Hexabromocyclododecane (HBCD)
Action Plan

I. Overview

HBCD is a brominated flame retardant found world-wide in the environment and wildlife. Human exposure is evidenced from its presence in breast milk, adipose tissue and blood. It bioaccumulates and biomagnifies in the food chain. It persists and is transported long distances in the environment, and highly toxic to aquatic organisms. It also presents potential human health concerns based on animal test results indicating potential reproductive, developmental and neurological effects. For these reasons, the Environmental Protection Agency (EPA) intends to consider initiating action under the Toxic Substances Control Act to address the manufacturing, processing, distribution in commerce, and use of HBCD.

As part of the Agency's efforts to address HBCD, EPA also intends to evaluate the potential for disproportionate impact on children and other sub-populations.

II. Introduction

As part of EPA's efforts to enhance the existing chemicals program under the Toxic Substances Control Act (TSCA)[1], the Agency has identified certain widely recognized chemicals, including HBCD, for action plan development based on their presence in humans; persistent, bioaccumulative, and toxic (PBT)[2] characteristics; use in consumer products; production volume; or other similar factors. This Action Plan is based on EPA's initial review of readily available use, exposure, and hazard information on HBCD. EPA considered which of the various authorities provided under TSCA and other statutes might be appropriate to address potential concerns with HBCD in developing the Action Plan. The Action Plan is intended to describe the courses of action the Agency plans to pursue in the near term to address its concerns. The Action Plan does not constitute a final Agency determination or other final Agency action. Regulatory proceedings indicated by the Action Plan will include appropriate opportunities for public and stakeholder input, including through notice and comment rulemaking processes.

III. Scope of Review

HBCD is a category of brominated flame retardants, consisting of 16 possible isomers. It has a molecular formula of $C_{12}H_{18}Br_6$ and its structure consists of a ring of 12 carbon atoms to which 18 hydrogen and six bromine atoms are bound. Hexabromocyclododecane may be designated as a non-specific mixture of all isomers (Hexabromocyclododecane; CASRN 25637-99-4) or as a mixture of three main diastereomers (1,2,5,6,9,10-hexabromocyclododecane; CASRN 3194-55-6. Both CASRNs are listed on the TSCA Inventory. Commercial preparations of HBCD may contain some possible impurities, such as tetrabromocyclododecene or other.

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1 15 U.S.C. §2601 *et seq.*

2 Information on PBT chemicals can be found on the EPA website at: http://www.epa.gov/oppt/newchems/pubs/pbtpolcy.htm

isomeric HBCDs (UNEP, 2009). All isomers of HBCD are the subject of this Action Plan, irrespective of the particular CASRN or name used to identify them[3].

IV. Uses and Substitutes Summary

Uses

HBCD, with an 8% share in the brominated flame retardant (BFR) global market in 2001, is the third most commonly used BFR, following tetrabromobisphenol A (TBBPA; approximately 59% of the market), and decabromodiphenyl ether (deca-BDE; 26% market share) (Morose, 2006).

The main use of HBCD is as a flame retardant in expanded polystyrene foam (EPS) and extruded polystyrene foam (XPS) (Weil and Levchik, 2009). EPS and XPS are used primarily for thermal insulation boards in the building and construction industry (Morose, 2006). HBCD is used because it is highly effective at low concentrations; EPS boards contain approximately 0.5% HBCD by weight in the final product (Morose, 2006).

HBCD may also be used as a flame retardant in the backcoating of textiles for upholstered furniture, upholstery seating in transportation vehicles, draperies, wall coverings, mattress ticking, and interior textiles such as roller blinds (Morose, 2006; ECHA, 2009). The maximum concentration of CASRN 3194-55-6 for use in fabrics and textiles and in rubber and plastic products ranges from 1-30% (US EPA, 2006). The majority of HBCD used in textiles is for upholstered furniture, in order to meet the stringent fire safety laws of the United Kingdom and California (Morose, 2006). However, according to the 2006 TSCA Inventory Update Rule (IUR) data (which includes information for chemicals manufactured and imported in amounts of 25,000 pounds or greater at a single site), less than 1% of the total commercial and consumer use of HBCD was used for fabrics, textiles and apparel (US EPA, 2006).

In addition, HBCD is used as a flame retardant in high impact polystyrene (HIPS) for electrical and electronic appliances such as audio-visual equipment, and some wire and cable applications (Morose, 2006 and ECHA, 2009). Less than 10% of all HBCD used in Europe is used in HIPS (ECHA, 2009).

