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Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

Conference of the Parties to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
Ninth meeting
Geneva, 29 April–10 May 2019
Item 5 (b) of the provisional agenda**

Matters related to the implementation of the Convention: listing of chemicals in Annex III to the Convention

Inclusion of hexabromocyclododecane in Annex III to the Rotterdam Convention

Addendum

Draft decision guidance document

Note by the Secretariat

As is mentioned in document UNEP/FAO/RC/COP.9/7, at its fourteenth meeting, in its decision CRC-14/2, the Chemical Review Committee adopted a draft decision guidance document on hexabromocyclododecane. The draft decision guidance document is set out in the annex to the present note for the consideration of the Conference of the Parties. It has not been formally edited.

* Reissued for technical reasons on 22 March 2019.
** UNEP/FAO/RC/COP.9/1.

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Annex

Rotterdam Convention

Operation of the prior informed consent procedure for banned or severely restricted chemicals

Draft Decision Guidance Document

Hexabromocyclododecane

Secretariat of the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

Food and Agriculture Organization of the United Nations

UNEP

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Introduction

The objective of the Rotterdam Convention is to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm and to contribute to their environmentally sound use, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties. The Secretariat of the Convention is provided jointly by the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization of the United Nations (FAO).

Candidate chemicals[2] for inclusion in the prior informed consent (PIC) procedure under the Rotterdam Convention include those that have been banned or severely restricted by national regulatory actions in two or more Parties[3] in two different regions. Inclusion of a chemical in the PIC procedure is based on regulatory actions taken by Parties that have addressed the risks associated with the chemical by banning or severely restricting it. Other ways might be available to control or reduce such risks. Inclusion does not, however, imply that all Parties to the Convention have banned or severely restricted the chemical. For each chemical included in Annex III of the Rotterdam Convention and subject to the PIC procedure, Parties are requested to make an informed decision whether they consent or not to the future import of the chemical.

At its [...] meeting, held in [...] on [...], the Conference of the Parties agreed to list hexabromocyclododecane in Annex III of the Convention and adopted the decision-guidance document with the effect that this chemical became subject to the PIC procedure.

The present decision-guidance document was communicated to designated national authorities on [...], in accordance with Articles 7 and 10 of the Rotterdam Convention.

Purpose of the decision guidance document

For each chemical included in Annex III of the Rotterdam Convention, a decision-guidance document has been approved by the Conference of the Parties. Decision-guidance documents are sent to all Parties with a request that they make a decision regarding future import of the chemical.

Decision-guidance documents are prepared by the Chemical Review Committee. The Committee is a group of government-designated experts established in line with Article 18 of the Convention, which evaluates candidate chemicals for possible inclusion in Annex III of the Convention. Decision-guidance documents reflect the information provided by two or more Parties in support of their national regulatory actions to ban or severely restrict the chemical. They are not intended as the only source of information on a chemical nor are they updated or revised following their adoption by the Conference of the Parties.

There may be additional Parties that have taken regulatory actions to ban or severely restrict the chemical and others that have not banned or severely restricted it. Risk evaluations or information on alternative risk mitigation measures submitted by such Parties may be found on the Rotterdam Convention website (www.pic.int).

Under Article 14 of the Convention, Parties can exchange scientific, technical, economic and legal information concerning the chemicals under the scope of the Convention including toxicological, ecotoxicological and safety information. This information may be provided directly to other Parties or through the Secretariat. Information provided to the Secretariat will be posted on the Rotterdam Convention website.

Information on the chemical may also be available from other sources.

Disclaimer

The use of trade names in the present document is primarily intended to facilitate the correct identification of the chemical. It is not intended to imply any approval or disapproval of any particular company. As it is not possible to include all trade names presently in use, only a number of commonly used and published trade names have been included in the document.

While the information provided is believed to be accurate according to data available at the time of preparation of the present decision-guidance document, FAO and UNEP disclaim any responsibility for omissions or any

[2] According to the Convention, the term "chemical" means a substance, whether by itself or in a mixture or preparation and whether manufactured or obtained from nature, but does not include any living organism. It consists of the following categories: pesticide (including severely hazardous pesticide formulations) and industrial.

[3] According to the Convention, the term "Party" means a State or regional economic integration organization that has consented to be bound by the Convention and for which the Convention is in force.

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consequences that may arise there from. Neither FAO nor UNEP shall be liable for any injury, loss, damage or prejudice of any kind that may be suffered as a result of importing or prohibiting the import of this chemical.

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of FAO or UNEP concerning the legal status of any country, territory, city or area or of its authorities or concerning the delimitation of its frontiers or boundaries.

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Standard core set of abbreviations[4]

STANDARD CORE SET OF ABBREVIATIONS	
<	less than
≤	less than or equal to
>	greater than
≥	greater than or equal to
µg	Microgram
µm	micrometre
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
bw	body weight
BMDL	Benchmark Dose lower confidence bound
BMR	Benchmark Response
°C	degree Celsius (centigrade)
CAS	Chemical Abstracts Service
cm	centimetre
DNA	deoxyribose nucleic acid
DT_{50}	dissipation time 50%
DfE	Design for the Environment (US EPA program)
dw	dry weight
EC	European Community
EC_{50}	median effective concentration
ECHA	European Chemicals Agency
EEC	European Economic Community
EPS	Expanded polystyrene
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
g	gram
h	hour
IARC	International Agency for Research on Cancer

[4] *This core list should serve as the basis for DGDs for industrial chemicals, pesticides and severely hazardous pesticide formulations. It should be augmented by abbreviations used in the individual DGDs relevant to the chemical(s) in question.*

Definitions and spelling should, as far as practicable, follow the IUPAC glossary of terms in toxicology and the IUPAC glossary of terms relating to pesticides in their current editions.

As a general rule, it is preferable that acronyms used only once in the text be spelled out rather than included in the list of abbreviations.

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STANDARD CORE SET OF ABBREVIATIONS

IPCS	International Programme on Chemical Safety
IUPAC	International Union of Pure and Applied Chemistry
k	kilo- (x 1000)
kg	kilogram
L	litre
LC_{50}	median lethal concentration
LD_{50}	median lethal dose
LOAEL	lowest-observed-adverse-effect level
lw	liquid weight
m	metre
mg	milligram
ml	millilitre
MW	Molecular Weight
NES	no effects at saturation
ng	nanogram
NOAEL	no-observed-adverse-effect level
NOEC	no-observed-effect concentration
NOHSC	National Occupational Health and Safety Commission
OECD	Organisation for Economic Co-operation and Development
POPRC	Persistent Organic Pollutants Review Committee of the Stockholm Convention
PPE	personal protective equipment
ppm	parts per million (used only with reference to the concentration of a pesticide in an experimental diet. In all other contexts, the terms mg/kg or mg/L are used).
TH	Thyroid hormone
TSH	Thyroid-stimulating hormone
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
w/w	weight for weight
WHO	World Health Organization
wt	weight
wwt	Wet weight
XPS	Extruded polystyrene

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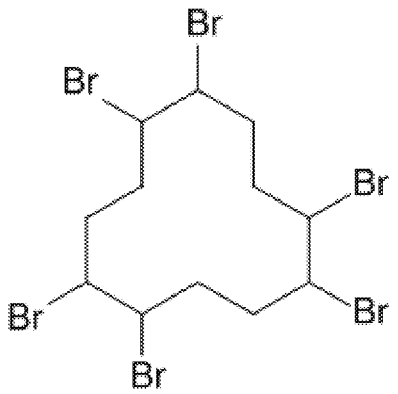
Decision guidance document for a banned or severely restricted chemical

HEXABROMOCYCLODODECANE **Published:**

1. Identification and uses (see Annex 1 for further details)

Common name	Hexabromocyclododecane
Chemical name and other names or synonyms	Hexabromocyclododecane 1,2,5,6,9,10-hexabromocyclododecane
Molecular formula	$C_{12}H_{18}Br_6$
Chemical structure	
CAS-No.(s)	25637-99-4: Hexabromocyclododecane Commercial substance (does not specify the bromine positions) 3194-55-6: 1,2,5,6,9,10- Hexabromocyclododecane 134237-50-6: α- Hexabromocyclododecane stereoisomer 134237-51-7: β- Hexabromocyclododecane stereoisomer 134237-52-8: γ- Hexabromocyclododecane stereoisomer
Harmonized System Customs Code	2903.89
Other numbers	EC Number 247-148-4, EC Number 221-695-9
Category	Industrial
Regulated category	Industrial chemical
Use(s) in regulated category	**Japan:** Flame retardant **Norway:** Hexabromocyclododecane has been used to produce flame retarded expanded polystyrene (EPS) and extruded polystyrene (XPS) for onward use in building applications abroad.
Trade names	Cyclododecane, hexabromo; HBCD; Bromkal 73-6CD; Nikkafainon CG 1; Pyroguard F 800; Pyroguard SR 103; Pyroguard SR 103A; Pyrovatex 3887; Great Lakes CD-75P™; Great Lakes CD-75; Great Lakes CD75XF; Great Lakes CD75PC (compacted); Dead Sea Bromine Group Ground FR 1206 I-LM; Dead Sea Bromine Group Standard FR 1206 I-LM; Dead Sea Bromine Group Compacted FR 1206 I-CM. (UNEP/FAO/RC/CRC.13/8 section 1.3 of the Norwegian notification – also POPRC Risk Profile section 1.1) *This is an indicative list. It is not intended to be exhaustive.*
Formulation types	Not relevant.

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Uses in other categories	**Japan and Norway:** No reported use as a pesticide.
Basic manufacturers	BASF Corp. Albemarle Corp. Dow Chemical Co. Source: TOXNET (https://toxnet.nlm.nih.gov/cgi-bin/sis/search2/f?./temp/~jrwyMs:1) *This is an indicative list of current and former manufacturers. It is not intended to be exhaustive.*

2. Reasons for inclusion in the PIC procedure

Hexabromocyclododecane is included in the PIC procedure as an industrial chemical. It is listed on the basis of final regulatory actions notified by Japan and Norway that ban and severely restrict, respectively, its use as an industrial chemical.

No final regulatory actions relating to pesticidal uses of hexabromocyclododecane have been notified.

2.1 Final regulatory action (see Annex 2 for further details)

Japan:

This chemical is designated as Class I Specified Chemical Substances. It is prohibited to manufacture, import or use this chemical substance. (UNEP/FAO/RC/CRC.13/8 Sections 2 and 2.2.1 of the Japanese notification).

Reason: Human health

Norway:

Regulations to restrict production, import, export and sale of consumer products that contain hexabromocyclododecane exceeding certain limit values.

Hexabromocyclododecane is regulated by Chapter 4 of the Regulation related to restrictions on the manufacture, import and placing on the market of chemicals and other products hazardous to human health and the environment (Product Regulation) act no. 922 of June 2004. This is the Norwegian implementation of Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants and the implementation of the amendment to its Annex I, Commission Regulation (EU) 2016/293 of 1 March 2016. (UNEP/FAO/RC/CRC.13/8 sections 2, 2.2.1 and 2.2.2 of the Norwegian notification).

Reason: Human health and the environment

2.2 Risk evaluation (see Annex 1 for further details)

Japan:

The notification from Japan indicates that the regulatory action was based on a risk or hazard evaluation, which is provided with a focussed summary in English, and also includes the Risk Profile document for hexabromocyclododecane as prepared by the Persistent Organic Pollutants Review Committee (POPRC) of the Stockholm Convention.

When a substance is listed in the Stockholm Convention, and when it is on the market in Japan, the Japanese Government conducts a risk evaluation on the substance and its potential risks to inform the regulatory measures. This internal risk evaluation, in combination with the Risk Profile document for hexabromocyclododecane were supplied as supporting information by Japan in document UNEP/FAO/RC/CRC.13/INF/17/Rev.2. A brief English summary of that risk evaluation was provided along with the table of contents of the risk evaluation.

The internal risk evaluation was based on the monitoring data from fiscal year 2009 to fiscal year 2012 and revealed a number of sites with a high ecological risk, while there were no sites with any human health risk. The risk evaluation included a hazard assessment, an exposure assessment and risk estimation based on monitoring data, and an exposure assessment and risk estimation based on environmental releases estimated from manufacture data.

The POPRC Risk Profile document cites a Japanese study which found hexabromocyclododecane levels in human milk appearing to mirror the market consumption of hexabromocyclododecane. In mothers' milk from Japanese women (age 25–29) hexabromocyclododecane levels were below the detection limit in all samples collected during the 10-year period from 1973-1983, but then increased from 1988 onwards.

The POPRC Risk Profile document states the developmental and neurotoxic potential of hexabromocyclododecane observed in animal studies give cause for concern when considering risks to human health, particularly for unborn babies and young children. This concern, along with the human milk monitoring study and results of other studies in the Risk Profile document on cord serum, suggests some risk to unborn babies and young children in Japan.

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Despite the absence of a quantitative link between the risks and the exposure levels provided, the risk is relevant given the observed bioaccumulation and biomagnification of hexabromocyclododecane.

Norway:

The notification from Norway indicates that the regulatory action was based on a risk or hazard evaluation and that it was relevant to both human health and the environment. The notification specifically cites the European Union risk assessment for hexabromocyclododecane. The notification from Norway provides a summary of evidence of exposure to consumers in Norway, its detection in the environment (including remote areas of the arctic), biota, fish, moss, yolk sac of newly hatched chicks. Some temporal trends are noted.

