify actions the state may take to reduce threats posed by the class of flame retardants known as polybrominated diphenyl ethers (PBDEs).

In January 2004, Governor Gary Locke issued Executive Order 04-01, directing Ecology, in consultation with the DOH, to immediately develop a chemical action plan for PBDEs and to recommend actions by December 1, 2004. Implementation of the plan is to begin no later than July 1, 2005.

In the 2004 supplemental budget (Engrossed Substitute House Bill 2459), the state Legislature provided $83,000 solely for the development of a chemical action plan for the chemical compounds known as PBDEs (polybrominated diphenyl ethers).

The development of the Draft PBDE CAP was managed by the PBT Steering Committee. The PBT Steering Committee is a joint standing committee of Ecology and DOH. Members from Ecology include the deputy director, the director of governmental relations, the director of communication and education, and the managers of the Air Quality, Environmental Assessment, Hazardous Waste and Toxics Reduction, Solid Waste and Financial Assistance, Toxic Cleanup, and Water Quality programs. From DOH, the director of the Office of Environmental Health Assessments is a member of the PBT Steering Committee.

In February 2004, Ecology hired a staff person to write the PBDE CAP, and research on the topic began. In March, Ecology and DOH formed a joint Technical Committee with members from DOH's Office of Environmental Health Assessments and the following programs within Ecology: Air Quality, Communication and Education, Environmental Assessment, Hazardous Waste and Toxic Reduction, Solid Waste and Financial Assistance, Toxic Cleanup, and Water Quality. During the summer and fall, the Technical Committee was informally expanded to include staff from the Safety & Health Assessment & Research for Prevention (SHARP) program at the Washington State Department of Labor and Industries (L&I).

The Technical Committee met weekly to develop a broad understanding of PBDEs, including their use, possible alternatives, potential environmental pathways, regulatory structure, and environmental and health impacts. Based on this understanding, the Technical Committee developed a list of policy options to minimize threats posed by PBDEs. The options were then evaluated to form a list of recommended actions. At each step in the process, the Technical Committee received advice from an External Advisory Committee, described below, and by direction from the PBT Steering Committee. At critical points in the plan's development, the Technical Committee also received direction from Ecology's Senior Management Team, consisting of the director and senior staff.

Ecology, with advice from DOH, formed an External Advisory Committee with broad representation from business, recycling, environmental and consumer advocacy, and local government interests. When possible, individual members were chosen by the organization or association they represent. In addition to stakeholders, two science advisors and advisors from the governor's office, the state fire marshal's office, and the SHARP program of the Department of Labor and Industries participated in committee meetings. Committee members, advisors, and their affiliations are listed in the *External Advisory Committee Members* section near the beginning of this report. Cascadia Consulting was hired to facilitate advisory committee meetings.

The purpose of the advisory committee was to provide perspectives and knowledge on the wide range of topics covered by the PBDE CAP. While Ecology and DOH were interested in identifying areas of consensus among members, working toward consensus on issues or solutions was not an objective of the committee.

The advisory committee met once in June, once in July, twice in August and once in December. Throughout the process, the committee rarely reached consensus. Committee members did agree that Penta-BDE and Octa-BDE should be banned from commerce. Around Deca-BDE, advisory committee members did not agree on the toxicity or potential breakdown of Deca-BDE, the interpretation of the European Union's risk assessment for Deca-BDE, or proposed policy recommendations. A number of advisory committee members submitted written material to Ecology and DOH to support or clarify their positions on a range of topics.

The sections on human health and toxicity and photolytic degradation of PBDEs were reviewed in writing by A. Bergman (Stockholm University), L. Birnbaum (US EPA), J. de Boer (Netherlands Institute for Fisheries Research), C. deWit (Stockholm University), R. Hale (Virginia Institute of Marine Science), R. Hites (Indiana University), and B. Jansson (Stockholm University).

The Draft PBDE CAP was posted on-line October 11 through November 9 for a 30 day public comment period. Two public meetings were held, one in Seattle on October 19 and another in Spokane on October 26. Thirty-five people, many representing organizations, provided oral comments at the public meetings. Written comments were received from 52 organizations and more than 1,400 individuals.

Following the public comment period, Ecology and DOH revised the recommendations in light of comments received. The revised recommendations were presented to the External Advisory Committee at its final meeting on December 1. Committee members provided additional comments on the revisions. Ecology and DOH considered these comments and further revised the recommendations as presented in this document, the Interim PBDE CAP. Not all comments received on the body of the Draft CAP have been incorporated in the Interim CAP due to time constraints.

It became clear that there is more work to do in order to fully respond to the number of comments received and in order to determine specifically how certain recommendations would be implemented, including how to implement a ban on specific products containing Deca-BDE. The agencies propose to undertake this work in 2005 and complete the final PBDE CAP in December 2005.

II. Purpose and Use of PBDEs

IN BRIEF: PBDE flame retardants are used in a wide variety of everyday plastic and foam products, including computers and many other consumer products, that otherwise would be highly flammable or provide sources of fuel in a fire. The three commercial mixtures of PBDEs – Penta-BDE, Octa-BDE and Deca-BDE – have different applications. Penta-BDE is typically used in foam products such as seat cushions and carpet pads; Octa-BDE is typically used in automobile trim, telephone handsets and kitchen appliances; Deca-BDE is typically used in wire coatings, furniture upholstery, and casings for TV sets and computers and other home electronics.

Identification

Polybrominated diphenyl ethers (PBDEs) are a class of additive brominated flame retardants used in a variety of plastics and foams.

More than 175 flame retardant chemicals exist, in four major groups: halogenated organic (usually brominated or chlorinated), organophosphorous, nitrogen-based compounds and mixtures, and inorganic.[1] Brominated flame retardants (BFRs) are themselves a chemically diverse group, including diphenyl ethers, cyclic aliphatics, phenolic derivatives, aliphatics, phthalic anhydride derivatives, and others.[2]

BFRs are either reactive or additive. Reactive BFRs form covalent bonds with other ingredients in the plastics and foams to which they are added. Additive BFRs, including PBDEs, are mixed into plastics and foams but do not form chemical bonds. This makes additive BFRs much more likely to leach out of goods and products.[3]

The PBDE class includes 209 different theoretical forms of the PBDE molecule, called congeners. PBDEs are not known to exist naturally, but are manufactured by the chemical reaction of bromine with diphenyl ether. A diphenyl ether molecule consists of two rings of six carbon atoms each, where one carbon on each ring is bound to an oxygen atom. The amount of bromine and the time allowed for the reaction controls the extent of bromination on the diphenyl ether molecule. Congeners vary based on the number of bromines (1 – 10) attached to the two carbon rings and the position of the bromines on the rings. There appear to be fewer actual PBDE congeners in the commercial mixtures than the theoretical number possible, largely because many of the congeners lack stability and tend to debrominate.[4] A diagram of deca-BDE, the PBDE with the maximum number of bromine atoms, is shown in Figure 1.

[1] M. Alaee and R. Wenning, "The significance of brominated flame retardants in the environment: current understanding, issues, and challenges," Chemosphere 46 (2002) 579 – 582.
[2] OSPAR Commission, "Certain Brominated Flame Retardants: Polybrominated Diphenylethers, Polybrominated Biphenyls, and Hexabromo Cyclododecane," 2001, p. 8.
[3] Andreas Sjodin, Donald G. Patterson, Åke Bergman, "A review on human exposure to brominated flame retardants- particularly polybrominated diphenyl ethers" Environment International 29 (2003) 829 – 839.
[4] Birnbaum and Staskal, 2004. Brominated flame retardants: Cause for concern? Environmental Health Perspectives, 112(1)9 – 17.

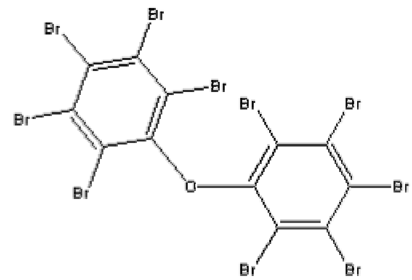

Figure 1: deca-BDE structure

Individual PBDE congeners are named BDE-1, BDE-2, BDE-3, and so on, through BDE-209, using the system developed by the International Union for Pure and Applied Chemistry for numbering PCBs. Numbering is based on the number and position of bromines on the carbon rings. However, the numbering system does not intuitively communicate either the number of bromines or their position. Homologues are groups of PBDEs that have the same number of bromines.

Table 1. PBDE congeners of particular interest

Congener	Homologue	Major constituent found in
BDE-47	tetra-BDE	General population*, occupational human samples, marine mammals, birds, fish
BDE-99	penta-BDE	Penta-BDE commercial product, also high in human samples and biota (wildlife)
BDE-100	penta-BDE	
BDE-153	hexa-BDE	High in human samples and biota
BDE-154	hexa-BDE	
BDE-209	deca-BDE	Some occupational human samples, sediment, sewage sludge and house dust.

* BDE-209 not widely analyzed for in general population samples (see Hites, 2004).

The major commercial PBDE products consist mainly of penta-BDEs, octa-BDEs or deca-BDE, but contain other PBDEs. The general compositions of the commercial products are provided in Table 2.

Table 2. General compositions of PBDE-based flame retardants given in percent of BDE congeners present[5]

	Congener Percent							
Commercial Product	tri-BDE	tetra-BDE	penta-BDE	hexa-BDE	hepta-BDE	octa-BDE	nona-BDE	deca-BDE
Penta-BDE	<1	24-38	50-60	4-8				
Octa-BDE				10-12	43-44	31-35	10-11	<1
Deca-BDE							<3	97-98

[5] World Health Organization, "Environmental Health Criteria 162: Brominated Diphenyl Ethers", www.inchem.org, viewed 4 May 2004.

For purposes of this report, the capitalized words "Deca-BDE," "Octa-BDE," and "Penta-BDE" refer to the commercial mixtures. Lower case mono-, di-, tri-, tetra-, penta-, hexa-, hepta-, octa-, nona-, and deca-BDE refer to homologues, groups of molecules that have between one and 10 bromine atoms.

The global demand for PBDEs has been estimated at 70,000 metric tons for 2001. Of world demand in 2001, North America used 44 percent of Deca-BDE, 40 percent of Octa-BDE, and 95 percent of Penta-BDE. Of the 165 million pounds of BFRs consumed in North America in 2001, about 35 percent were PBDEs, and 85 to 90 percent of that was Deca-BDE.[6] Once the production of Penta and Octa-BDE are discontinued at the end of 2004, Deca-BDE will account for 100 percent of PBDE production.

Table 3. PBDE volume estimates: Total market demand by region in 2001 in metric tons (and by percent)

PBDE Mixture	Americas	Europe	Asia	Other	Total
Deca-BDE	24,500 (44%)	7,600 (14%)	23,000 (41%)	1,050 (2%)	56,100 (100%)
Octa-BDE	1,500 (40%)	610 (16%)	1,500 (40%)	180 (5%)	3,790 (100%)
Penta-BDE	7,100 (95%)	150 (2%)	150 (2%)	100 (1%)	7,500 (100%)
Total	33,100 (49%)	8,360 (12%)	24,650 (37%)	1,330 (2%)	67,390 (100%)

Source: Major Brominated Flame Retardants Estimates, BSEF, viewed at http://www.bsef-site.com/docs/BFR_vols_2001.doc, March 25, 2004.

How PBDEs work

Flame retardants reduce the likelihood that an item will ignite. They also slow the initial burn rate of a fire. This increases the amount of time before a possible "flash over," which is when all combustible materials in a room ignite, allowing occupants extra time to escape.[7]

Purpose of PBDEs

During the twentieth century, manufacturers began to replace traditional materials such as wood, metal, and wool with petroleum-derived products such as plastics and polyurethane foam. The new materials are more flammable and, once alight, combust more rapidly, allowing people less time to escape.[8]

Fires are a leading cause of death among children in the U.S. Each year, more than 600 children ages 14 and under die, and nearly 47,000 are injured in fires (NSKC 2002). The elderly are also

[6] F. Gastrock, BRG Townsend, quoted by A. Tullo, "Resting Easier," Chemical and Engineering News, November 17, 2003, Vol. 81, Number 46, pp. 43 – 44.
[7] Bromine Science and Environmental Forum, "An introduction to Brominated Flame Retardants," October 19, 2000, http://www.ebfrip.org/download/weeeqa.pdf, viewed on March 16, 2003, p. 5.
[8] Bromine Science and Environmental Forum, "An introduction to Brominated Flame Retardants," October 19, 2000, http://www.ebfrip.org/download/weeeqa.pdf, viewed on March 16, 2003, p. 6.

especially vulnerable to being injured or killed in fires. Strict U.S. fire safety regulations may be a reason that flame-retardants are used more here than in other countries.

Manufacturing of PBDEs

Four companies, listed in Table 4, are known to produce Deca-BDE. One of these, Great Lakes Chemical, is the only company known to still produce Penta-BDE and Octa-BDE. Great Lakes will voluntarily stop producing Penta and Octa-BDE by the end of 2004.

Table 4. Companies that produce deca-BDE

Company	Product Name	Country
Albemarle Corporation	SAYTEX 102E	Richmond, Virginia, US
Dead Sea Bromine (subsidiary Israel Chemicals LTD)	FR 1210	Israel
Great Lakes Chemical Corporation	DE-83R, DE-83	West Lafayette, Indiana, US
Tosoh Corporation	Flamecut 110R	Japan

PBDE Applications

Penta-BDE is used in unsaturated polyester, rigid and flexible polyurethane foams, epoxies, laminates, adhesives and coatings.[9,10,11] Typical end products containing Penta-BDE include mattresses, seat cushions and other upholstered furniture, and rigid insulation.

Octa-BDE is used in acrylonitrile butadiene styrene (ABS), nylon, thermoplastic elastomers, and polyolefins.[12] Typical products containing Octa-BDE include housings for fax machines and computers, automobile trim, telephone handsets, and kitchen appliance casings.

Deca-BDE is used in thermoplastic, elastomeric and thermoset polymer systems, including high-impact polystyrene (HIPS), polybutylene terephthalate (PBT), nylon, polypropylene, low-density polyethene (LDPE), ethylene-propylene-diene rubber and ethylene-propylene terpolymer (EPDM), unsaturated polyester, and epoxy. Deca-BDE is also used in wire and cable insulation of all types, coatings and adhesive systems, including back-coatings for fabrics.[13,14] Examples of end products that use Deca-BDE include housings for televisions, computers, stereos, and other

[9] Great Lakes Chemical Corp., "Technical Information: Great Lakes DE-71" www.e1.greatlakes.com/pdf/datasheet/DE-71%20ds.PDF, viewed 6 July 2004.
[10] Great Lakes Chemical Corp., "Technical Information: Great Lakes DE-61" www.e1.greatlakes.com/pdf/datasheet/DD-61%20Data%20Sheet.PDF, viewed 6 July 2004.
[11] Great Lakes Chemical Corp., "Technical Information: Great Lakes DE-62" www.e1.greatlakes.com/pdf/datasheet/DE-62%20Data%20Sheet.PDF, viewed 6 July 2004.
[12] Great Lakes Chemical Corp., "Technical Information: Great Lakes DE-79" www.e1.greatlakes.com/pdf/datasheet/DE-79%20Data%20Sheet.PDF, viewed 6 July 2004.
[13] Great Lakes Chemical Corp., "Technical Information: Great Lakes DE-83R" www.e1.greatlakes.com/pdf/datasheet/DE-83%20Data%20Sheet.PDF, viewed 6 July 2004.
[14] Albemarle Corporation, http://www.albemarle.com/saytexbrochf.htm, viewed March 29, 2004.

electronics, audiotape cassettes, and upholstery textiles. Deca-BDE is not used in textiles used for clothing.[15]

In September 2004, the Safety & Health Assessment & Research for Prevention (SHARP) program at the Washington State Department of Labor and Industries conducted an informal telephone survey of Washington plastics and foam manufacturers to ascertain PBDE usage. Businesses were identified using a combination of the Qwest-Dex Yellow Page heading "Plastics-Foam" and SIC code 3086 (Plastics-Foam).

It appeared that companies fabricating items from plastic or foam feedstock did not know which, if any, flame retardants were added to their materials. SHARP staff was generally referred to the manufacturers of the raw materials. A representative of the Polyurethane Foam Alliance suggested that newly manufactured foams and plastics are no longer formulated with Penta-BDE or Octa-BDE, reflecting concerns expressed in international markets. Similarly, two principal Washington plastics and foam manufacturers reported that they no longer used PBDEs for the same reason.

[15] OSPAR Commission, "Certain Brominated Flame Retardants: Polybrominated Diphenylethers, Polybrominated Biphenyls, and Hexabromo Cyclododecane," 2001, p. 8.

III. Unintended Consequences: PBDEs, Human Health, and the Environment

IN BRIEF: Although PBDEs are present in people and many foods, these levels have not yet reached those shown to be toxic in lab animals and do not pose an immediate health threat. For instance, while PBDEs have been detected in breast milk and fish, the detected levels are so low that breastfeeding remains the healthiest way to nurse a baby and fish remains a beneficial part of a healthy diet. Studies on lab animals, however, suggest that exposure in the womb to higher levels of PBDEs than currently exist in the environment can impact the brain affecting behavior and learning after birth. Animal studies have also shown that PBDEs can affect the thyroid and liver. Most of these studies point to the components of Penta- and Octa-BDE formulations as being of primary concern with respect to human health. Deca-BDE is the least toxic of the three forms but may degrade into the more toxic Penta-BDE or Octa-BDE components.

The highest levels of PBDEs in human tissues have been found in the U.S. and Canada, which use about 98 percent of the world's supply of Penta-BDE. Levels of PBDEs in human tissues in the U.S. are 10 to 100 times higher than reported for Europe and Japan. Moreover, while levels in Japan and some European countries appear to have begun decreasing recently, levels in the U.S. appear to be increasing. People are exposed to PBDEs in food, household dust and indoor air although the contribution of each pathway remains unclear. PBDEs, like PCBs, can build up in the body and remain stored there for years.

Once in the environment, PBDEs can last a long time or break down into other forms, depending on surrounding conditions such as the availability of fluids or UV light. Similarly, depending on conditions, Deca-BDE – which is considered safe in its original state – can break down into more harmful forms. What happens to PBDEs once PBDE products are placed in landfills is unknown, but there are concerns that Deca-BDE in landfills may build up in large stockpiles that could over time break down into more harmful forms. It is possible that PBDE products that are incinerated will release furans and dioxins into the environment.

PBDEs and Human Health

Human exposure to PBDEs

PBDEs in human tissues

PBDEs have been measured in a variety of human tissues, including blood, fat, and breast milk collected from people around the world. Between 1972 and 1997, PBDE levels in human breast milk from Sweden were shown to exponentially increase, doubling every 5 years (Figure 2).[16] During this same time period, levels of PCBs and other organic pollutants in breast milk had

[16] Noren and Meironyte, 2000. Certain organochlorine and organobromine contaminants in Swedish human milk in perspective of past 20-30 years. Chemosphere 40:1111-1123.

decreased. Levels of PBDEs in Swedish breast milk are similar to those reported for many other European countries and Japan.[17] Levels of PBDEs in breast milk samples from Sweden began to decrease in the late 1990s.[18]

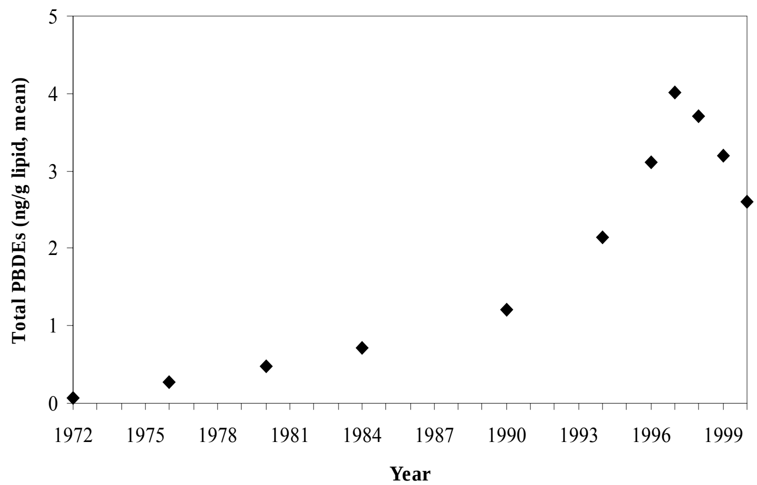

Figure 2. PBDEs in Swedish breast milk, 1972-2000.[19,20]

The highest levels of PBDEs in human tissues collected from the general public have been found in the U.S. and Canada (Figure 3).[21,22,23,24,25,26] Levels of PBDEs in human tissues in the U.S. are between 10-100 times higher than levels reported for Europe and Japan. One reason for the higher levels of PBDEs in U.S. and Canadian tissue samples may be that North America has used about 98% of the world's supply of the Penta-BDE commercial product.[27,28] While levels

[17] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[18] Meironyte, 2002. Organohalogen contaminants in humans with emphasis on polybrominated diphenyl ethers. PhD Thesis. Karolinska Instituted, Stockholm, Sweden. (data summarized in Sjodin et al., 2003)
[19] Noren and Meironyte, 2000. Certain organochlorine and organobromine contaminants in Swedish human milk in perspective of past 20-30 years. Chemosphere 40:1111-1123.
[20] Meironyte, 2002. Organohalogen contaminants in humans with emphasis on polybrominated diphenyl ethers. PhD Thesis. Karolinska Institute, Stockholm, Sweden. (data summarized in Sjodin et al., 2003)
[21] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[22] Schecter et al., 2003. Polybrominated diphenyl ethers (PBDEs) in U.S. mother's milk. Environmental Health Perspectives 111(14): 1723-1729.
[23] Mazdai et al., 2003. Polybrominated diphenyl ethers in maternal and fetal blood samples. Environmental Health Perspectives 111(9): 1249-1252.
[24] She et al., 2002. PBDEs in the San Francisco Bay area: measurements in harbor seal blubber and human breast adipose tissue. Chemosphere 46:697-707.
[25] Environmental Working Group (EWG), 2003. Mothers' milk, record levels of toxic fire retardants found in American mothers' breast milk. Available at www.ewg.org.
[26] Northwest Environment Watch, 2004. Flame retardants in Puget Sound residents. Available at: www.northwestwatch.org/pollution
[27] Hale et al., 2003. Polybrominated diphenyl ether flame retardants in the North American environment. Environment International 29: 771-779.

in Japan and some European countries appear to have begun decreasing recently, levels in the U.S. appear to be increasing.[29,30,31] In contrast, levels of another group of persistent environmental contaminants that were banned in the 1970s, PCBs, have been decreasing. Currently, U.S. levels of PBDEs in human tissue samples are similar to or greater than levels of PCBs.[32, 33]

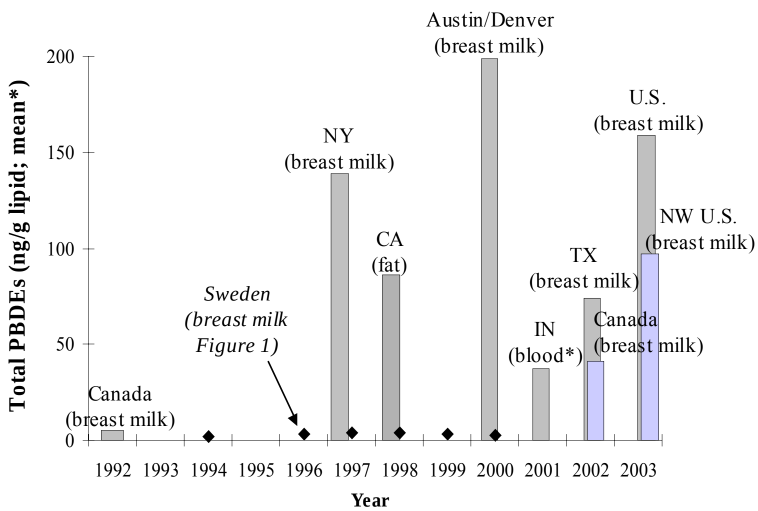

Figure 3. PBDE levels in human tissues from Sweden, Canada and the U.S., 1992-2003.[34]

There is a wide range of PBDE levels in tissues, including some people with very high tissue levels (high-end) compared to the average tissue levels among all people tested.[35] For example, a study in Texas reported levels of total PBDEs measured in breast milk ranging from 6 to 419 nanograms/gram lipid with an average of 74.[36] This wide variability is seen in tissue samples

[28] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[29] Lind et al., 2003. Polybrominated diphenyl ethers in breast milk from Uppsala County, Sweden. Environmental Research 93:186-194.
[30] Akutsu et al., 2003. Time-trend (1973-2000) of polybrominated diphenyl ethers in Japanese mother's milk. Chemosphere 53:643-654.
[31] Sjodin et al., 2004. Retrospective time-trend study of polybrominated diphenyl ether and polybrominated and polychlorinated biphenyl levels in human serum from the United States. Environmental Health Perspectives 112(6): 654-658.
[32] Sjodin et al., 2004. Retrospective time-trend study of polybrominated diphenyl ether and polybrominated and polychlorinated biphenyl levels in human serum from the United States. Environmental Health Perspectives 112(6): 654-658.
[33] Schecter et al., 2004. PBDE contamination of U.S. food and human milk; and PBDE, PCDD/F, PCB, and levels in the U.S. human blood (1973-2003). Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[34] Data from Noren and Meironyte, 2000; Meironyte, 2002; Sjodin et al., 2003; Mazdai et al., 2003 (*median value; mean value not published); Schecter et al., 2003; She et al., 2002; EWG, 2004; and Northwest Environment Watch, 2004.
[35] McDonald, 2004. Distribution of PBDE levels among U.S. women: estimates of daily intake and risk of developmental effects. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[36] Schecter et al., 2003. Polybrominated diphenyl ethers (PBDEs) in U.S. mother's milk. Environmental Health Perspectives 111(14): 1723-1729.

from the U.S. and from other countries.[37, 38] The reasons for the large variability in tissue levels and why some people have high-end exposures to PBDEs are not known.

Studies indicate that there are differences in routes and timing of human exposures between PCBs and PBDEs. People are mainly exposed to PCBs through the diet and age has been shown to be a predictor of PCB levels in human tissues.[39] Levels of PCBs and PBDEs were not correlated in a study that measured both in breast milk, i.e. the levels of these compounds were not both high in the same individuals.[40] Additionally, a study of PBDEs in adipose tissue of women in California found that the levels of PBDEs were not correlated with age.[41] Studies in Sweden and Norway have also found that PBDE tissue levels were not correlated with age.[42, 43] This suggests that exposures to PBDEs have occurred recently, i.e. PBDEs have not accumulated in older people over time.