Production

The annual United States (U.S.) import/production volume of CASRN 25637-99-4 was between 10,000 and 500,000 pounds as reported to EPA in 2002; no import/production was reported in 2006 (US EPA, 2006). The annual U.S. import/production volume of CASRN 3194-55-6 was 10-50 million pounds reported in 2002 and 2006 (US EPA, 2006). The U.S. International Trade Commission reported that 380,000 pounds of HBCD (1,3,5,7,9,11-HBCD isomer) were imported in 2008 (US ITC, 2010). In 2006, five facilities reported either the manufacture or importation of at least 25,000 pounds of HBCD: Albemarle (2 facilities), BASF, LG Chem America and Chemtura (US EPA, 2006).

[3] For example, The U.S. International Trade Commission December 2009 Publication 4121 reports importation of the 1,3,5,7,9,11-HBCD isomer which would be subject to this action plan.

Substitutes

According to the European Chemicals Agency (ECHA) there are currently no commercially or technically viable alternatives for HBCD as a flame retardant in polystyrene foam, as all alternative flame retardants it noted impair the structure and properties of the foam, making it unsuitable for use (ECHA, 2009). Some commercially available brominated flame retardants may be used in EPS foam (e.g., tetrabromo-cyclooctane, dibromoethyldibromo-cyclohexane and TBBPA), but a detailed analysis of their effectiveness in this application when compared with HBCD is not available (Morose, 2006). There are commercially available substitutes for XPS and EPS foam board in the construction process that do not use brominated flame retardants. Polyester and polyether polyols, as well as phenolic foam may be used to produce insulation boardstock from rigid foam. Other substitutes include alternative insulation types such as blanket, loose-fill, and reflective insulation (Morose, 2006).

Several chemicals may be used as alternatives for HBCD in textile applications. For textile backing, these include deca-BDE, chloroparaffins and ammonium polyphosphate (ECHA, 2009). There are several alternatives to HBCD for use in high-impact polystyrene (HIPS). Deca-BDE is currently the most widely used flame retardant in HIPS (Weil and Levchik, 2009) and is also used in electronic wire insulation. Deca-BDE and chloroparaffins may not be suitable for use as substitutes for HBCD due to concerns about their persistent, bioaccumulative and toxic properties. Other chemicals that can be used as alternatives to HBCD in HIPS include both halogenated flame retardants used in conjunction with antimony trioxide (ATO) and organic aryl phosphorus compounds (ECHA, 2009).

V. Hazard Identification Summary

Human Health Effects

HBCD is absorbed via the gastro-intestinal tract and accumulates in the adipose tissue (body fat), muscle and liver in experimental animals (Chengelis, 2001). Bioaccumulation was observed to be higher in female than male rats (Chengelis, 2001). The elimination of HBCD from body fat is markedly slower than from other tissues with an elimination half-life of weeks to months (Chengelis, 2001). Repeated exposure of HBCD to rats showed disturbances in thyroid hormone system and effects on the thyroid in males and females (Chengelis, 2001). A study by Eriksson, et al. (2006), concluded that neonatal exposure of HBCD to mice affected spontaneous motor behavior, learning and memory processes in adult mice. However, this study was not conducted according to established OECD[4] test guidelines. In a recently conducted, more robust, two-generation reproductive toxicity study in rats conducted according to established test guidelines, HBCD showed treatment-related reproductive effect (a significant decrease in the number of primordial follicles in the F1 females) (Ema, et al., 2008). Although this decrease in ovarian follicles did not affect any reproductive parameters in this study, this effect is suggestive of potential reproductive toxicity. Developmental effects were observed including delays in eye opening in the second (F2) generation and transient changes in learning

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and memory in F1 males, but exposure did not cause any changes in spontaneous behavior. In addition, there was high and dose-dependent pup mortality during lactation (Ema, et al., 2008).