Hazard endpoints are provided in the supporting information from Norway, originating from the United States Environmental Protection Agency 2014 report, *Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)*. High or very high hazards are noted for developmental effects, acute aquatic toxicity, and chronic aquatic toxicity. Hexabromocyclododecane is highly persistent and bioaccumulates.

3. Protective measures that have been applied concerning the chemical

3.1 Regulatory measures to reduce exposure

Japan: The regulatory action notified by Japan bans the manufacture, import and use of hexabromocyclododecane. There are no uses exempted from the ban. The regulatory action entered into force 1 May 2014. (UNEP/FAO/RC/CRC.13/8 sections 2.2 and 2.3 of the Japanese notification)

Norway: The regulatory action notified by Norway severely restricts production, import, export and sale of consumer products that contain hexabromocyclododecane exceeding certain limit values.

It is prohibited to manufacture, import, export, place on the market and use substances that contain 0.01 per cent by weight or more of hexabromocyclododecane (CAS number 25637-99-4, 3194-55-6, 134237-50-6, 134237-51-7, 134237-52-8).

It is prohibited to manufacture, import, export and make available on the market products or flame retarded parts of products that contain 0.01 per cent by weight or more of hexabromocyclododecane (CAS number 25637-99-4, 3194-55-6, 134237-50-6, 134237-51 -7, 134237-52-8).

The use of hexabromocyclododecane, whether on its own or in preparations, in the production of expanded polystyrene articles, and the production and placing on the market of hexabromocyclododecane for such use, shall be allowed provided that such use has been authorised in accordance with Title VII of Regulation (EC) No 1907/2006 of the European Parliament and of the Council, or is the subject of an application for authorisation submitted by 21 February 2014 where a decision on that application has yet to be taken.

The placing on the market and use of hexabromocyclododecane, whether on its own or in preparations, in accordance with this paragraph shall only be allowed until 26 November 2019 or, if earlier, the date of expiry of the review period specified in an authorisation decision or the date of withdrawal of that authorisation pursuant to Title VII of Regulation (EC) No 1907/2006.

(UNEP/FAO/RC/CRC.13/8 sections 2.2 and 2.3 of the Norwegian notification)

3.2 Other measures to reduce exposure

OSPAR Convention

Hexabromocyclododecane is included as part of the brominated flame retardants group in the List of Substances for Priority Action of The Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention). The OSPAR Convention is made up of representatives of the Governments of 15 Contracting Parties and the European Union.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 1.4 of the POPRC Risk Profile)

Stockholm Convention on Persistent Organic Pollutants

Hexabromocyclododecane is included in Annex A (elimination) of the Stockholm Convention on Persistent Organic Pollutants (decision SC-6/13). Specific exemptions exist for production and use of hexabromocyclododecane in expanded polystyrene and extruded polystyrene in buildings. Parties to the Stockholm Convention who register for the production and/or use exemption also agree, pursuant to Article 4, to take necessary measures to ensure that expanded polystyrene and extruded polystyrene containing

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hexabromocyclododecane can be easily identified by labelling or other means throughout its life cycle when allowing the production and use of hexabromocyclododecane for expanded polystyrene and extruded polystyrene in buildings.

(Decision SC-6/13: Listing of hexabromocyclododecane. http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-COP.6-SC-6-13.English.pdf)

3.3 Alternatives

It is essential that before a country considers substituting alternatives, it ensures that the use is relevant to its national needs, and the anticipated local conditions of use. The hazards of the substitute materials and the controls needed for safe use should also be evaluated.

Japan:

No information on alternatives to hexabromocyclododecane was provided by Japan (UNEP/FAO/RC/CRC.13/8 section 2.5.3.2 of the Japanese notification).

Norway:

A reference was provided to the document by the US EPA: Flame Retardant Alternatives for Hexabromocyclododecane. Final report June 2014. (UNEP/FAO/RC/CRC.13/8 section 2.5.3.2 of the Norwegian notification). The report provides information on hexabromocyclododecane used as a flame retardant in polystyrene building insulation, possible substitutes, and alternative materials. The report was developed by the U.S. Environmental Protection Agency with input from a partnership of stakeholders from business, government, academia, and environmental organizations. According to technical experts on the Partnership, between 2011 and 2014 there were only three viable flame retardant alternatives to HBCD for use in expanded and extruded polystyrene foam (EPS and XPS) insulation under current manufacturing processes. Alternative materials are also available as substitutes to HBCD-containing insulation. These alternatives may require additive flame retardants or other treatment to meet fire safety requirements. The Results section of that supporting document is reproduced below:

Results

Members of the Partnership identified many chemicals as potential alternatives; however, only three chemicals were identified as viable alternatives to hexabromocyclododecane in EPS and XPS foam: a butadiene styrene brominated copolymer (CASRN 1195978-93-8), a tetrabromobisphenol-A (TBBPA)-bis brominated ether derivative (CASRN 97416-84-7), and TBBPA-bis(2,3-dibromopropyl) ether (CASRN 21850-44-2). Only three alternatives were identified for evaluation in this report because flame retardants for EPS and XPS foam must allow the material to comply with fire safety codes while not compromising the performance of the foam. All three alternatives are brominated. No non-brominated flame retardants are known to be compatible in polystyrene manufacturing and associated flame tests. Figure ES-1 summarizes the hazard information for hexabromocyclododecane and the three alternatives assessed. (Figure ES-1 indicates whether endpoints were assigned based on empirical data or using values from predictive models and/or professional judgment. The caveats listed in Figure ES-1 must also be taken into account when interpreting the information in the table.) Few measured experimental data were available for the

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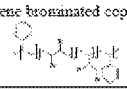
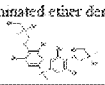
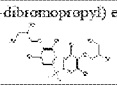
TBBPA-bis brominated ether derivative; therefore, estimated hazard designations were determined using TBBPA-bis(2,3-dibromopropyl ether) (CASRN 21850-44-2) as an analog.

ES-1 Hazard Summary for HBCD and Alternatives

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics (*VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.
This table contains hazard information for each chemical; evaluation of risk considers both hazard and exposure. Variations in end-of-life processes or degradation and combustion by-products are discussed in the report but not addressed directly in the hazard profiles. The caveats listed below must be taken into account when interpreting the information in the table.

d This hazard designation would be assigned MODERATE for a potential for lung overloading if >5% of the particles are in the respirable range as a result of dust forming operations.
§ Based on analogy to experimental data for a structurally similar compound.
¥ Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

Chemical For full chemical name and relevant trade names see the hazard profiles in Section 4.8	CASRN	Human Health Effects											Aquatic Toxicity		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization[1]	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Hexabromocyclododecane (HBCD)	25637-99-4; 3194-55-6	L	*M*	L	M	H	*M*	M	L		VL	VL	VH	VH	H	VH
Butadiene styrene brominated copolymer[¥] 	1195978-93-8	L	*L*	L	L	L	*L*	L[d]	L		M	L	*L*	*L*	*VH*	*L*
TBBPA-bis brominated ether derivative[¥] 	97416-84-7	*L*[§]	*M*[§]	*M*[§]	*M*[§]	*M*[§]	*L*	*M*[§]	*L*[§]		*L*	*L*	*L*	*L*	*H*	*H*
TBBPA bis(2,3-dibromopropyl) ether[¥] 	21850-44-2	L	*M*	M	*M*	*M*	*L*	*M*	L		L	L	L	*L*	VH	*H*

[1] At this time, there are no standard test methods for respiratory sensitization and no test data; as a result there was no designation for this endpoint.

The human health endpoints evaluated in Design for Environment (DfE) alternatives assessments include acute toxicity, carcinogenicity, genotoxicity, reproductive toxicity, developmental toxicity, neurotoxicity, repeated dose toxicity, skin sensitization, respiratory sensitization, eye irritation, and dermal irritation. Hexabromocyclododecane has been assigned a "High" hazard designation for developmental neurotoxicity, a "Moderate" hazard designation for reproductive toxicity and repeated dose toxicity, and an estimated "Moderate" hazard designation for carcinogenicity and neurotoxicity; other health endpoints have "Low" or "Very Low" hazard designations. The butadiene styrene brominated copolymer has "Low" hazard designations (either measured or estimated) for most human health endpoints due to its high MW and limited potential for absorption; there is one "Moderate" hazard designation for the eye irritation endpoint based on experimental data. The TBBPA-bis brominated ether derivative and TBBPA-bis(2,3-dibromopropyl) ether have a "Moderate" hazard designation for carcinogenicity, mutagenicity, reproductive toxicity, developmental toxicity, and repeated dose toxicity based on potential alkylating properties. "Low" hazard designations have been assigned to these similar substances for acute toxicity, neurotoxicity, skin sensitization and irritation.

The ecotoxicity endpoints evaluated in DfE alternatives assessments include acute and chronic aquatic toxicities. Hexabromocyclododecane is toxic for the aquatic environment and has "Very High" hazard designations for both acute and chronic aquatic toxicity. Aquatic toxicity for the three alternatives is "Low", driven by their lack of appreciable water solubility leading to "no effects at saturation". Ecotoxicity data for terrestrial species was limited, and thus the potential for impacts on high trophic level and terrestrial wildlife from hexabromocyclododecane and its alternatives or associated degradation products is unclear.

The environmental fate of hexabromocyclododecane and the three alternatives is described primarily in terms of persistence and bioaccumulation potential. All three chemicals have "High" or "Very High" persistence designations, a quality typical for the majority of flame retardants. Long-term fate of the three alternatives in the environment is not well understood. The butadiene styrene brominated copolymer is estimated to have "Low" bioaccumulation potential due to its size (average MW >1,000 daltons) and lack of low MW components, while hexabromocyclododecane, the TBBPA-bis brominated derivative, and TBBPA-bis(2,3-dibromopropyl) ether have "Very High", "High", and "High" potential for bioaccumulation.

Under conditions where fire or incineration occurs, a halogenated substance may contribute to halogenated dibenzodioxin and dibenzofuran formation, increase the generation of polyaromatic hydrocarbons, and impact fire parameters such as smoke and carbon monoxide (Sidhu, Morgan et al. 2013). However, combustion reactions are complex and variable and make inclusion of combustion by-products in hazard assessment challenging. Both

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halogenated and non-halogenated flame retardants may yield other toxic by-products that would need to be compared, not only halogenated dioxins and furans. For these reasons, the pyrolysis transformation products are not assessed in this report.

In addition to the chemical hazard assessment of hexabromocyclododecane and its alternatives, Chapter 5 of the report includes general information about alternative insulation materials. These technologies include rigid board alternatives (e.g., similar to EPS and XPS), alternatives for certain functional uses (e.g., blanket insulation, foamed-in-place insulation), and specialty and emerging alternative materials (e.g., aerogel, carbon foam). The report does not assess these materials, does not compare them to EPS or XPS, and does not assess flame retardancy needs for each of these materials.

(UNEP/FAO/RC/CRC.13/INF/18)

General:

The POPs Review Committee of the Stockholm Convention has undertaken an evaluation of alternatives to hexabromocyclododecane during the Annex F (Risk Management Evaluation) phase of its review of hexabromocyclododecane as a candidate POP. The information can be found in the document titled "*Additional information on alternatives to hexabromocyclododecane and use in expanded polystyrene (EPS) and extruded polystyrene (XPS)*" (UNEP/POPS/POPRC.8/16/Add.3) available online at: http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC.8-16-Add.3.English.pdf

3.4 Socio-economic effects

Japan:

No information on socio-economic effects of the regulatory action was provided by Japan (UNEP/FAO/RC/CRC.13/8 section 2.5.3.1 of the Japanese notification).

Norway:

Hexabromocyclododecane has traditionally not been used in expanded polystyrene or extruded polystyrene for constructions/buildings in Norway. Since these are the main uses of hexabromocyclododecane, low socio-economic effects are expected from of the final regulatory action.

(UNEP/FAO/RC/CRC.13/8 section 2.5.3.1 of the Norwegian notification)

4. Hazards and Risks to human health and the environment

4.1 Hazard Classification

WHO / IPCS	Not available.
IARC	Not available.
European Union	EU classification pursuant to Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures: Repr. 2, H361 (Suspected of damaging fertility or the unborn child) Lact., H362 (May cause harm to breast-fed children) (UNEP/FAO/RC/CRC.13/8 section 3.1 of the Norwegian notification)
US EPA	Not available.

4.2 Exposure limits

Studies establishing a tolerable daily intake for humans are not available.