BDE-47 is the PBDE congener reported at the highest concentration in human tissues analyzed from the general population and in wildlife including fish, birds, and marine mammals. BDE-47 is the second most abundant congener in the Penta-BDE commercial mixtures (BDE-99 is the most abundant congener). Differences in uptake and excretion between Penta-BDE congeners may account for BDE-47 being found at the highest levels even though it is not the most abundant congener in the Penta-BDE products.[44] Penta-BDE-associated congeners, BDE-99, -100 and -153, have also been detected at higher levels than other PBDE congeners in general population samples. A recent report from the Faroe Islands, found BDE-153, instead of BDE-47, as the most abundant PBDE congener in breast milk samples.[45]

BDE-209, the primary congener in Deca-BDE, had not been routinely included in earlier general population studies mainly because it was not suspected to build up in human tissues and it can be difficult to measure. More recent studies report BDE-209 in general population samples of breast milk, at levels on average 40-50 times lower than BDE-47.[46,47] Occupational studies have

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[37] Petreas et al., 2003. High body burdens of 2,2',4,4'-tetrabromodiphenyl ether (BDE-47) in California women. Environmental Health Perspectives 111(9):1175-1179.
[38] Lind et al., 2003. Polybrominated diphenyl ethers in breast milk from Uppsala County, Sweden. Environmental Research 93:186-194.
[39] Tee et al., 2003. A longitudinal examination of factors related to changes in serum polychlorinated biphenyl levels. Environmental Health Perspectives 111(5):702-707.
[40] Meironyte Guvenius, et al., 2003. Human prenatal and postnatal exposure to polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorobiphenylols, and pentachlorophenol. Environmental Health Perspectives 111(9):1235-1241.
[41] She et al., 2002. PBDEs in the San Francisco Bay area: measurements in harbor seal blubber and human breast adipose tissue. Chemosphere 46:697-707.
[42] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[43] Thomsen et al., 2002. Brominated flame retardants in archived serum samples from Norway: a study on temporal trends and the role of age. Environmental Science & Technology 36:1414-1418.
[44] Hakk et al., 2003. Metabolism in the toxicokinetics and fats of brominated flame retardants – a review. Environment International 29:801-828.
[45] Fangstrom et al., 2004. A retrospective study of PBDEs in human milk from the Faroe Islands. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[46] Schecter et al., 2003. Polybrominated diphenyl ethers (PBDEs) in U.S. mother's milk. Environmental Health Perspectives 111(14): 1723-1729.
[47] Northwest Environment Watch, 2004. Flame retardants in the bodies of pacific northwest residents. Available at www.northwestwatch.org.

found BDE-209 as a dominant congener in some workers (see section on Workplace Exposures). BDE-209 has generally been found as the dominant congener in sediments and sewage sludge that is land applied (biosolids).[48] BDE-209 has been found as a main congener, along with BDE-47 and BDE-99, in indoor air in homes and workplaces, and in house dust samples.[49] BDE-209 has been found in fish and other food.[50]

Human Exposures to PBDEs - General Population

PBDEs have been detected in foods, house dust and indoor air.[51, 52, 53, 54] With the exception of nursing infants and some workers, how much these different sources of PBDEs contribute to a person's total exposure is currently an area of active research.[55,56] An analysis of multiple exposure sources (air, water, food, and dust) by Health Canada estimated diet as the main route of exposure to PBDEs for adults in the general public.[57] However, dust was identified as the main source of exposure for 0-6 month old infants who were not breastfed, indicating that the contribution of different PBDE sources to total exposure can vary with age-related behaviors. A recent study based on food and air measurements, also from Canada, estimated that 96% of a person's total intake of PBDEs was through diet, however this study did not include household dust exposures.[58] A study in the U.K. that evaluated PBDEs in indoor air and the diet, estimated that 93% of a person's total daily intake of PBDEs came from the diet.[59]

Recent assessments have shown that nursing infants are mainly exposed to PBDEs through breast milk.[60, 61] In the analysis by Health Canada, breast fed 0-6 month old infants were

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[48] Hites, 2004. Polybrominated diphenyl ethers in the environment and in people: a meta-analysis of concentrations. Environmental Science & Technology 38(4): 945-956.
[49] Butt et al., 2004. Spatial distribution of polybrominated diphenyl ethers in southern Ontario as measured in indoor and outdoor window organic films. Environmental Science & Technology 38(3):724-731.
[50] Schecter et al., 2004. Polybrominated diphenyl ethers contamination of United States food. Environmental Science & Technology, web release September 1, 2004.
[51] Schecter et al., 2004. Polybrominated diphenyl ethers contamination of United States food. Environmental Science & Technology, web release September 1, 2004.
[52] Luksemburg et al., 2004. Levels of polybrominated Diphenyl ethers (PBDEs) in fish, beef, and fowl purchased in food markets in northern California USA. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[53] Sjodin et al., 2004. Concentration of polybrominated diphenyl ethers (PBDEs) in house hold dust – inhalation a potential route of human exposure. Abstract presented at BFR2004 Conference, Toronto Canada, June 2004.
[54] Harrad et al., 2004. Preliminary assessment of U.K. human dietary and inhalation exposure to polybrominated diphenyl ethers. Environmental Science & Technology 38(8):2345-2350.
[55] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.
[56] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[57] Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004)
[58] Jones-Otazo et al., 2004. A preliminary comparison of Canadian PBDE exposures from oral and inhalation routes. Poster presented at BFR 2004 Conference in Toronto Canada, June 2004.
[59] Harrad et al., 2004. Preliminary assessment of U.K. human dietary and inhalation exposure to polybrominated diphenyl ethers. Environmental Science & Technology 38(8):2345-2350.
[60] Jones-Otazo et al., 2004. A preliminary comparison of Canadian PBDE exposures from oral and inhalation routes. Poster presented at BFR 2004 Conference in Toronto Canada, June 2004.
[61] Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004)

identified as having the greatest exposures of all age groups, where 92% of their exposure came from breast milk.[62] Studies of PBDE levels in maternal and cord blood indicate that prenatal exposure to PBDEs occurs.[63, 64] While the levels of PBDEs in breast milk are of concern and will likely be monitored further by researchers, health agencies including DOH continue to recommend breastfeeding as the best choice for feeding infants.[65] Breast milk contains factors to protect the infant from the effects of prenatal exposure, boost the immune system and develop brain tissue.

There are some recent data on levels of PBDEs in food in the U.S. (Table 5). Two studies tested mainly foods of animal origin bought at grocery stores in Texas or California. The highest concentrations of total PBDEs were found in fish. These studies, however, used small sample sizes, especially for diary products, meat and poultry. In another study, the U.S. Department of Agriculture (USDA) collected meat and chicken fat products from nine grocery stores nationwide finding PBDEs levels in these samples to be highest in chicken and pork fat.

Studies in Texas and California of store-bought food, including fish, meat and dairy products, reported higher levels of PBDEs than similar studies in Japan and Spain.[66, 67] USDA testing of meat indicated that PBDEs in pork and chicken were higher in the U.S. compared to levels reported in Europe, but that PBDE levels in beef were similar.[68] Studies in the U.S. and other countries report that fish contain the highest PBDE levels of different foods tested.[69, 70, 71] A study in Sweden reported that increasing blood plasma levels of PBDEs were associated with increasing intake of fatty fish (mainly salmon and herring).[72] A study in Japan found higher PBDE levels in breast milk from women who had higher dietary intake of fish and shellfish.[73]

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[62] Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004)
[63] Meironyte et al., 2003. Human prenatal and postnatal exposure to polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorobiphenylols, and pentachlorophenol. Environmental Health Perspectives 111(9): 1235-1241.
[64] Mazdai et al., 2003. Polybrominated diphenyl ethers in maternal and fetal blood samples. Environmental Health Perspectives 111(9): 1249-1252.
[65] Pronczuk et al., 2004. Breast milk: an optimal food. Environmental Health Perspectives 112(13): A722-723.
[66] Schecter et al., 2004. Polybrominated diphenyl ethers contamination of United States food. Environmental Science & Technology, web release September 1, 2004.
[67] Luksemburg et al., 2004. Levels of polybrominated diphenyl ethers (PBDEs) in fish, beef, and fowl purchased in food markets in northern California USA. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[68] Huwe, 2004. Polybrominated diphenyl ethers in meat samples collected from supermarkets across the U.S. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[69] Bocio et al., 2003. Polybrominated diphenyl ethers (PBDEs) in foodstuffs: human exposure through the diet. Journal of Agricultural and Food Chemistry 51:3191-3195.
[70] Ohta et al., 2002. Comparison of polybrominated diphenyl ethers in fish, vegetables, and meats and levels in human milk of nursing women in Japan. Chemosphere 46:689-696.
[71] Schecter et al., 2004. Polybrominated diphenyl ethers contamination of United States food. Environmental Science & Technology, web release September 1, 2004.
[72] Sjodin et al., 2000. Influence of the consumption of fatty Baltic Sea fish on plasma levels of halogenated environmental contaminants in Latvian and Swedish men. Environmental Health Perspectives 108:1035-1041.
[73] Ohta et al., 2002. Comparison of polybrominated diphenyl ethers in fish, vegetables, and meats and levels in human milk of nursing women in Japan. Chemosphere 46:689-696.

Table 5. Levels of PBDEs in food from the U.S., Japan and Europe.

Location (date)	Type of sample	PBDE congeners	Food (Sample size)[a]	Total PBDE Concentration, ppt wet weight, except where noted	Ref.
Texas (2003)	Grocery stores	13 total including BDE-47, 99, 100, 153, 154, 209	Fish (9)	Median 1725; range 8.5– 3078	[74]
			Meat (9)	Median 283; range 0.9-679	
			Dairy products (9)	Median 31.5; range ND -1373	
			Soy formula (1)	16.9	
			Eggs (1)	73.7	
			Calf liver (1)	115	
California (2003 and 2004)	Grocery stores	25 total including BDE-47, 99, 100, 153, 154, 209	Fish, wild (8)	Range 255 – 4955	[75]
			Fish, farmed (5)	Range 506 – 3063	
			Meat (3)	Range 164 – 379	
			Fowl (6)	Range 196 – 2516	
Nine U.S. cities (2001)	Grocery stores	BDE-28, 47, 99, 153, 154, 183. 209 data given separately.	Bacon (11)	Mean 296; range ND – 7831; BDE-209 ND	[76]
			Chicken fat (17)	Mean 1593; range 86 – 8965; mean BDE-209 1845	
			Steak fat (11)	Mean 165; range ND – 586; BDE-209 ND	
			Pork fat (9)	Mean 1282; range 17 – 7831; mean BDE-209 1913	
Spain (2000)	Grocery stores	BDE-47, 99, 153, 154, 183	Fish & shellfish (8)	Mean 333.9 [a]	[77]
			Meat (15)	Mean 109.2 [a]	
			Eggs (2)	Mean 64.5 [a]	
			Milk (2)	Mean 16.9 [a]	
			Dairy products (2)	Mean 47.9 [a]	
			Fats and oils (3)	Mean 587.7 [a]	
			Fruits (6)	Mean 5.8 [a]	
			Cereals (4)	Mean 35.7 [a]	
			Pulses (2)	Mean 10.7 [a]	
			Tubers (2)	Mean 7.4 [a]	
			Vegetables (8)	Mean 7.9 [a]	

[74] Schecter et al., 2004.
[75] Luksenburg et al., 2004.
[76] Huwe, 2004.
[77] Bocio et al., 2003.

Table 5 cont'd. Levels of PBDEs in food from the U.S., Japan and Europe.

Location (date)	Type of sample	PBDE congeners	Food (N)[a]	Total PBDE Concentration, ppt wet weight, except where noted	Ref.
Japan (2001)	Grocery stores	BDE-28, 47, 99, 100, 153, 154	Fish (16)	Median 1400; range 17.7-1720	[78]
			Shellfish (2)	Median 52; range 43 – 61	
			Meat (3)	Range 6.25 – 63.6	
			Vegetables (3)	Range 38.4 – 134	
U.S., U.K., Norway, and Canada (2001 and 2002)	Fish farms and fish suppliers	43 congeners including BDE-28, 47, 99, 153, 154, 183	Salmon, farmed (153)	Median 2500 (approx.); range 500 – 4000 (approx.)	[79]
			Salmon, wild (45)	Median 150 (approx.); range 100 – 4200 (approx.)	
Sweden (1999)	Grocery stores	BDE-47, 99, 100, 153, 154	Diary Products (sample size not provided)	Mean 360 ppt (lipid basis)	[80]
			Meat Products	Mean 360 ppt (lipid basis)	
			Eggs	Mean 420 ppt (lipid basis)	
Europe (incl. North Sea and Baltic Sea) (various years)	Not provided	BDE-47 only or various congeners	Herring (N not provided)	Range 17,000 – 528,000 ppt (lipid basis) total PBDEs; Range 9,000 – 100,000 ppt (lipid basis) BDE-47 only.	[81]
Scotland and Belgium (1999 and 2001)	Fish markets	BDE-28, 47, 71, 75, 66, 99, 100, 153, 154	Salmon, farmed and wild (13)	Range 1,100 – 85,200 ppt (lipid basis)	[82]

ND, non-detect.
[a] Mean values are assumed because actual method of calculation is unclear from report.

Additional data on PBDEs in a variety of foods, including foods not derived from animal products, are needed to provide a complete picture of possible dietary exposures to PBDEs. A person's dietary intake of PBDEs will depend on the amounts and types of food they eat. One recent study in the U.K described lower PBDE dietary intakes among people who ate vegan (non-animal based) diets compared to those who ate animal products.[83]

While some of the higher levels of PBDEs have been detected in fish, DOH continues to encourage people to eat a variety of fish as part of a healthy diet. Fish are an excellent source of protein and beneficial fatty acids. Currently, there are no fish advisories in effect for PBDEs in Washington State. Choosing fish low in PCBs and mercury and preparing fish and meats in ways that reduces fat will also reduce the levels of PBDEs. For additional information on the

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[78] Ohta et al., 2002.
[79] Hites et al., 2004.
[80] As cited in Darnerud et al., 2001.
[81] Ibid.
[82] Jacobs et al., 2002. Investigation of selected persistent organic pollutants in farmed Atlantic salmon (Salmo salar), salmon aquaculture feed, and fish oil components of the feed. Environmental Science and Technology 36: 2797 – 2805.
[83] Harrad et al., 2004.

health benefits of eating fish and existing fish advisories and recommendations, please visit DOH's "Fish Facts" website at http://www.doh.wa.gov/fish.

PBDEs have been detected in dust from homes and other buildings. Studies have identified mainly Penta-BDE associated congeners and BDE-209 in dust samples and some studies have reported higher levels in the U.S. compared to Europe. Household dust collected in Massachusetts had 5-10 times higher levels of PBDEs than levels reported for Germany and the U.K.[84] House dust sampled from 10 homes across the U.S. found that BDE-47, BDE-99 and BDE-209 were found in the highest concentrations.[85] Another recent study of household dust from 16 U.S. homes found that Penta-BDE congeners (BDE-47, -99 and -100) and BDE-209 accounted for most of the total PBDEs detected.[86] A study of dust in Parliament buildings from eight European countries identified BDE-209 as the predominant congener.[87] The contents of vacuum bags were used to assess household dust exposures to PBDEs in a total of 20 U.S. and German homes.[88] This study found that BDE-47, BDE-99 and BDE-209 were present in the highest concentrations and that U.S. samples were approximately 50 times higher than samples from Germany. Computer wipe samples collected from 16 offices around the U.S. detected PBDEs, with BDE-209 found as the predominant congener, although levels of Penta-BDE congeners were not reported.[89]

Higher PBDE levels have been found in indoor air compared to outdoor air. A study in Canada used organic window films as a measure of ambient air levels of PBDEs both indoors and outdoors.[90] In general, PBDEs in indoor films were 1.5-20 times higher than outdoor films. Exterior window films in urban areas had approximately 10 times higher PBDE levels than in rural areas. BDE-209 was the predominant congener detected in the indoor and outdoor organic window films. A study in the U.K. measured Penta-BDE congeners (BDE-47, BDE-99, BDE-100, BDE-153 and BDE-154) inside homes and offices and in outdoor air.[91] Indoor levels were reported to be 120-150 times higher than outdoor levels. Workplaces were found to have approximately eight times higher concentrations of PBDEs than homes. A recent study in

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[84] Rudel et al., 2003. Phthalates, alkylphenols, pesticides, polybrominated diphenyl ethers, and other endocrine-disrupting compounds in indoor air and dust. Environmental Science & Technology 37(20): 4543-4553.

[85] Environmental Working Group, 2004. In the dust - levels of toxic fire retardants contaminate American homes. Available at www.ewg.org/reports/inthedust/summary.php.

[86] Stapleton et al., 2004. Polybrominated diphenyl ether measurements in household dust. Abstract presented at BFR 2004 Conference, Toronto Canada, June 2004.

[87] Greenpeace Research Laboratories, 2001. The presence of brominated flame retardants and organotin compounds in dusts collected from Parliament buildings from eight countries. Available at http://archive.greenpeace.org/toxics/reports/eudust.pdf .

[88] Sjodin et al., 2004. Concentration of polybrominated diphenyl ethers (PBDEs) in house hold dust – inhalation a potential route of human exposure. Abstract presented at BFR2004 Conference, Toronto Canada, June 2004.

[89] Computer Take-Back Campaign and Clean Product Action, 2004. Brominated flame retardants in dust on computers. Available at: www.computertakeback.com/the_problem/bfr.cfm .

[90] Butt et al., 2004. Spatial distribution of polybrominated diphenyl ethers in southern Ontario as measured in indoor and outdoor window organic films. Environmental Science & Technology 38(3): 724-731.

[91] Harrad et al., 2004. Preliminary assessment of U.K. human dietary and inhalation exposure to polybrominated diphenyl ethers. Environmental Science & Technology 38(8):2345-2350.

Ottawa Canada of 74 homes found that indoor air levels of total PBDEs (BDE-17, -28, -47, -99, -100, -153, -154) were approximately 50 times higher than outdoor air levels.[92]

Studies report that indoor air levels vary widely between homes and within buildings. For example, the study of Ottawa homes reported a thousand-fold difference between the lowest and highest total PBDE concentrations.[93] The study from the U.K. reported that total PBDE levels varied from 100 to 15,000 pg/m^3 within different rooms of one building at a university. The reason for the variability in PBDE indoor air levels is not well understood, but is likely related to the presence of PBDE containing products as well as other factors including ventilation and activities that can liberate PBDEs. The U.K. study reported that PBDE levels in indoor air increased with an increasing number of electrical appliances (including computers) and with increasing numbers of polyurethane foam chairs. In the Ottawa study, the highest indoor air PBDE levels were in homes that had recently been paint stripped and insulated, had new windows installed, received new carpets or had new electronics.

Human Exposures to PBDEs – Workers

Occupational studies of PBDE exposures are mainly limited to studies conducted in Sweden. PBDEs have been detected in air samples taken from a variety of workplaces (electronics recycling plant, a factory assembling printed circuit boards, a computer repair facility, and offices equipped with computers).[94] The highest PBDE concentrations in air were found at an electronics recycling plant, where products such as computers, printers, TVs, and microwave ovens were dismantled and the plastic components shredded. PBDEs, especially Deca-BDE, are used in some plastic components of electronics. BDE-183 and BDE-209 were the most abundant congeners detected at the electronics recycling plant, while BDE-47 was the most abundant congener detected in air sampled from other workplaces. PBDEs were mostly detected in the particles in air samples. The measured levels of BDE-209 at the electronics recycling plant were more than 25,000 times below the Workplace Environmental Exposure Level (WEEL) of 5 mg/m^3 set by the American Industrial Hygiene Association.[95] For comparison, the Washington State occupational limits for PCBs are 1 mg/m^3 as an 8 hour time weighted average. There are currently no occupational limits for PBDEs in Washington State.[96]

Studies of workers at the Swedish electronics recycling facility found that blood levels of PBDEs in workers who dismantle electronics were higher than levels found in hospital cleaners and computer clerks (control groups).[97] Researchers also reported a difference in the types of PBDE

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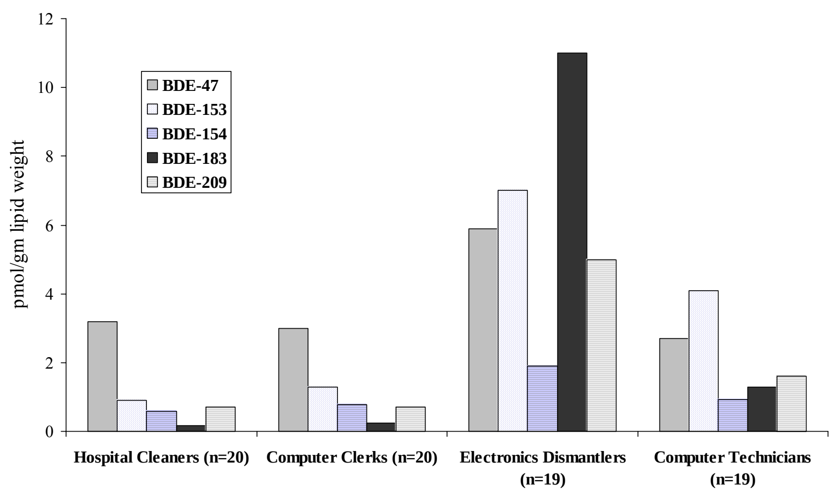
[92] Wilford et al., 2004. Passive sampling survey of polybrominated diphenyl ether flame retardant in indoor and outdoor air in Ottawa, Canada; implications for sources and exposure. Environmental Science and & Technology, web release September 14, 2004.
[93] Wilford et al., 2004. Passive sampling survey of polybrominated diphenyl ether flame retardant in indoor and outdoor air in Ottawa, Canada; implications for sources and exposure. Environmental Science and & Technology, web release September 14, 2004.
[94] Sjodin et al., 2001. Flame retardants in indoor air at the an electronics recycling plant and at other work environments. Environmental Science & Technology 35(3):448-454.
[95] American Chemistry Council, 2002. Voluntary children's chemical evaluation program (VCCEP), data summary, decabromodiphenyl ether.
[96] Available at: http://www.lni.wa.gov/WISHA/Rules/respiratoryhazards/default.htm
[97] Sjodin et al., 1999. Flame retardant exposure: polybrominated diphenyl ethers in blood from Swedish workers. Environmental Health Perspectives 107: 643-648.

congeners found in the blood of workers from these three occupational groups. BDE-47 was the congener detected at the highest levels in the blood of the two control groups; however, BDE-183 and BDE-209 were detected in high levels in the blood of the electronics dismantlers (Figure 4). Computer technicians were also found to have higher levels of PBDE in their blood compared to hospital cleaners and computer clerks, but not as high as in electronics dismantlers.[98] BDE-153, BDE-183 and BDE-209 contributed more to the total PBDEs measured in blood of the computer technicians compared to the two control groups. A recent follow-up study reported a reduction in blood levels of BDE-183 and BDE-209 among electronics dismantlers following workplace changes such as upgrading the ventilation system and moving some equipment outside.[99] However, PBDE blood levels of electronics dismantlers remained higher than hospital cleaners.



Sources: Sjodin et al., 1999 and Jakobsson et al., 2002.

Figure 4. Serum PBDE levels in four occupational groups (Sweden)

[98] Jakobsson et al., 2002. Exposure to polybrominated diphenyl ethers and tetrabromobisphenol A among computer technicians. Chemosphere 46:709-716.

[99] Thuresson et al., 2004. Polybrominated diphenyl ethers in blood from Swedish workers – a follow up study in an electronics recycling industry. Abstract presented at BFR2004 Conference, Toronto Canada, June 2004.

Estimates of human daily intake of PBDEs

Several studies have estimated the daily intake of PBDEs for people in different countries (Table 6). While many of these estimates have primarily focused on the diet, more recent estimates include exposures from air and occupational exposures. Several estimates of human exposures identify infants and children as the most highly exposed groups.[100] [101]

Table 6. Estimates of PBDE daily human intake for different countries.

Daily PBDE intake (mg/kg bodyweight)	Country	Age	Sources of exposure	PBDE congeners	Ref.
0.0000007	Sweden	adult	food	47, 99, 100, 153, 154	102
0.00001[a]	Sweden	infant (0-6 mo.)	breast milk	47, 99, 100, 153, 154	103
.00000062[b] (0.044 μg/day)	Canada	adult	food	28, 47, 99, 100, 153, 154	104
0.00000019 – 0.000003 [b] (0.013-0.213 μg/day)	The Netherlands	adult	food	28, 47, 99, 100, 153, 154	105
0.0000014 - .0000011 [b] (0.097-0.082 μg/day)	Spain	adult	food	Sum of tetra- to octa-BDEs	106
.00000059 [b] (0.041 μg/day)	Sweden	adult	food	47, 99, 100, 153, 154	107
0.0000013 [b] (0.091 μg/day)	U.K.	adult	diet, air, occupational	47, 99, 100, 153, 154	108
0.00000073 [b] (0.051 μg/day)	Canada	infant	breast milk	Sum of tri-BDEs to hepta-BDEs	109
0.00000043 [b] (0.030 μg/day)	Canada	adult	diet, air, occupational	Sum of tri- to hepta-BDEs	110
0.0002 - .0026	Canada	0-6 mo., 0.5-4, 5-11, 12-19, 20-59, 60+ yrs.	air, water, food, breast milk, and dust	Sum of (tetra- to deca-BDEs)	111

Notes: mg/kg, milligram per kilogram bodyweight per day; μg/day, microgram per day; Ref., reference
[a] Calculated from value in cited reference using an assumed 7.5 kg bodyweight for infant.
[b] Calculated from value in cited reference using an assumed 70 kg bodyweight for adult.
[c] Calculated from value in cited reference using an assumed 60 kg bodyweight for adult woman.

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100 Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004).
101 Schecter et al., 2004. PBDE contamination of U.S. food and human milk; and PBDE, PCDD/F, PCB, and levels in the U.S. human blood (1973-2003). Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
102 Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.
103 ibid.
104 Ryan and Patry, 2001. Organohalogen Compounds 51:226-229, as cited in Harrad et al., 2004.
105 De Winter-Sorkina et al. Dietary intake of brominated flame retardants by the Dutch population; RIVM Report 310305001/2003. As cited in Harrad et al., 2004.
106 Bocio et al., 2003. Polybrominated diphenyl ethers (PBDEs) in foodstuffs: human exposure through the diet. Journal of Agricultural and Food Chemistry 51:3191-3195.
107 Lind et al., 2002. Organohalogen Compounds 58:181-184. As cited in Harrad et al., 2004.
108 Harrad et al., 2004. Preliminary assessment of U.K. human dietary and inhalation exposure to polybrominated diphenyl ethers. Environmental Science & Technology 38(8):2345-2350.
109 Jones-Otazo et al., 2004. A preliminary comparison of Canadian PBDE exposures from oral and inhalation routes. Poster presented at BFR 2004 Conference in Toronto Canada, June 2004.
110 ibid.
111 Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004).

Table 6 continued.

Daily PBDE intake (mg/kg bodyweight)	Country	Age	Sources of exposure	PBDE congeners	Ref.
0.000355 (U.S) 0.000011 (Germany)	U.S. and Germany	nursing infants	breast milk	17, 28, 47, 66, 77, 85, 99, 100, 138, 153, 154, 183, 209	112
max 0.000004 (child); max 0.000003 (adult)	U.S. (CA)	children (<18 yrs) and adults	food (fish, meat, fowl)	Sum of (mono- to deca-BDEs)	113
0.00004-0.0009	U.S.	<1 yr, 1-2 yrs, 3-5 yrs.	multiple pathways	Penta-BDE congeners	114, 115
0.000014 – 0.000054 [c]	U.S.	adult women	back-calculated from tissue levels	Total; mostly 47, 99, 100, 153, 154	116

Notes: mg/kg, milligram per kilogram bodyweight per day; µg/day, microgram per day; Ref., reference
[a] Calculated from value in cited reference using an assumed 7.5 kg bodyweight for infant.
[b] Calculated from value in cited reference using an assumed 70 kg bodyweight for adult.
[c] Calculated from value in cited reference using an assumed 62 kg bodyweight for adult woman.