Environmental Effects

Laboratory studies have shown that HBCD is capable of producing adverse effects in a variety of organisms including algae, fish, invertebrates and soil-dwelling organisms at environmentally relevant concentrations. HBCD is toxic to algae and acutely toxic to fish embryos (Desjardins, et al., 2004; Deng, et al., 2009). A number of sub-lethal effects (e.g., altered thyroid status, protein metabolism, oxidative stress, reproductive activity) have also been observed in fish (Palace, et al., 2008; Kling and Förlin, 2009; Zhang, et al., 2008; Ronisz, et al., 2004). Drottar and Krueger (1998) reported a reduced number and size of daphnid offspring in first and second generations. Thyroid hormone-dependent developmental effects were observed in tadpoles (*Xenopus laevis*) exposed to HBCD (Schriks, et al., 2006). HBCD has been reported to reduce egg production and lower biomass in soil dwelling organisms (*Lumbriculus variegatus*) (Oetken, et al., 2001). HBCD administered to chicken (*Gallus domesticus*) embryonic hepatocytes *in vitro* resulted in significant alterations in expression of genes (mRNA) associated with liver and thyroid function (Crump, et al., 2008). Thinner egg shells were measured in American kestrels exposed to a combination of PBDEs and HBCD (Fernie, et al., 2009).

VI. Physical-Chemical Properties and Fate Characterization Summary

The members of the HBCD flame retardants category are solids with negligible to low vapor pressure and negligible to low water solubility. [Molecular Weight = 642; Melting Point = 190 °C (average); Vapor Pressure 6.3 x 10^{-5} Pa at 21°C; log K_{ow} = 5.6 (technical product); and Water Solubility 66 ppb (μg/L) (EC 2008).

Persistence

Limited data are available on the degradation of HBCD in soil, water or sediment. Laboratory studies have shown that HBCD is degraded by abiotic and biotic processes in soil and aquatic sediment with reported half-lives of 2 days to 2 months (Davis, et al., 2005; 2006). These data are consistent with low persistence according to half-life criteria set forth in the PMN program (64 FR 60194, November 4, 1999) and international Persistent Organic Pollutants (POPs) protocols (UNEP, 2007; Norden, 2008). However, environmental monitoring data shows frequent occurrence of HBCD in biota over large areas and in remote locations where no demonstrable sources have been shown to account for the exposures (see discussion of environmental exposures in Section VII below), supporting the finding that HBCD is sufficiently persistent in the environment to be of concern within the scope of these international protocols. Measured levels of HBCD in dated sediment core samples also provide evidence of persistence (UNEP, 2007). The frequent detection of HBCD over a large geographic area, with increasing exposure in remote locations such as the Arctic, where no demonstrable local sources exist that can account for these exposures, suggest that HBCD is persistent and undergoes long-range atmospheric transport (UNEP, 2007).

Bioaccumulation

HBCD is highly bioaccumulative. Veith, et al. (1979) reported a measured bioconcentration factor (BCF) of 18,100 for HBCD in fathead minnows, and this value was later confirmed by a kinetic study with rainbow trout (Drottar, et al., 2001), for which the mean BCF was 19,200. A monitoring study by deBoer, et al. (2002) included a wide variety of biota (invertebrates, fish, birds and marine mammals) and showed that HBCD bioaccumulates easily and biomagnifies in food chains. In a Swedish monitoring study (Sellstrom, et al. 1998), a fish-to-sediment ratio of 15 to 1 (expressed as a biota/sediment accumulation factor or BSAF of 15) was reported for one of two sites, indicating that HBCD is bioavailable and bioaccumulative. Isomer-specific biomagnification has been demonstrated based on monitoring of a Lake Ontario food web (Tomy, et al. 2004). Monitoring in Sweden found much higher levels of HBCD in eggs from wild peregrine falcons than from captive populations feeding on chickens (Lindberg, et al., 2004) or guillemot from the Baltic Sea (Sellstrom, et al., 2003), demonstrating that HBCD may also bioaccumulate in terrestrial organisms and food chains.

VII. Exposure Characterization Summary

Releases

HBCD is not reported in the Toxics Release Inventory. No readily available quantitative release information in the U.S. was found. ECHA reported a total of about 3,100 kg/year of HBCD released to the environment in Europe in 2008, of which 50% were to wastewater, 29% to surface water and 21% to air (ECHA, 2009). The overall volume used in 2007 was estimated at 11.6 million kg/year (ECHA, 2009). A Swedish article indicates the primary source of release of HBCD in Europe is from textile applications (KEMI, 2006). Based on IUR data, the volume of HBCD used for textile application in the U.S. is estimated to be < 1 % of the total volume of HBCD produced/imported and hence releases from this use in the U.S. are expected to be relatively small (as a percentage of overall volume produced/imported).