There are several studies on reproductive effects of hexabromocyclododecane. Saegusa et al. (2009) performed a one-generation developmental toxicity study in rats, with maternal dietary exposure to 0, 100, 1,000 or 10,000 ppm hexabromocyclododecane from gestation day 10 until weaning of the offspring. The LOAEL of this study is 1,000 ppm (81-213 mg/kg/day), and the NOAEL 100 ppm (8-21 mg/kg/day). The long continuous exposure study of van der Ven et al. (2009) suggest that male reproductive organs are particularly sensitive to hexabromocyclododecane exposure, i.e. a decreased testicular weight was observed at a BMDL of 52 µg/g bw in F1 males. A weight reduction in other male organs; prostate, the adrenals, heart and brain as well as in F1 males' total weight was also observed. The observed body weight loss makes it impossible to say whether any of these effects on organs' weights are specific or secondary to the general body weight loss. In females the cytochrome P450 19 enzyme activity, based on group

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averages, showed a correlation to the internal concentration of γ- hexabromocyclododecane (linear correlation coefficient of 0.90). The cytochrome P450 19 enzyme converts androgens to estrogens (Norris 2006), and is essential for differentiation and development of gonads and brains of higher vertebrates, maintenance of reproductive tissues, and sexual behavior (Conley and Hinshelwood, 2001, Simpson et al. 2002). In females the time to vaginal opening was also delayed, but only at the top dose (BMDL 82.2 µg/g bw at a benchmark response (BMR) of 10%).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.4 of the POPRC Risk Profile)

4.3 Packaging and labelling

The United Nations Committee of Experts on the Transportation of Dangerous Goods classifies the chemical in:	
Hazard Class and Packing Group:	UN number: 3077 Proper shipping name and description: Hexabromocyclododecane, ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S. Chemical name: Hexabromocyclododecane Class: 9 Classification code: M7 Packaging group: III Labels: 9 Remarks: Hazard identification No: 90 (ECHA Guidance on Safe Use – Hexabromocyclododecane)
International Maritime Dangerous Goods (IMDG) Code	UN number: 3077 Proper shipping name and description: Hexabromocyclododecane, ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S. Chemical name: Hexabromocyclododecane Class: 9 Packaging group: III EmS number 1: F-A EmS number 2: S-F Labels: 9 Marine pollutant: yes (PP) (ECHA Guidance on Safe Use – Hexabromocyclododecane)
Transport Emergency Card	Not available.

4.4 First aid

NOTE: The following advice is based on information available from the World Health Organisation and the notifying countries and was correct at the time of publication. This advice is provided for information only and is not intended to supersede any national first aid protocols.

General: If you feel unwell seek medical advice (show this information or the container label where possible). Do not give anything by mouth to unconscious person.

Inhalation: Remove to fresh air, Seek medical attention immediately.

Skin: Remove any contaminated clothing, completely launder clothing to ensure that no contamination remains before reusing clothing. Wash skin thoroughly with soap and water for at least 15 minutes. If skin irritation occurs seek medical attention immediately.

Eye: Hold eyelids apart and flush eyes with plenty of water for at least 15 minutes. Seek medical attention.

Ingestion: If the subject is conscious rinse the mouth with water and make the subject drink 1 to 2 glasses of water, seek medical attention immediately.

(ECHA Guidance on Safe Use – Hexabromocyclododecane)

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	Prevention	First Aid
Inhalation	Use ventilation. Use local exhaust.	Fresh air, rest.
Skin	Protective gloves. Protective clothing.	Rinse skin with plenty of water or shower.
Eyes	Wear safety spectacles.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then refer for medical attention.
Ingestion	Do not eat, drink, or smoke during work. Wash hands before eating.	Rinse mouth.

IPCS (2001): International Chemical Safety Card (ICSC) 1413

4.5 Waste management

Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with hexabromocyclododecane:

- Best practice for the End-of-Life management of Polystyrene Foams in Building & Construction (European Chemical Industry Council (CEFIC) and PlasticsEurope, 2014;
- End-of-life treatment of HBCD-containing polystyrene insulation foams: Large-scale demonstration of the treatment of Expanded Polystyrene Foam (EPS) and Extruded Polystyrene Foam (XPS) containing Hexabromocyclododecane (HBCD) as a flame- retardant by co-incineration in the Würzburg Municipal Solid Waste Incinerator. Technical Summary report (PlasticsEurope, 2015)
- HBCD Hexabromocyclododecane in Polystyrene Foams Product Safety Assessment - 2016 Edition

Source: Basel Convention POPs Waste, Additional Resources

DISPOSAL: Dispose of as hazardous waste in compliance with local, regional and national regulations. Dispose of wastes in an approved waste disposal facility.

Source: Source: ECHA Guidance on Safe Use – Hexabromocyclododecane

Annexes

Annex 1 **Further information on the substance**

Annex 2 **Details on final regulatory action reported**

Annex 3 **Address of designated national authorities**

Annex 4 **References**

Annex 1 Further information on the substance

Introductory text to Annex I

The information presented in the present annex reflects the conclusions of the two notifying Parties, namely Japan and Norway. Where possible, information provided by these two Parties on hazards has been presented together, while the risk assessments, which are specific to the conditions prevailing in the Parties, are presented separately. This information is taken from the documents referenced in the notifications in support of the final regulatory actions relating to hexabromocyclododecane.

The notifications from Japan and Norway were first reported in PIC Circular XLIV of 12/12/2016.

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Annex 1 – Further information on *notified chemical*

1.	Identity and Physico-Chemical properties	
1.1	**Identity**	Hexabromocyclododecane and 1,2,5,6,9,10 –hexabromocyclododecane (UNEP/FAO/RC/CRC.13/INF/17/Rev.2, POPRC Risk Profile)
1.2	**Formula**	$C_{12}H_{18}Br_6$ (UNEP/FAO/RC/CRC.13/INF/17/Rev.2, POPRC Risk Profile)
1.3	**Colour and Texture**	White odourless solid (UNEP/FAO/RC/CRC.13/INF/17/Rev.2, POPRC Risk Profile)
1.4	**Decomposition temperature**	Decomposes at >190 °C (UNEP/FAO/RC/CRC.13/INF/17/Rev.2, POPRC Risk Profile)
1.6	**Density (g/cm^3)**	2.38 Albemarle Corporation (1994) 2.24 Great Lakes Chemical Corporation (1994) (UNEP/FAO/RC/CRC.13/INF/17/Rev.2, POPRC Risk Profile)
1.7	**Resistance to acids**	Not available.
1.8	**Resistance to alkalis**	Not available.
1.9	**Tensile strength (10^3 kg/cm^2)**	Not available.

2	Toxicological properties	
2.1	**General**	
2.1.1	**Mode of Action**	Recent studies with fish models suggest that hexabromocyclododecane may induce oxidative stress and apoptosis. (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.1 of the POPRC Risk Profile).
2.1.2	**Symptoms of poisoning**	Not available.
2.1.3	**Absorption, distribution, excretion and metabolism in mammals**	<u>Absorption:</u> The extent of oral absorption of hexabromocyclododecane in humans is largely unknown (ECHA 2008a). Estimations suggest that the uptake of hexabromocyclododecane via this exposure route ranges from 50-100% (ECHA 2008a, European Union 2008). According to calculations made in the EU risk assessment (European Union 2008) intake of hexabromocyclododecane via breast milk is 1.5 ng/kg bw/day for 0-3 month olds and 5.6 ng/kg bw/day in 3-12 month old babies. However, with the levels found in mothers' milk from some locations in northern Spain (A Coruña), Eljarrat et al. 2008 calculated the intake to be 175 ng/kg bw/day for 1 month olds. This is 12 times higher than the estimated daily intake (EDI) for 0-3 month old infants as determined in the EU risk assessment (European Union 2008) and 25-1,458 times higher than the EDI for adults in Sweden, Netherlands, United Kingdom and Norway (KEMI, 2009; Eljarrat et al. 2009, Roosens et al. 2010). A Flemish dietary study suggests that the age group between 3 and 6 years seems to be the highest exposed with an EDI for the sum of hexabromocyclododecane isomers of 7 ng/kg bw/day. Newborns and adults are less exposed with EDI's of 3 and 1 ng/kg bw/day, respectively (Roosens et al. 2010). In all instances, however, children appear to be more exposed than adults. (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the POPRC Risk Profile) <u>Distribution:</u> Hexabromocyclododecane can be absorbed from the gastro-intestinal tract, and the highest concentrations are subsequently reached in adipose tissue and muscles followed by liver, and with much lower activities present in lung, kidney, blood, brain, and gonads. (UNEP/FAO/RC/CRC.13/8 section 3.2.2 of the Norwegian notification)

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In rodents, hexabromocyclododecane is readily absorbed through the gastrointestinal tract with highest concentrations in adipose tissue and muscle, followed by the liver; it has been found in much lower concentrations in the lungs, kidneys, blood and brain. (ECHA, 2008; reported in a secondary source with limited study details.)

(UNEP/FAO/RC/CRC.13/INF/18 US EPA: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)).

Bioaccumulation and metabolism:

Several studies in laboratory, in local food webs and local ecosystems confirm the potential for hexabromocyclododecane to bioaccumulate and biomagnify. The field studies show a general increase of concentrations in biota with increasing trophic level in aquatic and Arctic food webs. No field studies in the terrestrial environment have been identified, but two laboratory studies show that hexabromocyclododecane has a potential to bioaccumulate in terrestrial mammals.

Two studies in the laboratory have examined the bioaccumulation of hexabromocyclododecane in mammals (WIL 2001; Velsicol Chemicals 1980). In a 90-day repeated dose (technical hexabromocyclododecane, 1,000 mg/kg bw/day) toxicity study with rats, WIL (2001) found that concentrations of the α-isomer were much greater than that of the β- and γ-isomers at all sampling time points. The relative percentage of the isomers measured in the rats (α-: 65-70%; β-: 9-15% and γ-: 14-20%) was markedly different to the proportions in the hexabromocyclododecane formulation used (α-: 8.9%; β-: 6.6% and γ-: 84.5%). Velsicol Chemicals (1980) studied the pharmacokinetics of radiolabelled hexabromocyclododecane (14C-hexabromocyclododecane, purity > 98%) administered to rats as a single oral dose. The authors found that the test substance was distributed throughout the body with the greatest amounts measured in fat tissue, followed by liver, kidney, lung and gonads. Rapid metabolism to polar compounds occurred in the blood, muscle, liver and kidneys, but hexabromocyclododecane remained mostly unchanged in the fatty tissue. The study concluded that hexabromocyclododecane accumulated in fatty tissues following repeated exposure.

Findings have been made in the Norwegian Arctic. Sørmo et al. (2006) analyzed representative species from different trophic levels of the polar bear food chain, using samples collected from 2002 to 2003 at Svalbard in the Norwegian Arctic. hexabromocyclododecane was below detection limits (minimum 0.012 ng/g lw) in the amphipod, *Gammarus wilkitzkii*. Hexabromocyclododecane biomagnified strongly from polar cod (*Boreogadus saida*) to ringed seal (BMF of 36.4, based on whole body wet weight concentrations), but did not biomagnify from ringed seal to polar bear (BMF of 0.6). Lower levels in the polar bear samples were considered to indicate possible enhanced metabolic capability in the bears. In East Greenland the comparative bioaccumulation, biotransformation and/or biomagnification from East Greenland ringed seal (*Pusa hispida*) blubber to polar bear (*Ursus maritimus*) tissues (adipose, liver and brain) of hexabromocyclododecane and legacy POPs was investigated by Letcher et al. (2009). α-hexabromocyclododecane was found to only bioaccumulate in the polar bear adipose tissue. The ringed seal blubber to polar bear adipose BMF for total-(α)- hexabromocyclododecane >1. The authors concluded that even if the metabolism of hexabromocyclododecane in polar bears was enhanced compared to other species, the high exposure of hexabromocyclododecane ensures biomagnification.

Morris et al. (2004) reported on biomagnification of hexabromocyclododecane in the North Sea food web. Although individual BMFs were not reported, the authors suggested that because concentrations of hexabromocyclododecane were higher in species in the top of the food chain it implied that hexabromocyclododecane was biomagnifying. For example, hexabromocyclododecane concentrations in top predators such as harbour seals (*Phoca vitulina*) and harbour porpoise (*Phocoena phocoena*) were several orders of magnitude greater than those measured in the

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aquatic macroinvertebrates such as sea-star and common whelk. Similarly, hexabromocyclododecane concentrations were high in liver samples from cormorant, a predator bird-species and in eggs of the common tern, while lower levels of hexabromocyclododecane were detected in their prey, cod and yellow eel (*Anguilla Anguilla*).

Tomy et al. (2008) investigated isomer-specific accumulation of hexabromocyclododecane at several trophic levels of an eastern Canadian Arctic marine food web. There was a significant positive relationship of α-hexabromocyclododecane with trophic level, with a TMF of 7.4 ($p<0.01$), indicative of biomagnification throughout the food web, while a significant negative relationship was observed between concentrations of γ-hexabromocyclododecane and trophic level (i.e. trophic dilution). α-hexabromocyclododecane contributed greater than 70% of the total hexabromocyclododecane burden in shrimp (*Pandalus borealis*, *Hymenodora glacialis*), redfish (*Sebastes mentella*), arctic cod (*Boreogadus saida*), narwhal (*Monodon monoceros*) and beluga (*Delphinapterus leucas*), while γ-hexabromocyclododecane was greater than 60% of total hexabromocyclododecane in zooplankton (mix), clams (*Mya truncata*, *Serripes groenlandica*), and walrus (*Odobenus rosmarus*). The observed differences in diastereoisomer predominance were attributed in part to differing environmental fate and behaviour of the isomers, with the least water soluble γ-isomer more likely to diffuse passively from the water column into zooplankton, which have proportionately high lipid content. Similarly, as benthic filter feeders, clams may be more likely to absorb a higher proportion of the γ-isomer from sediment. The presence of higher proportions of α-hexabromocyclododecane, such as with the beluga and narwhal, may indicate enhanced metabolic capability based on evidence of stereoisomer-specific biotransformation of the γ-isomer to the α-form (Zegers et al. 2005, Law et al. 2006d). This also corresponds with the findings of Tomy et al. (2009) where the α-isomer accounted for >95% of the overall burden of hexabromocyclododecanes in the beluga, while the Arctic cod, the primary prey species of beluga in the western Canadian arctic marine food web, had a hexabromocyclododecane-profile dominated by the γ-isomer (>77%). The authors concluded that this was further evidence that beluga can bioprocess the γ- to the α-isomer.

