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Polybrominated diphenyl ethers in articles: a review of its applications and legislation

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Abstract Polybrominated diphenyl ethers (PBDEs), especially commercial decabrominated diphenyl ethers (c-decaBDE), have been widely produced and applied to numerous materials because of their highly effective flame-retardant capabilities. The production of commercial pentaBDE (c-pentaBDE) and commercial octaBDE (c-octaBDE) ended in 2004 because they are persistent, bioaccumulative, and toxic to both humans and the environment, but decaBDE production and use continue. Furthermore, many congeners of PBDEs are still prevalent in consumer products and articles that they pose enormous threat to both the environment and human health. PBDEs have been detected in the casing of electrical and electronic equipment, textile materials, automotive interiors, polyurethane foam (PUF) in seat cushions, children's toys, kitchenware, and other products. With increasing evidence about PBDE pollution and the adoption of international conventions, many developed countries have drawn more public attention to PBDEs and developed sound strategies for their management. This review summaries the utilization and management of PBDEs in a number of countries and reaches the conclusion that PBDEs are still prevalent in consumer articles, while specific regulations or policies for articles containing PBDEs are rare. Public awareness should be raised on the importance of sound management of articles containing PBDEs.

Keywords PBDEs · POPs in articles · e-products · Household products · Transportation · Management

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Introduction

Polybrominated diphenyl ethers (PBDEs) are a group of industrial aromatic organobromine chemicals that have been used since the 1970s as additive flame retardants in a wide range of consumer products and articles (Bergman et al. 2012). PBDEs are commercially produced in three forms: pentaBDE, octaBDE, and decaBDE (Chen et al. 2012b). Because of their outstanding flame-retardant properties, good thermal stability, and low price, the global demand for PBDEs has been growing rapidly in recent years (Ma et al. 2012).

Lately, however, environmental concerns have been raised about the adverse characteristics of PBDEs: persistence, bioaccumulation, and the potential for long-range environmental drift. PBDE congeners, commercial pentaBDE (c-pentaBDE) and commercial octaBDE (c-octaBDE), are classified as persistent organic pollutants (POPs), and their toxicity has been confirmed by many organizations and researchers (Birnbaum and Staskal 2004). Extensive research has been focused on abiotic samples including air (Sjodin et al. 2001); sewage sludge (Sellstrom et al. 2005); sediment (Oros et al. 2005); and biological sample such as chickens (Hakk et al. 2010), fish (Hale et al. 2001), mammals, and even humans (Sjodin et al. 2003). The manufacture, use, and disposal of articles containing PBDEs are the major sources of PBDEs in the environment. Although some research has been conducted on PBDEs emitted from the manufacture and disposal sector, little attention has been paid to the health and environmental influence of commonly used articles containing PBDEs. According to previous literatures, PBDEs lack binding sites on these products, so that they are not chemically bonded to the host material, and thus are classified as additives. Consequently, they can be released during the product life cycle and disposal process, leading to the possibility of extended or pronounced exposure from products used in daily life, such as elastomers, wires and cables, (European Communities 2002), flexible foams for domestic furniture and automotive applications (RPA Ltd. 2000), electronic housings, and components (Vonderheide 2009). It should be noted that degradation of PBDEs can yield by-products of lower brominated congeners, which are regarded as more dangerous because they are more toxic and bioaccumulate more readily. In a recent study, researchers declared that PBDEs were emitted from textile samples even at room temperature (20 °C), indicating that flame retardant-treated upholstery textiles have the potential to be major sources of brominated flame retardants (BFRs) in indoor air and dust (Kajiwara and Takigami 2013). Most current studies have focused on PBDEs in the environment; however, there has been a lack of attention to PBDE in specific items. Hence, it is urgent to find accurate information about PBDEs in household and office products and to investigate whether the plastic casing of electronic equipment, transportation interiors, furniture, textiles, construction sector, and other articles contain PBDEs. There is also a lack of information on PBDE management. This study aims to describe the current status of industrial PBDE production throughout the world, to summarize the uses of PBDEs in various products and articles, and finally to elaborate major regulations and restrictions related to articles containing PBDEs.

