Guidance on best available techniques and best environmental practices for the use of hexabromocyclododecane listed with specific exemptions under the Stockholm Convention

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STOCKHOLM CONVENTION

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Abbreviations and Acronyms

ABS	Acrylonitrile butadiene styrene
BAT	Best available techniques
BAT-AEL	BAT associated emission level
BEP	Best environmental practices
BREF	Best available techniques reference document
BFR	Brominated flame retardant
CAS	Chemical Abstracts Service
COP	Conference of Parties
ECHA	European Chemicals Agency
EMAS	Eco Management and Audit Scheme
EMS	Environmental management system
EPS	Expanded polystyrene
ESM	Environmentally sound management
EU	European Union
GC-FID	Gas chromatography flame ionization detection
HBCD	Hexabromocyclododecane
HIPS	High impact polystyrene
ISO	International Organization for Standardization
LDAR	Leak detection and repair
OTNOC	Other than normal operating conditions
PCDD	Polychlorinated dibenzo dioxins
PCDF	Polychlorinated dibenzo furans
POPRC	Persistent Organic Pollutants Review Committee
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
POPs	Persistent organic pollutants
PS	Polystyrene
SDS	Safety Data Sheet
SOP	Standard operating procedure
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
VECAP	Voluntary Emissions Control Action Programme
XRF	X-ray fluorescence
XPS	Extruded polystyrene

1. Introduction

This document supersedes the "Draft guidance on best available techniques and best environmental practices for the production and use of hexabromocyclododecane (HBCD) listed with specific exemptions under the Stockholm Convention" of January 2017[1], to include updated information pursuant to decision SC-9/7 on best available techniques and best environmental practices.

1.1. Purpose

The concept of best available techniques (BAT) is not aimed at the prescription of any specific technique or technology. BAT means the most effective and advanced activities, methods of operation, and techniques for providing the basis for release limitations designed to prevent and, generally to reduce releases of chemicals and their impact on the environment. Best environmental practices (BEP) describe the application of the most appropriate combination of environmental control measures and strategies (Article 5, f (i) and (v) of the Stockholm Convention on Persistent Organic Pollutants (POPs)).

Article 3, paragraph 6 of the Stockholm Convention, requests Parties that have a specific exemption and/or acceptable purpose in accordance with Annex A or B to the Convention to take measures to ensure that any production or use under such exemption or purpose is carried out in a manner that prevents or minimizes human exposure and releases to the environment (i.e. by applying BAT and BEP).

This guidance document has been developed and is updated to guide Parties in their actions to prevent or reduce releases of HBCD from use under the specific exemptions listed in the Convention at its 6th meeting in 2013 (COP-6, SC-6/13).

This document includes most up-to-date information and knowledge with status as of 2021. Previous version(s) of the guidance document are available at http://chm.pops.int/Implementation/NationalImplementationPlans/GuidanceArchive/NewlyDevelopedGuidance/DraftguidanceonBATBEPforPCP/tabid/7962/Default.aspx.

Chapter 1 outlines the purpose and structure of this document.

Chapter 2 provides an overview of the identity, production, and uses of HBCD, the relevant provisions under the Stockholm Convention and a summary of required measures under these provisions.

Chapter 3 includes high level BAT and BEP principles for general chemical management.

Chapter 4 provides specific BAT and BEP guidance for the management of HBCD for the applications listed as a specific exemption under the Convention, including information on available alternatives.

Chapter 5 addresses brief considerations for the identification of products and articles containing HBCD throughout their life cycles in accordance to Part VII of Annex A to the Convention.

Chapter 6 briefly discusses the environmentally sound management of contaminated sites.

2. Substances covered under this document

2.1. Specific substances

In May 2013, by decision SC-6/13, the Conference of the Parties to the Stockholm Convention listed HBCD into Annex A of the Convention. The listing includes specific exemptions for production as allowed for the Parties listed in the register of specific exemptions and for use in expanded polystyrene (EPS) and extruded polystyrene (XPS) in buildings in accordance with the provisions of Part VII of the Annex as follows:

[1] http://chm.pops.int/Implementation/NationalImplementationPlans/Guidance/GuidanceonBATBEPforHBCD/tabid/5526/Default.aspx

Chemical	Activity	Specific exemption
Hexabromocyclododecane	Production	As allowed for the parties listed in the Register in accordance with the provisions of Part VII of this Annex
	Use	Expanded polystyrene and extruded polystyrene in buildings in accordance with the provisions of Part VII of this Annex

In accordance with Part III of Annex A, "Hexabromocyclododecane" means hexabromocyclododecane (CAS No: 25637-99-4), 1,2,5,6,9,10-hexabromocyclododecane (CAS No: 3194-55-6) and its main diastereoisomers: alpha-hexabromocyclododecane (CAS No: 134237-50-6); beta-hexabromocyclododecane (CAS No: 134237-51-7); and gamma-hexabromocyclododecane (CAS No: 134237-52-8).