Toxicity of PBDEs

Information on the possible health impacts of PBDEs comes primarily from animal toxicity studies. In general, these studies indicate that Penta-BDE commercial products and specific PBDE congeners found in these products are more toxic than Octa-BDE and Deca-BDE (i.e. Penta-BDE produces adverse effects in animals at lower levels than Octa-BDE or Deca-BDE) (Table 7). Doses (milligrams PBDE per kilogram bodyweight per day; mg/kg/day) at which health effects were observed in animal studies are provided to allow comparisons between PBDE products. An overview of health effects associated with each of the three flame retardant commercial products (Penta-BDE, Octa-BDE and Deca-BDE) is also provided below. Two recent articles reviewed PBDE toxicity studies and are recommended as sources of additional background information.[117, 118]

Penta-BDE

Animal toxicity studies have been used to evaluate commercial Penta-BDE products (consisting of a mixture of PBDE congeners) or the predominant congeners in the commercial product

[112] Schecter et al., 2004. PBDE contamination of U.S. food and human milk; and PBDE, PCDD/F, PCB, and levels in the U.S. human blood (1973-2003). Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[113] Lukemburg et al., 2004. Levels of polybrominated diphenyl ethers (PBDEs) in fish, beef, and fowl purchased in food markets in northern California USA. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[114] Serex et al., 2004. Children's health risk assessment of the commercial pentabromodiphenyl ether product. The Toxicologist. Abstract presented at the Society of Toxicology annual meeting, 2004.
[115] Great Lakes Chemical Corporation, 2003. Tier 1 assessment of the potential health risks to children associated with exposure to the commercial pentabromodiphenyl ether product, voluntary children's chemical evaluation program pilot.
[116] McDonald, 2004. Distribution of PBDE levels among U.S. women: estimates of daily intake and risk of developmental effects. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.
[117] Birnbaum et al., 2004. Brominated flame retardants: cause for concern? Environmental Health Perspectives 112(1): 9-17.
[118] Darnerud, 2003. Toxic effects of brominated flame retardants in man and wildlife. Environment International 29:841-853.

(BDE-47 and BDE-99). The most sensitive toxic effect (i.e. effect that occurs at the lowest dose) associated with Penta-BDE congeners appears to be developmental neurotoxicity. Rodents exposed to Penta-BDE products either in the womb (*in utero*) or soon after birth (post-natally) showed impacts on brain function including changes in behavior, learning and memory. Some of these effects persisted and worsened into adulthood. The lowest dose that produced developmental neurotoxic effects in these studies is 0.8 mg/kg.[119, 120, 121]

Exposure to Penta-BDE commercial products and BDE-99 has been shown to decrease thyroid hormone levels in rodents exposed *in utero* and after birth at doses of 1 mg/kg.[122] Adequate thyroid hormone levels are necessary for normal brain development *in utero* and post-natally.[123] In humans, the critical time of rapid brain growth occurs during the final trimester of pregnancy and extends after birth until the age of two years.[124] Penta-BDE may also impact other hormone systems, with estrogen-like activity being one possible mechanism.[125] Recent animal studies report impacts on both male and female reproduction, occurring at doses as low at 0.06 mg/kg.[126, 127]

Octa-BDE

Fetal toxicity has been identified as a sensitive toxic endpoint in rat and rabbit studies involving Octa-BDE.[128] Exposure in the womb resulted in bone malformations and decreased fetal weight in rat and rabbit offspring beginning at doses of 2 mg/kg with fetal death occurring at higher doses. Liver changes were also observed in animal studies following exposure to Octa-BDE products at 10 mg/kg or higher.[129, 130]

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[119] Eriksson et al., 2001. Brominated flame retardants: a novel class of developmental neurotoxicants in our environment? Environmental Health Perspectives 109(9):903-908.
[120] Eriksson et al., 2002. A brominated flame retardant, 2,2',4,4',5-pentabromodiphenyl ether: uptake, retention, and induction of neurobehavioral alterations in mice during a critical phase of neonatal brain development. Toxicological Sciences 67:98-103.
[121] Birnbaum et al., 2004. Brominated flame retardants: cause for concern? Environmental Health Perspectives 112(1): 9-17.
[122] Zhou et al., 2002. Developmental exposure to brominated diphenyl ethers results in thyroid hormone disruption. Toxicological Sciences 66:105-116.
[123] Zoeller et al., 2002. Thyroid Hormone, Brain Development, and the Environment. Environmental Health Perspectives 110(Supp. 3): 355-361.
[124] Meironyte Guvenius, 2003. Human prenatal and postnatal exposure to polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorobiphenylols, and pentachlorophenol. Environmental Health Perspectives 111(9): 1235-1241.
[125] Birnbaum et al., 2004. Brominated flame retardants: cause for concern? Environmental Health Perspectives 112(1): 9-17.
[126] Talsness et al., 2003. Ultrastructural changes in the ovaries of adult offspring following single maternal exposure to low dose 2,2',4,4',5-pentabromodiphenyl ether. Organohalogen Compounds 61: 88-91.
[127] Kuriyama et al., 2003. Maternal exposure to low dose 2,2',4,4',5-pentabromodiphenyl ether (PBDE 99) impairs male reproductive performance in adult rat offspring. Organohalogen Compounds 61: 92-95.
[128] Darnerud, 2003. Toxic effects of brominated flame retardants in man and wildlife. Environment International 29:841-853.
[129] Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004).
[130] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.

Deca-BDE

Deca-BDE is the only PBDE product that has been evaluated in rodent cancer studies.[131] These studies indicate that dietary intake of Deca-BDE is associated with liver, pancreas and thyroid tumors, but at very high doses (2500 - 5000 mg/kg).[132] In addition, thyroid changes, liver and kidney effects and fetal death have been observed in rodent studies of Deca-BDE at a dose of 80 mg/kg. A recent study reported developmental neurotoxic effects of Deca-BDE at 20.1 mg/kg, however the methodology of this study has been criticized.[133, 134] BDE-209 is a large molecule and it had been thought that its size would prevent it from being absorbed into the body.[135] Recent studies indicate that BDE-209 is partially absorbed from the gut of rats and has been found in human tissue samples indicating that some absorption occurs.[136] Concern about the toxicity of Deca-BDE extends beyond consideration of the parent compound and is, in large part, driven by its potential to degrade in the environment to Penta-BDE congeners. The degradation of Deca-BDE is discussed in detail in Appendix A.

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[131] NTP, 1986. Toxicology and carcinogenesis studies of decabromodiphenyl oxide (CAS. No. 1163-19-5) in F344/N rats and B6C3F1 mice (feed studies).
[132] NAS, 2000. Toxicological risks of selected flame-retardant chemicals. National Research Council. Available at www.nap.edu/openbook/0309070473/html/78.html.
[133] Viberg et al., 2003. Neurobehavioral derangements in adult mice receiving decabrominated diphenyl ether (PBDE 209) during a defined period of neonatal brain development. Tox. Sciences 76: 112-120.
[134] Vijverberg et al., 2004. Letter to the Editor. Toxicological Sciences 79:205-206.
[135] Birnbaum et al., 2004. Brominated flame retardants: cause for concern? Environmental Health Perspectives 112(1): 9-17.
[136] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.

Table 7. Lowest observed effects levels in PBDE animal toxicity studies.

Associated PBDE product	PBDE congener or product	Endpoint	Duration/time of exposure (animal)	Lowest Observed Effects Level (mg/kg bodyweight)	Ref.*
Penta-BDE	BDE-47	Developmental neurotoxicity	1 day/post-natal day 10 (rat)	0.8	137
	Penta product	Decreased thyroid hormone (exposure during development)	15 days/ gestational days 6-20 (rat)	1.0	138
	BDE-99	Developmental reproductive effects	1 day/ gestational day (rat) 6	0.06	139
Octa-BDE	Saytex 111[a]	Fetotoxicity	13 days/ gestational days 7-19 (rat)	2-5	140
	Octa-BDE product	Liver changes	28 days and 13 weeks (rabbit)	10	141;142
Deca-BDE	BDE-209	Developmental neurotoxicity	1 day/post-natal day 3 (mouse)	20.1	143
	Deca-BDE	Thyroid changes, liver and kidney effects and fetal death	30 days (rat)	80	144
	Deca-BDE	Cancer	103 weeks (rat and mouse)	1120 - 3200	145

Notes: mg/kg, milligram per kilogram bodyweight per day; Ref., reference
[a] Saytex 111 is an Octa-BDE commercial product.

[137] Eriksson et al., 2001. Brominated flame retardants: a novel class of developmental neurotoxicants in our environment? Environmental Health Perspectives 109(9):903-908.
[138] Zhou et al., 2002. Developmental exposure to brominated diphenyl ethers results in thyroid hormone disruption. Toxicological Sciences 66:105-116.
[139] Kuriyama et al., 2004. Developmental exposure to low dose PBDE-99: 1 – effects on male fertility and neurobehavior in rat offspring. Environmental Health Perspectives. Available online Nov. 4, 2004.
[140] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.
[141] Health Canada, 2004. Screening assessment report – Polybrominated diphenyl ethers (PBDEs). Available at: http://www.hc-sc.gc.ca/hecs-sesc/exsd/screening_assessment.htm (accessed Sept. 2004).
[142] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.
[143] Viberg et al., 2003. Neurobehavioral derangements in adult mice receiving decabrominated diphenyl ether (PBDE 209) during a defined period of neonatal brain development. Tox. Sciences 76: 112-120.
[144] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.
[145] Darnerud et al., 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure and toxicology. Environmental Health Perspectives 109(Supplement 1): 49-68.

Comparing PBDE Effects Levels from Animal Studies to Estimates of Human Exposure

Environmental health agencies, including the U.S. EPA, rely on both animal and human toxicity studies to establish various criteria for the protection of human health. Key to the development of such criteria is the derivation of human exposure doses for specific chemicals below which adverse health effects are not expected. These so called "safe doses", as derived by EPA, are known as oral reference doses (RfDs). In order to provide adequate protection of health, toxic effects levels observed in animals or humans are divided by uncertainty (or safety) factors to give the lower, and more protective RfD. Factors of 10 to 10,000 are typically used to account for uncertainties when using animal toxicity data to predict human health effects that may result from exposure to environmental contaminants. It is the RfD, not the toxic effect level itself, that should be used to estimate whether or not exposure to a contaminant in the environment represents a potential health risk. The magnitude of the risk can be inferred by the degree to which the RfD is exceeded. Background information on safety factors and the derivation of RfDs can be found in several U.S. EPA guidance documents.[146, 147]

The levels at which toxic effects have been observed in animal studies for Penta-BDE congeners (Table 7) are between 10 to 1,000,000 times higher than estimates of daily human intake of total PBDEs (Table 6). Estimates of adult intake based on multiple sources of exposure have yielded higher intakes compared to estimates based on food intake only. For example, recent daily intake estimates based on diet, air and other sources range from 0.0002 – 0.0026 mg/kg for total PBDE (tetra to deca-BDE congeners) and 0.00004 – 0.0009 mg/kg for Penta-BDE congeners. This intake estimate for Penta-BDE congeners is between about 60 to 1,500 times higher than the lowest effect level reported from animal studies for BDE-99 of 0.06 mg/kg. This indicates that at least one study has predicted human intakes of Penta-BDE within the range of RfDs or MRLs that could be derived from existing animal studies. Newly emerging research will better define appropriate toxicity studies and human exposure estimates upon which new RfDs and MRLs can be derived.

Build Up of PBDEs in the Body

PBDEs, like PCBs, can build up in the body and remain stored there for years. The term biological half-life, refers to how long it takes the body to excrete half of an accumulated amount.[148] Different PBDEs have different half-lives.[149] For BDE-47 and BDE-153, human half-lives of 2 to 26 years have been predicted, respectively[150] BDE-209 has a much shorter half-life estimated to be about two days to one week in people, while the half-life estimated for

[146] U.S. EPA, 2004. RfD Background Document. Available at: http://www.epa.gov/iris/rfd.htm. Accessed 12/20/04.
[147] U.S. EPA, 2002. A review of the reference dose and reference concentration processes. EPA/630/P-02/002F. Available at http://www.epa.gov/iris/RFD_FINAL[1].pdf.
[148] Casarett & Doull's Toxicology, 1996. C.D. Klaassen editor. McGraw-Hill Publishers, New York.
[149] Hakk et al., 2003. Metabolism in the toxicokinetics and fate of brominated flame retardants – a review. Environment International 29:801-828.
[150] Geyer et al., 2004. Terminal elimination half-lives of the brominated flame retardants TBBPA, HBCD, and lower brominated PBDEs in humans. Organohalogen Compounds 66:3867-3872.

BDE-183 is three months.[151] [152] Half-lives of tetra-, penta- and hexa-BDEs in rats are much shorter than for people and range from about 19 to 119 days.[153]

Many of the rodent toxicity studies described above, especially the studies evaluating developmental toxicity, involve exposing rodents to PBDEs for durations of a single day to weeks. However, people are most likely exposed to PBDEs continually from many sources resulting in a build up of many PBDEs over time. Therefore, the toxic effects levels presented in Table 7 are not directly comparable to most of the human exposure estimates presented in Table 6 because of differences in half-lives and exposure durations between rodents and people.

Body burden (i.e. accumulated amount of PBDEs in the body) is a better measure than daily intake when comparing rodent and human exposures. Body burdens will vary depending on the type of PBDE, the amount and duration of exposure, as well as on individual differences in absorption, metabolism and excretion. One recent report suggests that after adjusting for PBDE body burdens between rodents and humans, high-end human exposures appear to be approaching toxic effects levels observed in animal studies, mainly for Penta-BDE associated congeners.[154]

[151] Watanabe et al., 2003. Environmental release and behavior of brominated flame retardants. Environment International 29:665-682.
[152] Sjodin et al., 2003. A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29:829-839.
[153] Hakk et al., 2003. Metabolism in the toxicokinetics and fate of brominated flame retardants – a review. Environment International 29:801-828.
[154] McDonald, 2004. Distribution of PBDE levels among U.S. women: estimates of daily intake and risk of developmental effects. Abstract presented at BFR 2004 Conference in Toronto Canada, June 2004.

Products Containing PBDEs at End-of-Life

While pathways for PBDEs from products to the environment are unknown, it is thought that much of the substance is likely released at the time of disposal. Potential pathways for PBDEs from three generic product types- electronics, automobiles, and upholstered furniture- are illustrated in Figures 5 through 7. Not all electronics, automobiles or upholstered furniture contain PBDEs, but PBDEs are used in all three types of products. The product types were chosen to show the wide variety of possible pathways. The volume of PBDEs released to the environment at any point illustrated below is unknown.

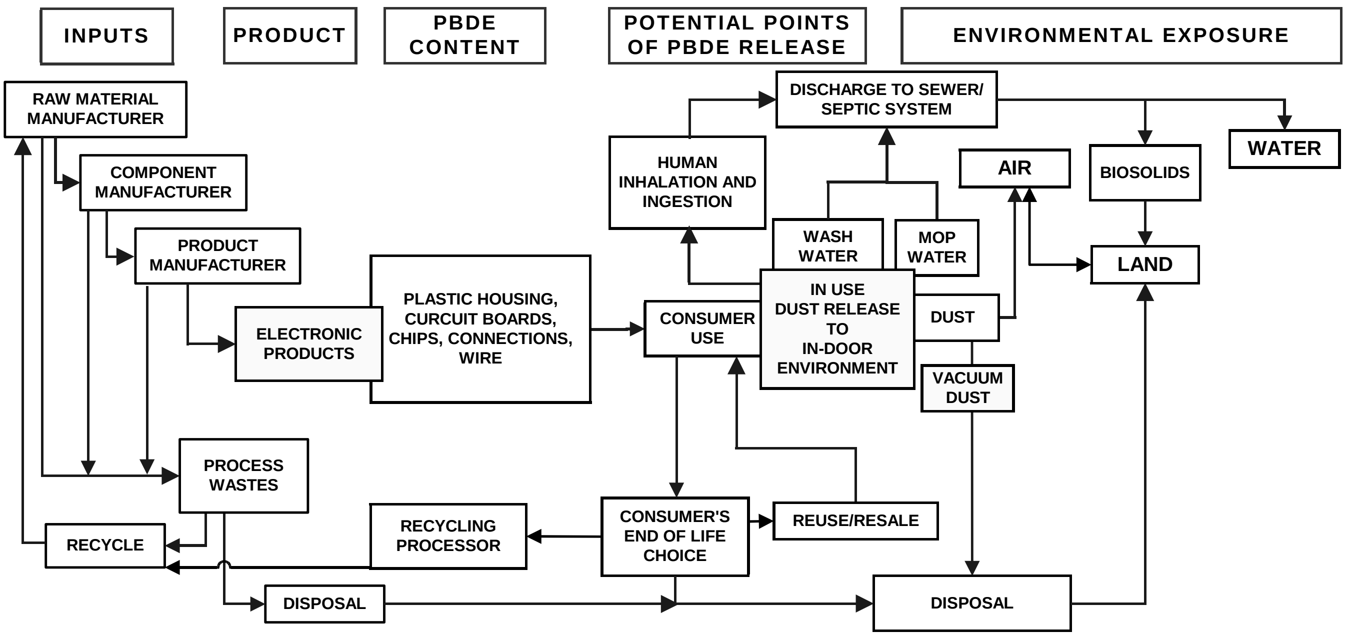

Figure 5. Electronic products and potential PBDE pathways to the environment

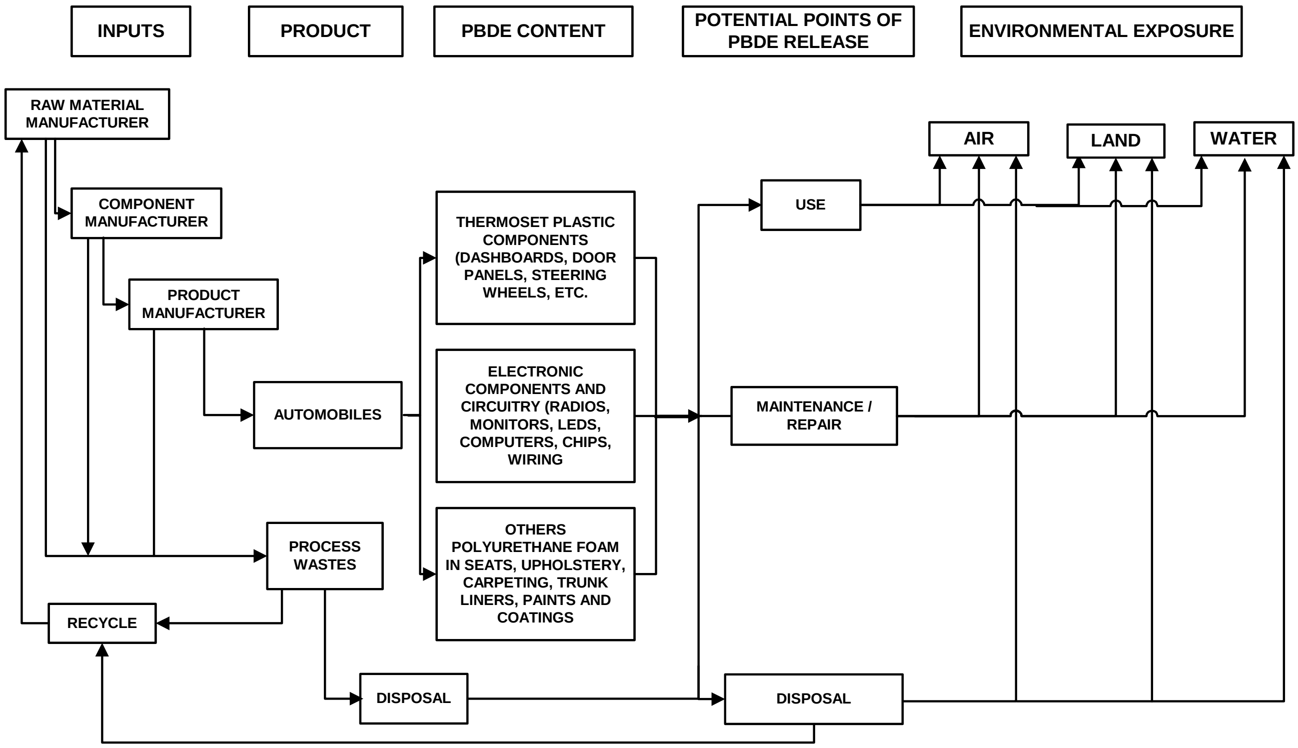

Figure 6. Automobiles and potential PBDE pathways to the environment

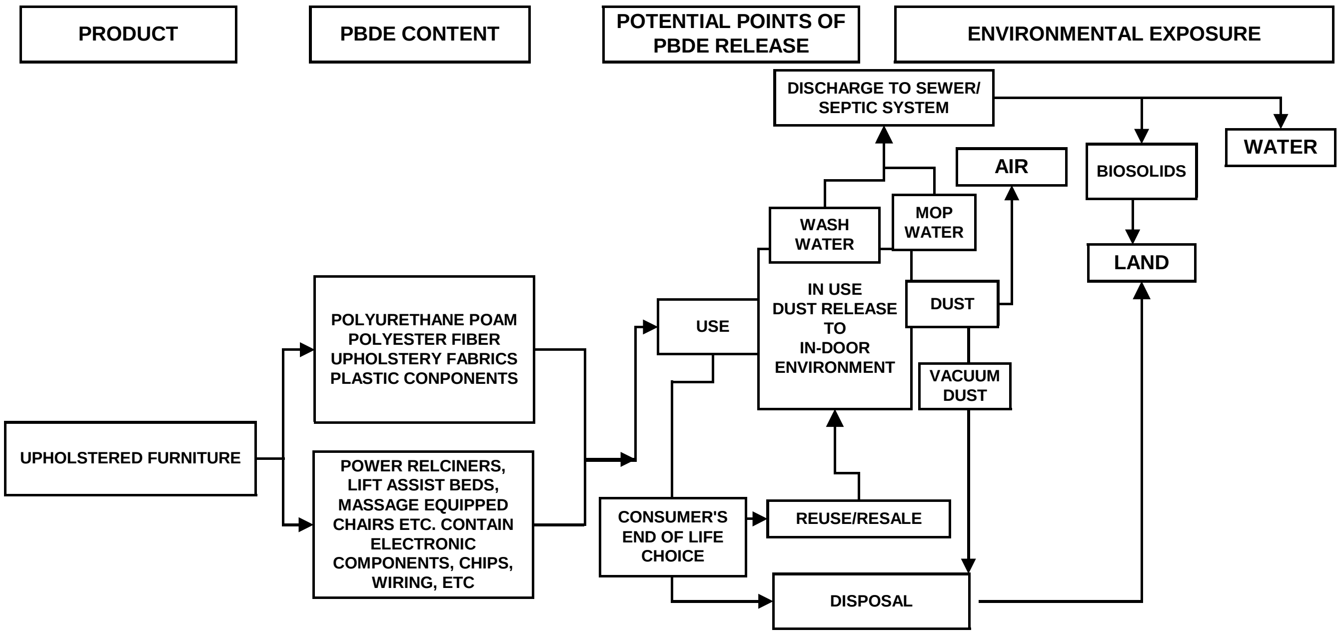

Figure 7. Upholstered furniture and potential PBDE pathways to the environment

Most products containing PBDE are long lived. Automobiles, for example, have a life expectancy of 12 years. Building materials can last 100 years or more. Electronics tend to become obsolete before they wear out, but many remain in storage, rather than being discarded.

Waste composition information available for the state of Washington indicates that as much as 6.5 percent, or 360,000 tons annually, of the discarded municipal solid waste stream could be products containing PBDEs.

Table 8. Waste composition analysis for the state of Washington, 2003

Waste category	Percent of total municipal solid waste
Plastics/other materials	2.5%
Electronics	0.3%
Furniture/mattresses	1.4%
Carpet and carpet pad	2.3%
Total percent of waste that may contain PBDEs	6.5%

Electronics Recycling

Electronics recycling facilities may represent a source of PBDEs to the surrounding environment. Concentrations of ambient PBDEs outside and inside an electronics recycling facility in Southern Ontario were approximately 4.4 and 22 times higher, respectively, than outdoor and indoor ambient PBDEs in Toronto.[155] Workers in a Swedish electronics recycling facility were found to have blood levels of five PBDE congeners that were significantly higher than those found in a control group.[156]

Landfills

The vast majority of solid waste in Washington is landfilled. With the exception of products diverted for recycling, such as electronics, most products containing PBDEs are probably landfilled in Washington. The fate of PBDEs in the landfill environment is unknown.

Auto fluff is waste that is left over after metals have been separated from shredded scrap cars. A large percentage of auto fluff is made up of plastic and foam, which may or may not be flame retarded with PBDEs. Auto fluff is used at the LRI landfill in Tacoma for daily cover and the construction of internal berms in the active cell. The environmental impact of this practice is unknown; it is possible that using auto fluff as daily cover is the best waste management practice with regard to PBDEs.

Formation of Polybrominated Dioxins and Furans

Aside from the direct release of PBDEs into the environment, disposal of PBDE-containing substances raises concern about the formation of polybrominated dioxins (PBDDs) and polybrominated furans (PBDFs). Most of these concerns relate to combustion of PBDE-containing plastics and foams that could result in the formation of polybrominated dioxins and furans. Some natural processes also result in formation of such compounds. Chlorinated dioxins and furans have been extensively studied because of their possible carcinogenic and other systemic effects in humans, and brominated dioxins are suspected to have similar effects.

Halogenated dioxins and furans (including brominated ones) are thought to form during combustion of halogenated compounds. Formation depends on the availability of halogenated compounds, combustion temperatures in the range of 400 to 1,000°F, and the presence of particles whose surfaces catalyze the reactions.

Dioxins and furans can from de novo during combustion from chlorine-, bromine- or fluorine-ion containing salt and the elements carbon, hydrogen and oxygen, or hydrocarbons, or result from the degradation of halogen containing compounds (such as plastics, halogenated pesticides and

[155] Craig M. Butt, Miriam L. Diamond, Jennifer Truong, Michael Ikonomou, and Arnout F. H. Ter Schure, "Spatial Distribution of Polybrominated Diphenyl Ethers in Southern Ontario as Measured in Indoor and Outdoor Window Organic Films," Environmental Science and Technology, Vol. 38, No. 3, 2004, pp. 724 – 731.
[156] Andreas Sjödin, Lars Hagmar, Eva Klasson-Wehler, Kerstin Kronholm-Diab, Eva Jakobsson, and Åke Bergman, "Flame Retardant Exposure: Polybrominated Diphenyl Ether Exposure in Swedish Workers," Environmental Health Perspectives, Vol. 107, No.8, 1999, pp. 643 – 648.

phenols). Photochemical reactions involving UV light and some biological processes may also form dioxins and furans.