In vivo studies with rats suggest that hexabromocyclododecane is also debrominated to PBCDe and TBCDe. In total, five different species of hydroxylated hexabromocyclododecane metabolites have been found by LCQ and GC-MS; monohydroxy- and dihydroxy-hexabromocyclododecane, monohydroxy- and dihydroxy-PBCDe and monohydroxy-TBCDe (Brandsma et al. 2009).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.2.2 of the POPRC Risk Profile)

Excretion:

Hexabromocyclododecane is excreted mainly through faeces with minor elimination in urine, and three polar metabolites as well as unextractable radioactivity have been detected. Elimination from body fat appears to be markedly slower than from other tissues, with an elimination half-life of the three diastereomers possibly being in the order of weeks to months.

(UNEP/FAO/RC/CRC.13/8 section 3.2.2 of the Norwegian notification)

Rats (2 males, 8 females) administered a single oral dose of 1.93 mg radiolabeled hexabromocyclododecane eliminated 86% of the dose within 72 hours (70% in feces and 16% in urine). (EPA, 2005; NICNAS, 2012; reported in a secondary source. Authors state that caution is urged in interpreting the data due to the small sample size and the brief nature of the final report.)

Four male Wistar rats orally administered 500 mg/kg-day hexabromocyclododecane in olive oil for 5 days Average daily rate of excretion in the feces was 29-37% of the dose; the cumulative excretion was constant at 32-35%; urinary excretion was

not observed; metabolites were not detected in the urine or feces; hexabromocyclododecane was detected only in adipose tissue (0.3-0.7 mg/g fat). (EPA, 2005; NICNAS, 2012, reported in a secondary source.)

(UNEP/FAO/RC/CRC.13/INF/18 US EPA: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)).

2.2 Toxicology studies

2.2.1 Acute toxicity

Oral:

Rat LD_{50} > 10,000 mg/kg (EPA, 2005; NICNAS, 2012; reported in a secondary source with limited study details.)

Rat LD_{50} > 6,400 mg/kg (EINECS, 2008; reported in a secondary source. Non-guideline study. Dose and particle size not reported; 7-day observation period.)

Dermal:

Rabbit LD_{50} > 8,000 mg/kg (EPA, 2005; NICNAS, 2012; reported in a secondary source with limited study details)

Rabbit LD_{50} > 20,000 mg/kg (EINECS, 2008; NICNAS, 2012; non-guideline study. Too few animals were used; clinical signs not reported.)

Inhalation:

Rat LC_{50} > 200 mg/L (EPA, 2005; NICNAS, 2012; reported in a secondary source with limited study details.)

(UNEP/FAO/RC/CRC.13/INF/18 US EPA: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)).

2.2.2 Short term toxicity

Not available for mammals/vertebrates.

2.2.3 Genotoxicity (including mutagenicity)

Gene mutation *in vitro*:

Negative in *Salmonella typhimurium* (strains not specified) in the presence and absence of metabolic activation. (EPA, 2005; NICNAS, 2012; reported in a secondary source with limited study details.)

Chromosomal aberrations *in vitro*:

Negative, mammalian chromosomal aberration test with human peripheral blood lymphocytes in the presence and absence of metabolic activation

- Doses: 10, 19, 38, 75, 150, 300 and 600 µg/mL.

(EPA, 2005; NICNAS, 2012; Guideline study. Performed according to current EPA, OECD guidelines, and GLP.)

Other *in vitro*:

Positive, intragenic recombination test in Sp5/V79 and SPD8 hamster cells; cell lines developed by study authors.

- Doses: 2-20 µg/mL.

(EPA, 2005; NICNAS, 2012; reported in a secondary source. Non-guideline study. Not a standard test used by regulatory agencies to assess genotoxicity. Reliability and predictive ability is unknown.)

Negative, mouse micronucleus test.

- Doses: 0, 500, 1,000 or 2,000 mg/kg in dimethyl sulfoxide.

(EPA, 2005; reported in a secondary source. Guideline study. Performed according to current EPA, OECD guidelines and GLP.)

(UNEP/FAO/RC/CRC.13/INF/18 US EPA: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)).

2.2.4 Long term toxicity and carcinogenicity

The EU risk assessment of hexabromocyclododecane completed in 2008 provides the most comprehensive assessment of toxic effects and risks of hexabromocyclododecane exposure to human health and welfare (European Union

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2008). This assessment concludes that hexabromocyclododecane may cause reproductive toxicity and long term toxicity, whereas there is no concern for acute toxicity, irritation, sensitization, mutagenicity and carcinogenicity.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.5 of the POPRC Risk Profile).

Repeated dose studies with oral exposure in rats and mice resulted in increased liver weight and effects on the pituitary weight and thyroid hormone parameters. A LOAEL of 22.5 mg/kg was proposed for repeated dose.

(UNEP/FAO/RC/CRC.13/8 section 3.2.2 of the Norwegian notification).

2.2.5 Effects on reproduction

There are several studies on reproductive effects of hexabromocyclododecane. Saegusa et al. (2009) performed a one-generation developmental toxicity study in rats, with maternal dietary exposure to 0, 100, 1,000 or 10,000 ppm hexabromocyclododecane from gestation day 10 until weaning of the offspring. In this study thyroid effects were observed both in dams (thyroid weight increase and follicular cell hypertrophy at 10,000 ppm) and offspring (thyroid weight increase, decreased serum T3 and increased serum TSH at 1,000 and 10,000 ppm). The thyroid effects together with the impaired oligodendroglial development in the brain cortex (statistically significant at the high dose (-24%) supported by a dose-dependent trend in the mid (-12%) and low (-8%) dose groups) and the decreased female body weight (9% in the high dose group) could indicate developmental hypothyroidism. The LOAEL of this study is 1,000 ppm (81-213 mg/kg/day), and the NOAEL 100 ppm (8-21 mg/kg/day). The long continuous exposure study of van der Ven et al. (2009) suggest that male reproductive organs are particularly sensitive to hexabromocyclododecane exposure i.e. a decreased testicular weight was observed at a BMDL of 52 μg/g bw in F1 males. A weight reduction in other male organs; prostate, the adrenals, heart and brain as well as in F1 males' total weight was also observed. The observed body weight loss makes it impossible to say whether any of these effects on organs' weights are specific or secondary to the general body weight loss. In females the cytochrome P450 19 enzyme activity, based on group averages, showed a correlation to the internal concentration of γ-hexabromocyclododecane (linear correlation coefficient of 0.90). The cytochrome P450 19 enzyme converts androgens to estrogens (Norris 2006), and is essential for differentiation and development of gonads and brains of higher vertebrates, maintenance of reproductive tissues, and sexual behavior (Conley and Hinshelwood, 2001, Simpson et al. 2002). In females the time to vaginal opening was also delayed, but only at the top dose (BMDL 82.2 μg/g bw at a benchmark response (BMR) of 10%).

Like the studies of van der Ven et al. (2009) and Saegusa et al. 2009, Ema et al. (2008) document reproductive and developmental effects (decreased pup viability, fewer primordial follicles), and also changes in organ weights (e.g. liver and thyroid), and thyroid hormone levels. Several effects were trans-generational and affected both F0 parents and F1 and F2 parents and offspring. From the point of view of reproductive toxicology, the general decrease in viability in F2 pups on post-natal days 4 and 21 at 1,500 and 15,000 ppm and the decrease in primordial follicles at 1,500 and 15,000 ppm hexabromocyclododecane exposure in F1 females were the most severe effects. A reduced number of primordial follicles suggests that reproductive potential of the female may be reduced, and is generally regarded as sensitive biomarkers for adverse reproductive effects (Parker et al. 2006). It should be noted however that the highest dose used by Ema et al. (2008) may be considered to be very high. However, dosing was in this study done by mixing hexabromocyclododecane particles into an appropriate amount of powdered basal diet for each dietary concentration. The absorption kinetics of hexabromocyclododecane likely depends on both the particle size and amount of particles administered, and is expected to be lower than for dissolved hexabromocyclododecane. The actual tissue doses from this study are therefore presumably lower than the original dose would suggest, as may also be assumed from the findings of similar studies such as that of WIL 2001 who only observed reversible effects at doses up to 1,000 mg/kg bw/day in their 90-day oral exposure study.

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(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.4 of the POPRC Risk Profile)

A NOAEL of 10 mg/kg/day has been deduced in a two-generation reproductive toxicity study in rats. The NOAEL is based on dose-dependent decrease in fertility index and a reduced number of primordial follicles. Other effects observed were effect on liver and thyroid weight and TSH hormone level, and increased mortality during lactation.

Neonatal hexabromocyclododecane exposure may cause developmental neurotoxic effects as illustrated by statistically significant changes in spontaneous behaviour, learning and memory defects. Male mice exposed orally with a single dose at day 10 postnatal (brain growth spurt in mice), were tested for behaviour effects at 3 months age. Clear effects were seen on all parameters tested at 13.5 mg/kg, and on some at 0.9 mg/kg, giving an indicative LOAEL of 0.9 mg/kg/day from this study (Eriksson et al., 2006, as described in the EU Risk assessment for HBCD 2008). Hexabromocyclododecane inhibited the high affinity uptake of neurotransmitters (dopamine and glutamate) into synaptosomes at similar concentration levels as previously shown for polychlorinated biphenyls (PCBs) (Mariussen and Fonnum, 2003, as described in the EU Risk assessment for HBCD 2008).

(UNEP/FAO/RC/CRC.13/8 section 3.2.2 of the Norwegian notification).

2.2.6 Neurotoxicity/ delayed neurotoxicity, Special studies where available

Thyroid hormones are required for normal development of the nervous system, as are retinoids (Forrest et al. 2002, Maden 2007), and disturbances in these systems may therefore result in long term neurotoxic effects in off-spring. For hexabromocyclododecane, a neurotoxic potential has previously been indicated both *in vivo* and *in vitro* with rodent models (Reistad et al. 2006, Mariussen and Fonnum, 2003, Dingemans et al. 2009, Eriksson et al. 2006, Lilienthal et al. 2009). In the *in vivo* study of Eriksson et al. (2006) neonatal direct exposure of pups to a single oral dose of hexabromocyclododecane (0.9 mg/kg or 13.5 mg/kg bw on postnatal day 10), induced alterations in spontaneous behavior with initial hypo-reactivity, followed by impaired habituation in adult mice. This study also reported effects on spatial learning and memory as assessed in a Morris water maze test with exposed mice. In contrast, in their two-generation study with rats where exposure of pups occurred indirectly via human breast milk, Ema et al. (2008), only observed transient changes in the performance of F1 males in a water-filled T-maze test at an exposure level of 1,500 ppm and higher and no effects on other parameters (locomotor activity). According to Ema et al. (2008), the discrepancy in their results from the results obtained in previous studies could be explained by differences in exposure regime and/or by differences in species sensitivity. Results from *in vitro* studies suggest that hexabromocyclododecane may be cytotoxic to nerve cells and possibly also interfere with neuronal signalling events such as Ca^{2+} and neurotransmitter uptake (Reistad et al. 2006, Mariussen and Fonnum 2003, Dingemans et al. 2009).

The *in vivo* neurotoxic potential of hexabromocyclododecane has also been studied by Lilienthal et al. 2009. In a one generation reproduction feeding study, they showed that hexabromocyclododecane-induced loss in hearing function was paralleled by changes in dopamine dependent behaviour (Lilienthal et al. 2009). Loss of hearing function was attributed to a cochlear effect of hexabromocyclododecane that resulted in increased thresholds and moderate prolongations of latencies in the lower frequency range from 0.5 to 2 kHz and after clicks. Both observed effects were dose-dependent with lower bounds of bench mark doses (BMDL) between ≤ 1 and 10 mg/kg bw. Saegusa et al. (2009) on the other hand detected weak hypothyroidism with increases in thyroid weight, thyroid follicular cell hypertrophy and serum TSH concentrations as well as a decrease in serum T3 levels in rat off-spring exposed to 10,000 ppm hexabromocyclododecane in a soy-free diet from gestation day 10 to day 20 after delivery. The TH changes were accompanied by a reduced density of CNPase-positive oligodentrocytes, which is indicative of impaired oligodendroglial development. Increased thyroid weights and decreased serum T3 concentrations were also observed in the adult stage from 1,000 ppm. Though the above data suggest that

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hexabromocyclododecane induced disturbances in TH-signalling is linked to effects on the nervous system in rodents, changes in behaviour and cognition may also be impacted by a decrease in apolar retinoids as observed in female rat livers following hexabromocyclododecane exposure (van der Ven et al. 2006, van der Ven et al. 2009). Moreover, the interferences of hexabromocyclododecane with sex-steroid hormones and their receptors should not be neglected as these hormones also exert non-genomic effects on brain functions such as learning and memory, fine motor control, pain perception and mood (Boulware and Mermelstein 2005, Chakraborti et al. 2007, Meaney et al. 1983, Schantz and Widholm 2001).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.4 of the POPRC Risk Profile).