Production and use of PBDEs

The production of PBDEs

c-PentaBDE is produced mainly in Israel, Japan, the USA, the European Union, and China (UNEP 2010a). Production ceased in the European Union in 1997. It is assumed that since the late 1990s, pentaBDE has been produced in decreasing quantities, and that production ended in 2004 (UNEP 2010b).

c-OctaBDE has been produced in the Netherlands, France, the USA, Japan, the UK, and Israel. Production stopped in the European Union, the USA, and the Pacific Rim in 2004, and there is no information indicating that it is being produced in developing countries (BSEF 2007).

A compilation of PBDE production data, prepared for the POPs Reviewing Committee of the Stockholm Convention, estimated the total production of all PBDEs from 1970 to 2005 as between 1.3 million and 1.5 million tonnes (UNEP 2010a). The total amounts of c-pentaBDE and c-octaBDE used globally were estimated at around 100,000 tonnes each. The production of commercial decabrominated diphenyl ethers (c-decaBDE), which is not listed as POPs, was estimated at over 1.1 million tonnes until 2005. While the production of POPs c-pentaBDE and c-octaBDE ended in 2004, the production of decaBDE continues. Since 2005, the production of decaBDE has been about 100,000 tons in the world; this figure has remained at approximately the same level for many years.

The application of PBDEs

The major manufacturing sectors that have used PBDEs are as follows (SSC et al. 2012a): the organobromine industry, the electrical and electronics industry, the transportation industry, the furniture industry, the textiles and carpet industry, the construction industry, and the recycling industry.

It is considered that between 90 and 95 % of the use of c-pentaBDE has been for the treatment of polyurethane foam (PUF) since 1999 (UNECE 2007); (Hale et al. 2002); (Vyzinkarova and Brunner 2013). These foams were mainly used in automotive (RPA Ltd. 2000) and upholstery (Sjodin et al. 2003) applications. Minor uses included textiles, printed circuit boards, insulation foam, cable sheets, conveyor belts, lacquers, and possibly oil drilling. The total amount of c-pentaBDE used for these minor uses is estimated to account for 5 % or less of the total usage (UNEP 2010b). Alcock et al. (2003) estimated that 85,000 tonnes of c-pentaBDE overall was used in the USA and the remaining 15,000 tonnes in Europe. There may have been production and use in Asia but reliable data are not available. An approximate distribution of c-pentaBDE use is 36 % in transportation, 60 % in furniture, and 4 % residual in other articles; these figures are considered to be reasonable and are generally consistent with the analytical data from various waste streams (UNEP 2010b). The average content of c-pentaBDE in PUF is reported to be around 3–5 % for upholstery, cushions, mattresses, and carpet padding, which was intended to meet the California TB 117 flammability standard and was influenced by the density of the foam (UNEP 2010a). Another use of c-pentaBDE was in rigid PUF for construction use. The use depends on the fire safety regulations of the country and insulation needs. In Europe where large quantities of polymer insulation materials and foam fillers were/are used, c-pentaBDE in construction was reported as of relevant use (Morf et al. 2002). PUF in the transportation sector might have used lower concentrations—0.5–1 wt%—for applications like seats or arm/head rests (Luedeka 2011).

The main former use of c-octaBDE was in acrylonitrile-butadiene-styrene (ABS) polymers, accounting for about 95 % of c-octaBDE supplied in the European Union. Modified ABS was mainly used for housings/casings of electrical and electronic equipment (EEE), particularly for cathode ray tube

(CRT) casings, and office equipment such as copying machines and business printers. Other minor uses were high-impact polystyrene (HIPS), polybutylene terephthalate (PBT), and polyamide polymers. Although the majority of these polymers were used in electronics, there was also some use in the transportation sector. Other minor uses found in the literature include nylon, low-density polyethylene, polycarbonate, phenolformaldehyde resins, unsaturated polyesters, adhesives, and coatings. Typical concentrations in the major applications were between 12 and 18 wt % (UNEP 2010a, b).