According to Part VII of Annex A, each Party that has registered for the exemption pursuant to Article 4 for the production and use of HBCD for EPS and XPS in buildings shall take necessary measures to ensure that EPS and XPS containing HBCD can be easily identified by labelling or other means throughout its life cycle.

2.2. Production and use of HBCD

The production of HBCD is allowed for the Parties listed in the register of specific exemptions and its use is allowed in EPS and XPS in buildings in accordance with the provisions of Part VII of Annex A. Information regarding the Parties that have registered for the specific exemption mentioned above can be found on the Convention's website at http://chm.pops.int/Implementation/Exemptions/SpecificExemptions/HexabromocyclododecaneRoSE/tabid/5034/Default.aspx. The register of specific exemptions is updated regularly by the Secretariat. Expired exemptions can be viewed as well.

Each Party that has registered for the specific exemption pursuant to Article 4 of the Convention is required to take measures to ensure that EPS and XPS containing HBCD can be easily identified by labelling or other means throughout its life cycle

HBCD is an additive type flame retardant that is not chemically bound to the matrix. Information on its use in EPS and XPS in buildings under the specific exemption is included in Sections 4.1.1. and 4.1.2. respectively, while information on former/non-exempted uses of HBCD can be found in the Annex to this document.

2.3. Summary of Best Available Techniques (BAT) and Best Environmental Practices (BEP)

Table 1 below summarizes information on BAT and BEP applicable to the use of HBCD in EPS and XPS in buildings. Additional details are available in Chapter 4, Section 4.2.; general principles on BAT and BEP are laid out in Chapter 3. Alternative flame retardants as well as alternatives to EPS and XPS, are widely available and described in Chapter 4, Section 4.3. It should be noted that chemical and non-chemical alternatives may have a broad range of environmental impacts. It is also unknown whether such alternatives are produced by deploying best practices. A case-by-case assessment is necessary to find the best alternative suitable for a specific use. It is important to consider all the available health and environmental data to obtain a comprehensive and robust understanding of the toxicological and ecotoxicological effects and recycling performance of the alternatives. Potential alternatives and their suppliers should therefore be carefully assessed by Parties before being considered as suitable alternatives.

Table 1: Summary of BAT and BEP applicable to the use of HBCD in EPS/XPS in buildings (European Commission 2007, 2016, 2019)

Process steps	BAT	BEP*
General	Regular inspection and maintenance of plant and equipment	Implementation and adherence to an internationally accepted EMS, such as ISO 9001 and ISO 14001.

Process steps	BAT	BEP*
	Monitoring of emissions / releases Substitution of harmful / hazardous substances Limiting the number of emission points	Establishment, maintenance and regular review of a channelled and diffuse emissions to air inventory
Measures for the reduction of channelled emissions	Use of the following techniques to reduce channelled emission to air of organic compounds: adsorption, absorption, catalytic oxidation condensation, thermal oxidation Use of the following techniques to reduce channelled emissions to air of PCDD/PCDF: optimised catalytic or thermal oxidation, rapid waste-gas cooling, adsorption using activated carbon The use of absolute filter, absorption, fabric filter and/or high-efficiency air filter to reduce channelled emissions to air of dust and particulate-bound metals	
Measure for the reduction of diffuse emissions	Limiting the number of emission sources (e.g. minimising pipe lengths, reducing number of pipe connectors and valves, using welded fittings and connections, using compressed air or gravity for material transfer) Collection of diffuse emissions and treating off-gases Facilitating access to potentially leaky equipment (installing platforms, using drones for monitoring) Use of high-integrity equipment: valves with bellow or double packing seals or equally efficient equipment, magnetically driven or canned pumps/compressors/agitators, or pumps/compressors/agitators using double seals and liquid barrier, certified high-quality gaskets, corrosion-resistant equipment	Establishing and implementing a leak detection and repair (LDAR) programme for fugitive emissions and reviewing and updating the programme Establishing and implementing a detection and reduction programme for non-fugitive emissions and reviewing and updating this programme Estimation of diffuse and fugitive emissions to air using a combination of different techniques (such as emission factors, mass balance, thermodynamic models) Review and update of operating conditions (e.g. frequency and duration of reactor opening, preventing corrosion)
Measures referring to emissions from storage	Minimization of level variation Gas balance lines Floating roofs (large tanks only) Installed condensers Vent recovery to treatment	
Measures referring to water emissions	Use of an integrated waste water management and treatment strategy that includes a combination of the following techniques: process-integrated techniques, recovery of pollutants at source, waste water pre-treatment, final waste water treatment Pre-treatment of waste water that contains pollutants that cannot be dealt with adequately	Establishment and maintenance of an inventory of waste water and waste gas streams as part of the environmental management system Monitoring of emissions to water using EN, ISO, national or international standards with a minimum frequency

Process steps	BAT	BEP*
	during final waste water treatment (e.g. remove toxic compounds) Preventing water pollution by appropriate piping design and materials Separating effluent collection systems Use of efficient waste water treatment techniques	

*General BEP guidance is provided in Chapter 3.