For all industrial and natural processes that create dioxins, it would be logical to expect dioxins to be present in all products or materials created by the process to the extent such products or materials actually contain organic matter. Accordingly, it would be logical to expect that all residues from combustion processes creating dioxins also contain dioxins. Where dioxins are created during plastic manufacturing, products containing these plastics should be expected to contain dioxins (has been confirmed for both brominated dioxins /IPCS 1998/ and chlorinated dioxins /Carroll et al 1999 quoted by Greenpeace 2000/). On the other hand glass and metals containing virtually no organic matter should not be expected to contain dioxins.[157]

Municipal Waste Combustors

Washington State has one operating municipal waste combustor, in Spokane. The minimum temperature for the Spokane incinerator is given in WAC 173-434-160, not below 982 C (1800 F) for a 15 minute average and not below 871 C (1600 F) for any reading.

Biosolids and Sewage Sludge

Biosolids are sewage sludge processed for land application. PBDEs have been detected in biosolids and sewage sludge in the US and Europe. Hale et al. examined biosolid samples from Virginia, Maryland, New York and California and found significant amounts of tetra-, penta-, and hexa-BDEs with relative contributions that match the commercial formulation of Penta-BDE. Total concentration was 1,100 – 2,290 µg/kg dry weight. The study's authors suggest that this indicates the input was high and consistent, regardless of the region of origin and irrespective of pretreatment application. While constituents of Penta were fairly consistent across samples, concentrations of deca-BDE, or BDE-209, varied widely among US biosolids analyzed.[158] Washington State does not monitor PBDEs in biosolids.

Washington State has five sewage sludge incinerators, in Anacortes, Bellingham, Edmonds, Lynnwood, and Vancouver. A few smaller communities also send biosolids to these cities to be incinerated. In Washington, the U.S. EPA has the authority to permit sludge incinerators for their emissions. The criteria for sewage sludge incinerators are located in 40 CFR 503. Specific requirements for minimum temperatures are not included.

Other Burn Facilities

Ecology is not aware of any facility that specifically burns only plastics or foam. Some wood boilers at pulp mills burn some plastics (mostly polyethylene and some PVC). Boiler

[157] Substance Flow Analysis for dioxins in Denmark http://www.mst.dk/udgiv/Publications/2000/87-7944-295-1/html/kap01_eng.htm
[158] Robert C. Hale, Mark J. LaGuardia, Ellen P. Harvey, Michael O. Gaylor, Matteson Mainor, William H. Duff, "Flame Retardants: Persistent Pollutants in Land-Applied Sludges," Nature, Vol. 412, July 12, 2001.

temperature is not subject to legal regulation but would typically be in the 1200˚ to 1800˚F range.

Episodic Fires

Episodic fires may be a source of release for PBDDs and PBDFs. A furniture factory, store or even an apartment house blaze may release more PBDDs or PBDFs than an incinerator because of the uncontrolled combustion/pyrolyzing nature of the event.

Ash Reuse

Chapter 173-306 WAC includes provisions for allowing the reuse of municipal incinerator ash rather than sending ash to landfills. If brominated dioxins and furans were present in substantial quantities, this could be a pathway for release to the environment.

PBDEs and the Environment

PBDEs were first detected in the environment in 1981 in the River Viskan, downstream from a textile manufacturing plant southwest of Stockholm.[159,160] Subsequent studies, primarily in Europe, North America, and Japan, indicate that PBDEs are ubiquitous in sediment and biota, and that their levels appear to be increasing rapidly. Levels detected in the United States tend to be much higher than those detected in similar media in Europe or Japan. While PBDEs are the subject of increasing study, knowledge of environmental behavior, exposure, and toxicity remains limited. Specific data on the presence of PBDEs in Washington State is also limited.

Air

PBDEs have been detected in air, both outdoor and indoor. Strandberg et al. found that PBDEs were widely distributed in the air over the Great Lakes region and could be transported to rural remote regions from urban areas through the atmosphere.[161]

Many sources of PBDEs are found indoors, resulting in elevated levels of PBDEs in indoor air. Indoor contaminants are less prone to degradation and atmospheric dilution, increasing their persistence. Butt et al. found indoor levels of PBDEs in Southern Ontario were 1.5 to 20 times greater than outdoor levels on a site-by site basis. They suggest that indoor air may serve as a significant source of PBDEs to outdoor air.[162]

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[159] Sjodin, Patterson, and Bergman, 2003. "A review on human exposure to brominated flame retardants-particularly polybrominated diphenyl ethers," Environment International (29) 829 – 839.
[160] Maria Cone, "Cause for Alarm Over Chemicals," Los Angeles Times, April 20, 2003, pp. A1 and A30.
[161] Bo Strandberg, Nathan Dodder, Ilora Basu, and Ronald Hites, "Concentrations and Spatial variations of Polybrominated Diphneyl Ethers and Other Organohalogen Compounds in Great Lakes Air" Environmental Science and Technology, 2001, vol. 35, pp. 1078 – 1083.
[162] Craig M. Butt, Miriam L. Diamond, Jennifer Truong, Michael Ikonomou, and Arnout F. H. Ter Schure, "Spatial Distribution of Polybrominated Diphenyl Ethers in Southern Ontario as Measured in Indoor and Outdoor Window Organic Films," Environmental Science and Technology, Vol. 38, No. 3, 2004, pp. 724 – 731.

Three studies were identified that examined PBDEs in household dust in the United States. All three used small sample sizes, and two have not been peer-reviewed.

Rudell et al. measured tetra- and penta-BDE in residential dust in five houses on Cape Cod, Massachusetts, with 90th percentile concentrations ranging from 0.7 to 4.1 µg/g dust.[163]

In 2004, Sharp and Lunder measured concentrations of 13 BDE congeners in dust samples from 10 houses across the United States. Results varied widely between houses, from 614 to 16,366 ppb for total PBDEs. One house was treated separately because the study participant had used her vacuum to clean up polyurethane foam residues when she removed carpet padding, two mattress pads, and an uncovered foam cushion from her home. Her sample contained 41,203 ppb total PBDEs. Three congeners, BDE-47, -99, and -209, accounted for 90 percent of the PBDEs by weight. BDE-47 and -99, major components of Penta-BDE; each accounted for 24 percent on average. BDE-209, the major component of Deca-BDE, accounted for an average of 42 percent of the samples. Levels of BDE-209 averaged 2,394, ranging from less than 400 ppb to 7,510 ppb.[164]

Stapleton et al. measured 14 congeners in 16 household dust samples from the Washington, D.C. area. Total BDE concentrations ranged from 310 ng/g dry mass to 30,140 ng/g dry mass.

Sediment

PBDEs have been detected in sediment and soil in North America. Song et al. took sediment cores in 2001 and 2002 in Lake Superior at six locations away from lakeshores. Total PBDEs showed a significant increase in recent years. Excluding BDE-209, concentration of total PBDEs ranged from 0.5 to 3 µg/kg. Concentrations of BDE-209 were about an order of magnitude higher than the sum of the other congeners, comprising 83 - 94 percent of total PBDEs measured in the sediments.[165] Rayne et al. measured PBDE concentrations ranging from 2.7 to 91 µg/kg in 11 surficial sediments collected in 2001 from several sites along the Columbia River system in Southeastern British Columbia.[166]

Biota

Animal species appear to vary widely in their ability to metabolize or accumulate specific PBDE congeners. Wolker et al examined congener-specific accumulation and transfer of PBDEs in two arctic food chains. In the first, consisting of polar cod, ringed seal and polar bears, the pattern in the ringed seal was somewhat simpler than that of polar cod, while only one congener was

[163] Ruthann Rudell, David Camann, John Spengler, Leo Korn, and Julia Brody, "Phthalates, Alkyphenols, Pesticides, Polybrominated Diphenyl Ethers, and Other Endocrine Disrupting Hormones in Indoor Air and Dust" Environmental Science and Technology,
[164] Renee Sharp and Sonya Lunder, "In the Dust: Toxic Fire Retardants in American Homes" Environmental Working Group, 2004
[165] Song et al., 2004. Polybrominated diphenyl ethers in the Sediments of the Great Lakes. 1. Lake Superior. Environmental Science and Technology 38(12)3286 – 3293.
[166] Rayne et al. 2003. Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000. Environmental Science and Technology, 37(13) 2847 – 2854.

detected in polar bears. In the second, polar cod and beluga whale, the beluga whale, with similar diet to ringed seal, showed higher and more complex PBDE levels than ringed seal.[167]

Buck measured total PBDEs in bald eagle eggs collected along the Lower Columbia River at 446 to 1,206 µg/kg wet weight.[168]

In 2000, the Washington State Department of Ecology analyzed 16 freshwater fish samples from various locations in Washington State. Concentrations of total PBDEs ranged from 1.4 µg/kg (wet weight) in remote Douglas Creek rainbow trout to 1,250 µg/kg in mountain whitefish from the Spokane River. The highest concentrations were found in areas draining urbanized watersheds (Spokane, Yakima and Snake Rivers) compared to undeveloped watersheds (Douglas Creek, Rock Island Creek, and Soleduck River). Results for the latter three watersheds probably represent background for PBDEs in local freshwater fish. Tetra and penta isomers were the major congeners present, in ratios similar to the commercial formulation Penta. There appeared to be substantial inter-species differences in the ability of the fish to metabolize PBDEs, with relatively low accumulation by large-scale suckers and carp relative to rainbow trout and mountain whitefish.[169]

Rayne et al. measured PBDEs in orcas from three communities from the northeastern Pacific Ocean, including Puget Sound and Georgia Basin. Communities sampled included northern residents, southern residents, and transients. Total PBDE levels were 2 to 10 times greater than those reported for sperm whales from the north Atlantic near industrialized regions of Europe and the range of total PBDE concentrations in pilot whales in the North Sea. Unlike total PCB levels, no significant age-related relationships were observed for total PBDE concentration. Reasons for this difference are unknown and are confounded by the effects of increasing PBDE production levels over the past 20 years, potentially different environmental stability as compared to PCBs, and the unknown influence of lifetime exposure to PBDEs. With PBDE concentrations only 1 to 2.5 orders of magnitude less than total PCB concentrations in orcas in the northeastern Pacific, the authors stated that PBDEs must be considered as one of the potentially dominant organohalogen contaminants in aquatic biota.[170]

Temporal trends indicate increasing levels of PBDEs in animals. Ikonomou et al. measured the blubber of Arctic male ringed seals over the period 1981 to 2000. Mean total PBDE concentrations increased exponentially from approximately 0.6 µg/kg lipid in 1981 to 6.0 µg/kg lipid in 2000.[171] Between 1989 and 1998, PBDE concentrations in tissue from harbor seals in

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[167] Hans Wolkers, Bert van Bavel, Øystein Wiig, Kit M. Kovacs, Christian Lydersen, and Gunilla Lindstrom, "Congener-Specific Accumulation and Food Chain Transfer of Polybrominated Diphenyl Ethers n Two Arctic Food Chains," Environmental Science and Technology, Vol. 38, No. 6, 2004, pp. 1667 – 1674.
[168] Buck, 1999. Changes in productivity and environmental contaminants in bald eagles nesting along the lower Columbia River, US Fish and Wildlife Service, Portland, Oregon.
[169] A. Johnson, N. Olsen, "Analysis and Occurrence of Polybrominated Diphenyl Ethers in Washington State Freshwater Fish," Archives of Environmental Contamination and Toxicology, 2001, 41, pp. 339 – 344,
[170] Rayne et al., 2004. PBDEs, PBBs, and PCNs in three communities of free-ranging killer whales (Orcinus orca) from the Northeastern Pacific Ocean. Environmental Science and Technology, (38)4293 - 4299.
[171] Ikonomou et al., 2000. Congener patterns, spatial and temporal trends of polybrominated diphenyl ethers in biota samples from the Canadian West Coast and the Northwest Territories. Organohalogen Compounds 47: 77 – 80.

San Francisco Bay doubled every 1.8 years.[172] Lebeuf et al. measured PBDEs in blubber from beluga whales in the St. Lawrence Estuary in Canada for the period 1988 to 1999. Total PBDEs measured exponentially increased over the period, with a doubling period of no longer than three years.[173]

Table 9 summarizes PBDEs measured in North American biota.

[172] She W. et al, 2002. PBDEs in the San Francisco Bay Area: Measurements in harbor seal blubber and human breast adipose tissue. Chemosphere (46)697 – 707.
[173] Lebeuf et al. 2004. Levels and Temporal Trends (1988 – 1999) of polybrominated diphenyl ethers in beluga whales (Delphinapterus leucas) from the St. Lawrence Estuary, Canada. Environmental Science and Technology, 39(11)2971 – 2977.

Table 9. Measured concentrations of PBDEs in North American biota

Organism	Location; year	Total PBDEs	Reference
Biota measured in Pacific Northwest			
Dungeness crab hepatopancreas	West coast, Canada; 1993 - 1995	4.2 – 480 µg/kg lipid	174
Bald eagle egg	Lower Columbia River, Washington and Oregon, 1994 - 1995	446 – 1,206 µg/kg ww	175
Heron egg	British Columbia; 1983 - 2000	1.308 – 288 µg/kg ww	176
Orca blubber	Northeastern Pacific Ocean; 1993 - 1996	87 – 1,620 µg/kg lipid	177
Mountain whitefish (muscle)	Columbia River, British Columbia; 1992 - 2000	0.726 – 131 µg/kg ww	178
Rainbow trout	Spokane River, Washington; 1999	297 µg/kg ww	179
Mountain whitefish		1250 µg/kg ww	
Largescale sucker		105 µg/kg ww	
Biota measured in other areas of North America			
Murre egg	Northern Canada; 1975 - 1998	0.442 – 2.93 µg/kg ww	180
Fulmar egg	Northern Canada; 1975 - 1998	0.212 – 2.37 µg/kg ww	
Herring gull egg	Great Lakes; 1981 - 2000	9.4 – 1544 µg/kg ww	181
Beluga whale blubber	Canadian Arctic	81.2 – 160 µg/kg lipid	182
Beluga whale blubber	St. Lawrence Estuary, Canada, 1988 - 1999	17.2 – 935 µg/kg lipid	183
Lake trout	Lake Ontario; 1997	95 µg/kg ww	184
	Lake Erie; 1997	27 µg/kg ww	
	Lake Superior; 1997	56 µg/kg ww	
	Lake Huron; 1997	50 µg/kg ww	
Carp	Virginia; 1998 - 1999	1140 µg/kg ww	185

[174] Ikonomou et al., 2002. Occurrence and congener profiles of polybrominated diphenyl ethers (PBDEs) in environmental samples from coastal British Columbia, Canada. Chemosphere (46) 649 – 663.
[175] Buck, 1999. Changes in productivity and environmental contaminants in bald eagles nesting along the lower Columbia River, US Fish and Wildlife Service, Portland, Oregon.
[176] Wakeford et al. 2002. Analysis of polybrominated diphenyl ethers (BDEs) in wildlife tissues – Canadian Wildlife Service contributions. Abstracts of the 4th Annual Workshop on Brominated Flame Retardants in the Environment, June 17 – 18, Canada Center for Inland Waters, Burlington, Ontario.
[177] Rayne et al., 2004. PBDEs, PBBs, and PCNs in three communities of free-ranging killer whales (Orcinus orca) from the Northeastern Pacific Ocean. Environmental Science and Technology, (38)4293 - 4299.
[178] Rayne et al. 2003. Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000. Environmental Science and Technology, 37(13) 2847 – 2854.
[179] Johnson and Olson, 2001. Analysis and occurrence of polybrominated diphenyl ethers in Washington State freshwater fish. Bulletin of Environmental Contamination and Toxicology, 41: 339 – 344.
[180] Wakeford et al. 2002. Analysis of polybrominated diphenyl ethers (BDEs) in wildlife tissues – Canadian Wildlife Service contributions. Abstracts of the 4th Annual Workshop on Brominated Flame Retardants in the Environment, June 17 – 18, Canada Center for Inland Waters, Burlington, Ontario.
[181] Norstrom et al. 2002. Geographical distribution (2000) and temporal trends (1981 – 2000) of brominated diphenyl ethers in Great Lakes herring gull eggs. Environmental Science and Technology, 36(22)4783 - 4789
[182] Alaee et al. 1999. Distribution of polybrominated diphenyl ethers in the Canadian environment. Organohalogen Compounds (40) 347 – 350.
[183] Lebeuf et al. 2004. Levels and Temporal Trends (1988 – 1999) of polybrominated diphenyl ethers in beluga whales (Delphinapterus leucas) from the St. Lawrence Estuary, Canada. Environmental Science and Technology, 39(11)2971 – 2977.
[184] Luross et al. 2002. Spatial distribution of polybrominated diphenyl ethers and polybrominated biphenyls in lake trout from the Laurentian Great Lakes. Chemosphere, 46: 665 – 672.
[185] Hale et al. 2001. Polybrominated diphenyl ether flame retardants in Virginia freshwater fishes (USA). Environmental Science and Technology 35(23):4585 – 4591.

Environmental Fate and Pathways

Long-range transport

Swedish and Dutch scientists measured atmospheric deposition of PBDEs in the Baltic Sea for the first time in research published in January 2004. Measurements were taken from an island in the central basin of the Baltic Sea far from human settlement; deposition of PBDEs would therefore be the result of long-range transport through the atmosphere. The research compared deposition of PBDEs to the better documented deposition of PCBs. The atmospheric deposition of PBDEs exceeded that of PCBs by a factor of 40, while deposition of PCBs was decreasing.

By far the largest percentage of PBDEs detected were of the decabrominated BDE-209 congener, a marker for the environmental distribution of the commercial deca-BDE formulation. This was followed by the tetrabrominated BDE-47 and the pentabrominated BDE-99 congeners.

Concentrations of total PBDEs were highly correlated with concentrations of total PCBs, suggesting similar atmospheric transport mechanisms. More detailed regression analysis showed similar regression slopes for total PCBs, BDE-47 and BDE-100, with a different regression slope for BDE-209. The researchers suggest that BDE-209 has different underlying atmospheric transport processes and/or sources from PCBs, BDE-47, and BDE-100. BDE-47 and BDE-100 both originate from the commercial penta-BDE formulation, which has been phased out in the European Union. The researchers hypothesize that BDE-47 and BDE-100 may originate from secondary sources, similar to PCBs, while BDE-209 still has primary sources. The difference in PBDE congeners reflects the change in usage of commercial PBDE formulations.

BDE-17, a tribrominated congener, was also detected in the air on the Baltic Sea island. It has not been detected in the air at source areas, such as electronics recycling facilities and highly urbanized environments. The researchers believe it is likely BDE-17 is a breakdown product from atmospheric debromination processes, possibly from BDE-209.[186]

PBDEs have been identified in polar cod, ringed seal, polar bear and beluga whale.[187] PBDE concentrations in Canadian beluga whales increased between 1982 and 1997. PBDEs appear to be increasing in marine mammals and may surpass PCBs as the most prevalent POP in arctic habitats.[188]

Environmental breakdown of PBDEs

A number of studies, summarized in Appendix A, suggest that PBDEs may break down in the environment, both as a result of exposure to light, known as photolytic degradation, and as a

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[186] Ter Schure, Larsson, Agrell, and Boon, 2004. Atmospheric Transport of Polybrominated Diphenyl Ethers and Polychlorinated Biphenyls to the Baltic Sea. Environmental Science and Technology, 38(5)1282 – 1286.
[187] Wolkers, van Bavel, Wiig, Kovacs, Lydersen, and Lindstrom, 2004. Congener-Specific Accumulation and Food Chain Transfer of Polybrominated Diphenyl Ethers n Two Arctic Food Chains. Environmental Science and Technology, 38(6)1667 – 1674.
[188] National Marine Fisheries Service, 2004. Alaska Essential Fish Habitat Environmental Impact Statement: Appendix G: Non-fishing Impacts to Essential Fish Habitat and Recommended Conservation Measures. p. G-61, http://www.fakr.noaa.gov, viewed 17 May 2004.

result of biological processes. Environmental degradation would be important because PBDEs become more water soluble and bioavailable the fewer the bromines attached to the molecule.

Photochemical reaction rates for PBDEs as a class appear to vary as a result of a number of conditions.

Photolytic reaction rates become slower as the number of bromine atoms attached to the PBDE molecule decrease. Deca-BDE breaks down more quickly than nona-BDE, which breaks down more quickly than octa-BDE, and so on.

Molecules with the maximum of five bromine atoms attached to one of the carbon rings appear to degrade more quickly. The effect of bromine position on photolytic reaction rate for molecules with less than five bromine atoms on one of the carbon rings is unclear. Bezares-Cruz et al. found greatest reactivity for congeners with bromine atoms in all of the ortho positions, while Ericksson et al. found inconclusive results for congeners with less than five bromine atoms attached to one of the carbon rings.

In experiments with BDE-209, or deca-BDE, where the molecule is in or on a substance that maximizes exposure to UV light, for example, a smooth, hard, surface or in a clear solution, photolytic reaction rates increase. Conversely, it appears that when the BDE-209 molecule is in or on a substance that minimizes exposure to UV light, such as sediment or soil, photolytic reaction rates decrease.

Reaction rates are fastest in or on substances with readily available hydrogen donors, such as organic solvents. Photolytic reaction rates appear slower when PBDEs are in or on substances with lower concentrations of hydrogen donors or less favorable hydrogen donors, such as humic acids in water. Photolytic reaction rates are also expected to be slower where organic carbon may bind to the PBDE molecule.

Degradation products and rate both appear to vary with the intensity of UV light. As the number of bromine atoms on the PBDE molecule decreases, the molecule's ability to absorb solar radiation decreases. This is because the upper limit on the range of light wavelengths that the molecule can absorb decreases as the number of bromine atoms decreases. The overlap in the range of solar wavelengths at ground level and the range of wavelengths absorbed by PBDE molecules thus decreases as the number of bromine atoms decreases.

The chemical properties of the matrix may also affect breakdown products. The first step in the photolysis reaction is the cleavage of the carbon-bromine bond. In laboratory experiments using organic solvents, water with dissolved humic substances, sand, soil, and sediment, the nonabrominated aryl radical formed can abstract a hydrogen atom from the solvent or from humic substances dissolved in water or on the sand, soil or sediment. The debrominated product is thus formed through reductive debromination. As reductive debromination has been observed in experiments using water with dissolved humic substances, it must be assumed that this may also occur in the environment. Other factors, not yet explored, may also influence photolytic degradation rate and products.

Globally, Deca-BDE has become the most used commercial PBDE product; after December 2004, it will be the only PBDE product still in production. There is a weight of evidence suggesting that highly brominated PBDEs are precursors of the more bioaccumulative and persistent lower brominated PBDEs, as well as PBDFs. While the degree to which this phenomenon adds to the overall risk presented to organisms from formation of the more toxic and persistent tetra- to hexa-BDE congeners or from the formation of PBDFs is not known, there is sufficient evidence to warrant concern.

IV. PBDEs and the Regulatory Environment

IN BRIEF: The EPA is developing a rule to complement a national flammability standard for residential upholstered furniture under consideration by the Consumer Product Safety Commission. The rule would require notification to, and review by the EPA of Deca-BDE and 15 other flame retardant chemicals or categories of chemicals likely to be used on furniture fabrics. This section includes a roundup of what actions other states and countries are taking on the use of PBDE flame retardants.

State Overview

Only one Washington State regulation was identified that pertains to PBDEs, WAC 173-303-100, Dangerous Waste Regulations, Persistence Criteria. The regulation describes methods for determining whether a solid waste is a dangerous waste based on toxicity and/or persistence. Persistent constituents are defined as chemical compounds which are either halogenated organic compounds (HOC), or polycyclic aromatic hydrocarbons (PAH). PBDEs are HOCs. Under these criteria, many products containing PBDEs would probably be considered dangerous waste at end-of-life.

A web search was conducted to identify regulations and legislation pertaining to PBDEs at the state, federal, and international levels. Activities other than those identified below may also exist.

Federal Overview

Deca-BDE is the only one of the commercial PBDE formulations for which reporting is required for the U.S. EPA's Toxic Release Inventory. The Toxics Release Inventory (TRI) is a publicly available EPA database that contains information on toxic chemical releases and other waste management activities reported annually by certain covered industry groups as well as federal facilities. This inventory was established under the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and was expanded by the Pollution Prevention Act of 1990. Covered industry groups and federal facilities that dispose of more than 10,000 pounds of Deca-BDE annually are required to report how much they discard. Only one facility in Washington has reported on the use of Deca-BDE under TRI. The company operating the facility, Matsushita, has stated an intent to phase out the use of all PBDEs, including Deca-BDE, by March 2005.

On December 6, 2004, U.S. EPA issued a draft Significant New Use Rule (SNUR) for Penta-BDE and Octa-BDE. This proposed rule would require manufacturers and importers to notify EPA at least 90 days before commencing the manufacture or import of Penta-BDE or Octa-BDE on or after January 1, 2005. The required notice would provide EPA with the opportunity to evaluate any intended new use and associated activities and, if necessary, to prohibit or limit that activity before it occurs. The proposed rule would not prohibit the import of products containing

Penta-BDE or Octa-BDE (e.g., mattresses, upholstered furniture). The comment period for the SNUR closes February 4, 2005.

EPA is developing a rule to complement a national flammability standard for residential upholstered furniture under consideration by the Consumer Product Safety Commission (CPSC). The rule would require notification to, and review by, EPA of 16 flame retardant chemicals or categories of chemicals, including Deca-BDE, identified by CPSC and industry as likely to be used to flame retard fabrics on furniture in order to comply with such a standard.[189]

TSCA contains an "unreasonable risk" regulatory standard, which is the basis, for control of new flame retardants introduced into commerce through EPA's New Chemicals Program. It is also the basis for certain brominated flame retardants to determine dioxin and furan contamination under EPA's 1987 TSCA Section 4 Dioxin/Furan Test Rule (CFR 766). Since 1979, approximately 150 Premanufacture Notices submitted for new flame retardant chemicals have been reviewed by EPA.

Directly or through grant mechanisms, EPA research managed by the Office of Research and Development is aimed at determining PBDE levels in children, house dust, food, and breast milk; developmental and reproductive toxicity of PBDEs; and the environmental fate of PBDEs upon release or after disposal and incineration of electronic equipment.

The furniture manufacturing industry and EPA's Design for the Environment Program have initiated a partnership to explore a variety of approaches to achieve environmentally sound fire protection. Approaches include identifying and evaluating environmentally preferable flame retardants and identifying and evaluating technological barriers to sustainable design as well as alternative formulations for foam.

EPA is conducting an Integrated Risk Information System assessment of PBDEs to be completed by the end of 2004.

The Interagency Working Group on Fire and Materials (IWGFM), formed in 1993, is a group of federal scientists and engineers from over 40 agencies that implements coordinated, long-range, national research efforts to understand the fire and thermal behavior of materials and develop advanced materials with improved performance. IWGFM objectives are:

- Develop uniform test procedures for fire performance evaluation of materials for consideration by government agencies
- Provide a mechanism to coordinate and communicate among government/ industry/ university research activities
- Analyze current research, development and technology in light of present and projected national needs
- Advance defense/ civilian agency dual-use objectives

[189] Kenneth Moss, "BFR Regulatory Update" The Third International Workshop on Brominated Flame Retardants: BFR 2004 abstracts, p. 7.

- Promote research and development of advanced fire-safe materials by strengthening the case for more government and industrial funding[190]

Other States: Overview

California

In August 2003, the California State Legislature passed AB 302, which prohibits, on and after January 1, 2008, a person from manufacturing, processing, or distributing in commerce a product containing more than one-tenth of 1% penta-BDE or octa-BDE, by mass.[191] In 2004, the California State Legislature passed into law AB 2587, which moves the date of the California ban from 2008 to June 1, 2006.[192] See: http://www.leginfo.ca.gov/pub/bill/asm/ab_2551-2600/ab_2587_bill_20040921_chaptered.pdf for the text of the law.