Most of the decaBDE—99 %—is supplied to plastic modification companies for producing flame-retardant plastic. Among these, about 70 % is used in electrical and electronic equipment including computers, televisions, air conditioners, washing machines (Sakai et al. 2006), refrigerators components (Park et al. 2013), equipment casings, high-voltage coil, etc.; about 10 % is applied to fire-resistant wire/cable and their accessories including wire and cable insulation, buchsenleiste, insulated switchgear, etc.; about 10 % is utilized by the transportation sector and related ancillary facilities including plastic and upholstery in cars, trains, ships, airplanes, bus and train stations, airports, wharfs, etc.; and the final 10 % goes to flame-retardant plastic used in mining and construction, including conveyor belts, ventilating ducts, guard fences, sealing tape, etc. Only 1 % of the decaBDE is supplied to textile, rubber, and lacquer companies.

PBDEs are ostensibly added in the manufacturing of circuit boards, casings for home and office electronics, furniture and upholstery, and car interiors. However, although literature was reviewed to determine the inventory of products and articles that contain PBDEs, information about the application of PBDEs in specific products is typically not available or is very limited.

Electrical and electronic equipment

PBDEs are the most common flame retardants applied to electrical and electronic equipment to reduce their flammability.

PBDEs have been added not only into epoxy resins and unsaturated (thermoset) polyesters (UPE) applied to printed circuit boards but also into polyvinylchloride (PVC) used in cable sheets, wires, cables, floor mats, and industrial sheeting (UNEP 2009).

Computer and TV casings (mainly CRTs), cold-resistant separators in refrigerators, casings, and other parts in electrical and electronic appliances are made of ABS, HIPS, or PBT, which may contain PBDEs (ESWI 2011), as shown in Table 1.

The presence of PBDEs in the waste stream of TV sets and PC monitors was confirmed by application of handheld XRF technique during a test series examining over 3000 pieces of TV waste plastics and almost 1600 pieces of PC waste plastics (Aldrian et al. 2015).

Three kinds of waste electrical and electronic equipment (WEEE) plastics and a type of printed circuit boards scraps were collected from a WEEE dismantling plant in Guangzhou, South China, and the results showed that the following articles all contained PBDEs: printed circuit boards, computer casings made of ABS, and TV casing made of HIPS. The PCBs contained PBDEs with contents of 17,285 mg/kg (three kinds of BDE 14,567 and 2718 mg/kg, respectively). The amounts of PBDEs found in computer housings were 3060 mg/kg (1540, 1340, and 180 mg/kg; three kinds of BDE, respectively), and the amount of PBDEs found in TV housings were 1943.3 mg/kg (1471, 467, and 5.3 mg/kg; three kinds of BDE, respectively) (Chen et al. 2012a). Also, in Takigami's study (Takigami et al. 2008), the PBDE concentrations (range from 2.4 to 22,000 μg/g; 4500 μg/g as a mean value) detected were highest in five circuit board, and besides, PBDEs were measured in five TV front cabinet with a mean value of 30,000 μg/g (range from 0.76 to 150,000 μg/g) and in five TV rear cabinet with a mean value of 48,000 μg/g (range from 1.5 to 130,000 μg/g).

Textile

Textile materials are common applications for protection against fire and are based on the synergy between antimony and PBDEs, usually decaBDE.

The Stapleton group's study (Keller et al. 2014) investigated flame-retardant applications in camping tents and demonstrated that decaBDE was the most common flame retardant, detected in four tent fabric samples at concentrations of 3.92, 8.85, 16.8, and 17.8 mg/g, respectively.

PBDEs were also detected in two curtain samples collected by a Japanese group (Kajiwara et al. 2011) at concentrations of 7.4 and 9.1 ng/g. In their previous study, PBDEs were found in 6 of 10 upholstery textiles, and the highest concentration was 120,000 mg/Kg (0.011, 1.0, 2.3, 2.7, 11, 120, 000 mg/Kg, respectively) (Kajiwara et al. 2009).

Chivas' study showed that brominated flame retardant with antimony oxide and a boron-containing additive is one of the most popular flame retardants for cotton fabrics (Chivas et al. 2009).

In addition, PBDEs have also been applied to back coatings and impregnation for carpets, as well as furniture coating in homes and office buildings, and PBDEs are added into polyamide polymers as coating for furniture (UNEP 2009).