Information from the United Kingdom indicates that the primary sources of HBCD in the environment are from fugitive emissions during its manufacture and use in subsequent products, potentially from leaching in landfills, and from incinerator emissions (UKEA, 2009). As an additive flame retardant, HBCD is not chemically bound to the matrix of the material it protects, and thus has the potential to enter the environment from the finished products in use or after disposal (US EPA, 2008b). ECHA states: "A substantial proportion of articles containing HBCD will have very long service life (30+ years for typical insulation like EPS and XPS) and environmental releases will continue for a long time into the future." (ECHA, 2009). It is not known how comparable the releases of HBCD from manufacturing and use operations in the U.S. are to those reported in Europe.

Human Exposure

HBCD is typically manufactured as a powder of approximately 100 microns in size; however, a portion of the materials is micronized to 1 micron during manufacture (U.S. Patent 4980382), which poses the potential of deep lung particulate exposure (Rozman, et al., 2001)).

Workers who do not wear appropriate respiratory protection have the high potential for deep lung exposure of the 1 micron material. Particles 1 micron and smaller are able to penetrate to the alveolar sacs of the lungs. They may be absorbed into blood or cleared through the lymphatics. The overall removal of particles from the alveoli is relatively inefficient; on the first day only about 20 percent of particles are cleared, and the portion remaining longer than 24 hours is cleared very slowly. Some particles may remain in the alveoli indefinitely (Rozman, et al., 2001). Commercial workers also may have potential dermal and inhalation exposure to the chemical during application (EC, 2008). The Occupational Safety and Health Administration (OSHA) has not established a Permissible Exposure Limit for HBCD. An occupational exposure study at an industrial plant in Europe producing EPS, reported measured elevated airborne dust levels and measured HBCD in the blood of workers (Thomsen, et al., 2007). No readily available HBCD occupational exposure information (including biomonitoring data) was found for U.S. workers. Based on available IUR reporting, the maximum total number of industrial workers likely to be exposed to this chemical during manufacturing and industrial processing and use is between 100 and 999 (US EPA, 2006); however, this is likely an underestimate since it does not include the commercial workers and some IUR submitters did not have to report numbers of workers because they manufacture below the threshold required for reporting or the information was reported to be not readily obtainable.

HBCD has been detected in human adipose tissue, milk, and blood (Covaci, et al, 2006; Johnson-Restrepo, et al, 2008; Arnot, et al., 2009). General population exposure to HBCD is likely from its presence in food (Hiebl and Vetter, 2007; Fernandes, et al., 2008; van Leeuwen and de Boer, 2008), outdoor air, particularly near point sources (Covaci, et al., 2006), and indoor air (Law, et al., 2008). HBCD has also been detected in indoor dust (Covaci, et al., 2006; Law, et al., 2008; Roosens, et al., 2009).

The IUR information suggests either that HBCD will not be used in children's consumer products or that this type of information is not readily available. However, to the extent it is present in household applications (e.g., building foam, furniture upholstery, carpeting), children could be exposed, especially given children's increased exposure via dust and the hand-to-mouth ingestion pathway. *In vitro* experiments conducted to demonstrate leaching of HBCD from textiles showed that the presence of simulated biological fluids (sweat, saliva) and fruit juices enhances the leaching of HBCD from back-coated samples (Ghanem, 2009). Children's exposure to HBCD from mouthing of textiles and from ingestion of dust has been estimated (EC, 2008).

Environmental Exposure

HBCD has been measured in air and sediment in Scandinavian countries, North America and Asia (Covaci, et al., 2006, Arnot, et al., 2009). HBCD has been measured in marine and arctic mammals, freshwater and marine fish, aquatic invertebrates, birds and bird eggs, and one plant species (Covaci, et al., 2006; Arnot, et al., 2009). HBCD has been detected in Arctic air in northern Scandinavia and in Arctic birds and bird eggs, Arctic fish, ringed seals and polar bears (UNEP, 2009). It has been detected in freshwater, marine, and avian organisms, and in upper trophic-level mammals (polar bears and seals). The majority of these studies are European, some

are from North America, and a few are from Asia. A study reported decreased levels of HBCD in biota once a United Kingdom manufacturing plant was closed (Law, et al., 2008b).

VIII. Risk Management Considerations

HBCD is of international concern because of its PBT properties. HBCD was added to ECHA's list of Substances of Very High Concern (SVHCs) on October 28, 2008 (ECHA, 2008). HBCD is under consideration for listing under the POPs Protocol to the Convention on Long-Range Transboundary Air Pollution, as technical review has concluded that HBCD is persistent, bioaccumulative, can cause adverse effects to humans or the environment, and has the potential to be transported long distances within the meaning of the Protocol (UNECE, 2010). Under the Stockholm Convention for Persistent Organic Pollutants, the POPs Review Committee decided in October 2009 that Annex D screening criteria have been met for HBCD; further determinations have not been made (UNEP, 2010).