As required by AB 302, in June 2004 the Senate Office of Research submitted a report entitled "Polybrominated Diphenyl Ethers (PBDEs): Potential Hazards from DecaBDE and Unresolved Issues from AB 302" to the President Pro Tempore of the Senate and the Senate Environmental Quality Committee. The report stated that, based on the "likely potential harm to humans posed by decaBDE and the known human exposures to this chemical, it does not appear that human exposure to decaBDE is occurring at a level that is likely to be unsafe for human health or development." The report concluded that, at this time, it would be premature to add Deca-BDE to the list of banned PBDEs contained in AB 302.[193]

The report went on to state that, because of inherent problems in extrapolating from rodent studies to human effects and the limited data on human exposure, it was not possible to say that deca-BDE does not pose a danger to human health. Rather, the data available does not conclusively show that there is a danger to human health at this time. While the potential breakdown of deca-BDE is mentioned in the body of the report, potential breakdown products are not referenced in the conclusion or its rationale.[194]

The report recommends that California's Office of Environmental Health Hazard Assessment set a reference dose for Deca-BDE based on the level in human tissue that would represent an unsafe level. It also recommends that the state create a breast milk monitoring program.[195]

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[190] US Navy. Interagency Workgroup on Fire and Materials. Available at: http://www.dt.navy.mil/sur-str-mat/fun-mat/fir-pro-sea/int-wor-gro/, viewed 1 October 2004.
[191] State of California Legislative Counsel, http://www.leginfo.ca.gov/, viewed 15 September 2004.
[192] Official California Legislative Information, http://www.leginfo.ca.gov/pub/03-04/bill/asm/ab_2551-2600/ab_2587_bill_20040921_chaptered.pdf, viewed 30 November 2004
[193] Wiley and McCarthy, 2004. Polybrominated Diphenyl Ethers (PBDEs): Potential Hazards from DecaBDE and Unresolved Issues from AB 302. California Senate Office of Research.
[194] Wiley and McCarthy, 2004. Polybrominated Diphenyl Ethers (PBDEs): Potential Hazards from DecaBDE and Unresolved Issues from AB 302. California Senate Office of Research.
[195] Wiley and McCarthy, 2004. Polybrominated Diphenyl Ethers (PBDEs): Potential Hazards from DecaBDE and Unresolved Issues from AB 302. California Senate Office of Research.

Hawaii

In June 2004, Hawaii enacted HB2013/SD2/CD1, which prohibits the manufacture, processing, or distribution of a product or flame-retarded part of a product containing more than 0.1% by mass of Penta-BDE, Octa-BDE, or any other chemical formulation that is part of these classifications, on or after January 1, 2006.[196]

New York

In August 2004, New York enacted A 10050/S 7621, which prohibits the manufacture, process, or distribution of BFRs. It does not prohibit the use or sale of products containing BFRs. The bill also establishes a Task Force on Flame Retardant Safety to study the risks associated with Deca-BDE and the availability, safety and effectiveness of alternatives to Deca-BDE.[197]

Maine

In April 2004, Maine enacted legislation [PL 2003, c 629] to reduce contamination from PBDEs. Section 1 of the bill prohibits the sale of products that contain more than 1% Penta-BDE or Octa-BDE beginning January 1, 2006. Section 2 expresses the intent of the Legislature to reduce risks associated with Deca-BDE either by implementing risk management measures or by prohibiting the sale of products that contain more than 1% Deca-BDE beginning January 1, 2008 provided a safer, nationally available alternative is identified. To assist the Legislature in deciding which if either of these strategies to pursue, the Department of Environmental Protection is required to review emerging information on PBDEs and other BFRs, including information on alternatives to DecaBDE, and report annually to the Legislature's Committee on Natural Resources beginning January 5, 2005.[198, 199]

Massachusetts

Bills H 2275/S 1268 relate to alternatives to the use of toxic chemicals. PBDEs are included on the list of chemicals to be phased out. The bills were heard in September 2003 in the Joint Committee on Natural Resources and Agriculture and were eligible for Executive Session.

Deca-BDE is subject to the Massachusetts Substance List. [200]

[196] Hawaii State Legislature, http://www.capitol.hawaii.gov/, viewed 1 September 2004.
[197] New York State Assembly, http://assembly.state.ny.us/leg, viewed 8 October 2004.
[198] Maine State Legislature, http://janus.state.me.us/, viewed 29 April 2004.
[199] pers. comm., J. James, Maine DEP, to C. Peele, 3 December 2004.
[200] Great Lakes Chemical Corporation, Material Safety Data Sheet for Great Lakes DE-83R and DE83, viewed at http://www.greatlakes.com/common/msdspdf/00001.pdf on March 29, 2004.

Michigan

Proposed Legislation:

HB 4406 regulates release of PBDEs and was referred to the House Committee on Land Use and Environment in March 2003.

HB 4407 provides sentencing guidelines for the crime of releasing polybrominated diphenyl ethers (PBDEs) into the environment and was referred to the House Committee on Criminal Justice in March 2003.

New Jersey

Deca-BDE is subject to the New Jersey Right to Know Hazardous Substance List (1 percent reporting limit) [201]

Pennsylvania

Deca-BDE is subject to the Pennsylvania Environmental Hazard List.[202]

International Overview

European Union

Directive 2003/11/EC of February 6, 2003, bans the marketing and use of Penta-BDE, including the marketing of articles containing Penta-BDE, as of August 15, 2004.

In January 2003, the European Parliament and the Council of the European Union passed Directive 2002/95/EC, restricting the use of certain hazardous substances in electrical and electronic equipment (RoHS). Article 4(1) lists the substances which are to be phased out of electrical and electronic equipment by July 1, 2006, including all forms of PBDE. The Directive also states that the European Commission Joint Research Center should evaluate applications for Deca-BDE to establish whether the Directive should be amended, i.e., certain applications of Deca-BDE should be exempted from the ban.

In February 2004, France completed the Human Health Draft of the Draft Update Risk Assessment of Bis(Pentabromophenyl) Ether (Decabromodiphenyl Ether) within the framework of the Existing Substances Regulation (793/93 EEC). This portion of the risk assessment drew one conclusion on Deca-BDE, with regard to neurotoxicity. The Draft Update concluded that

[201] Great Lakes Chemical Corporation, Material Safety Data Sheet for Great Lakes DE-83R and DE83, viewed at http://www.greatlakes.com/common/msdspdf/00001.pdf on March 29, 2004.
[202] Great Lakes Chemical Corporation, Material Safety Data Sheet for Great Lakes DE-83R and DE83, viewed at http://www.greatlakes.com/common/msdspdf/00001.pdf on March 29, 2004.

there is at present no need for further information and/or testing or for risk reduction measures beyond those which are being applied already.[203]

In May 2004, the United Kingdom completed the Final Environmental Draft of the Draft Update Risk Assessment of Bis(Pentabromophenyl) Ether (Decabromodiphenyl Ether). This portion of the Draft Update drew two conclusions about Deca-BDE.

First, it concluded that there is a need for further information and/or testing with regard to the PBT assessment for Deca-BDE. The Draft Update stated that, using criteria presented in the Technical Guidance document used for the risk assessment, Deca-BDE is likely to be very persistent but not bioaccumulative or toxic in the marine environment. However, the PBT assessment is complicated by data available on the:

- widespread occurrence of the substance in top predators (e.g. birds and mammals, including terrestrial species) and the Arctic;
- neurotoxic effects and uptake of the substance by mammals in laboratory studies; and
- possible formation of more toxic and accumulative products such as lower brominated diphenyl ether congeners and brominated dibenzofurans in the environment.

The risk assessment states that this means the available assessment methodology might not be applicable to Deca-BDE. Further, it states that at a minimum there is a continued need to monitor environmental contamination for a suitable time period for both Deca-BDE and, if possible, its more toxic and bioaccumulative degradation products. At a minimum, estuarine sediment, bird of prey tissue and sewage sludge should be sampled. Any programme should be reviewed at a suitable point to decide if further action is necessary.

The risk assessment points out that this additional work will take some years to deliver results. It states that the evidence presented in the updated assessment should be examined further at the policy level to review whether precautionary risk management is still considered necessary.

The second conclusion stated that there is at present no need for further information and/or testing or for risk reduction measures beyond those already being applied with regard to the assessment of surface water and sediment (freshwater and marine), waste water treatment plants, the terrestrial compartment, the air compartment and secondary poisoning for all life cycle stages.[204]

Some confusion has resulted over the meaning of these conclusions. In an effort to clarify matters, Ecology staff wrote to EU staff working on the risk assessment and asked: “The Risk Assessment is being circulated here as proof that Deca is a safe product, with no further regulation required. Would you agree with this conclusion?”

[203] European Commission Joint Research Center, 2004. Update of the risk assessment of Bis(Pentabromophenyl) Ether (Decabromodiphenyl Ether): Human Health Draft of February 2004.
[204] European Commission Joint Research Center, 2004. Update of the risk assessment of Bis(Pentabromophenyl) Ether (Decabromodiphenyl Ether): Final Environmental Draft of May 2004.

EU staff responded: "The Conclusion is that further information and testing are required in an attempt to demonstrate whether the substance is or is not a safe product. So the current risk assessment does not support the above statement."[205]

In a letter dated August 24, 2004, Margot Wallström, the European Union's Commissioner for the Environment, stated that she sees "outstanding safety concerns related to DecaBDE and … that proportionate precautionary measures are necessary to reduce DecaBDE's emissions in the environment. (She) therefore will not propose to the (European) Commission that it lift the ban on DecaBDE currently existing under the RoHS Directive."[206]

Deca-BDE is being evaluated by the European Commission for exemption from the ban under the RoHS Directive. Through July 5, 2004, the Commission solicited written stakeholder comments in response to the following questions with regard to Deca-BDE:

- Do feasible substitutes currently exist in an industrial and/or commercial scale?
- Do any restrictions apply to such substitutes?
- What are the costs and benefits and advantages and disadvantages of such substitutes?

Responses are posted on the Commission's website at http://europa.eu.int/comm/environment/waste/weee_index.htm.

Australia

Australia published an assessment of PBDEs in June 2001, conducted under its National Industrial Chemicals Notification and Assessment Scheme. The assessment recommended that, due to identified health and environmental effects of concern with some PBDEs, the lack of adequate data on others and their wide use, a full risk assessment be considered when hazard data is available from international assessments. The assessment further recommended that, on the basis of known hazards for specific PBDEs, material safety data sheets and other hazard communication materials be revised to reflect the information on hazards already available.[207]

Canada

Deca-BDE is listed on the Domestic Substances List, [208] which includes substances that were, between January 1, 1984, and December 31, 1986, in Canadian commerce, used for manufacturing purposes, or manufactured in or imported into Canada in a quantity of 100 kg or more in any calendar year. The purpose of the List was to define what was "New to Canada;" it currently contains about 23,000 substances.[209]

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[205] *pers. comm.*, S. Munn to C. Peele, August 26, 2004 by e-mail.
[206] M. Wallström in letter to J. Hontelez, M. Taylor, J. Riss, and M. Warhurst, August 24, 2004.
[207] "Polybrominated Flame Retardants (PBFRs): Priority Existing Chemical Assessment Report No. 20" National Industrial Chemicals Notification and Assessment Scheme, June 2001.
[208] Great Lakes Chemical Corporation, Material Safety Data Sheet for Great Lakes DE-83R and DE83, viewed at http://www.greatlakes.com/common/msdspdf/00001.pdf on March 29, 2004.
[209] Environment Canada, "Existing Substances Evaluation: Domestic Substances List Categorization and Screening Program," www.ec.gc.ca, viewed 26 May 2005.

In February 2004, Environment Canada released a Draft "Environmental Screening Assessment Report on Polybrominated Diphenyl Ethers (PBDEs)" for Public Comment. The draft proposes that PBDEs, including tetra-BDE, penta-BDE, hexa-BDE, hepta-BDE, octa-BDE, nona-BDE and deca-BDE, be considered "toxic" under section 64 of the Canadian Environmental Protection Act of 1999 (CEPA 1999). It further proposes that consideration be given to adding tetra-BDE, penta-BDE, and hexa-BDE to the Virtual Elimination List under CEPA 1999 and that that PBDEs, including tetra-BDE, penta-BDE, hexa-BDE, hepta-BDE, octa-BDE, nona-BDE, and deca-BDE, be considered as "Track 1" substances under the Toxic Substances Management Policy.[210]

The Virtual Elimination List is compiled by the Canadian Ministers of Environment and Health. The Ministers must specify the level of quantification for each substance on the List and, having done so, must prescribe the quantity or concentration of the substance that may be released into the environment either alone or in combination with any other substance from any source or type of source.[211] A "Track 1" substance is one that has been determined to be persistent, bioaccumulative, toxic and primarily the result of human activity and subsequently targeted for virtual elimination from the environment. This objective will be achieved by addressing sources of release to the environment or by removing or managing the substance if it is already in the environment.[212]

In February 2004, Health Canada released a "Screening Assessment Report- Health: Polybrominated Diphenyl Ethers (PBDEs) [Tetra-, Penta-, Hexa-, Hepta-, Octa-, Nona- and Deca- Congeners]". The report also proposes that, principally on the basis of environmental considerations, PBDEs as a group be considered "toxic" as defined in Section 64 of CEPA 1999.[213]

China

China's Ministry of Information draft regulation entitled the "Management Methods for the Prevention and Control of Pollution from Electronics Information Products" (Methods) is expected to be finalized by mid-2004. Among other chemicals, the Methods ban PBDEs in electronic information products. The list of products covered is still under development, as are standards for maximum tolerated thresholds and labeling requirements.[214]

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[210] Environment Canada, "Draft for Public Comments: Canadian Environmental Protection Act 1999 Environmental Screening Assessment Report on Polybrominated Diphenyl Ethers (PBDEs)" February 2004, p. 14.
[211] Environment Canada, "CEPA Environmental Registry Substances Lists: Virtual Elimination List" http://www.ec.gc.ca/CEPARegistry/subs_list/VirtualEliminationList.cfm, viewed 12 July 2004.
[212] Environment Canada, "Management of Toxic Substances: Track 1", http://www.ec.gc.ca/toxics/TSMP/en/track1.cfm, viewed 12 July 2004.
[213] Health Canada, "Screening Assessment Report- Health: Polybrominated Diphenyl Ethers (PBDEs) [Tetra-, Penta-, Hexa-, Hepta-, Octa-, Nona- and Deca- Congeners]", February 2004, p. 6.
[214] American Electronics Association, "AeA Update: International Environmental Regulations affecting High-Tech Companies," www.aeanet.org, viewed 4 May 2004.

Denmark

The Danish Environmental Protection Agency published an "Action Plan for Brominated Flame Retardants" in 2001 to serve as the foundation for future regulation of brominated flame retardants in Denmark. The action plan states as one of its short-term objectives the phase-out of PBDEs. The plan outlines seven areas of activity to accomplish its objectives, including international regulation, international cooperation, national initiatives, build-up of knowledge, standardization, information activities and the support of cleaner production.[215]

Germany

Deca-BDE is not used on a voluntary basis in Germany by association-bound companies in the plastics and textile industry.[216] In 1989, the Chemical Industry Association and the Association of the Plastics Producing Industry, in a statement to the Federal Government, voluntarily agreed to discontinue the production and further use of PBDEs.[217]

Sweden

In May 2004, Sweden commissioned the national chemicals inspectorate, KemI, to draft plans for banning Deca-BDE, in advance of an EU ban. KemI is considering a national ban on all brominated flame retardants and is examining risks associated with a number of other substances.[218]

OECD

The Organization for Economic Cooperation and Development (OECD) is made up of 30 member countries, including the U.S., and has active relationships with about 70 other countries.[219] As part of the OECD's Risk Reduction Programme, a risk assessment of PBDEs, along with two other flame retardants, polybrominated biphenyls and tetrabromobisphenol A, was published in 1994. This led producers of PBB and PBDE to enter into a voluntary agreement with the OECD in 1995 to minimize the risk of production spills and for the industry to refrain from producing other PBDEs than those already on the market. Joint meetings between OECD and the industry oversee industry's implementation of the commitments.[220]

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215 "Action Plan for Brominated Flame Retardants" Danish Environmental Protection Agency, March 2001, p. 7.
216 A. Leisewitz, H. Kruse, and E. Schramm, "Substituting Environmentally-Relevant Flame Retardants: Assessment Fundamentals" Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, June 2001, p. 74.
217 Carsten Lassen, Søren Løkke, Lina Ivar Andersen, Brominated Flame Retardants: Substance Flow Analysis and Assessment of Alternatives, Danish Environmental Protection Agency, 1999, p. 122.
218 Environment Daily 1662, 06/05/04
219 "About OECD" Organization for Economic Development and Cooperation, http://www.oecd.org/about/0,2337,en_2649_201185_1_1_1_1_1,00.html, viewed 13 July 2004.
220 "Action Plan for Brominated Flame Retardants," Ministry of Environment and Energy Danish Environmental Protection Agency, English Translation, March 2001, p. 22.

OSPAR Commission

The OSPAR Commission is made up of the countries that have ratified or approved the Convention for the Protection of the Environment of the North-East Atlantic (the "OSPAR Convention"). As of 2001, Belgium, Denmark, Finland, France, Germany, Ireland, Iceland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland, and the United Kingdom had ratified the Convention, and the European Union and Spain had approved it. In 1998, the OSPAR Commission placed PBDEs on its "List of Chemicals for Priority Action."[221] 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.[222]

POPS Treaty

The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from persistent organic pollutants (POPs). The Convention outlines measures to reduce or eliminate releases from the intentional production and use of 12 chemical substances to be taken by nation states that become members of the Convention. PBDEs are not included. The Convention was adopted by a Conference of Plenipotentiaries on May 22, 2001, and entered into force on May 17, 2004, following ratification by 50 nations.[223]

The U.S. has signed the Stockholm Convention, but has not yet ratified it. A bill to implement the Convention in the US, S. 1486, was introduced by Senators Chafee and Jeffords on July 29, 2003, and reported from the Committee on Environment and Public Works by Senator Inhofe with amendments on April 29, 2004. Under S. 1486, if the "Conference of Parties," the organization of nations that have signed the Stockholm Convention, decides to add a chemical substance to the 12 initially covered, the United States will not automatically adopt the change. Instead, the EPA administrator will follow an independent process to determine whether and how the chemical substance will be restricted in the United States. On April 29, 2004, the bill was placed on the Senate Legislative Calendar under General Orders.[224]

Jim Willis, the head of the United Nations Environment Programme chemicals division, told Reuters that "brominated flame retardants are a possibility (for addition to the list) as are many other chemicals."[225] The Nordic countries are working together to nominate Penta-BDE as a POP candidate.[226]

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[221] OSPAR Commission, "Certain Brominated Flame Retardants- Polybrominated Diphenylethers, Polybrominated Biphenyls, Hexabromo Cyclododecane" 2001

[222] OECD, "Brominated Flame Retardants (BFRs): Hazard/Risk Information Sheets" February 2004, http://www.oecd.org/dataoecd/53/60/32021808.pdf, viewed 12 July 2004.

[223] United Nations Environment Programme, "Stockholm Convention on Persistent Organic Pollutants (POPs), www.pops.int, viewed May 17, 2004.

[224] US Senate, "S. 1486" 108th Congress, Second Session, Calendar No. 481, thomas.loc.gov, viewed 17 May 2004.

[225] Alistar Doyle, "'Dirty dozen' toxins are banned by UN pact," The Guardian, 17 May 2004.

[226] OECD, "Brominated Flame Retardants (BFRs): Hazard/Risk Information Sheets" February 2004, http://www.oecd.org/dataoecd/53/60/32021808.pdf, viewed 12 July 2004.

V. Alternatives and Market Changes

IN BRIEF: PBDE flame retardants can be replaced in three ways; a different flame retardant can be substituted; a different flame retardant in a different type of plastic or foam can be substituted; or a product can be redesigned so that its very structure eliminates the need for flame retardants. This section summarizes four studies of alternatives to PBDE flame retardants. One study also examines Deca-BDE, but does not reflect health and environmental data that has come to light since 2000. A number of electronics manufacturers are phasing out the use of all PBDEs, including Deca-BDE. Some governments and corporations have instituted procurement guidelines that prohibit the use of PBDEs in certain electronic products.

Alternatives to PBDEs

Four documents have been identified that evaluate chemical flame retardants. Three focus on alternatives to the larger class of brominated flame retardants, as opposed to considering the merits of using other brominated flame retardants as alternatives to PBDEs.

The Danish Environmental Protection Agency issued "Brominated Flame Retardants: Substance Flow Analysis and Assessment of Alternatives" in June 1999. The report assesses 11 non-brominated flame retardants.

Leisewitz, Kruse, and Schramm produced "Substituting Environmentally Relevant Flame Retardants: Assessment Fundamentals: Results and Summary Overview" for the German Environmental Research of the Federal Ministry of the Environment, Nature Conservation, and Nuclear Safety in June 2001. The report examines the properties of 13 major flame retardants and six product categories that typically use brominated flame retardants.

Fisk, Girling and Wildey produced "Prioritization of Flame Retardants for Environmental Risk Assessment," for the United Kingdom Environment Agency in August 2003. The report presents an overview of flame retardants in use in the United Kingdom and identifies substances that might require detailed consideration based on their impact to the environment. The report does not consider human health benefits or risks. It summarizes the uses, mechanisms of action and environmental regulation of flame retardants and considers routes by which they may enter the environment.

The fourth document was produced in 2000, by the National Academy of Sciences (NAS). NAS reviewed the toxicological and exposure data of 16 flame retardants, including Deca-BDE, to assess the potential health risk to consumers and the general population from potential exposure from the chemicals in residential furniture.

Despite the lack of a complete database, the report concluded that Deca-BDE, along with a number of other flame retardants listed in Table 10, could be used on furniture with minimal risk, even under worst-case assumptions. It should be noted that Ecology's and DOH's concerns about Deca-BDE stem mainly from its potential to break down in the environment, supported by studies conducted primarily since 2000. [227]

Conclusions from the four reports are summarized in Table 10.

Table 10. Summary of evaluation of alternative flame retardants

Substance	Perceived availability of data on substitutes for BFR's (UK and Denmark, 2003)			German recommendation (2001)	NAS recommendation (2000)
	Physico-chemical data	Health data	Environmental data		
Ammonium polyphosphates	medium	medium	medium	Application unproblematic	Could be used on residential furniture with minimal risk
Aluminum trioxide	not addressed	not addressed	not addressed	Application unproblematic	not addressed
Alumina trihydrate	not addressed	not addressed	not addressed	not addressed	Could be used on residential furniture with minimal risk
Antimony pentoxide	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Antimony trioxide	good	good	good	Problematic properties, reduction sensible	Recommend exposure studies
Aromatic phosphate plasticizers	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Calcium and zinc molybdates	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Chlorinated parafins	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Hexabromocyclodo decane	not addressed	not addressed	not addressed	Problematic properties, reduction sensible	Could be used on residential furniture with minimal risk
Magnesium hydroxide	medium	good	medium	not addressed	Could be used on residential furniture with minimal risk
Melamine	good	good	good	not addressed	not addressed
Melamine cyanurate	not addressed	not addressed	not addressed	Recommendation impossible due to data deficit	not addressed
Organic phosphonates	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Phosphonic acid (dimethyl ester)	poor	poor	poor	not addressed	Could be used on residential furniture with minimal risk

[227] National Research Council, 2000. Toxicological risks of selected flame retardant chemicals. Available at http://www.nap.edu/catalog/9841.html.

Interim Plan

Substance	Perceived availability of data on substitutes for BFR's (UK and Denmark, 2003)			German recommendation (2001)	NAS recommendation (2000)
	Physico-chemical data	Health data	Environmental data		
Pyrovatex CP new	not addressed	not addressed	not addressed	Recommendation impossible due to data deficit	not addressed
Red phosphorus	medium	medium	medium	Application unproblematic	not addressed
Resorcinol bis(diphenyl phosphate)	medium	medium	medium	Recommendation impossible due to data deficit	not addressed
Sodium antimonate	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Sodium borate decahydrate	not addressed	not addressed	not addressed	Problematic properties, reduction sensible	not addressed
Tetrabromobisphenol A, additive	not addressed	not addressed	not addressed	Application rejected	not addressed
Tetrabromobisphenol A, reactive	not addressed	not addressed	not addressed	Reduction sensible, substitution desired	not addressed
Tetrakis (hydroxymethyl) phosphonium salts (chloride salt)	not addressed	not addressed	not addressed	not addressed	Could be used on residential furniture with minimal risk
Tricresyl phosphate	good	good	good	not addressed	not addressed
Triphenyl phosphate	good	good	good	not addressed	not addressed
Tris(1-chloro-2-propyl) phosphate	not addressed	not addressed	not addressed	Reduction sensible, substitution desired	Recommend exposure studies
Tris (1,3-dichloropropyl-2) phosphate	not addressed	not addressed	not addressed	not addressed	Recommend exposure studies
Zinc borate	medium	medium	medium	not addressed	Could be used on residential furniture with minimal risk

Replacing PBDEs can take place in three ways.

1. PBDEs could be replaced by another flame retardant without changing the base polymer, or substrate.
2. The plastic material, i.e., the base polymer with flame retardants and other additives, could be replaced by another plastic material.
3. The product could be replaced by another product, or the function of the PBDEs could be fulfilled by a totally different solution.

For the selection of alternative flame retardants for a specific application the following subjects must be considered:

- Physical/chemical properties of alternatives during manufacturing
- Physical/chemical properties of alternatives during use
- Environmental and health risk of alternatives during manufacturing, use and disposal
- Price of alternatives
- Expenses of changes in tools and machinery

In principle alternatives to PBDEs will exist for almost all applications, though cost and technical disadvantages may prove prohibitive.[228]

Alternatives to Penta-BDE

Alternative flame retardants for Penta-BDE are listed by substrate in Table 11. Ecology and DOH have not examined the human health or environmental impacts of these alternatives. However, US EPA, working with textile manufacturers, flame retardant manufacturers, foam manufacturers, and furniture manufacturers, is in the process of writing and alternatives assessment for Penta-BDE, scheduled to be released in January 2005.[229]

[228] Danish Environmental Protection Agency, 1999. Brominated flame retardants: substance flow analysis and assessment of alternatives.
[229] Pers. comm., K. Rindfusz to J. Shepard by e-mail, September 29, 2004.