2.4. Relationship to the Basel Convention

In addition to the provisions of the Stockholm Convention, those of the Basel Convention are directly relevant to the application of BAT and BEP to address HBCD releases from wastes. Considering that several waste streams are major potential HBCD-containing material flows, synergies between the Stockholm Convention and Basel Convention are of high importance. The Basel Convention places obligations on countries that are Parties to, inter alia: minimize generation of hazardous waste; ensure that adequate disposal facilities are available; and ensure environmentally sound management (ESM) of wastes.

Under the Stockholm Convention, POP-containing wastes are, in accordance with Article 6, paragraph 1 (d) (ii), to be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs or otherwise, they may be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, as well as relevant global and regional regimes governing the management of hazardous wastes.

Paragraph 2 of Article 6 of the Stockholm Convention, which addresses measures to reduce or eliminate releases from stockpiles and wastes, contains the following provisions:

“The Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal to, inter alia:

(a) Establish levels of destruction and irreversible transformation necessary to ensure that the characteristics of persistent organic pollutants are not exhibited;

(b) Determine what they consider to be the methods that constitute environmentally sound disposal referred to above; and

(c) Work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1 (d) (ii).”

The Conference of the Parties to the Basel Convention adopted:

- The updated general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (UNEP/CHW.14/7/Add.1/Rev.1); and
- Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with hexabromocyclododecane (HBCD) (UNEP/CHW.12/5/Add.7/Rev.1).

The general technical guidelines developed under the Basel Convention address matters related to all three of the outstanding definitional issues raised in paragraph 2 of Article 6 of the Stockholm Convention. The two documents listed above provide the framework for the ESM of HBCD wastes.

The documents are available on the Convention´s website at:

http://www.basel.int/Implementation/POPsWastes/TechnicalGuidelines/tabid/5052/Default.aspx.

3. General principles and guidance on BAT and BEP for managing chemicals

3.1. Best Environmental Practices (BEP)

BEP describe the application of the most appropriate combination of chemical management strategies and environmental control measures, including best practices relating to the continuous improvement of environmental, health and safety performance. BEP provide the framework for ensuring the identification, adoption and adherence to management options that play an important role in improving the occupational and environmental performance of a facility.

Key ecological and economic advantages achieved through BEP implementation include protection of workers, the surrounding community and the environment. Specifically, worker and community health, minimizing/optimizing the use of chemicals and auxiliary materials, freshwater and energy, minimizing waste and ecological loading of chemicals from wastewater and off-gassing. Committed senior level company executives are key to making BEP implementation and adherence a success. Well-trained employees are a prerequisite for implementing BEP measures. Limiting factors for improving existing equipment also need to be taken into consideration with the application of BEP, e.g. new equipment has to be rebuilt/modified or installed (for example, automated dosing systems, etc.).

The following section provides basic information on environmental management systems. Their implementation improves worker safety and environmental performance of the facility.

3.1.1. Environmental management systems

A number of environmental management techniques have been determined to be BEP. An Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organizational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation. The scope and nature of an EMS will generally be related to the nature, scale and complexity of the facility, and the range of environmental impacts it may have (GTZ 2008, ZDHC 2015).

BEP is to implement and adhere to an EMS that incorporates the following features:

- Commitment, leadership and accountability of management, including senior management, for the implementation of an effective EMS;
- An analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested Parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
- Definition and/or development of an environmental policy for implementation that includes the continuous improvement of the environmental performance of the installation led by top management (senior corporate leadership commitment and accountability is regarded as a precondition for a successful application of the EMS);
- Establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
- Planning and implementing the necessary procedures (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
- Implementation of the procedures, paying particular attention to:
    - Organizational structure and responsibility;

  - Provision of the financial and human resources needed;
  - Training, awareness and competence;
  - Communication (internal and external);
  - Employee involvement;
  - Documentation;
  - Efficient operational planning and process control;
  - Maintenance programme;
  - Emergency preparedness and response;
  - When (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
  - Implementation of a monitoring and measurement programme;
  - Safeguarding compliance with environmental legislation;
- Performance checks and taking corrective action:
  - Monitoring and measurement;
  - Records Maintenance;
  - Establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
  - Performing periodic independent (where feasible) internal auditing to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
  - Evaluation of causes for nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions and determination of whether similar nonconformities exist or could potentially occur.

Specifically for the chemical sector, BAT is also to incorporate the following features in the EMS (European Commission 2019):

- an inventory of channelled and diffuse emissions to air;
- an other than normal operating conditions (OTNOC) management plan for emissions to air;
- an integrated waste gas management and treatment strategy for channelled emissions to air;
- a management system for diffuse VOC emissions to air.