HBCD is persistent, bioaccumulative and toxic, especially to aquatic organisms. HBCD biomagnifies in food chains. Given its presence in the environment including wildlife, and the high hazard for HBCD to algae and aquatic invertebrates, EPA has a concern for the potential risk to these aquatic organisms.

EPA has presented evidence which strongly suggests there is potential for exposure to the general population from HBCD in the environment, as well as exposure to HBCD from products and dust in the home and workplace. HBCD shows toxicity in repeated-dose (28- and 90-day feeding studies) tests. There may be some human health hazard concern based on thyroid effects and indications of developmental and transient neurobehavioral effects. These health effects combined with potential exposures suggests some concern for a potential risk to the general population from HBCD is warranted. Greater concern is warranted for workers who manufacture the chemical and produce products that contain it, given available expose information.

Availability of substitutes for HBCD uses is an unresolved issue, especially for EPS and XPS building foam board applications, where other, more suitable flame retardants may not be readily available.

HBCD is currently on the Integrated Risk Information System (IRIS) program agenda. The anticipated date for a completed assessment has not yet been determined. (US EPA, 2010). HBCD is under consideration for inclusion in the NHANES human bio-monitoring program, which could provide data on exposure in the U.S.

Potential Impacts on Children

HBCD is found in household dust, and it is used in the U.S. in certain consumer products, both of which could represent exposure pathways to children. HBCD has been measured in blood serum and breast milk, so that a developing fetus or nursing infant could be exposed to it. The reproductive, developmental and neurotoxic health hazards that could result from exposures to HBCD are an important consideration in protecting children's health. These factors suggest

that concerns for potential risks to children and pregnant women should be considered with any actions taken to manage this chemical.

IX. Next Steps

In conducting this review of HBCD, EPA considered a number of potential risk management actions, including regulatory actions under TSCA sections 4 and 5 and under the Emergency Planning and Community Right-to-Know Act (EPCRA) 313, as well as voluntary actions through such programs as Design for the Environment (DfE).

Based on its screening-level review of hazard and exposure information, EPA intends to initiate actions to protect humans and the environment from exposure to HBCD due to manufacture (including import) use, or disposal of commercial HBCD. In addition, as part of the Agency's efforts to address these chemical substances, EPA also intends to evaluate the potential for disproportionate impact of exposure to HBCD on children and other sub-populations.

On the basis of existing information, the Agency believes that the following actions would be warranted:

- Consider initiating rulemaking under TSCA Section 5(b)(4) of TSCA to add HBCD to the list of chemicals which present or may present an unreasonable risk of injury to health or the environment. EPA intends to publish a notice of proposed rulemaking by the end of 2011.

- Initiating rulemaking under TSCA section 5(a)(2) to designate manufacture or processing of HBCD for use in consumer textiles as a flame retardant as a significant new use which would require manufacturers and processors to notify EPA before manufacturing or processing HBCD for the significant new use. This Significant New Use Rule (SNUR) also would be proposed to apply to imports of consumer textiles articles containing HBCD. EPA has evidence to suggest that the use of HBCD in textiles may be limited to specialty commercial applications, and that general consumer textile use may be so limited it would be appropriate for SNUR regulation. If information shows this assumption to be incorrect, EPA will consider initiating rulemaking under TSCA section 6(a) to address general consumer textile use.

- Consider initiating rulemaking under TSCA section 6(a) to regulate HBCD. A section 6(a) action could take the form of a comprehensive ban on the manufacturing, processing, distribution in commerce and use of a chemical substance, or a more targeted regulation to address specific activities. The extent of the rule for HBCD would be determined during the rulemaking process.

- Initiating rulemaking in late 2011 to add HBCD to the Toxics Release Inventory. HBCD is currently not listed by any CASRN on the Emergency Planning and Community Right-to-Know (EPCRA) section 313 list of toxic substances. Listing will require manufacturers or importers to provide environmental release information not currently captured by IUR.

- Conduct a Design for the Environment and Green Chemistry alternatives assessment of HBCD. The information developed could be used to encourage industry to move away from HBCD instead of, in addition to, or as part of any regulatory action taken under TSCA. The alternatives assessment would build upon existing knowledge and would consider various exposed populations, including sensitive human subpopulations, as well as environmental exposure. The work will begin in 2011, with completion expected in 2013.

X. References

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