Table 11. Alternative flame retardants for penta-BDE by substrate
(except where indicated, based on Danish Action Plan, 2001, and Prioritization of Flame Retardants for Environmental Assessment, UK Environment Agency, 2003)

Substrate	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[230] • Tetrabromophthalic Anhydride Based Diol[231] • Tetrabromophthalic Anhydride[232] • Bis (Tribromophenoxy) ethane[233]	None identified
Rigid polyurethane foam	• Insulation of cold-storage plants/freezing rooms, pipes, etc.	• Ammonium polyphosphate • Red phosphorus • Tetrabromophthalate Diol[234] • Tetrabromophthalic Anhydride Based Diol[235] • Bisphosphate [236]	• Some applications: mineral wool or other technical solutions
Flexible polyurethane foam	• Furniture • Components in transportation	• Ammonium polyphosphate • Melamine • Reactive phosphorus polyols • Tetrabromophthalic anhydride derivative[237] • Phosphorous-Bromine[238] • Reofos NHP (halogen-free phosphorus flame retardant)[239] • Bisphosphate [240]	None identified

[230] Great Lakes Chemical Corp., "Technical Information: Great Lakes DBS" www.e1.greatlakes.com/pdf/datasheet/DBS%20Data%20Sheet.PDF, viewed 7 July 2004.
[231] Great Lakes Chemical Corp., "Technical Information: Firemaster® 520" www.e1.greatlakes.com/pdf/datasheet/firemaster_520_tech_data_sheet_finalfinal.PDF, viewed 7 July 2004.
[232] Great Lakes Chemical Corp., "Technical Information: Great Lakes PHT4" www.e1.greatlakes.com/pdf/datasheet/PHT4%20ds.PDF, viewed 7 July 2004.
[233] Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF viewed 15 July, 2004
[234] Great Lakes Chemical Corp., "Technical Information: Great Lakes PHT4-DIOL" www.e1.greatlakes.com/pdf/datasheet/PHT4%20Diol%20Data%20Sheet.PDF, viewed 7 July 2004.
[235] Great Lakes Chemical Corp., "Technical Information: Firemaster® 520" www.e1.greatlakes.com/pdf/datasheet/firemaster_520_tech_data_sheet_finalfinal.PDF, viewed 7 July 2004.
[236] Great Lakes Chemical Corp.; "Technical Information: Great Lakes Reofos RDP" http://www.e1.greatlakes.com/pdf/datasheet/Technical Data Sheet - Reofos RDP.pdf
[237] Great Lakes Chemical Corp., "Technical Information: Great Lakes Firemaster® BZ-54" www.e1.greatlakes.com/pdf/datasheet/BZ-54%20Data%20Sheet.PDF, viewed 7 July 2004.
[238] Great Lakes Chemical Corp., "Technical Information: Firemaster® 550" www.e1.greatlakes.com/pdf/datasheet/Firemaster_550P_ds.PDF, viewed 7 July 2004.
[239] Great Lakes Chemical Corp.; "Technical Information: Great Lakes Reofos NHP" http://www.e1.greatlakes.com/pdf/datasheet/Reofos NHP Data Sheet -Revised 09.02.pdf
[240] Great Lakes Chemical Corp.; "Technical Information: Great Lakes Reofos RDP"

Substrate	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
Laminates		• Triaryl phosphate isopropylated[241]	None identified
Adhesives		• Tetrabromophthalate diol[242] • Tetrabromophthalic anhydride based diol[243] • Hexabromocyclododecane[244] • Reomol® TOP[245] • Bis (Tribromophenoxy) ethane[246]	None identified
Coatings		• Tetrabromophthalate Diol[247] • Tetrabromophthalic anhydride based diol[248] • Hexabromocyclododecane[249] • Triaryl phosphate[250] • Bis (Tribromophenoxy) ethane[251]	None identified

Alternatives to Octa-BDE

Alternative flame retardants for Octa-BDE are listed by substrate in Table 12. Ecology and DOH have not evaluated the human health or environmental impacts of these alternatives.

http://www.e1.greatlakes.com/pdf/datasheet/Technical Data Sheet - Reofos RDP.pdf
241 Great Lakes Chemical Corp.; "Technical Information: Great Lakes Refos35" http://www.e1.greatlakes.com/pdf/datasheet/Reofos 35 Data Sheet.PDF
242 Great Lakes Chemical Corp., "Technical Information: Great Lakes PHT4-DIOL" www.e1.greatlakes.com/pdf/datasheet/PHT4%20Diol%20Data%20Sheet.PDF, viewed 7 July 2004.
243 Great Lakes Chemical Corp., "Technical Information: Firemaster® 520" www.e1.greatlakes.com/pdf/datasheet/firemaster_520_tech_data_sheet_finalfinal.PDF, viewed 7 July 2004.
244 Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
245 Great Lakes Chemical Corp.; "Technical Information: Great Lakes Remol TOP" http://www.e1.greatlakes.com/pdf/datasheet/Reomol TOP.pdf
246 Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF viewed 15 July, 2004
247 Great Lakes Chemical Corp., "Technical Information: Great Lakes PHT4-DIOL" www.e1.greatlakes.com/pdf/datasheet/PHT4%20Diol%20Data%20Sheet.PDF, viewed 7 July 2004.
248 Great Lakes Chemical Corp., "Technical Information: Firemaster® 520" www.e1.greatlakes.com/pdf/datasheet/firemaster_520_tech_data_sheet_finalfinal.PDF, viewed 7 July 2004.
249 Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
250 Great Lakes Chemical Corp.; "Technical Information: Great Lakes Kronitex TCP" http://www.e1.greatlakes.com/pdf/datasheet/kronitex TCP data sheet.pdf
251 Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF viewed 15 July, 2004

Table 12. Alternative flame retardants for octa-BDE by substrate
(except where indicated, based on Danish Action Plan, 2001, and Prioritization of Flame Retardants for Environmental Assessment, UK Environment Agency, 2003)

Substrate	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
ABS	• Housings for electronic products	• Tetrabromobisphenol A[252, 253] • Triaryl phosphate[254] • Triaryl phosphates butylated[255] • Bisphosphate[256] • Bis (Tribromophenoxy) ethane[257] • Phenoxy-terminated carbonate oligomer of tetrabromobisphenol A[258] • No non-halogenated alternatives identified in commercial use	• PC/ABS blends or PPE/PS blends with organic phosphorus compounds
Synthetic textiles	• Furniture, textiles • Components in transportation • Protective clothing	• Reactive phosphorus constituents • Hexabromocyclododecane[259]	None identified
Thermoplastic elastomers		• Bis (Tribromophenoxy) ethane[260] •Tribromophenyl allyl ether[261]	None identified
Polyolefins		• Polypropylene-dibromostyrene[262,263] • Dibromostyrene[264] • Tetrabromobisphenol A bis[265] • No non-halogenated alternatives identified in commercial use	None identified

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[252] Great Lakes Chemical Corp., "Technical Information: Great Lakes BC-52" www.e1.greatlakes.com/pdf/datasheet/BC-52%20Data%20Sheet.PDF, viewed 7 July 2004.
[253] Great Lakes Chemical Corp., "Technical Information: Great Lakes BA-59P" www.e1.greatlakes.com/pdf/datasheet/BA-59%20Data%20Sheet.PDF, viewed 7 July 2004.
[254] Great Lakes Chemical Corp., "Technical Information: Great Lakes Reofos TPP" http://www.e1.greatlakes.com/pdf/datasheet/Reofos TPP Data Sheet.PDF
[255] Great Lakes Chemical Corp., "Technical Information: Great Lakes Refos 507" http://www.e1.greatlakes.com/pdf/datasheet/Reofos 507 Data Sheet.PDF
[256] Great Lakes Chemical Corp., "Technical Information: Great Lakes Reofos RDP" http://www.e1.greatlakes.com/pdf/datasheet/Technical Data Sheet - Reofos RDP.pdf
[257] Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF
[258] Great Lakes Chemical Corp., "Technical Information: Great Lakes BC52-HP" http://www.e1.greatlakes.com/pdf/datasheet/BC-52HP Data Sheet.PDF viewed 15 July, 2004
[259] Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
[260] Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF
[261] Great Lakes Chemical Corp., "Technical Information: Great Lakes PHE 65" http://www.e1.greatlakes.com/pdf/datasheet/PHE-65 Data Sheet.PDF viewed 15 July, 2004
[262] Great Lakes Chemical Corp., "Technical Information: Great Lakes GPP-39" www.e1.greatlakes.com/pdf/datasheet/GPP-39%20Data%20Sheet.PDF, viewed 7 July 2004.
[263] Great Lakes Chemical Corp., "Technical Information: Great Lakes GPP-36" www.e1.greatlakes.com/pdf/datasheet/GPP-36%20Data%20Sheet.PDF, viewed 7 July 2004.
[264] Great Lakes Chemical Corp., "Technical Information: Great Lakes DBS" www.e1.greatlakes.com/pdf/datasheet/DBS%20Data%20Sheet.PDF, viewed 7 July 2004.
[265] Great Lakes Chemical Corp., "Technical Information: Great Lakes PE-68" www.e1.greatlakes.com/pdf/datasheet/datasheet/Pe-68.PDF, viewed 7 July 2004.

Alternatives to Deca-BDE

Alternative flame retardants for Deca-BDE are listed by substrate in Table 13. Ecology and DOH have not evaluated the human health or environmental impact of these alternatives.

Table 13. Alternative flame retardants for deca-BDE by substrate
(except where indicated, based on Danish Action Plan, 2001, and Prioritization of Flame Retardants for Environmental Assessment, UK Environment Agency, 2003)

Substrate	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(?)[266] • Hexabromocyclododecane[267] • Bis (Tribromophenoxy) ethane[268]	None identified
Polystyrene	• Housings for electronic products • Wiring parts.	• Organic phosphorus compounds • Magnesium hydroxide • Hexabromocyclododecane[269] • Tetrabromobisphenol A[270]	None identified
PBT/PET	• Switches • Sockets • Parts of electrical machines	• Poly(dibromostyrene)[271,272,273] • Firemaster® CP-44HF (no generic name indicated)[274] • Tetrabromobisphenol A (oligomer)[275]	Some applications: • Polyamide • Polyketone • Ceramics • Self-extinguishing plastics

[266] Great Lakes Chemical Corp., "Technical Information: Great Lakes DBS" www.e1.greatlakes.com/pdf/datasheet/DBS%20Data%20Sheet.PDF, viewed 7 July 2004.
[267] Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
[268] Great Lakes Chemical Corp., "Technical Information: Great Lakes FF 680" http://www.e1.greatlakes.com/pdf/datasheet/FF-680 ds.PDF viewed 15 July, 2004
[269] Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
[270] Great Lakes Chemical Corp., "Technical Information: Great Lakes BA-59P" www.e1.greatlakes.com/pdf/datasheet/BA-59%20Data%20Sheet.PDF, viewed 7 July 2004.
[271] Great Lakes Chemical Corp., "Technical Information: Great Lakes PBDS-80" www.e1.greatlakes.com/pdf/datasheet/PBDS%2080%20Data%20Sheet.PDF, viewed 7 July 2004.
[272] Great Lakes Chemical Corp., "Technical Information: Great Lakes PBS-64" www.e1.greatlakes.com/pdf/datasheet/PBS-64%20Data%20Sheet.PDF, viewed 7 July 2004.
[273] Great Lakes Chemical Corp., "Technical Information: Firemaster®CP-44B" www.e1.greatlakes.com/pdf/datasheet/Firemaster%20CP-44B%20ds.PDF, viewed 7 July 2004.
[274] Great Lakes Chemical Corp., "Technical Information: Firemaster® CP-44HF" www.e1.greatlakes.com/pdf/datasheet/Firemaster_CP-44HF.PDF, viewed 7 July 2004.
[275] Great Lakes Chemical Corp., "Technical Information: Great Lakes BC-52" www.e1.greatlakes.com/pdf/datasheet/BC-52%20Data%20Sheet.PDF, viewed 7 July 2004.

Interim Plan

Substrate	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
Polypropylene and polyethylene	• Roofing foils • Injection molded parts (electronic equipment)	• Ammonium polyphosphate • Magnesium hydroxide • Reogard® 1000 (proprietary composition)[276]	None identified
Cotton textiles	• Furniture, textiles • Components in transportation	• Ammonium polyphosphate • Diammonium phosphate • Tetrabromophthalate ester[277] • Hexabromocyclododecane[278]	None identified
Synthetic textiles	• Furniture, textiles • Components in transportation • Protective clothing	• Reactive phosphorus constituents • Tetrabromophthalate ester[279] • Hexabromocyclododecane[280]	None identified
PVC	• Wire and cable insulation	• Tetrabromophthalate ester[281] • Triaryl phosphates isopropylated[282]	None identified

Evaluating human health and environmental data generated since 2000 for the other products covered by the NAS report is beyond the scope of this document. However, it appears that a number of alternative flame retardants exist for Deca-BDE used on upholstery fabric.

EPA, working with textile manufacturers, furniture manufacturers, foam manufacturers, and flame retardant manufacturers, plans to evaluate alternatives to Deca-BDE for use in textiles as the second phase of its Design for the Environment alternatives analysis currently being conducted for Penta-BDE.[283]

In 2000, representatives from the electronics industry wrote to U.S. EPA, requesting that the agency's Design for the Environment Program investigate the environmental and public health implications of brominated flame retardants and their alternatives.[284] EPA has not started such a project.

[276] Great Lakes Chemical Corp., "Technical Information: Great Lakes Reogard 1000" http://www.e1.greatlakes.com/pdf/datasheet/Reogard_1000_ds.PDF
[277] Great Lakes Chemical Corp., "Technical Information: Great Lakes DP-45" www.e1.greatlakes.com/pdf/datasheet/DP-45%20Data%20Sheet.PDF, viewed 7 July 2004.
[278] Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
[279] Great Lakes Chemical Corp., "Technical Information: Great Lakes DP-45" www.e1.greatlakes.com/pdf/datasheet/DP-45%20Data%20Sheet.PDF, viewed 7 July 2004.
[280] Great Lakes Chemical Corp., "Technical Information: Great Lakes CD-75P" www.e1.greatlakes.com/pdf/datasheet/CD-75P%20Data%20Sheet.PDF, viewed 7 July 2004.
[281] Great Lakes Chemical Corp., "Technical Information: Great Lakes DP-45" www.e1.greatlakes.com/pdf/datasheet/DP-45%20Data%20Sheet.PDF, viewed 7 July 2004.
[282] Great Lakes Chemical Corp., "Technical Information: Great Lakes Reofos 65" http://www.e1.greatlakes.com/pdf/datasheet/Reofos 65 Data Sheet.pdf
[283] pers. comm, K. Rindfusz to C. Peele, October 11, 2004.
[284] Letter to K. Hart, US EPA, from J. Lott, IPC ("Association Connecting Electronics Industries"); H. Evans, Electronic Industries Alliance; and D. Bendz, Institute of Electrical and Electronics Engineers, Inc.; May 11, 2000, viewed at www.halogenfree.org, 5 May 2004.

Market Changes

Consumer Electronics Manufacturers and Deca-BDE Alternatives

In anticipation of the phase-out of Penta-BDE and Octa-BDE, it is expected that manufacturers are moving away from these products and identifying alternatives. In addition, a number of electronics manufacturers have been identified that are phasing out all PBDEs, including Deca-BDE. Specific policies are listed in Appendix C. Electronics manufacturers phasing out PBDEs in some or all of their products include: Apple, Brother, Daikin, Dell, Ericsson, Hewlett Packard, Matsushita, Mitsubishi, NEC, Samsung, Sharp, Sony, ViewSonic, and Xerox. IKEA has also phased out all PBDEs.[285]

Environmentally Preferable Purchasing

According to Dell Corporation, many governments and large corporations have developed green procurement guidelines that prohibit the use of PBDEs in electronic products.[286] Three government requests for proposal (RFPs) for computers with restrictions on PBDEs were identified.

Commonwealth of Massachusetts

Massachusetts' RFP for computers specifies that no brominated flame retardants be used. http://www.state.ma.us/osd/enviro/info/factsheets2/Computer_EPP_Language.pdf

Denver, CO

Denver's RFP for computers specifies that the vendor must offer equipment that has been certified by third-party certification organizations such as TCO, Blue Angel, or others.

Seattle, WA

Seattle's RFP for laptops specifies that vendors must disclose the use of halogenated flame retardants. http://www.seattle.gov/environment/Documents/Laptops.pdf

[285] M. Bjork, 2004. Banning brominated flame retardants, BFR2004.
[286] Dell Corporation, "Industry Use of Brominated Flame Retardants," www.dell.com, viewed 27 April 2004.

VI. Policy Recommendations

IN BRIEF: This section lists the key findings, policy options, recommendations and rationale for each area of action proposed by Ecology and Health.

Products Containing PBDEs at End-of-Life

Key Findings

PBDEs are found in a vast number of consumer products, with vast potential for continued human exposure. Under WAC 173-303, Dangerous Waste Regulations, Persistence Criteria, most products containing PBDEs would probably be considered hazardous waste at end-of-life. Currently, these products are handled by the solid waste system. Many products containing PBDEs, particularly electronics, are recycled or could be recycled, which conserves valuable resources. It is unknown whether the current system for disposing of and recycling products containing PBDEs adequately protects human health and the environment.

Policy Options

- Identify products containing PBDEs that may be entering the waste stream, along with the estimated percent of PBDEs in the product.

- Establish a separate process to examine known information about potential pathways of PBDEs from products to the environment. Evaluate and recommend the most effective methods for preventing PBDEs from entering the environment.

- Create effective and practical methods to dispose of products containing PBDEs that is consistent in hazardous waste, solid waste, water quality, and toxic cleanup regulations.

- Create a "special waste" designation that is consistent in the hazardous waste, solid waste, water quality, and toxic cleanup regulations to isolate PBDEs and remove them from the waste stream. This could include chronic, sub-lethal criteria for designation.

- Remove foam and other materials with Penta-BDE and Octa-BDE from the recycling stream unless the recycling or processing activity safely handles and removes the PBDEs, and workers are adequately protected.

- Require separation of electronics containing brominated flame retardants during disposal.

- Ban the resale of designated products containing polyurethane foam, such as upholstered furniture.

- Establish a voluntary program with charities, reuse organizations, and businesses to minimize the resale of upholstered furniture containing polyurethane foam. Financing would be provided by the bromine industry to charities to properly dispose of foam containing items that are "dumped" on them, whether or not they are accepted by the charity.

- Restrict the disposal of products containing PBDEs to landfills that do not release leachate into the environment or to waste water treatment plants.

- If it is determined that disposal of existing PBDE containing materials are not safely handled in most available landfills or incineration facilities, require the bromine industry to establish and finance a collection, transportation and proper disposal system for the state.

- Require manufacturers that continue to use Penta-BDE and Octa-BDE in products sold to the general public (as opposed to specialty industries, such as aeronautics) to establish and finance a proper disposal system for their products.

- Place a tax on products sold in Washington State that contain PBDEs to fund a public information campaign and proper collection and disposal system. The tax should be adequate to cover all related costs to the public and private sector.

- No action.

Recommendations

Ecology should establish a process, to be completed by July 2006, to evaluate and determine appropriate disposal and recycling practices for products containing PBDEs, including potential financing options. Ecology will involve appropriate stakeholders in this process, including, but not limited to, local government, private waste haulers and landfill operators, recyclers, manufacturers, environmental advocates, and human health advocates. Ecology anticipates that this may require a rule revision of WAC 173-303, outlining recommended methods for recycling and disposal. If necessary, the rule revision will be complete by July 2007. As part of the evaluation, Ecology will:

1. Identify known information about potential pathways of PBDEs at end-of-life. Both PBDE releases to the environment and occupational exposure to workers would be examined at waste collection facilities, recycling facilities, waste disposal facilities, manufacturers using PBDEs and service industries such as carpet installers and upholsterers.

2. Through a literature search and limited product testing, characterize PBDE content of products along high-priority exposure pathways.

3. Establish where monitoring of PBDEs associated with end-of-life, including biosolids, leachate, and incinerator emissions, is warranted and, if so, for what purposes.

Rationale

Currently, not enough is known about the environmental and relative cost impacts of disposal practices for products containing PBDEs. In particular, the reuse and recycling of products containing PBDEs conserves valuable resources. Additional study is required before wellfounded recommendations can be made. If special handling, recycling or disposal of products or wastes containing PBDE is required, adequate financing mechanisms will need to be identified.

Source Control

Penta-BDE and Octa-BDE

Key Findings

The only current manufacturer of Penta-BDE and Octa-BDE, Great Lakes Chemical Corp., will phase out production of both products at the end of December 2004. Both Penta-BDE and Octa-BDE have a guaranteed shelf life of six months, so new products containing Penta-BDE and Octa-BDE theoretically will not be produced past June 2005.

On December 6, 2004, U.S. EPA issued a draft Significant New Use Rule (SNUR) for Penta-BDE and Octa-BDE. This proposed rule would require manufacturers and importers to notify EPA at least 90 days before commencing the manufacture or import of Penta-BDE or Octa-BDE on or after January 1, 2005. The required notice would provide EPA with the opportunity to evaluate any intended new use and associated activities and, if necessary, to prohibit or limit that activity before it occurs. The proposed rule would not prohibit the import of products containing Penta-BDE or Octa-BDE (e.g., mattresses, upholstered furniture). The comment period for the SNUR closes February 4, 2005.

Policy Options

- Ban the import and use of Penta-BDE and Octa-BDE in Washington State.

- Ban the sale of new products containing Penta-BDE and Octa-BDE in Washington State with a phase-in period, allowing existing stock to be sold.

- Ban the sale of new products containing Penta-BDE and Octa-BDE in Washington State with a phase-in period, allowing existing stock to be sold. Allow recycled PBDE content of foam to be no more than 0.5% by mass, where the sole source of the PBDE can only be from recycled foam. This level of recycling might be permitted for a few years such as until 2010, after which content would be reduced to less than 0.1% by mass.

- Require labeling of new products containing Penta-BDE and Octa-BDE; the label should identify the PBDE formulation.

- Identify which Washington manufacturers use Penta-BDE and Octa-BDE in their products.

- No action.

Recommendation

The Washington State Legislature should ban the manufacture, distribution (but not transsshipment) or sale of new products containing Penta-BDE and Octa-BDE in Washington State by July 2006. The ban may include an exemption for the use of recycled material containing Penta-BDE and Octa-BDE in new products, pending further review. The ban should include an exemption for products where no alternative for Penta-BDE or Octa-BDE is available. The ban would not include the reuse of products containing Penta-BDE or Octa-BDE (for example, the sale of used cars or upholstered furniture).

Rationale

Currently, there is no provision that would prevent a manufacturer, either domestic or foreign, from reintroducing Penta-BDE and Octa-BDE on the market. Penta-BDE and Octa-BDE are known persistent, bioaccumulative toxins, found in increasing concentrations in environmental media and humans. A ban on the manufacture, distribution, or sale of new products containing Penta-BDE and Octa-BDE would be consistent with similar laws in the European Union, California, Hawaii, Maine, and New York. Such a ban also would provide a disincentive to manufacturers from reintroducing these products. This should have little or no impact on manufacturers since they are already arranging alternatives for these chemicals in order to comply with the EU ban and the discontinuation of supplies to the U.S. A temporary exemption for the use of recycled material containing Penta-BDE and Octa-BDE in new products is necessary until it can be determined that disposal is preferable.

Deca-BDE

Key Findings

Globally, Deca-BDE has become the most used PBDE product; after December 2004, it is expected to be the only PBDE product in production. Recent scientific evidence suggests that Deca-BDE breaks down into more bioaccumulative and potentially toxic compounds. The amount of Deca-BDE in use, the expected increase in its use, and its expected breakdown in the environment argue that Deca-BDE use should not be allowed to increase and should be decreased.

Consumer electronics currently account for approximately 80 percent of Deca-BDE use. In preparation for the European Union's Restriction on Hazardous Substances (RoHS) ban on Deca-BDE, currently in effect for July 2006, most major consumer electronics manufacturers have announced that they have phased out or plan to phase out the use of Deca-BDE. These manufacturers include: Apple, Brother, Daikin, Dell, Hewlett Packard, IBM, Matsushita, Samsung, Sharp, Sony, and Xerox. A ban on Deca-BDE in these products might therefore have little or no effect on these manufacturers.

At the same time, the market for Deca-BDE is expected to shift and grow in response to a national flammability standard for residential upholstered furniture under consideration by the Consumer Product Safety Commission (CPSC). Sixteen flame retardant chemicals or categories of chemicals – including Deca-BDE – have been identified by CPSC and industry as likely to be used to flame retard fabrics on furniture in order to comply with the standard. EPA is developing a rule to complement this standard, which would require notification to and review by EPA of flame retardants used by upholstery fabric manufacturers. With this rule, EPA may or may not restrict the use of Deca-BDE. If Deca-BDE is banned for these fabrics now, prompting manufacturers to choose another flame retardant from the start, it would eliminate a potential new source of Deca-BDE in the environment without forcing manufacturers to incur costs for redesign or retooling to replace Deca-BDE later. However, no other state in the U.S. has banned Deca-BDE.

Policy Options

- Ban the import and use of Deca-BDE and the sale of new products containing Deca-BDE in Washington State with a phase-in period, allowing existing stock to be sold.

- Ban the import and use of Deca-BDE and the sale of products containing Deca-BDE for applications where alternatives are available.

- Ban the import and use of Deca-BDE and the sale of products containing Deca-BDE for applications where known, safer alternatives are available.

- Examine the implications and logistics of a ban on products containing Deca-BDE to maximize benefits while minimizing negative impacts, including possible impacts on fire safety.

- Re-examine known information on the health and environmental impacts of Deca-BDE, along with the availability of safe alternatives, on a regular basis (e.g., annually) to determine if a ban, restricted use, or other actions are warranted.

- Identify which Washington manufacturers use Deca-BDE in their products.

- No action.

Recommendations

Ecology and DOH, in consultation with stakeholders, will develop a proposal for a ban on appropriate products containing Deca-BDE, with recommendations by December 2005. This ban would not cover the reuse of products containing Deca-BDE (for example, the sale of used televisions). The process will include the following:

- Identification of which types of products containing Deca-BDE would be covered by a ban.

- Examination of what sort of exemption process, if any, would be established. Of particular interest would be products containing recycled plastic that may contain Deca-BDE.

- Evaluation of human health, environmental, and economic impacts, which may include qualitative and quantitative analysis.

- Investigation of alternative materials, product design changes, and chemicals that meet fire safety standards.
- Investigation of potential impacts on fire safety.
- Investigation of impacts on Washington retailers and consumers.
- Continued monitoring of emerging information on Deca-BDE.

This process may be limited by the availability of information.

Rationale

Because Deca-BDE is present in so many products and is nearly impossible to capture or control, it is necessary to develop and implement a ban on appropriate products containing Deca-BDE. While Ecology and DOH recognize this need, a more complete analysis is necessary to maximize the benefits of a ban, while minimizing impacts on manufacturers, retailers, and consumers and ensuring adequate levels of fire protection.

US Chemical Policy

Key Findings

In exploring chemical alternatives to PBDEs, it became clear that little is known about the safety and potential impacts of other chemicals which would be allowed for use as flame retardants under existing federal regulations. The allowed use of chemicals about which we know little points to significant flaws in U.S. laws for regulating existing chemicals. In addition, EPA's ability to provide public information on chemical production and risk is hindered by strict confidential business information provisions of the Toxic Substance Control Act.

U.S. law creates a disadvantage for manufacturers, who cannot make fully informed decisions about the products they use; retailers, who are unaware of environmental and health implications of the products they sell; consumers, who cannot make fully informed purchasing decisions; industries dependent on a healthy environment, such as fishing and whale watching, whose "products" may be adversely impacted by chemical contamination; and regulators, who lack necessary information on product safety. Local governments, primarily responsible for municipal waste disposal and recycling, bear increased costs when products discovered to be hazardous are disposed. State governments are spending considerable funds to clean up contaminated sites and sediments.