2.2.7 Summary of mammalian toxicity and overall evaluation

Hexabromocyclododecane exerts reproductive, developmental and neurotoxic effects in mammals with a NOEC/NOAEL in the order of 1 mg/kg/day. *In vivo* data include:

- Decreased pup survival and fewer primordial follicles in rats at 100 mg/kg/day, NOAEL 10 mg/kg/day (Ema et al. 2008).
- Decreased pup weight, decreased testis and prostrate weights, impaired hearing, and reduction in female bone mineral density in rat offspring at 30-100 mg/kg/day (van der Ven et al. 2009, Lillienthal et al. 2009).
- TH imbalance and impaired oligodendroglial development in the brain cortex of rat offspring at 1,000 ppm (81-213 mg/kg/day), NOAEL 8-21 mg/kg/day (Saegusa et al. 2009).
- Behavioural effects in mice exposed to 13.5 mg/kg/day at day 10, NOAEL 0.9 mg/kg/day (Eriksson et al. 2006).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 3 of the POPRC Risk Profile)

3 Human exposure/Risk evaluation

3.1 Food

In humans hexabromocyclododecane is found in blood, plasma and adipose tissue. The main sources of exposure presently known are contaminated food and dust. For breast feeding children, mothers' milk is the main exposure route but hexabromocyclododecane exposure also occurs at early developmental stages as it is transferred across the placenta to the foetus. Human breast milk data from the 1970s to 2000 show that hexabromocyclododecane levels have increased since hexabromocyclododecane was commercially introduced as a brominated flame retardant in the 1980s. Though information on the human toxicity of hexabromocyclododecane is to a great extent lacking, and tissue concentrations found in humans are seemingly low, embryos and infants are vulnerable groups that could be at risk, particularly to the observed neuroendocrine and developmental toxicity of hexabromocyclododecane.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 Executive Summary of the POPRC Risk Profile)

Reported dietary exposure levels in humans vary globally and regionally (Shi et al. 2009, Roosens et al. 2009). Surveys in Europe and the US reveal dietary exposure levels for hexabromocyclododecane in the range of <0.01-5 ng/g w/w (see Roosens et al. 2009 for overview). Fatty foods of animal origin such as meat and fish are likely a major source of dietary human exposure, and the exposure situation closely depends on the consumption of those products in the population (e.g. Shi et al. 2009; Remberger et al. 2004, Lind et al 2002, Driffield et al. 2008). Among all dietary samples, the highest hexabromocyclododecane concentrations (up to 9.4 ng/g w/w) are reported for fish (Knutsen et al. 2008, Remberger et al. 2004, Allchin and Morris 2003). Accordingly in Norway, where fish is an important part of the diet, intake of fish has been found to closely correlate with serum hexabromocyclododecane levels (Thomsen et al. 2008; Knutsen et al. 2008). Eggs are another potential source of human exposure (Hiebl et al. 2007, Covaci et al. 2009). A survey of home-grown chicken eggs sampled near contaminated sites in developing countries showed eggs to contain <3.0-160 ng/g lipid weight (IPEN, 2005). hexabromocyclododecane levels in eggs were high in Mexico (91 ng/g lipid), Uruguay (89 ng/g lipid), Slovakia (89 ng/g lipid), relatively high in Turkey (43 ng/g lipid), and extremely high in Kenya (160 ng/g lipid). That vegetables may contain

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		hexabromocyclododecane at similar concentrations as have been reported for meat and fish, was shown by Driffield et al. (2008), who assessed 19 different food groups representing the UK diet for 2004 for brominated flame retardants. The presence of hexabromocyclododecane in vegetables and vegetable oils and fats may arise from the presence of this substance in sewage sludge and the subsequent use of sewage sludge as a food crop fertilizer (Kupper et al. 2008, Brändli et al. 2007). Stereoisomeric patterns in food samples suggest both global and regional variation, as well as stereoisomeric differences depending on food type (Roosens et al. 2009; Shi et al. 2009). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the POPRC Risk Profile)
3.2	**Air**	A study by Abdallah et al (2009) found hexabromocyclododecane in household air (median concentration 180 pg m-3), household dust (median concentration 1,300 ng/g), offices (median concentration 760 ng/g), and cars (median concentration 13,000 ng/g). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the POPRC Risk Profile)
3.3	**Water**	Not available.
3.4	**Occupational exposure**	In the work environment, direct dermal exposure and inhalation of fine hexabromocyclododecane dust or particles are particular concerns. In a study by Thomsen et al. (2007) industrial workers at plants producing EPS with hexabromocyclododecane were found to have elevated hexabromocyclododecane levels in their blood (i.e. 6-856 ng/g lw serum). Serum/blood levels in non-occupationally exposed individuals are typically much lower (i.e. 0.005-6.9 ng/g lw) though the data indicates potentially significant sources of exposure (see KEMI 2008 for overview). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the POPRC Risk Profile)
3.5	**Medical data contributing to regulatory decision**	Not available.
3.6	**Public exposure**	In non-occupationally exposed individuals indirect exposure via the environment or products, be it oral, dermal or by inhalation, is the main concern. In a study by Stapleton et al. (2008) hexabromocyclododecane levels in dust samples from indoor environments ranged from <4.5 ng/g to a maximum of 130,200 ng/g with a median value of 230 ng/g. As a result of continuous exposure in homes, offices and cars, hexabromocyclododecane is found in human adipose tissue (Pulkrabová et al. 2009; Johnson-Restrepo et al. 2008; Antignac et al. 2008; Abdallah and Harrad 2009) and blood (Weiss et al. 2004; Weiss et al. 2006; Lopez et al. 2004; Brandsma et al. 2009; Thomsen et al. 2007; Meijer et al. 2008; Roosens et al. 2009). Exposure occurs at an early stage of development as hexabromocyclododecane is transferred across the human placenta to the fetus (Mejier et al. 2008), and is also transferred from mother to child via breast milk. Hexabromocyclododecane has been detected in breast milk in Europe (Covaci et al. 2006; Lignell et al. 2009; Eljarrat et al. 2009, Colles et al. 2008; Polder et al. 2008a; Polder et al. 2008b; Fängström et al. 2008; Antignac et al. 2008), in Asia (Kakimoto et al. 2008; Shi et al. 2009; Malarvannan et al. 2009; Tue et al. 2010), in Russia (Polder et al. 2008b), Mexico (Lopez et al. 2004) and in USA (Schecter et al. 2008). Hence exposure to hexabromocyclododecane occurs at critical stages of human development, both during pregnancy and postnatally via breast milk. Reported concentrations of hexabromocyclododecane in breast milk range from below detection limit to 188 ng hexabromocyclododecane/g lw (for overview see European Union 2008). According to EBFRIP 2009b the typical range of total hexabromocyclododecane concentrations in human breast milk in populations inhabiting industrialized areas appears to be <1 to 5 ng/g lw. Geographically, the highest hexabromocyclododecane levels have been found in mothers' milk from two areas in Northern Spain (Catalonia and Galicia). The reported hexabromocyclododecane

levels from these studies ranged from 3-188 and 8 -188 ng/g lw, with median values of 27 and 26 ng/g lw, respectively (Eljarrat et al. 2009; Guerra et al. 2008a).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the POPRC Risk Profile)

3.7 Summary-overall risk evaluation

The EU risk assessment of hexabromocyclododecane completed in 2008 provides the most comprehensive assessment of toxic effects and risks of hexabromocyclododecane exposure to human health and welfare (European Union 2008). This assessment concludes that hexabromocyclododecane may cause reproductive toxicity and long term toxicity, whereas there is no concern for acute toxicity, irritation, sensitization, mutagenicity and carcinogenicity. It moreover states that hexabromocyclododecane poses no risk to adult consumers or to workers when standard industrial hygiene measures are applied (current EU practice). These conclusions are founded on an extensive list of toxicity studies and on a comprehensive selection of exposure and risk assessments that consider not only workers and adult consumers, but also indirect exposure of humans via the environment (European Union 2008). The EU risk assessment documents that currently in the general (human) population, hexabromocyclododecane tissue concentrations are much below those reported to induce adverse effects in other mammals (European Union 2008).

The substance is suspected of damaging fertility or the unborn child (Repr. 2; H361), and the substance may cause harm to breast-fed children (Lact.; H362) (KEMI 2009).

Significant levels of hexabromocyclododecane in human milk and exposure through food has been reported near local sources. In humans, the main risks of hexabromocyclododecane exposure are possible neuroendocrine and developmental disturbances from exposure during the early developmental phases of the child.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.5 of the POPRC Risk Profile).

In humans, the main risks of hexabromocyclododecane exposure are possible neuroendocrine and developmental disturbances from exposure during the early developmental phases of the child.

In addition to the findings in the *in vivo* animal studies, there are a large number of recent *in vitro* studies that document how hexabromocyclododecane upon adsorption may act on, and possibly interfere with biological processes such as cell homeostasis, protein repair, metabolism, intracellular signalling and neuroendocrine processes. Such studies add to the understanding that exposure to hexabromocyclododecane has various effects on human health and the environment, and should also be regarded when considering the toxicity of hexabromocyclododecane.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 3 of the POPRC Risk Profile).

4 Environmental fate and effects

4.1 Fate

4.1.1 Soil

The rate of degradation of hexabromocyclododecane is slower in the presence of oxygen. Davis et al. (2005) reported on the biodegradation of technical hexabromocyclododecane in freshwater sediments and soils. Using OECD test guidelines 307 and 308, the authors demonstrated that the rate of loss of hexabromocyclododecane at 20°C was appreciably faster under anoxic conditions in both media. Relative to biologically sterile controls, biotransformation of hexabromocyclododecane was faster in the presence of microorganisms and DT_{50} values ranged from 11 to 32 days (aerobic) and 1.1 to 1.5 days (anaerobic) in sediment. In soil, half-lives under aerobic and anaerobic conditions were 63 and 6.9 days, respectively. However, in this study only the degradation of γ-hexabromocyclododecane was studied since the test concentration was too low to

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allow detection of α- and β-hexabromocyclododecane. It was also not possible to detect transformation products.

In the EU Risk Assessment, the degradation half-lives in aerobic sediment were calculated at 20°C to be 113, 68 and 104 days for α-, β- and γ-hexabromocyclododecane, respectively (European Union 2008). In sediment, technical-hexabromocyclododecane was observed to be subject to primary degradation with half-lives of 66 and 101 days in anaerobic and aerobic sediment at 20°C, respectively. The EU Risk Assessment notes that the study was conducted at hexabromocyclododecane concentrations much greater (mg/kg) than Davis et al. (2005) (μg/kg), so the degradation kinetics may be limited by the mass transfer of chemical into the microbes. The main transformation product was 1,5,9-cyclododecatriene (CDT) which was formed via a step-wise reductive dehalogenation of hexabromocyclododecane. No CO_2 was detected during the study. However, in a study performed according to OECD guideline 301F (Davis et al. 2006b), it was shown that t,t,t-CDT can be degraded to CO_2.

Degradation rate constants of hexabromocyclododecane, under anaerobic conditions in sewage sludge have also been reported (Gerecke et al. 2006). Experiments were conducted by adding individual target compounds or mixtures to freshly collected digested sewage sludge. The sewage sludge was amended with yeast and starch. Experiments, performed at 37°C, with racemic mixtures of individual diastereoisomers showed that (+/-)-β-hexabromocyclododecane and (+/-)-γ-hexabromocyclododecane degraded faster than (+/-)-α-hexabromocyclododecane by an estimated factor of 1.6 and 1.8, respectively. Based on the investigations of Davis et al. (2006a) and Gerecke et al. (2006), α-hexabromocyclododecane seems to be subject to a slower degradation than β- and γ-hexabromocyclododecane.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.2.1 of the POPRC Risk Profile).

4.1.2 Water

There are no reliable empirical data on the degradation kinetics of hexabromocyclododecane in water. The hydrolysis of hexabromocyclododecane has not been studied. Hydrolysis should however, not be considered as a significant route of environmental degradation for this substance due to the low water solubility, the high partitioning to organic carbon, and the lack of hydrolysable functional groups (OECD 2007). According to calculations in the EMEP report on hexabromocyclododecane, the physical-chemical properties of the technical mixture and γ-hexabromocyclododecane stereoisomer give a half-life in water of about 5 years (EMEP 2009).

According to EBFRIP (2009b) the half-life for water and soil derived from comparing different model estimations lies in the range 8.5 – 850 days, with a median of 85 days and confidence factor (CF) of 10. The half-life in freshwater and marine sediments lies in the range 6 – 210 days, with a median of 35 days and CF of 6. EBFRIP (2009b) does not differentiate between fresh water and marine sediment.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.2.1 of the POPRC Risk Profile).

4.1.3 Air

The atmospheric degradation half-life of hexabromocyclododecane by gas-phase reaction with hydroxyl radicals (OH) has not been experimentally measured but can be modeled, providing an estimate (by AopWin v1.91) of 76.8 hours (3.2 days). The estimate was obtained by assuming a concentration of 5×10^5 OH molecules·cm^{-3} and that the reaction takes place 24 hours a day (these are values used in the European Union risk assessments). It is noted that the model is sensitive to the chosen OH concentration (NCM 2008).