Four additional features are considered as progressive measures; their absence, however, is generally not inconsistent with BEP:

- Examination and validation of the management system and audit procedure by an accredited certification body or an external EMS verifier;
- Preparation and publication of a regular environmental statement describing all the significant environmental aspects of the facility, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate (i.e., continuous improvement plan and annual progress report);
- Consideration of applicable industry-specific standards, when available;
- Implementation and adherence to an internationally accepted EMS, such as ISO 14001 or the Eco Management and Audit Scheme (EMAS).

This last voluntary step could give higher credibility to the EMS, particularly internationally accepted and transparent standards, such as ISO9001 and ISO14001. Non-standardized systems can in principle be equally effective provided that they are properly designed and implemented.

3.1.2. Specific education and training of employees

The following basic training and education opportunities are beneficial for raising awareness for sound chemicals management:

- Establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
- Appropriate education of workers concerning handling, storing, using and disposing of chemicals and auxiliaries, especially in case of hazardous substances;
- Fostering employee involvement in good environmental management practices;
- Process- and machinery-specific training to increase the level of environmental awareness;
- Regular maintenance of technical equipment (machines in production as well as abatement and recovery devices such as filters and scrubbers); general maintenance (e.g. pumps, valves, level switches);
- Calibration of equipment for measuring and dispensing chemicals;
- Appropriate disposal systems for chemicals.

3.1.3. Additional considerations

It is also important to consider the following forward-looking features of the EMS:

- At the plant (or parts thereof) design stage, consider its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning of the unit;
- Give consideration to the development of cleaner technologies;
- Where practicable, conduct sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, water consumption and generation of waste;
- Ensure full details provision for activities carried out on-site, such as:
    - Descriptions of the waste treatment methods and procedures in the place of installation;
    - Diagrams of the main plant items that have some environmental relevance, together with process flow diagrams (schematics);
    - Details on the control system philosophy and how the control system incorporates environmental monitoring information;
    - Details on how protection is provided during abnormal operating conditions such as momentary stoppages, start-ups, and shutdowns;
    - Annual survey of the activities carried out and the waste treated, which contains a quarterly balance sheet of the waste and residue streams, including the auxiliary materials used for each site;
- Have sufficient staff available on duty with the requisite qualifications at all times. All personnel should undergo specific job training and further education, e.g. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation.

Processes must be designed to state-of-the-art safety and environmental standards as outlined, for example, in the European Union BREFs (http://eippcb.jrc.ec.europa.eu/reference/) and other comparable regulations. Acceptable process design must take into account the potential for side products and wastes, and make provisions for their safe handling or destruction. It must recognize that if the process carries the potential for generation of chemicals listed in Annex C to the Convention, the four streams being emitted from a facility – air, water, residues and product – also carry that potential. Modern process design takes into account that potential, monitors for and controls emissions and includes operations to reduce or eliminate emission of those materials, commensurate with the requirements of the Convention. Modern safety management includes extensive training for operators and sufficient analytical and control instrumentation so that the facility as a whole operates to responsible standards.

The main demands for modern and safe chemical production can be found, for example, in relevant BREF documents (European Commission 2006, 2016).

The principle of green chemistry to promote the use of alternative synthetic routes and alternative reaction conditions rather than existing less environmentally friendly processes should be promoted (see for instance European Commission 2006, 2016), i.e. by:

- Improving process designs to maximise the incorporation of all the input materials used into the final product;
- Using substances that possess little or no toxicity to human health and the environment. Substances should be chosen in order to minimise the potential for accidents, releases, explosions and fires;
- Avoiding the use of auxiliary substances (e.g. solvents, separation agents, etc.) wherever possible;
- Minimising energy requirements, in recognition of the associated environmental and economic impacts. Reactions at ambient temperatures and pressures should be preferred;
- Using renewable feedstock rather than depleting, wherever technically and economically practicable;
- Avoiding unnecessary derivatisation (e.g. blocking or protection groups) wherever possible;
- Applying catalytic reagents, which are typically superior to stoichiometric reagents.

3.2. General BAT and BEP measures applicable to handling all chemicals

This section describes general principles, measures and safety precautions that apply to all types of chemicals and industries handling them (GTZ 2008, ZDHC 2015).

Chemical Knowledge, Storage, Handling, Dosing, Dispensing and Transport

The following principles and/or measures apply:

- When storing, handling, dosing, dispensing, and transporting any chemical, caution should be used, necessary protective measures implemented and proper personal protective equipment worn.
- Before ordering/receiving any chemical, review the local language Safety Data Sheet (SDS). If possible, avoid CMR (carcinogenic, mutagenic, reproductive toxin) and PBT (persistent, bioaccumulative and toxic) substances, and substances that can degrade to CMR or PBT substances (see SDS Section 2, 11, and 12).
- In case a complete SDS is not available from one supplier, order the product from an alternative supplier that provides a complete SDS.
- Before handling any chemical, review the SDS carefully.
- Gather information from the supplier on amounts of residual raw materials, by-products and potential degradation products in the product you intend to order.
- A trained representative of the receiving company should authorise and attend the delivery of the product, whether it is to be delivered in bulk quantities or smaller packages and containers.