Construction material

PBDEs are incorporated into potentially flammable construction materials to slow down and/or inhibit combustion. Polyurethane foam containing PBDEs is also used for sound insulation (UNEP 2009).

Table 1 Application of PBDEs in WEEE

Materials	Applications	Articles
Epoxy resins	Circuit boards, protective coatings	Computers, electronic parts
Polyvinylchloride (PVC)	Cable sheets	Wires, cables
Unsaturated (thermoset) polyesters (UPE)	Circuit boards, coatings	Electrical equipment
Acrylonitrile-butadiene-styrene (ABS)	Polymer casings/parts in electrical and electronic appliances	Computer and TV casings (CRTs); office equipment (other electronic equipment)
High-impact polystyrene (HIPS)	Polymer casings/parts in electrical and electronic appliances	Computer and TV casings (CRTs); office equipment
	Cold-resistant separators	Refrigerators
Polybutylene-terephthalate (PBT)	Polymer casings	Electronic appliances

PBDEs are impregnated into polyamide polymers using as pipes and plastic foil (ESWI 2011).

These compounds can be readily found in building materials in countries that have not strictly banned PBDEs (Tan et al. 2007).

Four wallpaper rolls were purchased in retail stores in Tsukuba City, Ibaraki Prefecture, Japan in 2008, and in all of which were detected of PBDEs at concentrations of 3.1, 14, 6.6, and 7.3 ng/g (Kajiwara et al. 2011).

An investigation of PBDEs in old consumer products in India showed 4798.72 mg/kg of decaBDE in the window blind (Kumari et al. 2014).

DecaBDE was found in the rubber insulating board used for consumer products and building materials at content of 6 % (Kemmlein et al. 2003).

Transportation

Most present-day PBDEs are used in the transportation in conveyor belts; rubber pipes for insulation; and the textile coatings of seating in automotive, aircraft, and trains.

Chen's group studied household products from South China, including car plastic interiors and seat PUF; textile coating; and samples of sofa, mattress, pillow, and carpet padding collected from resident homes of Guangzhou City. PBDEs were detected in four out of the five samples of car plastic interiors, seat PUF, and coatings, and total concentrations were in the range of 42.7–34,609 ng/g with a mean value of 8705 ng/g (Chen et al. 2010).

In a recent study (Shin and Baek 2012), three kinds of automotive interior foam and two kinds of other automotive interior materials were collected, and PBDEs were detected in all. The total PBDE levels were 2436.542, 1857.703, and 654, 959.112 ng/g for the interior foam of the car and 10,413.268 and 13,876.385 ng/g for car interior materials.

Other products and articles

Recently, PBDEs have also been identified in children's toys (Stapleton et al. 2011). The Stapleton group tested a large number of baby products that contain polyurethane foam to investigate the existence of flame-retardant chemicals. In these samples, such as car seats, changing table pads, portable mattresses, and rocking chair and car seat cushions, pentaBDE were detected in the highest concentrations with an average concentration of 32.3 mg/g, range from 16.6 to 51.54 mg/g (approximately 3–4 % by weight).

PBDEs were also found in children's toys purchased from South China (Chen et al. 2009). PBDEs were detected in all of the hard plastic toys with a mean concentration of 263,135 ng/g; PBDEs were also detected in all the foam toys with a mean value of 5761 ng/g. The mean concentration of PBDEs in the rubber/soft plastic toys was 5349 ng/g; PBDEs were found in all of the stuffed toys, where the concentrations of total PBDEs had a mean value of 347 ng/g.

PBDEs were also found in lighting equipment according to results of the Swiss market survey in 2008 (Eva et al. 2008).

Among the 30 samples of black thermo cups and selected kitchen utensils purchased on the European market, in 9 samples, 14 bromine-positive PBDEs were detected. The articles containing PBDEs were thermo cups and egg cutters (Samsonek and Puype 2013).

Regulations and policies

In order to solve the environmental problems and potential risk on human health and safety associated with PBDEs, many countries have legislated environmental protections, yet problems persist.