This dilemma is clearly illustrated in the struggle to identify alternatives to Deca-BDE that will have a minimal impact on the environment and human health. Because so few studies have been conducted on these alternatives and because much of the information collected on new and some existing chemicals by U.S. EPA is considered proprietary and not subject to public review, an adequate evaluation of alternatives to Deca-BDE is made extremely difficult, if not impossible.

Interim Plan

Recommendations

Ecology and DOH will actively seek opportunities to work with other states and interested parties to contribute to the national dialogue regarding needed improvements to US chemical policy, with a goal of developing and advocating practical solutions. As a first step, Ecology will participate as a member of the organizing committee for the Stakeholder Summit on Framing a Future Chemicals Policy, organized by the Lowell Center for Sustainable Production, to take place in April 2005.

Rationale

Change in national chemical policy must occur at the federal level. However, Ecology and DOH can work to facilitate and participate in a process to develop solutions.

Minimizing Human Exposure

State Purchasing

Key Findings

Executive Order 04-01 states that the Department of General Administration's Office of State Procurement shall make available for purchase and use by all state agencies equipment, supplies, and other products that do not contain persistent, toxic chemicals unless there is no feasible alternative. In circumstances where a product that does not contain persistent, toxic chemicals is not available, preference shall be given to the purchase of products that contain the least amount of persistent, toxic chemicals.

Policy Options

- Specify that goods purchased through state contracts should not contain PBDEs.
- Specify that bidders on state contracts should disclose which PBDE formulations, if any, are used in products.
- No action.

Recommendations

Consistent with Executive Order 04-01, restrict the state's purchase of PBDEs in appropriate contracts.

- General Administration should prefer products that do not contain Deca-BDE.

Rationale

Alternatives are available for many, but not all, applications of Deca-BDE. Alternatives will be available for all applications of Penta and Octa-BDE, as neither product will be produced past December 2004.

General Public

Key Findings

Human health risks are associated with exposure to PBDEs, though pathways and levels necessary to result in harm are not clearly understood.

Policy Options

- The Department of Health should develop recommendations for the general public to reduce PBDE exposure.

- Direct the bromine industry, at its expense, to provide best management practices and a public information campaign on how to reduce human and environmental exposure.

- No action.

Recommendation

The Department of Health should develop methods and materials for health education about PBDEs. The Department of Health should develop and implement a strategy to communicate with health care providers about PBDEs and provide guidance appropriate for both the general public and health care providers concerning reduction of exposure to contaminants in the environment, including PBDEs. This strategy will include information on the benefits of breastfeeding and the benefits of eating fish as part of a healthy diet.

Rationale

Levels of PBDEs measured in people in the U.S. vary widely but are consistently much higher than levels found in people outside of the U.S. and Canada. Several potential routes of exposure exist. Humans appear to be exposed primarily through eating PBDE contaminated foods and through indoor air and household dust. Though PBDEs are used in many consumer products, individuals cannot easily identify which products contains PBDEs. PBDEs differ from many other environmental pollutants because they are associated with several sources and because it is so difficult for individuals to identify how they might be exposed.

PBDEs accumulate in the body over time. Levels in women build up prior to conceiving a child and can be passed on to the child during fetal development and through breast milk. Because of this, public health education will focus on young women and their health care providers.

Interim Plan

Currently, there are uncertainties about the relative contribution of different sources of PBDEs to total exposure and why some people have higher than average levels. Efforts to develop strategies to reduce human exposures will need to rely on continual monitoring of the research literature related to PBDEs. Public health recommendations for exposure reduction and educational strategies to communicate those recommendations will be revised to reflect new information as needed.

Occupational Exposure

Key Findings

Workers may be exposed to PBDEs in computers and electronics. A Swedish study showed that workers who dismantle and discard electronics at a recycling plant are exposed to PBDEs. PBDE exposure was also found in computer technicians, although at lower levels than for those in the recycling plant. The source of the exposure is thought to be dust from plastic components. Reducing the amount of PBDE-containing dust in the workplace led to reductions in worker exposures. Although appropriate occupational exposure studies have not yet been conducted, it is reasonable to assume that workers may also be exposed to PBDEs during the manufacture and recycling/disposal of polyurethane foams treated with these flame-retardants.

Policy Options

- To minimize occupational exposure to PBDEs, develop recommendations for employers and employees stating that exposure to PBDE-containing dusts should be controlled using standard industrial hygiene controls. Make employers and employees in potentially high exposure industries aware of the resources available from the Department of Labor and Industries (L&I) to assist them in controlling exposure to PBDE containing dusts. L&I would focus on the most significant workplace exposures, which are likely associated with the manufacture and recycling/disposal of foams and plastics, rather than the office environment. There are no legally enforceable occupational exposure limits for PBDEs; however, L&I would apply the existing regulation for nuisance dust, i.e., particulates not otherwise regulated.

- No action.

Recommendation

- To minimize occupational exposure to PBDEs, develop recommendations for employers and employees stating that exposure to PBDE-containing dusts should be controlled using standard industrial hygiene controls. Make employers and employees aware of the resources available from the Department of Labor and Industries to assist them in controlling exposure to PBDE containing dust. There are no legally enforceable occupational exposure limits for PBDEs; however, apply the existing regulation for nuisance dust, i.e., particulates not otherwise regulated. This process should be informed by the proposed study to 1) identify industrial processes that generate high levels of PBDE-containing dust or fume and 2) conduct biological monitoring for PBDEs in high-exposure workers.

Rationale

In the Swedish electronics recycling plant, dust control had a significant impact on PBDE exposures. Exposure was reduced when the shredder was moved away from the workers, the ventilation system was upgraded and cleaning procedures were improved. Therefore, recommending standard industrial hygiene controls to reduce exposures is warranted.

Monitoring and Research

Key Findings

Current regulations do not require monitoring for PBDEs in Washington State. As a result, very little data exist on PBDEs specific to Washington. While sampling of human tissue and laboratory animal studies indicate a risk to human health, a lack of knowledge persists regarding exposure pathways. Additional information needs include:

- Environmental monitoring data to establish baselines and monitor trends.
- Biomonitoring to establish baselines and monitor trends.
- Public awareness and perspectives on PBDEs.
- Magnitude and pathways for potential occupational exposure.
- Levels of occupational exposure to establish baselines and monitor trends.
- Deca-BDE debromination in various environments.
- The fate of PBDEs in the landfill environment.
- Alternative, non-brominated flame retardants, including their current presence in the environment and biological organisms, including people, to establish a baseline for future studies.
- Product design and other solutions to chemical fire retardants.

Research and monitoring efforts are typically conducted in coordination with other government agencies and research institutions to maximize efficient use of resources.

Policy Options

- Bring together regional government agencies and research institutions involved in environmental monitoring and research to develop a multi-media monitoring program for PBDEs.
- Establish a biomonitoring program that includes examination of PBDEs in blood and breast milk to monitor trends and identify at-risk populations.

Interim Plan

- Devise a sampling strategy to determine the relative contributions of PBDEs from various products and processes. This would include an evaluation of environmental releases from manufacturing processes (e.g., foams) in addition to recycling and disposal operations. This study could be funded via legislative request – similar to the study conducted on metals in fertilizers.

- A two-phase workplace exposure study in collaboration with CDC. This study could be funded jointly by Ecology, CDC, and potentially NIOSH, with some logistical support provided by L&I. Once Washington State workplaces with the greatest potential for PBDE exposures have been identified, the following study could be conducted in a two-phased approach.

    - Phase 1 - Air and surface sampling for PBDEs to determine the magnitude of potential exposures via the inhalation, dermal, and ingestion routes. If this evaluation suggests that there is a potential for exposure, proceed to Phase 2.
    - Phase 2 – Biomonitoring of workers who are potentially exposed to PBDEs in the workplace.

- Test biosolids, leachate and incinerator emissions for PBDEs. Top priorities may include biosolids used for food production and leachate from the LRI landfill, which uses auto fluff for daily cover.

- Require the bromine industry or manufacturers of products containing PBDEs to finance monitoring and research through direct financing or a tax on products containing PBDEs.

- In collaboration with other government agencies and research institutions, conduct research on the following issues:

    - The fate of PBDEs in the landfill environment, with particular attention to Deca-BDE debromination.

    - Deca-BDE debromination in various environments as a result of UV light exposure and metabolic processes, with particular attention to biosolids.

    - Alternative, non-brominated flame retardants, including current presence in the environment and biological organisms, including people, to establish a baseline for future studies.

    - Product design and other solutions to fire retardant needs.

Recommendations

Human Health Monitoring

- DOH should coordinate with federal agencies on existing national biomonitoring of PBDEs.

- DOH should explore whether additional regional biomonitoring is needed.

- DOH should research public awareness and perspectives to assure correct message development and environmental health communications strategy. This research is necessary to minimize unintended consequences of information delivery.

- DOH and L&I should implement a two-phase workplace exposure study in collaboration with CDC. Once Washington State workplaces with the greatest potential for PBDE exposures have been identified, the following study could be conducted in a two-phased approach.

  - Phase 1 - Air and surface sampling for PBDEs to determine the magnitude of potential exposures via the inhalation, dermal, and ingestion routes. If this evaluation suggests that there is a potential for exposure, proceed to Phase 2.

  - Phase 2 – Biomonitoring of workers who are potentially exposed to PBDEs in the workplace.

Environmental Monitoring

- Develop a monitoring program for PBDEs in the environment. To maximize efficient use of limited funds, this will be done using existing systems for multi-agency coordination, for example, the Puget Sound Ambient Monitoring Program.

Research

Encourage other government agencies and research institutions to conduct research on the following issues:

- Deca-BDE debromination in various environments.

- The fate of PBDEs in the landfill environment.

- Alternative, non-brominated flame retardants, including their presence in the environment and biological organisms, including people, to establish a baseline for future studies.

- Product design and other solutions to chemical fire retardants.

- A better characterization of how people in the U.S. are being exposed to PBDEs. This should include further monitoring of PBDEs in U.S. foods, identifying sources and levels of PBDEs in homes and other buildings, and identifying behaviors that contribute to PBDE levels in human tissues.

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Appendix A: Degradation of PBDEs

A number of studies have shown that PBDEs are subject to some degree of degradation under a variety of laboratory conditions. The section below on photolytic degradation, along with the conclusions on photolytic degradation presented in the body of the report were reviewed in writing by A. Bergman (Stockholm University), L. Birnbaum (US EPA), J. de Boer (Netherlands Institute for Fisheries Research), C. deWit (Stockholm University), R. Hale (Virginia Institute of Marine Science), R. Hites (Indiana University), and B. Jansson (Stockholm University). Additionally, the section was discussed at length by phone with C. Jafvert (Purdue University). The following section, on biological degradation, was not reviewed.

Photolytic degradation

Norris et al. found that both Deca-BDE and Octa-BDE were photodegraded in xylene by reductive debromination with half lives of 15 hours and 40 hours respectively when exposed to UV light. Stepwise photoreduction led to the formation of a variety of lower brominated diphenyl ethers and brominated biphenyls. An initial study performed on Deca-BDE dissolved in octanol and exposed to UV light showed Deca-BDE to decompose with a half-life of four hours. Degradation products for this study were not reported. In an attempt to model more environmentally relevant conditions, they also exposed Deca-BDE in water to natural sunlight for three months and found that it degraded. Breakdown products were not identified, though they appeared not to be mono-, di-, or tri-brominated diphenyl ethers.[287]

Watanabe and Tatsukawa examined photolysis of Deca-BDE in a mixture of hexane, benzene, and acetone exposed to UV light and natural sunlight. After 16 hours of exposure to UV light, they identified tri- to octabrominated diphenyl ethers and polybrominated dibenzofurans (PBDFs) with 1 to 6 bromine atoms as the major degradation products. PBDFs appeared to form as secondary products from debrominated diphenyl ethers, but not directly from Deca-BDE.[288]

Jafvert and Hua examined photochemical reactions of BDE-209 when precipitated onto hydrated surfaces, including quartz glass, silica particles (sand), and humic acid-coated silica particles. When adsorbed to sand and exposed to sunlight for 84 hours, approximately 80 percent of the initial amount of BDE-209 was recovered. The concentration of BDE-209 was similar in the exposed samples and in control samples kept in the dark. The authors concluded that little or insignificant photodegradation had occurred. They pointed out that light does not penetrate beyond a few millimeters into the sand and, therefore, only BDE-209 close to the exposed surface is exposed to light. When adsorbed to humic acid-coated sand and exposed to sunlight for 96 hours, approximately 88 percent of BDE-209 remained on the sand.

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[287] Norris et al., 1973. Toxicological and environmental factors involved in the selection of decabromodiphenyl oxide as a fire retardant chemical. Applied Polymer Symposium 22:195 – 219.

[288] Watanabe and Tatsukawa, 1987. Formation of brominated dibenzofurans from the photolysis of flame retardant decabromobiphenyl ether in hexane solution by UV and sunlight. Bulletin of Environmental Contamination and Toxicology 39: 953 – 959.

Jafvert and Hua adsorbed BDE-209 to quartz tubes containing humic acid solution and exposed the tubes to sunlight for 72 hours. After 72 hours, approximately 70 percent of the BDE-209 remained. BDE-209 appeared to transform quickly within the first 24 hours, after which the concentration remained relatively steady. In contrast, the accumulation of bromide ion was nearly linear after the first 12 hours, implying the production of the bromide ion continued after the loss of the parent compound, BDE-209, slowed. HPLC analysis of samples did not indicate large peaks of lower brominated diphenyl ether congeners, except possibly nona- or octa-BDE congeners.

Jafvert and Hua suggested that the apparent absence of organic products in their experiments using reagent grade water could be due to condensation polymerization within the precipitated Deca-BDE. The initial reaction in photolysis of Deca-BDE is agreed to be the cleavage of a carbon-bromine bond. Because the Deca-BDE was precipitated onto a solid and placed in water, a hydrogen donor was not readily available. Following the initial reaction, the authors proposed that the nonabrominated aryl radical instead reacted with another nonabrominated aryl radical, forming a macromolecule that was not detected. When humic acid solution was used instead of reagent grade water, the degradation products were altered because the humic acid acted as a reducing agent and a hydrogen source.[289]

Ohta et al. examined the degradation of Deca-BDE in toluene and a mixture of toluene, ethanol and water (1:3:6) under UV light, tungsten light and sunlight. Deca-BDE completely decomposed in toluene after 40 minutes. By 60 minutes, mono- to nona-BDEs were observed. In sunlight, after 24 hours, tri- to nona-BDEs had been observed. Decomposition products appeared to be temporarily concentrated in two kinds of hepta-BDE. The authors thought the concentration of hepta-BDE could be a result of the difference in intensity between the UV light and natural sunlight. They performed an additional experiment exposing BDE-209 to tungsten light where two hepta-BDEs were also observed, one identified as BDE-183.[290]

As reported in the European Union's Update of the Risk Assessment of Bis(pentabromophenyl) ether (decabromodiphenyl ether), Palm et al. performed an in-depth investigation on the photodegradation of BDE-209. The first series of experiments determined the UV spectrum of BDE-209 in toluene, dichloromethane, tetrahydrofuran (THF), methanol, and ethanol. The spectrum obtained was similar in all solvents used and showed a weak absorption band above 290 nm, which is in the range of the solar spectrum at ground level. The spectrum of BDE-209 in THF was also compared to those of BDE-47, other brominated diphenyl ethers. As the number of bromine atoms per molecule decreases, overlap of the absorption spectra with light of wavelength >290 nm is reduced, implying a reduced susceptibility for photodegradation in the environment.[291]

Palm et al. also examined the degradation of BDE-209 under filtered (300 nm) xenon lamps in toluene, dichloromethane, and a mixture of hexane, benzene and acetone (8:1:1). The half-life in

[289] Jafvert and Hua, 2001. Photochemical reactions of decabromodiphenyl oxide and 2,2'4,4'-tetrabromodiphenyl oxide. Submitted to American Chemistry Council Brominated Flame Retardant Industry Panel.
[290] Ohta et al. Characterization of the Photolysis of Decabromodiphenyl ether and the levels of PBDEs as its photoproducts in atmospheric air of Japan
[291] European Chemicals Bureau. Update of the Risk Assessment of Bis(pentabromophenyl) ether (decabromodiphenyl ether). Final draft of May 2004.

all three solutions was about 0.5 hours. Reductive debromination was found to occur, with all three nona-BDE congeners forming, which further reacted to form six congeners of octa-BDE, which reacted to form two major hepta-BDE congeners, along with several minor hepta-BDE congeners. Traces of hexa-BDE congeners were then formed. Mass balance calculations showed that degradation products identified accounted for 75 percent of BDE-209 in the study. Products from the remaining 25 percent were not identified.

Palm et al. examined BDE-209 in toluene under natural sunlight for two days in July, which resulted in the complete disappearance of BDE-209. Degradation products identified at the end of the exposure period included three nona-BDE isomers, several octa-BDE congeners, several hepta-BDE congeners with two isomers dominating, a group of hexa-BDE isomers with a single congener dominating, and a group of penta-BDE congeners. Similar results were obtained by examining BDE-209 in THF under a sunlamp for 84 hours. With the longer exposure, tri-BDE and tetra-BDE congeners were also observed but not identified. The gas chromatographic pattern for the experiment did not resemble those found in the Octa-BDE or Penta-BDE commercial products. The authors concluded that the much simpler fingerprint of congeners found in the Octa-BDE and Penta-BDE products implies that the lower brominated PBDEs found in the environment are not derived from the photolysis of Deca-BDE.

Palm et al. exposed BDE-209 in THF to a polychromatic light source and determined the half-life to be 1.9 minutes. Degradation products included three nona-BDE isomers, three octa-BDE isomers, and several hepta-BDE isomers, lower brominated congeners and brominated dibenzofurans. Seventeen percent of the degradation could not be explained. A separate experiment was performed to confirm the presence of mono-, di-, tri-, and tetrabromodibenzofurans. Higher brominated furans were not found, though it was indicated that their presence may have been masked by the formation of equivalent brominated diphenyl ethers formed in higher amounts. By changing the light source in this experiment from $\lambda > 280$ nm to light using a cut-off filter at 320 nm, the half-life for BDE-209 was found to increase by 26 minutes and the pattern of nona-BDE congeners formed changed. The authors concluded that the product distribution depends on the light source used.

Palm et al. adsorbed BDE-209 onto silicon dioxide and placed this in suspension in water. The test suspension was then exposed to polychromatic light for 45 minutes. Around 45 percent of the BDE-209 was found to have degraded after 45 minutes. Details of degradation products were not available, but the test report indicated that brominated furans were formed.[292]

Söderstrom et al. examined debromination time trends and half-lives of BDE-209 in toluene and on silica gel, sand, sediment and soil. All samples were exposed to UV light, and samples on soil, sand, and sediment were additionally exposed to outdoor sunlight. BDE-209 degraded in all five matrices, though at different rates. Half-lives in toluene and on silica gel were less than 15 minutes following continuous exposure. The half-life for BDE-209 on sand exposed to UV light was 12 hours; the half-life for BDE-209 on sand exposed to sunlight was 37 hours. Exposure to sunlight was not continuous, while the exposure to UV light was. The authors calculated that the irradiance over the outdoor exposure approximated 13 hours of continuous exposure, comparable

[292] European Chemicals Bureau. Update of the Risk Assessment of Bis(pentabromophenyl) ether (decabromodiphenyl ether). Final draft of May 2004.

to UV light results. The half-life for BDE-209 exposed to UV light on sediment was 53 hours. The half-life for BDE-209 exposed to UV light on soil was between 150 and 200 hours. BDE-209 exposed to sunlight on sediment and soil showed irregular degradation; the half-life for soil was not reported. The half-life for sediment was estimated as 80 hours for discontinuous sunlight and 30 hours for continuous sunlight.[293]

Söderstrom et al. explained the difference in half-lives by pointing to the differences in surface structure and chemical composition of the matrices. The smooth surfaces of silica gel and sand allow greater exposure to UV light, while the porous nature of sediment and soil enables the BDE-209 to be adsorbed into the particle where it is shielded from UV radiation. In addition, the authors suggest that organic carbon contained in sediment and soil could noncovalently bind with BDE-209, possibly increasing half-lives both by physically shielding the molecule from UV radiation and by stabilizing the molecule as a result of the chemical bond.

While the matrix used impacted rate of degradation, Söderstrom et al. found consistent degradation pathways across matrices. Degradation appeared to be, at least initially, a stepwise debromination process. As BDE-209 disappeared, nona- to hexa-BDEs were formed. After the peak formation of hexa-BDEs, only small amounts of lower brominated compounds were formed with a discontinued mass balance. Tetra-BDFs, penta-BDFs, and hexa-BDF were identified in soil and sand samples, but no PBDFs were identified on the other matrices. BDE congeners that were identified as degradation products on all matrices included BDE-128, -154, x-183, -206, -207, and -208. In addition, two unknown hexaBDEs, one unknown heptaPBDE, and four unknown octaBDEs were formed. BDE-47, -99, -100, and -153 were found only on some matrices. Too few samples were analyzed for PBDFs to draw conclusions about exposure times and matrix dependence.[294]

Eriksson et al. examined the photodegradation rates and products of 15 individual PBDEs, including BDE-209. Photolysis of BDE-209 was measured in methanol/water (4:1), pure methanol, THF, water, and water containing humic substances. With the exception of water, photolysis of decaBDE in all other media measured resulted in an almost identical set of products, though in water containing humic substances a higher proportion of pentaBDFs was observed. Each of the three nonaBDEs were formed and produced a number of octaBDEs, although the major products were different for each nonaBDE congener. Hepta- and hexaBDEs and mono- to pentaBDFs were also formed. The UV degradation products of two heptaBDEs, BDE-190 and BDE-183, and three hexaBDEs, BDE-155, BDE-154, and BDE-139 were also identified. The substances followed the same trend of consecutive debromination with the exception that tri- and tetraBDEs were also observed as products from the latter reactions. The authors found that the total area under the HPLC chromatogram decreased by approximately 15% after most of the BDE-209 had decomposed. They suggested that this could be due to the formation of PBDFs or uncharacterized products. Some minor peaks in the mass chromatogram

[293] Söderstrom et al., 2004. Photolytic debromination of decabromodiphenyl ether (BDE 209). Environmental Science and Technology 38(1):127-132.
[294] Söderstrom et al., 2004. Photolytic debromination of decabromodiphenyl ether (BDE 209). Environmental Science and Technology 38(1):127-132.

could not be characterized as PBDE or PBDF congeners. One such peak was consistent with a methoxylated tetrabromodibenzofuran.[295]

Eriksson et al. found that the photolytic reaction rate was 700 times greater for BDE-209, the congener with the fastest reaction rate, than for BDE-77, the congener with the slowest reaction rate. Lower brominated congeners generally degraded more slowly than higher brominated congeners. They attributed much of the difference to the fact that higher brominated diphenyl ethers absorb UV light at longer wavelengths. They also found more subtle differences within groups with the same number of bromine substituents. Photolysis rates for tetra-BDE through hepta-BDE congeners were faster for congeners with a fully brominated ring. However, for congeners with less than fully brominated rings, the impact of structural parameters on degradation rate was unclear. The reaction rate was also dependent on the solvent such that the reaction rate in the methanol/water solution was consistently about 1.7 times lower than in pure methanol and two to three times lower than in THF.

Eriksson et al. also attempted to measure the photolytic degradation rate and breakdown products of BDE-209 in pure water. The BDE-209 disappeared from solution, but no degradation products were found. The authors suggest this may have been due to adsorption to glass walls rather than chemical transformation, given the extremely low water solubility, < 1 µg/L, of BDE-209.[296]

Bezares-Cruz et al. examined the reaction rate and products of solar degradation of BDE-209 in hexane under a range of solar wavelengths. They reported that the range of wavelengths where both the molar absorptivity of BDE-209 and the solar irradiance flux are significant occurs between 300 and 350 nm. They found that upon solar irradiation, BDE-209 reductively dehalogenated to other PBDEs. During 34 hours of irradiation, PBDEs from nona- to tri-bromodiphenyl ethers were observed. In total, 43 PBDEs were detected, and 21 were identified by matching them to available congener standards. BDE-47 and BDE-99 were among the congeners identified. In additional experiments, BDE-156, -184, -191, -197, -206, and -207 dissolved in hexanes were exposed individually to solar radiation for reactivity and product analysis. Comparable appearance of less substituted PBDEs was observed in all cases, with greatest reactivity apparent for those congeners fully substituted in all ortho positions. Whether this was a result of higher quantum yields of molar absorptivities of those congeners was unknown.[297]

Biological transformation of PBDEs

Several studies indicate the potential for PBDEs to break down as a result of biological processes.

[295] Eriksson, et al., 2004. Photochemical decomposition of 15 polybrominated diphenyl ether congeners in methanol/water. Environmental Science and Technology 38:3119 – 3125.
[296] Eriksson, et al., 2004. Photochemical decomposition of 15 polybrominated diphenyl ether congeners in methanol/water. Environmental Science and Technology 38:3119 – 3125.
[297] Bezares-Cruz, et al., 2004. Solar Photodecomposition of Decabromodiphenyl ether: products and quantum yield. Environmental Science and Technology 38:4149 – 4156.

Kierkegaard et al. exposed rainbow trout to food amended with the commercial Deca-BDE formulation for 16, 49, and 120 days with an exposure of 7.5 – 10 mg/kg body weight/day.BDE-209 concentrations in muscle increased from <0.6 ng/g of fresh weight to 38 (±14) ng/g after 120 days. Several hexa- to nona-BDEs were observed, which increased in concentration with exposure length. The authors suggested that these could originate from metabolism of BDE-209 or selective uptake of minor components of the commercial formulation. Following a depuration period, BDE-209 concentrations declined significantly, but concentrations of some of the lower brominated congeners were unaffected.[298]

Stapleton et al. exposed juvenile carp to food amended with BDE-209 for 60 days with an exposure concentration of 940 ng/day/fish. During the following 40 days, the fate of BDE-209 was monitored. No net accumulation of BDE-209 was observed, though seven apparent breakdown products, identified as penta- to octa-BDEs, accumulated over the exposure period.[299]

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[298] Kierkegaard et al., 1999. Dietary uptake and biological effects of decabromodiphenyl ether in rainbow trout (*Oncorhynchus mykiss*). Environmental Science and Technology (33)1612 – 1617.
[299] Stapleton et al., 2004. Debromination of the flame retardant decabromodiphenyl ether by juvenile carp (*Cyprius carpio*) following dietary exposure. Environmental Science and Technology, (38)112 – 119.

Appendix B: Comments from Reviewers

In preparation for the October 11 Draft PBDE CAP, draft sections on photolytic debromination and human health effects of PBDEs were sent to eight reviewers. Reviewers were chosen because they had published primary research in peer reviewed journals on PBDEs.

Robert Hale, Virginia Institute of Marine Science

September 30, 2004

I think you did a very good job on the specific subjects at hand. I would only note that sewage sludge and biosolids are not exactly the same thing and some might not know what the latter is. To my knowledge our group (in the Nature paper) has been the only one so far to look at biosolids (sludge processed for land application), while several Europeans and now a few N Americans have examined sewage sludge for PBDEs.

What about the issue of biological PBDE transformation? Photolysis in the lab gets a lot of coverage here, yet this abiotic strand seems to get unraveled when people enter the field. I think Stapleton's work (building on Kierkegard's), showing probably debromination in fish, and Mark La Guardia's recent BFR2004 presentation suggesting debromination occurring in the field (mainly in fish near a STP) should be considered somewhere. Perhaps u have another section?