- Reject leaking or dented containers upon receiving.
- Deliveries should be made according to a written supervision procedure that includes a checklist covering all the safety-critical steps in the delivery process.
- Proper storage according to the instruction of the most up to date SDS, preferably in Global Harmonization System (GHS) format.
- Proper labelling of containers and equipment; storage in special compartments, containers or locations for toxic and explosive chemicals to avoid leakage and spills.
- Dosing and dispensing without spilling in automated dosing systems.
- All areas where chemicals are delivered, stored, transferred and used should be secure: the site itself should be secure with local measures to ensure security, such as lockable connections to storage tanks or a lockable container storage area.
- The plant and equipment should be regularly inspected and serviced to ensure proper functioning; this especially includes checking the integrity and/or leak-free status of valves, pumps, pipes, tanks, pressure vessels, drip trays, containment facilities and bunds and the functionality of alarms/warning systems.

Minimization/Optimization of the Chemicals Used

The following principles and/or measures apply:

- Minimize the use of all chemicals and auxiliary materials.
- Measure, mix and dose chemicals carefully to avoid losses.
- Minimize residual, leftover chemicals, by calculating exactly how much is needed for the process step.
- Substitution of overflow rinsing or minimization of water consumption in overflow rinsing by means of optimized process control.
- Reuse of rinsing baths, including final rinsing baths – where possible.
- Reversing of current flows in continuous washing.
- Cleaning and recycling of process water – where possible.

Engineering, Design and Equipment

It is recommended to:

- Use equipment, pipes, valves, etc. that are suited to handle the material (e.g., corrosion resistance) to ensure a long equipment life and to avoid equipment breakdown and leaks.
- Prevent releases to the environment via air, install dust collectors, scrubbers or similar devices.
- All waste should be managed in an environmentally sound manner in accordance with the Stockholm Convention provisions and taking into account the Basel Convention technical guidelines (UNEP 2019a, 2015).

Leak and Spill Procedure

It is recommended to:

- Follow instructions according to information provided on the SDS.
- Make such a procedure part of the operator training to enhance preparedness.

- Implement routine monitoring and maintenance (M&M) programme or leak detection and repair (LDAR) programme. Components leak rates should be checked on a regular basis to identify leaking components for repair and future monitoring.
- Over time, it is possible to build up a picture of priority areas and persistent critical components enabling effective targeting of maintenance work and/or improvement in design.

Emissions Reductions and Waste Management

It is recommended to:

- Follow all procedures as outlined above.
- All waste should be managed in an environmentally sound manner in accordance with the Stockholm Convention provisions and taking into account the Basel Convention technical guidelines (UNEP 2019a, 2015).

4. Specific BAT and BEP measures

4.1. Process description

4.1.1. Expandable polystyrene (EPS) in buildings

Formulation of EPS compound

EPS is produced in a batch process, i.e. discontinuously, by suspension polymerization of styrene in water. Styrene is dispersed in water in the form of small droplets. Prior to combining the water with the organic phase, additives are introduced. Typically, these include suspension agents, free-radical forming initiators and the flame retardant. HBCD-powder, most often delivered in 25 kg paper bags with a plastic liner, is suspended at low temperatures in styrene prior to the addition of the water phase.

Normally the bags are emptied into an intermediate storage container from where the HBCD is transported via pipes and a weighing station prior to the addition to the styrene. In the reactor, styrene forms the disperse phase as small monomer droplets in the continuous water phase. Final droplet size (0.01 to 0.5 mm) is determined by the ratio of disperse to continuous phase (typically 50:50) and by stirrer speed. The suspension agents prevent coalescence (Posner et al. 2010).

Within the monomer droplets (bulk), polymerization occurs while the reactor content is heated up and held at its reaction temperature. During this free-radical polymerization, an expansion agent (e.g. pentane) is added to the reactor under pressure, where it is absorbed in the polymer droplets. In the final EPS beads, HBCD is incorporated as an integral and encapsulated component within the polymer matrix with uniform concentration throughout the bead (Posner et al. 2010).

After complete conversion of the styrene monomer to EPS-beads, the reactor is cooled down and the beads are separated from the water by centrifugation. The decanted water, which could contain dissolved and dispersed HBCD, is reused and exchanged on an annual basis or less frequently. The EPS beads are dried, and thereafter classified into various size fractions and surface coated. These different grades are packed in bins, bags, or transported in bulk trucks to the EPS-converters. The typical concentration of HBCD in EPS beads is assumed to be 0.7%, and the maximum concentration 1.0% (European Commission 2008).