Implementation deficiencies for the environmentally sound management of PBDEs and PBDE-containing materials in 10 Asian countries were investigated, and the results demonstrated that most of the countries studied lacked environmental policies and regulations or even standards for PBDE pollution management and emission control actions (Li et al. 2014).

In this study, China and several developed countries were investigated as examples.

Legislative actions on PBDEs in China

In order to protect human health and the environment and ensure the safety of hazardous chemicals, in line with the guidelines of "safety first, prevention first," China's government formulated a series of special environmental laws, regulations, standards, technical guidelines, and norms aimed at PBDEs and many other hazardous chemicals. A series of national and local standards on environmental quality were developed, to control the discharge of hazardous chemicals including POPs as well as other environmental pollutants: these are shown in Table 2.

Legislative actions on PBDEs in developed countries

Information about PBDEs has increasingly come to the attention of policymakers and researchers at the international, national, and provincial levels. Regulatory actions are being implemented in various countries around the world, and these actions exert direct impacts on the use of PBDEs, as shown in Table 3.

Discussion

The main routes of human exposure to PBDEs include inhalation of PBDE-contaminated air and ingestion of dust, in particular house dust (Besis and Samara 2012). In published statistic, PBDEs have been documented in indoor air and dust at

Table 2 Major regulations on PBDEs in China

Law/regulation name	Issuing institution	Implementation date	Main content concerning PBDEs
Technical Policy on Pollution Prevention of Discarded Appliances and Electronic Products	Ministry of Industry and Information Technology, Ministry of Science and Technology, State Environmental Protection Administration	27 April 2006	Encourages the establishment of multivariate recycling system for e-waste. Sets forth the "3R" and "polluter pays" principles. Stipulates general rules of eco-design and information disclosure of toxic substances contained in e-products. PBDE-containing plastic should be collected separately and treated properly
Labeling for control of pollution caused by electronic information products SJ/T11364—2006	Ministry of Industry and Information Technology	6 November 2006	Hazardous substances include PBDEs. Information such as name and concentration should be noted on the electronic information products label or in the specifications
Requirements for Concentration Limits for Certain Restricted Substances in Electrical and Electronic Products SJ/T 11363-2006	Ministry of Industry and Information Technology	6 November 2006	Concentrations of PBDEs (decaBDE not included) should be no more than 0.1 %
Measures for the Administration of the Pollution Control of Electronic Information Products	Ministry of Industry and Information Technology	1 March 2007	Restricts the use of hazardous substances in the design and production of electronic information products, corresponding with the RoHS Directive, to reduce or eliminate PBDEs and other toxic and harmful substances in electronic information products. PBDE content in electronic information products is not to be higher than 1000 ppm
Administrative Measure on the Prevention and Control of Environmental Pollution by Waste Electric and Electronic Products	Ministry of Environmental Protection	1 February 2008	Provision on the supervision and management responsibilities by relevant parties on the dismantling, use, and disposal of waste electrical and electronic products. The relevant parties should supply information on the concentration of PBDEs and the adverse effects of improper disposal of these wastes and recommend environmentally sound disposal technique for treat the PBDE-containing wastes
Technical Specifications of Pollution Control for Processing Waste Electrical and Electronic Equipment (HJ527-2010)	Ministry of Environmental Protection	1 April 2010	Applicable to waste electrical and electronic equipment in collection, transportation, storage, and dismantling, to implement pollution control in the process of management. Waste wires, cables, and plastic containing PBDE flame retardants should be separated during collection and disposed of with other e-waste; the e-waste containing PBDE flame retardants should be disposed of as hazardous waste

Table 3 Legislative actions on PBDEs in developed countries

Country/region	Law/regulation name	Implementation date	Main content on PBDEs
European Union	RoHS Directive	1 July 2006	Newly marketed EEE may not contain PBDEs above defined maximum concentration values (MCVs) for homogeneous materials
		1 July 2011	Newly marketed EEE may not contain PBDEs above defined maximum concentration values (MCVs) for homogeneous materials
	WEEE Directive	1 December 2003	Plastics containing brominated flame retardants, preparations, and components have to be removed from any separately collected WEEE at the minimum
	REACH	1 June 2007	REACH will abolish the existing or new substance distinctions and will establish a single legislative system for the marketing of chemical substances within Europe
USA	United States Environmental Protection Agency	2004	Phases out the production of pentaBDE and octaBDE
Canada	Canadian Environmental Protection Act	June 2008	Eliminates the use of pentaBDE and octaBDE commercial mixtures; decaBDE is listed as toxic