Linda Birnbaum, US EPA

October 4, 2004

PBDEs and Human Health:
1. Make the point that BDE209 IS in human milk and blood, as well as wildlife, including fish.
2. The reason we estimate the daily intake is so that we can compare different human populations. It is NOT appropriate to compare daily dose in animals to that in people because of differences in half-lives. The appropriate way to compare animals and people, when dealing with persistent bioaccumulative compounds, is on the basis of body burden or tissue dose. One contaminated meal is not going to cause a problem - its the long term, repeated exposures which lead to a build up.
3. There are no occupational studies in US workers. Therefore, its a problem to compare the European workers to US background populations.
4. To compare levels at which occur in animals and humans, you need to use a body burden or tissue dose approach. When you do that, using developmental neurotoxicity as the response, you see that there is little margin of exposure.
5. Table 2 - Clarify which studies involve a single dose (the developmental studies, etc.) and which involve repeated daily doses (the cancer studies, etc.).

Photolytic Degradation
this seems OK

you might want to mention that there is also growing evidence of anaerobic microbial degradation of BDE209

Åke Bergman, University of Stockholm

October 6, 2004

Regarding the draft on photolytic degradation of PBDEs.

This is well written and I only have one comment. It is related to the last page, 3rd para from the bottom "The EU Risk Assessment suggests ..." This is a very strange suggestion that I would like to argue very much. In case you want to include it it need to be looked at in detail from the original documentation. To the best of my knowledge this is a very unlikely reaction. I suggest that this para is omitted.

Cynthia de Wit, University of Stockholm

October 7, 2004

I have now read both documents as well as the comments from Prof. Bergman and Dr. de Boer. I agree with their comments and have the following additions.

For the human health document:

Prof. Bergman's group has shown that BDE-209 is rapidly metabolized and has a short half-life in humans (about 12 days). Thus, the fact that BDE-209 is being found in humans at all indicates that there must be sources of constant exposure to maintain even background levels. In mice, BDE-209 is metabolized to octabrominated hydroxylated BDEs among others (Mörck /et al/., 2003). Work in Per Eriksson's group implicates BDE-209 metabolites as being the neurotoxic agents and not BDE-209 itself, though more research is needed. Therefore, low levels of BDE-209 in humans do not necessarily reflect low uptake, but may reflect rapid metabolization with subsequent production of metabolites that we know very little about toxicologically. Uptake rates in mice were estimated to be quite high (as high as 65%) and in a recent experiment, Gareth Thomas (Lancaster University, England) and coworkers have shown more than 80% uptake of BDE-209 from the gut of seals.

Another aspect of human exposure that is not addressed but where I believe there is data is age trends in BDE concentrations. Some data are presented in the Sjödin et al. 2003 article. Prof. Bergman may know where more data on this is available - but as I recall, lower brominated BDEs show no age trends, i e, concentrations are similar in children as in adults, which is not the case for PCBs, which increase in concentration with age. The reasons for this lack of age trend are not completely clear but may indicate that this is a new enough exposure situation so everyone is being exposed to a similar degree and age trends have not had tíme to be established yet.

At BFR 2004, Heather Stapleton presented data on BDEs in house dust, which you refer to, and she also presented an estimation of BDE intake from house dust in small children. This was based on a risk assessment method that has been used previously to estimate children's lead intake from house dust, as children crawl on dusty floors and then stick their fingers constantly in their mouths. Her estimates were that house dust ingestion could be a major contributor to daily intake in infants, so there is need to be cautious when discussing sources of human exposures. There will be age-specific differences.

For the photolysis document:

On page 3, fourth paragraph, last sentence, it is stated: BDE-209 exposed to sunlight on sediment and soil showed irregular degradation; half-lives were not reported. This is not correct for sediment - the half-life was estimated as 80 hours for discontinuous sunlight and 30 hours for continuous sunlight.

On page 4, paragraph 2: Congener specific information should be added here: BDE congeners that were identified as degradation products on all matrices included BDE-154, -128, -183, -206, -207, -208. In addition two unknown hexaBDEs, one unknown heptaBDE and four unknown octaBDEs were formed. BDE-47, 99, 100 and 153 were found only on some matrices.

I also find it interesting that in several of the studies where BDE congeners were identified, two heptaBDEs are found of which one is BDE-183, implicating degradation of BDE-209 as being a potential source for this, as well as the OctaBDE technical product.

I hope these comments assist you in improving the documentation.

Jakob de Boer, Netherlands Institute for Fisheries Research

October 7, 2004

I have read the two parts Human Exposure and Photolytic degradation.

1. Human exposure: generally well written. Page 5, just above Estimates of daily ...: my impression is that furniture and carpets are the main PBDE containing products that act as sources of PBDEs in homes and offices, rather than computers or TV sets. Small polyurethane foam particles are easily transported through ventilation systems etc.

2. Photolytic degradation:

3. (Detail) Page 2 and 3: the refs. of Palm (EU) and Söderstrom only come one page later.

Page 4, 3rd par.: 4th line: photolysis of decaBDE in all (to make explicit that the rest of the text deals with decaBDE and not with the other PBDEs which are being mentioned in the 1st line. Line 6: replace peaks by quantities. Several large ...: could this be made more specific?

Page 5: top: mention <0.1 μg/L to show that we evn do not know how low the solubility is.

Page 6, 3rd par.: I agree with Aake Bergman that we need to look into the detaisl of this ref.

I agree with the general line of discussion: clearly there is a rapid degradation under light conditions of decaBDE in organic solvents. This may also occur, at a much slower rate, in water, but proper determinations of this process are hindered by the extremely low water solubility of decaBDE. DecaBDE will immediately adsorb to particles and bind to organic carbon. Söderstrom nicely explains the shielding effect of the porous sediment and soil that increases the half-lives of decaBDE. Although the degradation of decaBDE in the environment may be slowed down very much by these processes, I fully agree that there is enough concern for environmental threats from this process on the longer term. Sediment cores from Europe that we have investigated did not show a correlation between a sharp increase of decaBDE concentrations over a period of 10-20 years and penta-mix related PBDE congener concentrations that generally showed a decrease. This seems to correspond with the results of palm et al. (page 3, first par.) who conclude that mainly other than Penta and octa BDE related lower brominated PBDE congeners are being formed. This also corresponds with the work of Zetsch presented at SETAC (summary attached).

Follow-up question by C. Peele to J. de Boer, October 8, 2004

Thanks once again for your comments, which were the source of much discussion here today. I have a follow-up question: If congeners other than those related to the penta and octa commercial formulations are being formed by deca degradation, on what basis would we have concern for environmental threats? Bezares-Cruz et al. found that BDE-209 degraded in hexane to BDE-47 (among other congeners), with BDE-99 and -100 as intermediate products. However, if experiments in organic solvents do not accurately predict breakdown pathways or products in the environment, then it seems we do not know what products are formed or their toxicity.

Any insight you or others copied could provide would be most useful.

J. de Boer response to C. Peele, October 8, 2004

We do not know very much on the toxicity of PBDE congeners in general. The penta-and octa mix related congeners are not necessarily the most toxic ones (in the case of PCBs it took us years to identify the most toxic ones!). However, as soon as lower brominated (deca) PBDE congeners are being formed from decaBDE, these will be moderately to highly bioaccumulative. Although in the sediment this process may take place rather slowly, because of the high levels of decaBDE that are disposed in sediments, there is concern that on the long term (we do not know how long) several PBDEs originating from decaBDE may be found in aquatic organisms in increasing concentrations. Indeed, there is still a challenging task to study the degradation process of decaBDE in the aquatic environment.

Linda Birnbaum, US EPA

Response to C. Peele commenting on October 8 question sent to J. de Boer, October 8, 2004

Cheri - you have hit on one of the major issues. We do NOT know all of the breakdown products of BDE209. And we know less about their toxicity.

Interim Plan

Follow-up question by C. Peele, October 8, 2004

Thanks very much. It is good to understand that.

Our draft recommendations for Deca are to ban its use in consumer electronics and upholstered furniture as of 2008. Do you know if this contradicts (as opposed to "goes beyond") any position of EPA?

L. Birnbaum response to C. Peele, October 8, 2004

Epa has no position on banning deca.

Ronald Hites, University of Indiana

October 11, 2004

These are my comment on just the human exposure document:

This document is a bit unfocused, and to me at least, unclear in parts. I suspect part of the problem is that it is not obvious to me who the intended audience is. I assume it is aimed at technically literate Washington state employees, in which case, the document needs to be a bit more stringently organized.

Figure 1 is not very convincing particularly in light of Aake's comments. It would be more convincing and accurate to use Figure 1 from my recent review (ES&T 2004, pp. 945-956), which shows data for Europe, North America, and Japan as a function of time and makes the point that PBDEs are increasing everywhere as a function of time (doubling every 5 years) and that North American levels are significantly higher than European levels and that Japanese levels are significantly lower than European levels. I would also replace your Figure 2 with my Figure 2, which shows the same sort of data but in a clearer format. My figure also makes the point about a few high outliers that you mention in your text.

Somewhere at the beginning of this document you need to carefully define three terms: (a) "PBDEs", which include all congeners (from typically 47 to 209); (b) "less-brominated PBDEs", which include only the tetra, penta, and hexa congeners; and (c) BDE-209 only. Once defined, you should carefully select the correct term to agree with the literature being covered at that point. As it stands now, it is not always clear which group is being referred to. This is becoming an ever more important distinction.

Table 1 is confusing, at least in part, because of the units for the daily PBDE intake column – changing the units to nanograms per kg would wipe out a lot of unnecessary leading zeros and make it more readable. But even with this correction it is not clear what message the reader is supposed to carry away from this information. Is it that these levels are very small relative to the LOAEL levels given in Table 2 and that PBDEs are safe? I doubt that is the point, given Linda's comments and that the units are different, but that is what a cynic may conclude.

In the last paragraph on page 5, line 2, it should read "Table 1", should it not?

Some of the references are cited with different numbers even though they are the same paper; for example, the 2003 Environment International paper by Sjödin has numbers 2, 10, 20, and 82 (at least), and the 2001 EHP paper by Darnerud has numbers 86, 88, 90, and 92 (all on the same page!).

On page 8 at the end of the first paragraph, reference 58 is to the American Industrial Hygiene Association in the text but to the American Chemistry Council in the footnote. Surely, these are not the same organization.

My overall suggestion is to, perhaps, use fewer references and to draw more careful and detailed conclusions.

These are my comments on just the photolytic degradation document.

This is a workman-like review of the handful of papers on this subject. My main suggestion is to set up the discussion with an opening that indicates why we might be interested in this sort of science. It seems to me that the answer deals with issues of environmental transport and fate that are not even hinted at in the text. For example, if the only (or main) source of BDE-209 is house dust, then we are only interested in the question of degradation of this compound indoors and on particles. In this case, work on the degradation of BDE-209 in water or in organic solvents is irrelevant to the fate of this compound. In addition, the wavelengths of light to which the house dust is exposed are unlikely to be similar to wavelengths used in any of the experiments discussed in this review. If indoor exposure (even occupational exposure) is the most important pathway of BDE-209 into people, then one should be mostly interested in issues of metabolic (not photolytic) degradation, issues which are not covered in this review.

On the other hand, if BDE-209 makes it outdoors, it can be transported long distances before it is accumulated into biota or into lake or oceanic sediment. Under these conditions, it is known that BDE-209 is associated with the atmospheric particle phase (not the vapor or gas phase), and in this case, one is should be interested in the rate of photolytic (or other) degradation in the atmosphere on particles during the transport process and in the rate of degradation (if any) once this compound is accumulated in its environmental sink, particularly in the sediment. These issues are covered in this review, but they are not sufficiently separated from degradation rates in organic solvents, experiments which are not relevant under these circumstances. Thus, I would divide the text into three parts: the first giving the rational for looking at photolytic degradation and biotic degradation separately; the second reviewing the literature on photolytic degradation rates and products in organic solvents (pointing out that this information does not have much environmental relevance); and the third reviewing the degradation rates in water and on particles. In the latter case, I would link the results to the finding that BDE-209 is particularly abundant in sediments.

Some specific comments:

The term "artificial UV light" does not make sense. How could light be "artificial"? I suspect that what is meant here is that a light source was used that simulated the UV spectrum of sunlight. The best way to deal with this is to simply give the range of wavelengths used in these experiments.

Reference 4 is not complete.

The data are sufficiently orderly that it might be a good idea to summarize the experiments in a table, keeping in mind the three points above.

Bo Jansson, University of Stockholm

October 11, 2004

I've seen some of the comments given by other people, and I agree with most of what they said. The major discussion now is around the DeBDE, and if it degrades to compounds that are more bioaccumulative. This discussion seems less important as the compound itself have been found in many species. I think our major problem are the substitutes if we restrict the used of PBDEs.

In the paper on human health you have to be careful in figure 1 where you mix data from different investigations to describe a temporal trend. I guess that variation between investigations are larger than between sampling years. I also have some problems with figure 2, which can be understood as a description of a temporal trend, a table must be better.

Follow-up question by C. Peele, October 11, 2004

Thanks so much for your comments. To clarify, though, do you think the problem is that alternative flame retardants are likely worse than PBDEs, or that they are just no better? I have been reviewing some of the alternatives; it seems that large data gaps remain. That in and of itself poses a challenge.

B. Jansson response to C. Peele, October 12, 2004

For some of the alternatives (e.g. some of the phosphates) we have some knowledge, but for several of the brominated compounds (such as decabromodiphenylethane) we know nothing. We can guess that the latter has similar properties as the decabromodiphenyl ether, but a lot more data are needed before I would be comfortable to see them used in large amounts.

Sean Hayes, Intertox[300]

S. Hayes to D. Laflamme, November 11, 2004

[300] Sean Hayes was contacted to review the draft human health and debromination sections at the same time as the other reviewers. Due to the short amount of time provided and other obligations, his comments were received too late to be incorporated into the October 11 Draft. They have been incorporated in the December 31 Interim CAP.

You have done a good job of summarizing the issues. The attached file has comments on your section (Chapter III). Don't hesitate to call me if you have any questions about my comments.

Comments from the attached file, a copy of the October 11 draft, are below.

References 29 and 30 do not have data on US levels.

(With regard to Table 5, Estimates of PBDE daily human intake for different countries) Hays et al. 2004 is not cited. This study provides one of the most recent exposure assessments for deca, and specifically has estimates for children. Likewise, the VCCEP submission for penta and octa offers a comprehensive exposure assessment for these two congeners.

Reproductive effects is most sensitive in Table 2.

Reference 111 is a review paper, not a tox study. Only primary references for tox studies should be cited for this evidence.

References 116, 119, 120 and 121 are review papers, not tox studies. Only primary references for tox studies should be cited for this evidence.

(With regard to references 132 and 133) These are all review papers and not toxicology studies. Only primary references of tox studies should be cited.

(With regard to reference 136) It would be best to cite the NTP study here rather than a secondary review paper.

Appendix C: Companies Phasing out PBDEs

Company	Policy	Source	Date viewed
Apple Computer	No PBDEs in mechanical plastic parts heavier than 25-50g and none in the base material for the iMac 20" (11/21/03)	"Environmental Attributes" http://www.apple.com,	4/27/04 and 4/30/04
Brother Industries Ltd	PBDEs prohibited in product when concentration is 100ppm or more	Brother Green Procurement Standard http://www.brother.com,	5/14/2004
Daikin Industries	Plans to phase out PBDEs by the end of March 2006	"Environmental Assessment of Our Products" http://www.daikin.com/data/environment/pdf03/report2003_5.pdf	4/28/2004
Dell Computer Corp.	Dell has phased out PBDEs from its products. The company's goal is to phase out all other brominated flame retardants in desktop, notebook, and server chassis plastic parts by year-end 2004.	http://www.dell.com	3/10/2004
Eizo Nanao Corporation	Plastics do not contain brominated or chlorinated flame retardants.	http://www.eizo.com Eco-Products 2004	5/17/2004
Ericsson	Does not use PBDEs.	http://www.ericsson.com, "ECO Declaration"	4/27/2004
Hewlett Packard	Prohibits use of PBDEs.	"RoHS" Position Statement, http://www.hp.com/hpinfo/globalcitizenship/environment/pdf/leadposition.pdf	10/1/2004
Matsushita	Intends to phase out all PBDEs by March 2005.	Matsushita Electronic Components Group Chemical Substances Management Guidelines, http://panasonic.co.jp/maco/en/environment/pdf/kagaku_kanri.pdf; pers. comm., D. Swanson	6/3/2004
Mitsubishi Electric	Eliminate the use of PBDEs by December 31, 2005.	Environmental Sustainability Report 2004, http://global.mitsubishielectric.com/company/environ/pdf/Report_2004e2.pdf	7/26/2004
NEC	Goal of eliminating PBDEs by the end of FY 2005.	NEC Corporate Profile, http://www.nec-lcd.com/english/profile/environment_energy.html	10/1/2004
Philips Electronics Ind. (Taiwan) Ltd., CED	2002/95/EC requires the substitution of various heavy metals (lead, mercury, cadmium, hexavalent chromium) and brominated flame retardants (PBB and PBDE) in new electrical and electronic equipment put on the market from 1 July 2006.	http://www.cft.philips.com/	7/26/2004

Company	Policy	Source	Date viewed
Samsung Electronics Co. Ltd.	PBDEs will be banned in all applications. As of May 2004, threshold limit was under development.	Position Paper of Samsung Electronics with regard to the use and phase out of certain substances when appropriate. http://www.samsung.co.uk/	7/26/2004
Sharp Corporation	Use of PBDEs in its products except in CTV for the US	"Parts/Materials Contained Chemical Substance Investigation Manual (for Business Partners)," July 2003, p. 6. http://www.sharp.co.jp	4/29/2004
Sony Corporation	Sony will not accept parts from suppliers containing PBDEs except for parts made by dies that were made prior to January 2003. This exemption applies only to bodies of displays and TV sets to be shipped to non-European countries. As of January 1, 2005, parts whose dies were made in 2003 or later must not contain PBDEs.	Management Regulations for the Environment-Related Substances to be Controlled Which are Included in Parts and Substances, 3rd ed., p. 9, www.sony.com	4/29/2004
TOTOKU Electric Co., Ltd.	Totoku has developed lead-free wires that do not contain halogens. It intends to manufacture lead-free, halogen-free wires that satisfy UL standards.	"Environmentally friendly type electric wires"	5/5/2004
ViewSonic Corporation	ViewSonic has taken steps with its manufacturing partners to eliminate halogen and bromide-related flame retardant chemicals, particularly in CRT products. Specific model numbers are not provided by the company.	"Quality and Environment"	5/5/2004
Xerox	Goal to eliminate use of PBDEs in all products introduced in FY 2004.	"Activities in 2002" http://www.fujixerox.co.jp/eng/ecology/report2003/2003e_12.pdf	10/1/2004

Appendix D: Comments received on the Draft PBDE CAP

The following is a summary of the major points made by organizations and individuals who commented on the draft plan. Individual letters may be viewed at the Ecology PBDE web site (www.flameretardants.org). A responsiveness summary will be prepared for all comments and will be posted on this site sometime in February, 2005.

Note: *The comments summarized under each category represent the views of one or more members of that group but might not be shared by all members of the group.*

Businesses (13 groups)

Ecology heard from 12 businesses/organizations:
- Association of Washington Business (AWB)
- AeA (High-Tech electronics)
- Independent Business Association
- The Boeing Co.
- Bromine Science and Environmental Forum
- Washington Retail Association (WRA)
- Matsushita Kotobuki Electronics
- Northwest Biosolids Management Association (NBMA)
- Pierce County Recycling, Composting, and Disposal, LLC dba LRI
- MBA Polymers, Inc.
- LRI Landfill – Pierce County Recycling
- Total Reclaim
- Washington Refuse and Recycling Association (WRRA)

This is what they had to say:
- Don't ban Deca-BDE. .
- With no risk assessment, the plan is incomplete.
- Deca isn't toxic, and we don't believe there is convincing evidence that it breaks down into more harmful chemical forms in the environment.
- Alternatives to Deca not only will cost more to use but are less tested and might prove more harmful.
- If Washington businesses face tougher standards than those outside the state they ability to compete will suffer.
- If Deca is replaced with less effective alternatives, fire safety standards could be compromised.
- The harmful forms of PBDE chemicals showing up in the environment are not coming from Deca.

- It doesn't make sense to invest effort and money into controlling PBDEs until more is known about the pathways by which PBDEs get into the environment and our bodies and which are the major pathways.
- Ecology's plan is too extreme compared to what's being done in other states and countries.
- Don't ban PBDE-containing auto fluff that is used for landfill cover. It serve a good use, there's no evidence it's causing problems, and landfills are the best place for its disposal.
- Don't ban the recycling of PBDE products/materials; this would promote waste, create a need for more disposal capacity, remove a revenue stream for recyclers and raise the cost of new products that now use cheaper, recycled materials.
- If a ban on PBDEs leads to alternatives that are less flame retardant, it could open businesses to litigation over liability.
- Don't ban existing disposal practices, such as landfills, without having an alternative in place.
- The plan doesn't address local solid waste.
- The plan lacks information on end-of-life factors.
- A ban on Penta and Octa is unnecessary because those chemicals are being voluntarily phased out and a pending Significant New Use Rule will mostly prohibit its future use.
- For some applications, alternatives to PBDE flame retardants do not yet exist.
- Parts of the plan are unclear and need more clarity, and a number of its assumptions are confusing.
- The plan lacks exemptions or a waiver process for the proposed ban.
- Ecology should differentiate better between Penta, Octa and Deca. Too often, the plan refers to PBDEs in general, rather than the specific products, which have very different characteristics and uses.
- The plan fails to explain how a ban would work or which products would be affected.
- There is limited information available as to which products contain PBDEs.
- The plan lacks a cost-benefit analysis, which is vital to gauging its impact on the state economy and employers.

Advocates (33 groups)

Ecology heard from 32 environmental, children's health and church organizations:

- American Lung Association of Washington
- Asian Pacific Environmental Exchange
- Basel Action Network
- Breast Cancer Fund
- Breast Feeding Coalition of Washington
- Coalition for Environmentally Safe Schools
- Citizens for a Healthy Bay
- Duwamish River Clean-Up Coalition
- Earth Island Institute Orca Recovery Program
- Earth Ministry
- Friends of the Columbia Gorge
- Healthy Building Network

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- Healthy Mothers, Healthy Babies Coalition of Washington
- Institute for Children's Environmental Health
- Institute for Neurotoxicology and Neurological Disorders
- Kettle Range Conservation Group
- The Lands Council
- Lutheran Public Policy Office
- Newground Social Investment
- Northwest Environment Watch
- Nursing Program, University of Washington, Tacoma
- Oregon Center for Environmental Health
- Seattle Tilth
- Toxic Free Legacy Coalition
- People for Puget Sound
- RE Sources for Sustainable Communities
- Seattle Alliance for Good Jobs and Housing for Everyone (SAGE)
- Seattle Chapter Fellowship of Reconciliation
- S.H.A.W.L. Society (Sovereignty, Health, Air, Water, Land)
- Washington Association of Churches
- Washington Citizens for Resource Conservation
- Washington Public Interest Research Group (WashPIRG)
- Washington Toxics Coalition

This is what they had to say:
- Ban all forms of PBDEs, including all types of Deca.
- Ban Deca use sooner, in 2006 instead of 2008.
- Require labeling on PBDE products until a ban is in place.
- Ecology's plan is not extreme compared to what's being done in the European Union and in Sweden.
- There is plenty of evidence of debromination of Deca into more harmful chemicals.
- Ecology should limt state purchasing of any products that contain PBDEs.
- The state should create an institute that can research alternatives for PBDEs and other harmful chemicals.
- There is a critical need to change federal chemical policy.
- The plan should call for more monitoring of fish.
- The plan should call for the bio-monitoring of breast milk and blood.
- PBDEs are similar PCBs, both in structure and in the long-term threat to the environment and health.
- Ecology should accelerate the evaluation of end-of-life factors.
- The state should prohibit the incineration of PBDE products.
- The plan should call for the separation of materials at end of life.
- A ban on PBDEs will drive the development of alternatives; if there is no ban, there will be no incentive for manufacturers to develop alternatives.
- Businesses should provide information on the use and content of PBDE products.
- The plan fails to assess the conomic/social costs of damage to children from PBDEs.
- A ban of PBDE products is supported by new scientific studies of PBDEs.

Medical and Public Health Associations (5 groups)

- Washington Academy of Family Physicians
- Washington State Public Health Association
- Washington State Medical Association
- Washington Chapter of the American Academy of Pediatrics
- Washington Physicians for Social Responsibility

This is what they had to say:

- We recognize a human health threat.
- Physicians frequently have to make judgements based on partial or imperfect information. In this case, PBDEs, there is enough known to warrant caution and exposure prevention.
- We are concerned about rising levels of developmental problems in children, and believe we must do everything possible to limit pre-natal and post-natal exposure to harmful chemicals, like PBDEs.
- Support the phase out and elimination of the use of PBDEs while maintaining existing fire safety standards.

Individuals (27 people testified at meetings; 5 people submitted comments via e-mail; 300 people sent form letters; 1,176 sent postcards)

Ecology heard from more than 300 state residents. This is what they had to say:

- Ban all forms of PBDE, now.
- Make sure any alternatives are safe and don't simply create new problems for the environment and health.
- Revise U.S. chemical policy.
- Study possible links between PBDEs and the increase in behavioral/developmental problems in children.
- Businesses should pay for the cost of removing PBDEs from the environment.
- People don't want PBDEs in their households and represent a growing market for PBDE-free products.
- We're lagging behind other countries, such as Sweden, that have done more to remove PBDEs from the environment.
- Banning PBDEs will enhance the marketability of consumer and food products produced in Washington state.
- Since Deca is the most used PBDE, any plan that doesn't include (ban) it won't be effective.
- Washington businesses should join the ranks of other companies already developing PBDE-free products.
- The only responsible position to take on human health is to address potentially harmful chemicals before they harm people, not after the harm is apparent and abundant. Follow the Precautionary Principle.
- All major physicians' groups in the state have passed resolutions urging Ecology to ban all PBDEs.
- **M**anufacturers in Washington state, including Boeing, should take the lead in finding solutions to PBDEs rather than continue to rely on such products.

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State government (1 group)

Ecology heard from one representative of state government:
- Puget Sound Action Team

This is what it had to say:
- Ban all forms of PBDEs.
- Maintain existing flammability standards.
- Strengthen U.S. chemical policy.
- Eliminate PBDEs now, rather than later, because the longer we allow the use of PBDE products, the more it will cost to deal with PBDEs down the road.

Local government (5 groups)

Ecology heard from five entities of local government:
- King County Local Hazardous Waste Management Program
- Northwest Biosolids Management Association
- City of Tacoma Public Works Department
- Thurston County Public Health and Social Services Department
- Tacoma-Pierce County Public Health

This is what they had to say:
- They either called for a ban of PBDEs or were neutral; none voiced opposition to a ban.
- Don't limit biosolids
- More information is needed about existing and potential alternatives to PBDEs.
- The plan should identify what alternatives that are available.
- End of life and disposal issues need to be evaluated.
- Allow the continued use of auto fluff in landfills.
- Manufacturers should be required to pay for the end-of-life costs of disposing of PBDE products.