Industrial use of EPS compound

EPS foam is produced from EPS beads via pre-expansion of the beads with dry saturated steam, drying with warm air and shaping in shape moulds or in a continuous moulding machine. First, the raw material beads are pre-expanded in loose form with the help of dry saturated steam in pre-expanders. The raw materials are transported via pipes or tubes from the packaging containers to these stirred vessels. After expansion, the beads are partly dried in fluid bed driers with warm air (Posner et al. 2010).

The beads are subsequently stored in large permeable silos to “mature” for several hours, up to 24 hours. During this stage, the beads dry further and reach equilibrium with the ambient atmosphere around them. In the third phase the beads are transported/blown, via pipes/tubes into block or shape moulds or in a continuous moulding machine in which the product gets its shape. The foam can then be further formed by cutting, sawing or other machine operations (European Commission 2008).

Professional and private use of EPS containing HBCD

EPS containing HBCD can be used in insulation panels/boards in the construction sector (exempted use).

Secondary process activities of the EPS foam products, especially block foam, can be cutting, sawing and machining to manufacture shaped products such as interlocking boards. The cuttings and sawdust can be recycled in the moulding process within the plant. The EPS foam products, e.g. insulation boards, are normally transported shrink-wrapped, or packed in cartons (Posner et al. 2010).

4.1.2. Extruded Polystyrene (XPS) in buildings

At the production of XPS-material, the formulation stage can take place either at a separate site or at the same site as the following stage of industrial use.

Formulation of XPS compound

The HBCD is supplied either in powder or in low-dust granulated form in either 25 kg bags or in 1 tonne supersacks or “big bags”. The supersacks are emptied into hoppers designed to minimize dust emissions. The HBCD is then carried to the point of mixing with screw or air driven metering equipment. The compounded polystyrene is extruded and cut into granules, and packaged. The extrudate is either air-cooled or cooled by running in a water bath. According to industry information, the masterbatch can contain approx. 40% (w/w) of HBCD (European Commission 2008, Posner et al. 2010).

Industrial use of XPS- compound (masterbatch) / HBCD powder/granules at the manufacture of XPS

The manufacture of XPS materials is carried out in the following way:

- The polystyrene, the additives such as processing aids, flame retardant in the form of a compound, powder or granules, dye and blowing agent are fed continuously to an extruder.
- The polymer is melted; the blowing agent is mixed with the melted polymer and a “foamable gel” is formed.
- The gel is then cooled before it exits through an orifice called a die, where the dissolved blowing agent volatilizes, causing the plastic to assume a foam structure. The blowing agent reduces the density of the product by the formation of a myriad of closed cells within its structure.
- The foam is then trimmed to desired shape. The boards are packed into shrink-wrapped bundles and palleted. The pallets are stored for curing and are then ready for shipment.
- The trimmed foam accounts for about 15-25% of the feed material and is recycled back to the extruder. This material is mainly shavings from the side-profile and “skin” from the surface. The recycled material is compacted or pelletized; in the latter case the strands comes in contact with water during cooling.

One technology, which is not commonly used, known as the UCI technology, uses a vacuum in addition to blowing agents to produce the lighter (i.e., lower density) foams. In this technology, the product comes into contact with water in a water pond directly after the extrusion.

Insulation panels made from XPS can contain 0.8 to 2.5% (w/w) HBCD (European Commission 2008, Posner et al. 2010).

Professional and private use of XPS containing HBCD

XPS containing HBCD can be used in end-products such as insulation panels/boards in the construction sector (exempted use). The XPS product is transported usually to a main distributor’s warehouse, perhaps from there to a local distributor/dealer and hence to a building site on the orders of the building contractor. There is a small amount (5%) of “do it yourself”-business via “do it yourself”-stores/building material suppliers. For major building sites, the building contractor can have material delivered directly from the plant to the building site (Posner et al. 2010).

4.2. BAT and BEP measures applicable to the use of HBCD in EPS/XPS in buildings

The Reference Document on Best Available Techniques in the Production of Polymers (European Commission 2007) addresses a wide variety of BAT and BEP measures spanning the whole polymer production process. This document is being revised in the draft WGC BREF (Waste Gas Treatment in the Chemical Sector: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-12/WGC_D1.pdf), where also the production of polymers is included (European Commission 2019). For issues regarding waste water the Reference Document on Best Available Techniques for common waste water/waste gas treatment /management in the chemical sector (European Commission 2016) applies.