Bahm and Khalil (2004) derived a 24-hour global annual average OH concentration of 9.2×10^5 molecules·cm^{-3}, with a value of 9.8×10^5 molecules·cm^{-3} for the northern

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hemisphere and 8.5×10^5 molecules·cm^{-3} for the southern hemisphere. These values are consistent with Prinn et al. (1995) and Montzka et al. (2000) who deduced OH concentrations from atmospheric measurements of methyl chloroform, reporting 24 hour global annual average values of $9.7(\pm0.6)\times10^5$ and $1.1(\pm0.2)\times10^6$ molecules·cm^{-3} respectively. Considering the uncertainty in the model estimates of kOH, the half-life for photochemical degradation of hexabromocyclododecane ranges from 0.4 to 4 days and 0.6 to 5.4 days for the northern and southern hemisphere respectively (EBFRIP 2009b).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.2.3 of the POPRC Risk Profile).

4.1.4 Bioconcentration

From two flow-through bio-concentration tests with fish. A BCF of 18,100 in fathead minnow was chosen as a representative value in the EU risk assessment. hexabromocyclododecane levels have been shown to increase with trophic levels in a freshwater system: Fjeld (2006a) reported concentrations of hexabromocyclododecane in European smelt (*Osmerus eperlanus*), Vendace (*coregonus albula*), and Brown Trout (*Salmo trutta trutta*) from lake Mjosa in Norway. European smelt and Vendace are important preyfish for the trout. The concentrations of hexabromocyclododecane detected in 2005 were 466 µg/kg lwt (8.8 µg/kg wwt), 374 µg/kg lwt (10.7 µg/kg wwt), 729 µg/kg lwt (18 µg/kg wwt) for the European smelt, the Vendace, and the Brown trout, respectively.

HBCD has also been detected in other organisms high in rank in their food -chain such as birds, seals, marine fish, dolphins, harbour porpoise and polar bear.

(UNEP/FAO/RC/CRC.13/8 section 3.2.3 of the Norwegian notification).

4.1.5 Persistence

No or little degradation has been observed in water, soil and sediments. Furthermore, hexabromocyclododecane adsorbs to particles which slow down the degradation

Air: $T_{1/2}$ - 51.2 hours (Wania 2003, as referred in EC 2008)

Water: $T_{1/2}$ - 1140 hours (Wania 2003, as referred in EC 2008)

Soil: $T_{1/2}$ - 112-119 days (12°C) for γ-hexabromocyclododecane diastereomer

Aerobic sediment: $T_{1/2}$ ~ 197 days (recalculated to 12°C) for γ-hexabromocyclododecane in a simulation study.

(UNEP/FAO/RC/CRC.13/8 section 3.2.3 of the Norwegian notification)

To evaluate the persistency of hexabromocyclododecane a compilation of data on experimentally measured half-lives in different environmental compartments, data on half-lives derived from modeling, and field data have been undertaken. Results of the estimation model, BIOWIN (v4.10, EPI Suite v4.0), which estimates the probability for aerobic biodegradation in the presence of mixed populations of environmental microorganisms suggest that hexabromocyclododecane is not readily biodegradable; the expected time of primary degradation is in the order of weeks. Moreover, an early biodegradation study using Closed Bottle Test systems that were conducted in accordance with OECD Guideline 301D, found no biodegradation of hexabromocyclododecane over a 28-day study period (Wildlife International 1996). It should be noted that while the studies were performed using accepted test guidelines, the concentrations tested were about three orders of magnitude greater than the water solubility of hexabromocyclododecane (7.7 mg/L vs 66 µg/L).

Japanese authorities conducted a 28-day biodegradation study of 1,2,5,6,9,10-hexabromocyclododecane based on the OECD Test Guideline 301C. The degradation of the test substance, a mixture containing different stereoisomers, was assessed by high performance liquid chromatography. The percentage biodegradation of two hexabromocyclododecane isomeric forms (A and B), were calculated to be 5 and 6%, respectively. (Chemicals Inspection and Testing Institute, 1990).

Several studies using sediment cores show that hexabromocyclododecane congeners deposited in marine sediments in Asia and in Europe at the beginning of the 1970s/1980s are still present in significant amounts (Minh et al. 2007, Tanabe

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2008, Kohler et al. 2008, Bogdal et al. 2008), indicating a higher persistency in sediments than derived from experimental studies.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.2.1 of the POPRC Risk Profile).

4.2 Effects on non-target organisms

4.2.1 Terrestrial vertebrates

A recent study with American kestrels indicates that a technical hexabromocyclododecane mixture administered to birds via the diet is readily taken up and distributed to internal organs (BFR 2009a; SETAC 2009). The main stereoisomer detected in liver, fat and egg was α-hexabromocyclododecane, followed by γ-hexabromocyclododecane and β-hexabromocyclododecane. According to these observations, hexabromocyclododecane is preferentially stored in fat and is transferred to eggs during development. Tissue concentrations were such that fat>>eggs>liver>plasma (SETAC 2009). In this study, administration of 800 ng/g wwt of technical hexabromocyclododecane formulation in safflower oil for 21 days followed by a 25-day depuration period, resulted in environmentally relevant internal doses, i.e., sum of hexabromocyclododecane isomers of 934.8 ng/g lw (20 ng/g ww) in liver and 4216.2 ng/g lw (181. 5 ng/g ww) in eggs) with the level of α-hexabromocyclododecane being 164 ng/g wwt in egg) (BFR 2009b). A parallel study assessed reproductive effects of hexabromocyclododecane in American kestrels (*Falco sparverius*) (BFR 2009b; Dioxin 2010b). Also here kestrels were exposed daily to 800 ng/g wwt of a technical hexabromocyclododecane mixture in safflower oil from three weeks prior to pairing until two days before hatching. α-hexabromocyclododecane dominated in eggs, where it was found at a concentration of 164 ng/g wwt following exposure. While clutch size (number of eggs per female) was greater in the treated kestrels, hatchling numbers were comparable to that of controls (Dioxin 2010b). Treated kestrel nestlings were smaller in weight and had a slower growth rate than controls as determined by overall body weight. Behavioural parameters related to parental care were also affected by hexabromocyclododecane exposure (BFR 2009b; Dioxin 2010c).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.3 of the POPRC Risk Profile).

4.2.2 Aquatic species

Ecotoxicity testing of hexabromocyclododecane in aqueous media is complicated by its very low water solubility and high adsorption potential (EBFRIP 2009b, NCM 2008). hexabromocyclododecane has a low acute toxicity to aquatic organisms owing in part to its limited solubility in aqueous media (Wildlife International 1997, Walsh et al. 1987, CEPA 2007 and ACCBFRIP 2001 for overview). Regarding the long-term toxicity of hexabromocyclododecane it was concluded to be very toxic to aquatic organisms in the EU Risk Assessment (European Union 2008). This conclusion was based on the long-term ecotoxicity test with *Daphnia magna* (28d-NOEC 3.1 µg/l; Wildlife International 1998) and on the growth inhibition test with *Skeletonema costatum* (72h-EC_{50} 52 µg/L; Wildlife International 2005). In both tests calculated NOEC and EC_{50} values were below the water solubility of the technical mixture of hexabromocyclododecane (66 µg/L). Based on the effects in long-term tests with *Lumbriculus variegates*, hexabromocyclododecane is known to cause adverse effects to aquatic sediment organisms at exposure level relevant for the environment (Institute of Hydrobiology 2001).

Fish-feeding studies indicate effects on key biological processes. For example, an interference of hexabromocyclododecane with the HPT-axis and liver biotransformation enzymes were reported in rainbow trout exposed to individual hexabromocyclododecane diastereoisomers via food for 56 days followed by a depuration period of 112 days when fish were fed a reference diet (Palace et al. 2008). Lipid corrected concentrations of α-, β-, γ-isomers in the food were 29.14 ± 1.95, 11.84 ± 4.62, and 22.84 ± 2.26 ng/g, respectively (means ±SEM). Liver detoxification processes (P450 CYP1A activity) were inhibited by all hexabromocyclododecane stereoisomers after 7 days of dosing, and also after 56 days of dosing but then only in α- and β- exposed fish. Thyroid follicle epithelial cell heights were significantly greater in γ-hexabromocyclododecane exposed fish at day 56 of the uptake phase and in fish from the α- and

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γ-hexabromocyclododecane exposed groups at day 14 of the depuration phase. More recent studies also support that hexabromocyclododecane may interfere with the fish thyroid system (Palace et al. 2010). The link between hexabromocyclododecane induced disturbances in the HPT-axis and the importance of such effects to smoltification in Atlantic salmon has also been examined (Lower and Moore 2007). To assess this, Lower and Moore (2007) exposed juvenile salmon to 11 ng/L of a hexabromocyclododecane mixture for 30 days during the peak smoltification period in freshwater. The fish were then transferred to clean seawater for 20 days. Throughout the hexabromocyclododecane-dosing and saltwater exposures, 5-8 fish were sampled every 7 days and gill and blood tissues were collected. In addition, electro-olfactrograms were recorded in an additional 5 fish every 10 days using urine from salmon from the same stream (considered to be the cue for returning smolts) as an effector. The exposure to hexabromocyclododecane was not observed to affect seawater adaptability, although the peak of thyroxine was shifted and occurred one week earlier in hexabromocyclododecane exposed fish than in controls. A reduction in olfactory function, as evidenced by attenuated olfactory responses during early freshwater transition, was also observed. This latter effect is important as it can affect successful homing, and thereby ultimately also reproductive capacity in adult salmon. In contrast to the above findings, in a third reported study assessing TH effects in European flounders (*Platichtys flesus*), no effects neither on the liver's biotransformation capacity or TH-levels were reported, even though hexabromocyclododecane accumulated dose-dependently (Kuiper et al. 2007). The fish were in this instance exposed to hexabromocyclododecane in food (μg/g lipid) and sediment (μg/g total organic carbon) in the following combinations; 0+0 (control); 0.3+0.08; 3+0.8; 30+8; 300+80; 3,000+800; and 0+8,000 for 78 days. Lastly, hexabromocyclododecane may also interfere with amphibian metamorphosis, a process that is tightly regulated by TH-hormones. As shown *in vitro*, hexabromocyclododecane at 10, 100 and 1000 nM potentiates T3 induced tadpole tail regression in a concentration dependent manner (Schriks et al. 2006). *In vivo* such effects may result in precocious metamorphosis.

Recent studies with fish models suggest that hexabromocyclododecane may also induce oxidative stress and apoptosis. Deng et al. (2009) examined oxidative stress and the apoptosis pathway in four-hour post-fertilization zebrafish (*Danio rerio*) embryos by exposing them to waterborne hexabromocyclododecane at concentrations of 0, 0.05, 0.1, 0.5, and 1.0 mg/L for 92 hours. Survival was reduced at the three middle doses equivalently, but was elevated at the highest dose (1mg/L). Hatching rate was only affected at the highest dose (1 mg/L) with a 10% reduction from controls. Malformation rates (including epiboly deformities, yolk sac and pericardial edema, tail and heart malformations, spinal curvatures and improper inflation of the swimbladder) increased dose dependently, and heart rate and body length both also decreased with exposure to hexabromocyclododecane. The levels of reactive oxygen species (ROS) also increased dose dependently in fish exposed to hexabromocyclododecane concentrations above 0.05 mg/L. With regard to apoptosis, hexabromocyclododecane elevated expression of the pro-apoptotic genes p53, Bax, Puma, Apaf-1, and caspase-9 and caspase-3, of which the response of the latter two was verified at the enzyme level. The anti-apoptotic genes Mdm2 and Bcl-2 were both significantly down regulated at the highest hexabromocyclododecane exposure concentration. The overall results demonstrate that waterborne hexabromocyclododecane may produce oxidative stress in zebrafish embryos and lower survival at doses below the water solubility of technical hexabromocyclododecane. The latter effect is important since hexabromocyclododecane has been documented to be maternally transferred to offspring in oviparous animals, hereunder also fish (Nyholm et al. 2008, Jaspers et al. 2005, Lundsted-Enkel et al. 2006). The potential of hexabromocyclododecane to induce oxidative stress in zebra fish embryos has also been demonstrated by Hu et al. (2009). Here, the oxidative stress, assessed by lipid membrane damage (effects at 0.5, 2.5 and 10 mg/L) was also accompanied by delays in hatching (hexabromocyclododecane at ≤ 0.5 mg/ml), dose-independent changes in superoxide dismutase enzyme activity (higher at 0.1, lower at 2.5 and 10 mg/L) and an elevation of heat shock proteins (Hsp70) activity (≥0.1 mg/L), the latter effect

likely indicating increased protein repair activity. Moreover, in a study with Chinese rare minnows (*Gobiocyprinus rarus*) Zhang et al. (2008) observed a consistent increase in oxidative stress and cellular macromolecules in brain (ROS, carbonylation, TBARS) and erythrocytes (DNA) by waterborne hexabromocyclododecane in the 100-500 µg/l range (42 days). Protective enzymatic- (superoxide dismutase) and non-enzymatic antioxidant glutathione were compromised even at concentrations of 10 and 1 µg/L respectively. A shorter 28-day exposure resulted in somewhat higher effect concentrations. However, since most test concentrations in these studies are above the water solubility of hexabromocyclododecane, the studies may not be suited to derive dose-response relationships and to set thresholds of toxicity.

In fish proposed novel mechanisms of hexabromocyclododecane toxicity are decreased protein metabolism and changes in cytoskeleton dynamics and cellular defense mechanisms (Kling and Förlin 2009). Recently, hexabromocyclododecane was also demonstrated to have a genotoxic potential and to increase cell death in benthic clams (*Macoma balthica*) (Smolarz and Berger 2009).