ROHS Restriction of the use of certain Hazardous Substances in electrical and electronic equipment, *WEEE* Waste Electrical and Electronic Equipment, *REACH* The European Union Regulation concerning the Registration, Evaluation, Authorization and Restriction of Chemicals

the mean values of 760 pg/m^3 and 1910 ng/g, respectively, in the USA (Johnson-Restrepo and Kannan 2009); 37.8 pg/m^3 (Germany)–330 pg/m^3 (Sweden) and 74 ng/g (Germany)–10,000 ng/g (Britain) in EU countries; 8.2 pg/m^3 (Japan)—628.3 pg/m^3 (China) and 10 ng/g (Thailand)–1941 ng/g (China) in Asian countries (Besis and Samara 2012). Also, the concentration of PBDEs was found to be 28,000–57,000 ng/g in the vehicle dust in the USA (Lagalante et al. 2009).

In addition, food intake may cause a non-negligible PBDE exposure; research has shown BDE-47 in humans consuming large quantities of Baltic Sea fish, which means that fatty fish from contaminated areas are a major source. Besides, tri- to hexaBDE levels in spinach, potato, and carrot have been reported in Japan to be 134, 47.6, and 38.4 ng/g fresh weight, respectively, and 63.4 ng/g in pork, 16.2 ng/g in beef, and 6.25 ng/g in chicken. Dermal uptake of PBDEs seems not to be a major route of exposure (Sjodin et al. 2003).

Moreover, PBDEs were all detectable in the collected human tissue samples, such as placentas at 1.02±0.36 ng/g fat, umbilical cord blood at 5.226 ng/g, breast milk at 2.06±0.94 ng/g fat, blood and serum at 122.37 ng/g lipid, hair at 43.2 ng/g, kidney at 182.3 ng/g, liver at 174.1 ng/g, and lung at 174.2 ng/g; some researches showed significant statistical differences between the human in the exposed areas and control areas, which showed that they had entered the subjects' bodies through the environment and dietary exposure (Song and Li 2014).

Also, some health risk of PBDEs was summarized, cryptorchidism, organohalogen compounds present in the serum of pregnant women would transfer over the placenta to the infants, diabetes, and highest exposure individual scored five less IQ points (Yang et al. 2013).

Although human exposure route was investigated, sources of human exposure to PBDE are still poorly understood; therefore, a study of PBDE source is needed.

In this study, PBDEs were detected in electrical and electronic equipment, textiles, car interiors, children's toys, and even in kitchenware—items that all have large surface areas; PBDEs can be released from these products into the ambient environment and thus contribute to indoor air and dust pollution. Hence, there may be a link between PBDE levels in the indoor air and dust and the number of electronic appliances, PUF-containing furniture, and household products in a given building. Utilization of these products may be an important source of human exposure to PBDEs.

As shown Fig. 1, PBDEs have been detected in electrical and electronic equipment, textiles, automotive interior materials, building materials, and children's toys. In electrical and electronic equipment, there exist significant differences of PBDE concentration, which could be caused by the different manufacturing date; the directive of Restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) came into force on 1 July 2006; thereafter, newly marketed electrical and electronic equipment may contain PBDEs at limited concentration values. Textiles, while not containing the highest levels of PBDEs, are still significant sources. In some countries (e.g., USA, UK), in line with flammability standards, flame retardants are mandatorily added to PUF in domestic household furniture and textiles (SSC et al. 2012b). Although some regions may not apply such addition which would increase production costs, with the gradual establishment of stringent laws and regulations for fire prevention, textiles are believed to be the PBDE source for human exposure if PBDEs are applied as flame retardant. The PBDE concentration varies in toys; a plausible explanation is that some toys were manufactured using recycled plastic materials that contained PBDEs. Children come into close contact with many of these products, especially toys, and they are on the development stage of the endocrine, reproductive, and nervous