Measures (applicable to all polymer production processes) include:

- Implementation of an EMS (See Chapter 3 of this guidance document)
- Establishment, maintenance and regular review of a channelled and diffuse emissions[2] to air inventory as part of the EMS
- Use of an integrated waste gas management and treatment strategy that includes process integrated recovery and abatement techniques
- Limiting the number of emission points. The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment

Measures for the reduction of channelled emissions are:

- Use of the following techniques to reduce channelled emission to air of organic compounds: adsorption, absorption, catalytic oxidation condensation, thermal oxidation
- Use of the following techniques to reduce channelled emissions to air of PCDD/PCDF: optimised catalytic or thermal oxidation, rapid waste-gas cooling, adsorption using activated carbon
- The use of absolute filter, absorption, fabric filter and/or high-efficiency air filter to reduce channelled emissions to air of dust and particulate-bound metals

Measure for monitoring diffuse emissions include:

- Establishing and implementing an LDAR programme for fugitive emissions and reviewing and updating the programme for the next campaign
- Establishing and implementing a detection and reduction programme for non-fugitive emissions and reviewing and updating this programme
- Estimation of diffuse and fugitive emissions to air using a combination of different techniques (such as emission factors, mass balance, thermodynamic models)

Measures to prevent or reduce diffuse emissions:

- Limiting the number of emission sources (e.g. minimising pipe lengths, reducing number of pipe connectors and valves, using welded fittings and connections, using compressed air or gravity for material transfer)
- Collection of diffuse emissions and treating off-gases
- Facilitating access to potentially leaky equipment (installing platforms, using drones for monitoring)

[2] Channelled emissions that are those released via specific emission points such as stacks, while diffuse emissions are dispersed emissions which can result from both 'area' sources (geographically dispersed) or 'point' sources (fugitive emissions).

- Use of high-integrity equipment
    - valves with bellow or double packing seals or equally efficient equipment
    - magnetically driven or canned pumps/compressors/agitators, or pumps/compressors/agitators using double seals and liquid barrier
    - certified high-quality gaskets
    - corrosion-resistant equipment
- tightening of gaskets, installing tight caps on open ends
- replacement of leaky equipment parts
- review and update of operating conditions (e.g. frequency and duration of reactor opening, preventing corrosion)
    - use of closed systems
    - use of techniques to minimise emissions from surface areas
    - installing oil creaming systems on open surfaces
    - periodically skimming open surfaces
    - installing anti-evaporation floating elements on open surfaces
    - treating waste water streams to remove releases and send them to recovery and/or abatement
    - installing floating roofs on tanks

Measures referring to water emissions:

- Establishment and maintenance of an inventory of waste water and waste gas streams as part of the environmental management system
- Monitoring of emissions to water using EN, ISO, national or international standards with a minimum frequency
- Use of an integrated waste water management and treatment strategy that includes a combination of the following techniques: process-integrated techniques, recovery of pollutants at source, waste water pre-treatment, final waste water treatment
- Pre-treatment of waste water that contains pollutants that cannot be dealt with adequately during final waste water treatment (e.g. remove toxic compounds)
- Preventing water pollution by appropriate piping design and materials e.g.:
    - pipes and pumps placed above ground
    - pipes placed in ducts accessible for inspection and repair
- Measures for water pollution prevention also include separate effluent collection systems for:
    - contaminated process effluent water
    - potentially contaminated water from leaks and other sources, including cooling water and surface run-off from process plant areas, etc.
    - uncontaminated water
- Use of efficient waste water treatment techniques
- The treatment of the air purge flows coming from degassing silos and reactor vents, e.g.
    - Recycling

- Thermal oxidation
- Catalytic oxidation
- Flaring (only discontinuous flows)

In addition, for the production of polystyrene, the following BAT are to be taken into account (European Commission 2007):

Minimization and control of emissions from storage:

- minimization of level variation;
- gas balance lines;
- floating roofs (large tanks only);
- installed condensers;
- vent recovery to treatment.

Recovery of all purge streams and reactor vents:

- Purge streams are used as fuel oils or treated with thermal oxidizers that can be used for heat recovery and steam production.

Collection and treatment of exhaust air from pelletising:

- Usually, the air sucked off the pelletising section is treated together with reactor vents and purge streams (GPPS and HIPS processes).

Emission reduction from the dissolving system in HIPS processes:

- cyclones to separate conveying air;
- high concentration pumping systems;
- continuous dissolving systems;
- vapour balance lines;
- vent recovery to further treatment;
- condensers.

Emission reduction from EPS process-specific techniques:

- vapour balance lines;
- condensers;
- vent recovery to further treatment.

European Commission (2007) lists the following EPS process-specific techniques:

Emissions	Available techniques	Cost	Efficiency
Gas			
Storage	Minimize level variation Gas balance lines Floating roofs Condensers installed Vent recovery to treatment	L M H H H	M M H H H
Preparation of organic reactor charges	Vapour balance lines Vent recovery to external treatment (regenerative thermal oxidizer)	L M	H H
Pentane emission after polymerization	Adsorption/desorption systems/flare	H	H

Liquid			
Purge	Recovered to be used with fuel oil or incinerated	M	H
Wastewater	Biological treatment*	L	H
Solid waste**			
Hazardous and non-hazardous waste	Minimize the volume by good segregation Collect to external treatment	L M	M H
Management techniques		M	H

*existing treatment plant
**only insignificant quantities
L: Low; M: Medium; H: High