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.1 of the POPRC Risk Profile).

Hexabromocyclododecane is toxic to aquatic organisms such as *Daphnia magna*, a 21d-NOEC of 3.1 µg/l has been derived for a flow-through test.

Hexabromocyclododecane is not acute toxic to fish: In rainbow trout, no mortalities or other effects were observed in a 4-week toxicity test at a concentration of approximately 6.8 µg/l (mean measured concentration 2.5 µg/l).

(UNEP/FAO/RC/CRC.13/8 section 3.2.3 of the Norwegian notification)

Acute Aquatic Toxicity

Fish LC_{50}

Oncorhynchus mykiss 96-hour LC_{50} >0.0068 mg/L (nominal) or >0.0025 mg/L (mean measured)

(EPA, 2005; NICNAS, 2012; Reported in a secondary source. Guideline study. Performed according to current EPA, OECD guidelines and GLP. No toxicity at HBCD's limit of water solubility.)

Lepomis macrochirus 96-hour LC_{50} >100 mg/L (nominal)

(EPA, 2005; Reported in a secondary source with limited study details. Value exceeds water solubility.)

Leuciscus idus 96-hour LC_{50} >10,000 mg/L (nominal)

(EPA, 2005; Reported in a secondary source with limited study details. Value exceeds water solubility.)

Fish 96-hour LC_{50} = 0.30 mg/L (Estimated)

(ECOSAR v1.10; No effects at saturation (NES): The log K_{ow} of 5.6 for this chemical exceeds the SAR limitation for the log K_{ow} of 5.0; NES are predicted for these endpoints. Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Brachydanio rerio exposed to 0, 0.05, 0.1, 0.5 and 1.0 mg L for up to 96 hours.

- Cell apoptosis, induction of reactive oxygen species (ROS) at 0.1, 0.5 and 1.0 mg/L.

- Exposure to hexabromocyclododecane results in oxidative stress and may induce apoptosis through involvement of caspases
- NOEC = 0.05 mg/L
- LOEC = 0.1 mg/L

(Deng et al., 2009; Guideline study. Study details taken from abstract. This study is for a nontraditional endpoint for determining hazard designation. In addition, NOEC and LOEC values are above the limit of water solubility and will not be used to determine a hazard designation. No effects at saturation (NES) are predicted.)

Daphnid LC_{50}/EC_{50}

Daphnia magna 48-hour EC_{50} >0.0068 mg/L (nominal) or >0.0032 mg/L (mean measured).

(EPA, 2005; NICNAS, 2012; Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP. No toxicity at HBCD's limit of water solubility; NES.)

D. magna 48-hour EC_{50} = 146 mg/L (nominal)

- Nominal test concentrations were 0.01-1,000 mg/L (both below and above the water solubility)

(EINECS, 2008; Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP. Value exceeds water solubility.)

Daphnia 48-hour LC_{50} = 0.23 mg/L (Estimated).

(ECOSAR v 1.10; NES: The log K_{ow} of 5.6 for this chemical exceeds the SAR limitation for the log K K_{ow} of 5.0; NES are predicted for these endpoints. Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Green Algae EC_{50}

Skeletonema costatum 72-hour NOEC >0.01 mg/L (>10 µg hexabromocyclododecane)

- EC_{50} = 0.027 mg/L (biomass)
- EC_{50} = 0.052 mg/L (growth rate)

(Desjardins et al., 2005; ECHA, 2008; Reported in a secondary source with limited study details.)

Pseudokirchneriella subcapitata 96-hour EC_{50} >0.0068 mg/L (nominal) or >0.0037 mg/L (mean measured)

(EPA, 2005; NICNAS, 2012; Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP. No toxicity at HBCD's limit of water solubility; NES.)

Chlorella sp. 96-hour EC_{50} >1.5 mg/L

(EPA, 2005; NICNAS, 2012; Reported in a secondary source with limited study details. No toxicity at HBCD's limit of water solubility; NES.)

S. costatum 72-hour EC_{50} >0.0093-0.012 mg/L.

(EPA, 2005; NICNAS, 2012; Reported in a secondary source with limited study details. No toxicity at HBCD's limit of water solubility; NES.)

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S. costatum 96-hour EC_{50} >0.0025 mg/L

(ECHA, 2008; Reported in a secondary source with limited study details. The test substance was made up of a composite of HBCD samples from three manufacturers containing 6.0% α-, 8.5% β- and 79.1% γ-diastereomers; total HBCD was 93.6% of test substance. There were no effects at the highest concentration tested.)

S. costatum 72-hour EC_{50} >0.0406 mg/L (40.6 μg/L)

- NOEC >0.0406 mg/L (only concentration tested)
- LOEC = Not identified

(Desjardins et al., 2004 (as cited in ECHA, 2008; NICNAS, 2012);

Reported in a secondary source with limited study details; LOECs were not identified. One test concentration at the limit of water solubility; NES.)

Thalassiosira pseudonana 72-hour EC_{50} >0.05–0.37 mg/L

(Walsh et al., 1987 (as cited in EPA, 2005; NICNAS); Reported in a secondary source with limited study details. No toxicity at HBCD's limit of water solubility.)

Scenedesmus subspicatus 96-hour EC_{50} >500 mg/L

- No effect on growth inhibition

(Siebel-Sauer and Bias, 1987 (as cited in EINECS, 2008); Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP. Value exceeds water solubility.)

Green algae 96-hour EC_{50} = 0.29 mg/L (Estimated)

(ECOSAR v. 1.10; The estimated effect exceeds the water solubility of 0.66 mg/L, but not by 10x as required to be considered NES by ECOSAR.

Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Chronic Aquatic Toxicity

Fish ChV

Oncorhynchus mykiss 88-day NOEC > 0.0037 mg/L (γ-hexabromocyclododecane).

27-Day hatching period;

- 61 days posthatch showed no effects on hatching success, time to swim-up, larval survival, fry survival or growth

(Drotter et al., 2001; EPA, 2005; Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP; LOEC and MATC could not be determined due to absence of toxicity, but were considered >0.0037 or 0.0068 mg/L (more than twice γ-HBCD's water solubility). HBCD was not chronically toxic to rainbow trout at concentrations at or above its limit of solubility.)

Fish ChV = 0.043 mg/L (Estimated)

(ECOSAR v. 1.10; Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Chinese rare minnow 14-, 28- and 42-day waterborne hexabromocyclododecane exposure to 0.1-0.5 mg/L

- Induced hepatic enzymes (as measured by EROD and PROD).
- Induced oxidative stress in fish brain (as measured by ROS and TBARS).
- 28-day LOEC = 0.5 mg/L
- 42-day LOEC = 0.1 mg/L

(Zhang et al., 2008; Study details reported in abstract. Values exceed water solubility. This study is for a non-traditional endpoint for determining hazard designation. In addition, LOEC values are above the limit of water solubility and will not be used to determine a hazard designation. A NOEC was not identified.)

Daphnid ChV

D. magna 21-day life cycle toxicity test. Nominal test concentrations were 0.85, 1.7, 3.4 and 13.6 µg/L; measured test concentrations were 0.87, 1.6, 3.1, 5.6 and 11 µg/L.

- LOEC = 0.0056 mg/L (0.0042 mg/L geometric mean; reduced mean lengths)
- NOEC = 0.0031 mg/L (γ-hexabromocyclododecane, measured)

(Drotter and Kruger, 1998 (as cited in EINECS, 2008; EPA, 2005; NICNAS, 2012); Reported in a secondary source. Guideline study performed according to current EPA, OECD guidelines and GLP. Within the range of water solubility. The test substance was made up of a composite of HBCD samples from three manufacturers containing 6.0% α-, 8.5% β- and 79.1% γ-diastereomers; total HBCD was 93.6% of test substance. Reduced lengths, dry weight and fewer young observed in daphnia exposed to 0.011 mg/L.)

Daphnia ChV = 0.0.059 mg/L (Estimated)

(ECOSAR v. 1.10; Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Green Algae ChV

Green algae ChV = 0.38 mg/L (Estimated)

(ECOSAR v. 1.10; The effect level exceeds the water solubility of 0.66 mg/L, but not by 10x as required to be considered NES by ECOSAR.

Narcosis classes (neutral organics) are provided for comparative purposes; DfE assessment methodology will use the lowest estimated toxicity value provided by ECOSAR classes that have a more specific mode of action relative to narcosis.)

Earthworm Subchronic Toxicity

Lumbriculus variegates 28-day sediment bioassay (spiked and aged sediment) with hexabromocyclododecane at 0.05, 0.5, 5, 50 and 500 mg/kg dwt (nominal)

- LOEC = 28.7 mg/kg (rate of emergence)
- NOEC = 3.2 mg/kg dwt
- Mean number of eggs in F1 generation was significantly reduced at highest concentration (159 mg/kg dwt).

(EINECS, 2008; Oetken et al., 2001; Performed in contrast with OECD Draft Guideline 218, artificial sediment with a coarse grain size (100-2,000 µm) and other carbon sources (stinging-nettle and leaves of alder). EINECS states that the results for total emergence and emergence rate were not considered valid for the purpose of risk assessment due to the large variations in solvent control.)

(UNEP/FAO/RC/CRC.13/INF/18 US EPA: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)).

4.2.3 Honeybees and other arthropods

Not available.

4.2.4 Earthworms

Long-term toxicity of hexabromocyclododecane to earthworms has been assessed by ABC (2003), who measured survival and reproduction in *Eisenia fetida* (clittelate adults) following 56-day exposure to a technical hexabromocyclododecane mixture. Hexabromocyclododecane was mixed dry into

		artificial soil media at concentrations of 78.5 to 5,000 mg/kg dry soil weight. In this study, the NOEC for survival and reproduction for hexabromocyclododecane were determined to be 4,190 and 128 mg/kg dry soil respectively. The NOEC for reproduction was later recalculated to 59 mg/kg dry soil weight because the soil that was used contained a higher amount of organic matter than standard soil (NCM 2008). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.2 of the POPRC Risk Profile).
4.2.5	**Soil microorganisms**	For effects of hexabromocyclododecane on soil micro-organisms, the only conducted study reports a NOEC of ≥ 750 mg/kg dw using nitrate production as an endpoint for assessment (ECT 2007). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.2 of the POPRC Risk Profile).
4.2.6	**Terrestrial plants**	Not available.
5	**Environmental Exposure/Risk Evaluation**	
5.1	**Terrestrial vertebrates**	Collectively, the findings from studies suggest that there is reason for concern of reproductive and developmental effects in wild birds, because the 800 ng/g wwt dose that elicited effects in the studies by Marteinson and Fernie (see BFR 2009 for overview) are similar to what have previously been observed in wild birds in Central Europe and the Norwegian Arctic, i.e., (cormorant (liver): 138-1,320 ng/g lw and tern (egg): 330-7100 ng/g lw (Morris et al. 2004); glaucous gulls (liver):195-15,027 ng/g lw and great black- backed gulls (liver): 1,881 - 3,699 ng/g lw (KLIF 2007); glaucous gulls (liver): 75.6 ng/g wwt (Verreault et al. 2007). (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.3 of the POPRC Risk Profile). Further indications for concern come from recent preliminary data obtained with captive American kestrels which suggest a risk for reproductive and developmental effects in source regions. The findings from Marteinson et al. (Dioxin 200910c) and Fernie et al. (Dioxin 2010cb) suggest that there is reason for concern of reproductive and developmental effects in wild birds, not only because of the seasonal changes in fat stores experienced by wild birds and the observed transfer to eggs, but also because the 800 ng/g wwt dose and the subsequent *in ovo* hexabromocyclododecane concentrations that elicited effects in these studies are similar to what has previously been observed in wild birds in Central Europe, i.e., cormorant liver, 138-1,320 ng/g lw; and, tern eggs, 330-7100 ng/g lw (Morris et al. 2004). In the study, administration of 800 ng/g wwt of technical hexabromocyclododecane formulation in safflower oil for 21 days followed by a 25-day depuration period, resulted in environmentally relevant internal doses, i.e., the sum of hexabromocyclododecane isomers, 934.8 ng/g lw (20 ng/g ww) in liver; and, 4216.2 ng/g lw (181. 5 ng/g ww) in eggs (with the level of α-hexabromocyclododecane being 164 ng/g wwt in eggs) (BFR 2009b; SETAC 2009). Endocrine disruptor effects may arise from low dose exposure and are highly dependent on the timing of exposure (WHO and IPCS, 2002). The study on American kestrels (BFR 2009b; Dioxin 2010c) also suggests a risk for reproductive and developmental effects in wild birds in remote regions, where the internal doses (164 ng/g wwt of α-hexabromocyclododecane) that elicited effects in the studies by Marteinson and Fernie (BFR 2009b) is exceeded by internal doses observed in wild birds in the Norwegian Arctic, i.e. glaucous gulls (liver), 195-15,027 ng/g lw; and, great black- backed gulls (liver), 1,881 - 3,699 ng/g lw (KLIF 2007); glaucous gulls (liver): 75.6 ng/g wwt (Verreault et al. 2007). Muir et al. (2004) detected hexabromocyclododecane isomers in concentrations in the blubber of beluga whales (*Delphinapterus leucas*) in the Canadian Arctic in 2001, a species protected by the Convention on migratory species. The concentrations were in the range of 9.8-18 ng/g lw. Muir et al. (2006) detected levels of hexabromocyclododecane in adipose tissue of polar bears (*Ursus maritimus*) in several populations in the Arctic region in 2002. The highest levels were detected in the female bears from the