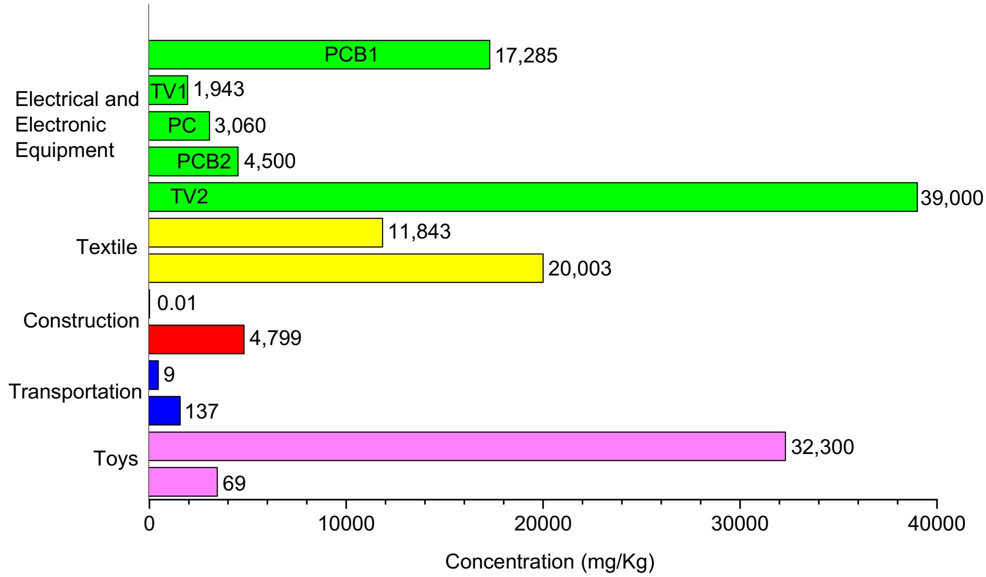

Fig. 1 The mean concentration of PBDEs in different articles

systems; they may be more vulnerable to these chemicals than are adults. Furthermore, to our knowledge, there is no international requirement on the maximum concentration of chemicals in toys. Such exposure should be a major concern.

Legislation associated with PBDEs was surveyed in this study, and it was found that while developed countries have implemented environmentally sound strategies for the management of PBDEs, developing countries conduct less risk assessment on these substances, and neither the public nor policymakers are sufficiently educated on this issue or motivated to take action on it. Moreover, in developing countries, regulatory authority is often decentralized into multiple agencies and departments, resulting in inefficient implementation of whatever regulations do exist (Ni et al. 2013). Furthermore, since decaBDE has not been explicitly banned or restricted in developing countries, it is still a widely used commercial additive for flame retardation,