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		Svalbard area (109 ng/g lw). Effects on polar bears and other marine mammals were not investigated in these studies. (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.6 of the POPRC Risk Profile).
5.2	**Aquatic species**	A comparison of measured concentrations in the tissues and organs of species of prey (fish) with the predicted no-effect concentration (PNEC) for secondary poisoning for hexabromocyclododecane reveals that the concentrations in fish exceed the PNEC of 5 mg/kg food for predators (mammals and birds) both near local point-sources and source regions. In the vicinity of point sources such as the river Skerne in the UK and the river Scheldt basin in Belgium, hexabromocyclododecane concentrations above 5 mg/kg wwt have been measured in fish (eel and brown trout). Also in marine mammals, concentrations higher than the PNEC have been measured, the highest being 6.4 mg/kg wwt whole body weight in harbour porpoise from the UK (European Union 2008). The potential risk of hexabromocyclododecane to wild life near local point-sources and source regions is further supported by the body/tissue residue based risk assessment made by EBFRIP (2009b). Notably the upper third of the monitoring data used in the assessment exceeds the specific-toxicity residue-based PNEC for freshwater fish and for mammals. The upper limit of the monitoring data for birds also enters this range. Hexabromocyclododecane has been detected in many Arctic species (invertebrates, birds, fish, terrestrial and marine mammals). Levels in Polar cod from Svalbard (Arctic Norway) have been reported at 1.38-2.87 ng/g lipid weight (see levels and effects tables in UNEP/POPS/POPRC.6/INF/25). The findings of hexabromocyclododecane in fish in remote regions suggest a potential for endocrine effects considering the laboratory studies done by Lower and More (2007), Palace et al. (2008 and 2010) showing effect on the thyroid axis for salmoid fish. (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.6 of the POPRC Risk Profile).
5.3	**Honey bees**	Not available.
5.4	**Earthworms**	Not available.
5.5	**Soil microorganisms**	Not available.
5.6	**Summary – overall risk evaluation**	Hexabromocyclododecane is persistent in the environment and has a strong potential to bioaccumulate and biomagnify in food chains. α-hexabromocyclododecane appears to be the more persistent of the isomers of hexabromocyclododecane and to biomagnify more than β-hexabromocyclododecane and γ-hexabromocyclododecane. Hexabromocyclododecane is widespread in the global environment and biota; elevated levels are found in top predators and other threatened species in the Arctic. Releases of hexabromocyclododecane to the environment are increasing in all regions investigated. The increasing standing masses of construction materials are potentially long-term sources of hexabromocyclododecane to the environment, as well as representing larger releases when demolished or renovated in the future. Releases during recycling of construction materials and electronic appliances can be of importance and are likely to increase in the future. A general trend seems to be that α-hexabromocyclododecane dominates in the upper trophic levels while the main isomer in the lower levels appears to be γ-hexabromocyclododecane. In human tissue α-hexabromocyclododecane seems to predominate in the general population. Most toxicological studies with hexabromocyclododecane focus on hexabromocyclododecane mixtures and the available data on stereoisomer specific toxicity is very limited. Hexabromocyclododecane is considered very toxic to aquatic organisms. There is a risk of adverse effects in marine mammals and fish in the vicinity of point sources and in regions with elevated background levels. The measured concentration levels in biota exceed the PNEC for secondary effects of 5 mg/kg wwt in the EU risk assessment of hexabromocyclododecane (European Union 2008). Levels in birds from European regions with elevated back ground levels or near local point sources

are concluded to lie near the threshold levels for adverse effects. In avian species, preliminary data from recent studies report effects such as reduced eggshell thickness, growth and survival. Further indications for concern come from recent preliminary data obtained with captive American kestrels which suggest a risk for reproductive and developmental effects also in wild birds in remote regions.

Both older and recent available literature suggest that hexabromocyclododecane can induce effects in mammals and that both chronic and subchronic, high and low dose exposure to hexabromocyclododecane may have wide ranging and potentially severe effects, particularly to the neuroendocrine system and to offspring during early phases of development. Hexabromocyclododecane has a potential to interfere with the hypothalamic-pituitary-thyroid (HPT) axis and cause reproductive and developmental effects. Many effects were trans-generational and affected both parents and offspring. Hexabromocyclododecane is maternally transferred to offspring, both in humans and in wildlife.

In addition to the findings in the *in vivo* animal studies, there are a large number of recent *in vitro* studies that document how hexabromocyclododecane upon adsorption may act on, and possibly interfere with biological processes such as cell homeostasis, protein repair, metabolism, intracellular signalling and neuroendocrine processes. Such studies add to the understanding that exposure to hexabromocyclododecane has various effects on human health and the environment, and should also be regarded when considering the toxicity of hexabromocyclododecane.

(UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 3 of the POPRC Risk Profile)

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Annex 2 – Details on final regulatory actions reported

Country Name: Japan

1	**Effective date(s) of entry into force of actions**	1 May 2014
	Reference to the regulatory document	The Chemical Substances Control Law (CSCL) and its Enforcement Order.
2	**Succinct details of the final regulatory action(s)**	This chemical is designated as a Class I Specified Chemical Substance. It is prohibited to manufacture, import or use this chemical substance.
3	**Reasons for action**	The regulatory action was based on concerns related to human health.
4	**Basis for inclusion into Annex III**	The regulatory action was taken to protect human health. The regulatory action was based on a risk evaluation taking into account the prevailing conditions in Japan.
4.1	**Risk evaluation**	This chemical is persistent, highly bioaccumulative and has long-term toxicity to humans. (UNEP/FAO/RC/CRC.13/8 Section 2.4.2.1 of the Japanese notification) When a substance is listed to the Stockholm Convention, and when it is on the market in Japan, the Japanese Government conducts a risk evaluation on the substance and its potential risks to inform the regulatory measures. This internal risk evaluation, in combination with the Risk Profile document for hexabromocyclododecane, were supplied as supporting information by Japan in document UNEP/FAO/RC/CRC.13/INF/17/Rev.2. A brief English summary of that domestic risk evaluation was provided along with the table of contents of the risk evaluation. The internal risk evaluation was based on the monitoring data from fiscal year 2009 to fiscal year 2012 and revealed a number of sites with a high ecological risk, while there were no sites with any human health risk. The risk evaluation included a hazard assessment, an exposure assessment and risk estimation based on monitoring data, and an exposure assessment and risk estimation based on environmental releases estimated from manufacture data. The notification from Japan indicates that the regulatory action was based on a risk or hazard evaluation and specifically cites the Risk Profile document for hexabromocyclododecane as prepared by the POPRC (UNEP/FAO/RC/CRC.13/8 section 2.4.1 of the Japanese notification). The POPRC document cites a Japanese study (Kakimoto et al. 2008) which found hexabromocyclododecane levels in human milk appear to mirror the market consumption of hexabromocyclododecane. In mothers' milk from Japanese women (age 25–29) hexabromocyclododecane levels were below the detection limit in all samples collected during the 10-year period from 1973-1983, but then increased from 1988 onwards. In the period 1988-2006, α-hexabromocyclododecane was detected in all 11 pooled milk samples with levels ranging from 0.4-1.9 ng/g lw. Mean total hexabromocyclododecane concentrations over the period 2000 – 2006 ranged from 1-4 ng/g lw. (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.3.2 of the Risk Profile document) The Risk Profile document states the developmental- and neurotoxic potential of hexabromocyclododecane observed in animal studies give cause for concern when considering risks to human health, particularly for unborn babies and young children (UNEP/FAO/RC/CRC.13/INF/17/Rev.2 section 2.4.6 of the Risk Profile document).
4.2	**Criteria used**	Risk to human health.
	Relevance to other States and Region	The notifying Party did not provide information on the relevance to other States and Regions.

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5	**Alternatives**	The notifying Party did not provide information on alternatives to hexabromocyclododecane.
6	**Waste management**	The notifying Party did not provide information on waste management of hexabromocyclododecane or articles containing it.
7	**Other**	None.

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Country Name: Norway

1	**Effective date(s) of entry into force of actions**	9 July 2016
	Reference to the regulatory document	Hexabromocyclododecane is regulated by Chapter 4 of the Regulation related to restrictions on the manufacture, import and placing on the market of chemicals and other products hazardous to human health and the environment (Product Regulation) act no. 922 of June 2004. This is the Norwegian implementation of Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants and the implementation of the amendment to its Annex I, Commission Regulation (EU) 2016/293 of 1 March 2016.
2	**Succinct details of the final regulatory action(s)**	Regulations to restrict production, import, export and sale of consumer products that contain hexabromocyclododecane exceeding certain limit values.
3	**Reasons for action**	The regulatory action was based on concerns related to human health and the environment.
4	**Basis for inclusion into Annex III**	The final regulatory action was taken to protect human health and the environment. The regulatory action was based on a risk evaluation taking into account the prevailing conditions in Norway.
4.1	**Risk evaluation**	The notification from Norway indicates that the regulatory action was based on a risk or hazard evaluation and that it was relevant to both human health and the Environment. The notification specifically cites the European Union Risk assessment for hexabromocyclododecane (UNEP/FAO/RC/CRC.13/8 section 2.4 of the Norwegian notification). Summarized in the body of the notification from Norway is evidence of exposure to consumers in Norway, its detection in the environment (including remote areas of the arctic), biota, fish, moss, yolk sac of newly hatched chicks. Some temporal trends are noted such as the increase in hexabromocyclododecane levels in eggs from Atlantic puffins and Atlantic cod liver. The abstracts of the scientific articles presented in the supporting information from Norway (UNEP/FAO/RC/CRC.13/INF/18) confirm the occurrence of hexabromocyclododecane in the environment and biota in Norway and its surroundings, and some cases of increasing concentrations over time. Hazard endpoints identified in the United States Environmental Protection Agency 2014 report, *Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)* are also provided in the supporting information from Norway. High or very high hazards are noted for developmental effects, acute aquatic toxicity, and chronic aquatic toxicity. Hexabromocyclododecane is highly persistent and has very high bioaccumulation. (UNEP/FAO/RC/CRC.13/INF/18)
4.2	**Criteria used**	Risk to human health and the environment.
	Relevance to other States and Region	The Stockholm Convention has agreed on listing hexabromocyclododecane in Annex A (ban), with exemptions for production and use in expanded polystyrene and extruded polystyrene in buildings. The global ban was introduced 26 of November 2014.
5	**Alternatives**	The notifying Party provided the US EPA document: United States Environmental Protection Agency: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD). Final report June 2014.
6	**Waste management**	The notifying Party did not provide information on waste management of hexabromocyclododecane or articles containing it.
7	**Other**	None.

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Annex 3 – Addresses of designated national authorities

Japan
CP

From PIC Website (20 November 2017): Name: Mr. Kentaro Mizuuchi Job title: Deputy Director Department: Global Environment Division / International Cooperation Bureau Institution: Ministry of Foreign Affairs Postal address: 2-2-1 Kasumigaseki, Chiyoda-ku 100-8919 Tokyo Japan	Phone: +81 3 5501 8245 Fax: +81 3 5501 8244 Email: kentaro.mizuuchi@mofa.go.jp

Norway
C

From PIC Website (20 November 2017): Name: Ms. Christel Moræus Olsen Job title: Senior Advisor, Rotterdam Convention Designated National Authority for Industrial Chemicals and Biocides Institution: Norwegian Environment Agency Postal address: Grensesvingen 7 0661 Oslo Norway	Phone: +47 735 80 500 Fax: +47 735 80 501 Email: christel.moraeus.olsen@miljodir.no; pic@miljodir.no

C Industrial chemicals
CP Pesticides and industrial chemicals

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Annex 4 – References

Regulatory actions

Japan

The Chemical Substances Control Law (CSCL) and its Enforcement Order.

Norway

Hexabromocyclododecane is regulated by Chapter 4 of the Regulation related to restrictions on the manufacture, import and placing on the market of chemicals and other products hazardous to human health and the environment (Product Regulation) act no. 922 of June 2004. This is the Norwegian implementation of Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants and the implementation of the amendment to its Annex I, Commission Regulation (EU) 2016/293 of 1 March 2016.

Supporting documentation provided by Japan

- POPRC (2010). Risk profile on hexabromocyclododecane. UNEP/POPS/POPRC.6/13/Add.2
- Environmental risk evaluation of hexabromocyclododecane, Ministry of Environment, Japan, October 2013. (The report is in Japanese. An informal English summary and a translation of the table of contents of the report are provided)

Supporting documentation provided by Norway

- European Union: Risk assessment hexabromocyclododecane, CAS-No.: 25637-99-4, EINECS No.: 247-148-4, Final Report May 2008. 492 pp.
- US EPA, United States Environmental Protection Agency: Flame Retardant Alternatives for Hexabromocyclododecane (HBCD). Final report June 2014.
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- Fjeld E, Schlabach M, Rognerud S, Källberg G, NIVA, NILU. Miljøgifter i sedimenter og fisk i Mjøsa, Drammensvassdraget og Drammensfjorden, Oppfølgende undersøkelser i 2004. 2006; pp 7. Norsk institutt for vannforskning, Norge. http://www.miljodirektoratet.no/old/klif/publikasjoner/overvaking/2051/ta2051.pdf Note: The above article is in Norwegian language with a Summary in English in page 6 of the article.

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