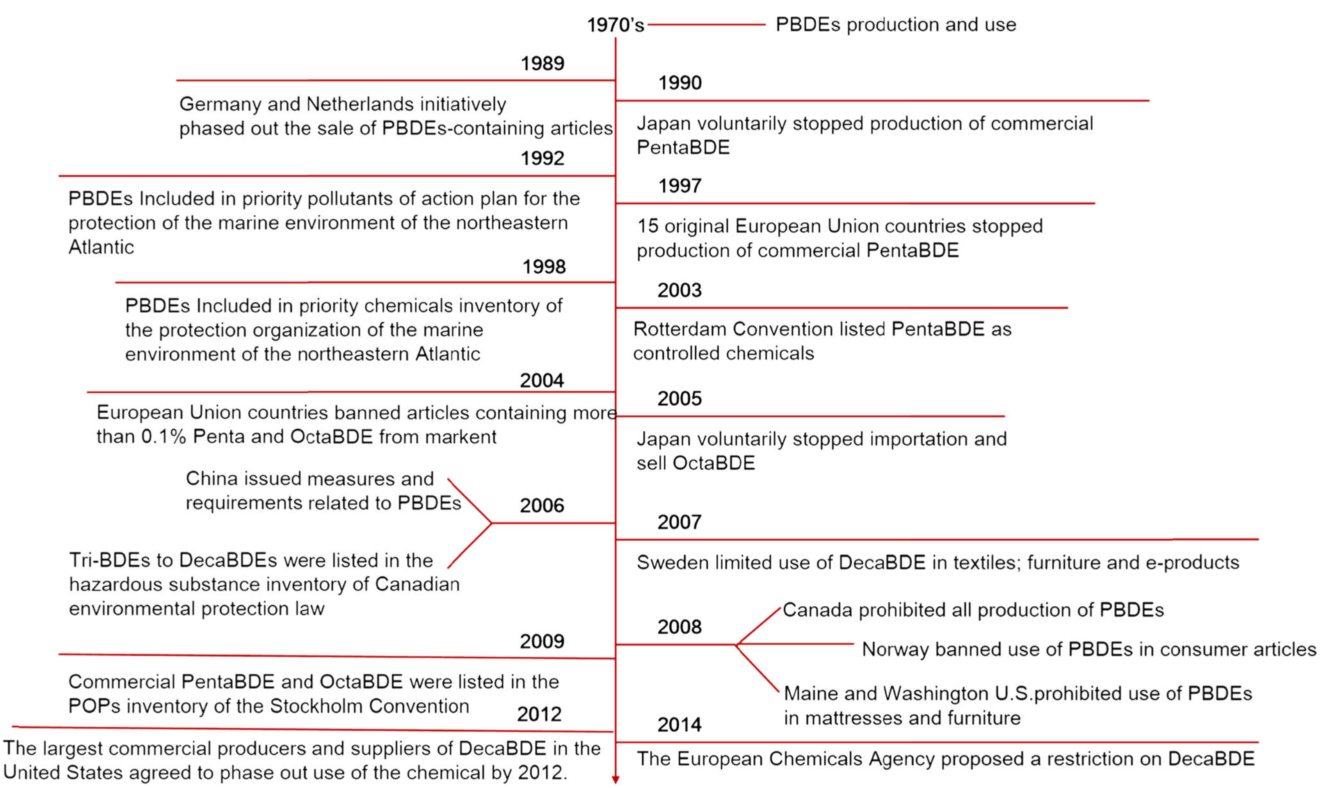

Fig. 2 Global PBDE restriction action in the recent 30 years

and supervision or regulation of decaBDE is either weak or nonexistent—a condition that could pose threats to the environment and human health.

Nevertheless, as shown Fig. 2, in both developed and developing countries, legislative actions on articles containing PBDEs have focused mainly on electronic equipment, rarely regulating other articles; only Sweden and the state of Maine and Washington in the USA have mentioned furniture and textiles. Toys have received hardly any attention; the Voluntary Children's Chemical Evaluation Program only provides consumers with information on the effects of chemicals, to enable them to make wise choices in the home and marketplace (US &EPA 2014). Therefore, effective regulations and voluntary actions are needed immediately, to control PBDE pollution in these articles.

Furthermore, a higher priority than PBDE management is the search for alternatives to PBDEs—substances that would be thermally stable and cost-effective and would not create new environmental hazards.

PBDE management needs to involve all players: the public, manufacturers, and downstream users. Everyone should be encouraged to participate in product stewardship, particularly in the control of emissions during the production, application, service, and end-of-life stages of products. Websites, newsletters, fact sheets and reports, publicity, and education can increase public awareness of the seriousness of PBDE pollution and the effects it has on the environment and human health.

Conclusions

This study reviewed and summarized the application and management of PBDEs in a number of countries. It was found that PBDEs are still ubiquitous in consumer articles, in the electrical and electronic equipment, car plastic interiors, children's toys, textiles, building materials, kitchenware, and other products.

To date, some governments have formulated environmental laws, regulations, and activities associated with PBDE management; however, rarely are legislative actions specifically related to articles and products containing PBDEs. Guidelines or legislation associated with such articles should be developed with all due speed.

Meanwhile, considering that PBDE-containing articles are still widely used in most countries, public awareness and education programs should also be developed, to help consumers make wise choices and limit their exposure to PBDEs.

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