In order to reduce the frequency of the occurrence of OTNOC and to reduce the emissions to air during OTNOC, the draft WGC BREF (European Commission 2019) requires the set up and implementation of a risk-based OTNOC management plan as part of the EMS that includes all of the following features:

- identification of potential OTNOC (e.g. failure of equipment critical to the control of channelled emissions to air, or equipment critical to the prevention of accidents or incidents that could lead to emissions to air (critical equipment), of their root causes and of their potential consequences;
- appropriate design of critical equipment (e.g. equipment modularity and compartmentalisation, backup systems, techniques to obviate the need to bypass waste gas treatment during start-up and shutdown, etc.);
- set-up and implementation of a preventive maintenance plan for critical equipment;
- monitoring (i.e. estimating or, where this is possible, measuring) and recording of emissions and associated circumstances during OTNOC;
- periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted as recorded in point iv.) and implementation of corrective actions if necessary;
- regular review and update of the list of identified OTNOC.

In order to reduce channelled emissions to air of organic compounds, BAT is to use one or a combination of the techniques given below (European Commission 2019):

Technique*	Applicability
Adsorption	Generally applicable
Absorption	Generally applicable
Catalytic oxidation	Applicability may be restricted by the presence of catalyst poisons in the waste gases
Condensation	Generally applicable
Thermal oxidation	Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by the design and/or operational constraints. Straight thermal oxidation is generally applicable.

* For the description of techniques see Section 4.4.1. of the draft WGC BREF (European Commission 2019)

The BAT associated emission level (BAT-AEL) for channelled emissions to air of total volatile organic carbon (TVOC) containing substances classified as CMR 1A or 1B is < 1-5 mg/Nm^3 as daily average or average over the sampling period and the mass flow threshold is 2.5 g/h (European Commission 2019).

The BAT associated emission level (BAT-AEL) for channelled emissions to air of total volatile organic carbon (TVOC) containing substances classified as CMR 2 is < 1-10 mg/Nm^3 as daily average or average over the sampling period and the mass flow threshold is 2.5 g/h (European Commission 2019).

Industry voluntary measures

The Voluntary Emissions Control Action Programme (VECAP) is a voluntary industry programme established to identify, control and reduce the potential for emissions of polymer additives into the environment. VECAP published an addendum to the Code of Good Practice, including BAT for emptying bags containing brominated flame retardants. VECAP (2019) recommends best practices for the following stages of the production and use processes:

- Transport and storage

Solid chemicals are transported to warehouses in bags that, on arrival, are brought to a storage area in the factory. During this stage in the process, potential emissions of chemicals could occur as bags could break. VECAP best practice recommends that bags are carefully checked on arrival, and when removed from storage, to ensure that they are not damaged and that all seals are intact. Any tears should be repaired immediately and spills cleaned up.

- Opening and emptying of packaging

At this stage, chemicals might spill on the floor, be discharged into the air as dust, or adhere to the personal protective clothing of workers. Emptying bags and intermediate bulk containers (IBCs) is also a critical point since any residues left in packaging could lead to environmental emissions during packaging disposal.

VECAP best practices recommend that when using a chemical in powder form, bags should only be opened in a sealed environment, with all windows and doors in the surrounding areas firmly closed. Furthermore, in well-maintained places where powder materials are handled, a local exhaust ventilation system should be in place, preferably a tiered system composed of several filters. This limits the risk of environmental emissions, allowing the air to be filtered and appropriate disposal of residual dust. When making liquid slurry, the recommended practice is that bags are securely connected to the entrance of the machine (the mal) before opening them.

Bags should be thoroughly emptied shaking all four corners of the bag carefully to ensure the maximum content is removed. IBCs should be tilted in order to allow remaining product to be accessed and removed.

In the event that chemicals spill on the floor at any stage of the process, spillage should be cleaned immediately, preferably with dry cleaning via a vacuum system. If using a wet clean process, cleaning water should be collected and treated, either on site or at a municipal water treatment facility. Sludge collected from waste water treatment should be incinerated.

- Ventilation

To reduce dust emissions to air, an exhaust ventilation system equipped with well-operated fabric filters should be the minimum in place. In addition, sucking the air stream into the mixer further reduces dust emissions including from doors and workers' clothing. The filter system should be properly maintained and filter dust and spent filters properly disposed.

- Disposal of packaging at the end of the production process

VECAP best practices extend to the end of the production process and the safe disposal of packaging and waste.

4.3. Alternatives to the use of HBCD in EPS/XPS in buildings

Alternative flame retardants as well as alternatives to EPS and XPS are available (UNEP 2019b). It should be noted that chemical and non-chemical alternatives may have a broad range of environmental impacts. It is also unknown whether such alternatives are produced by deploying best practices. A case-by-case assessment is necessary to find the best alternative suitable for a specific use. It is important to consider all the available health and environmental data to obtain a comprehensive and robust understanding of the toxicological and ecotoxicological effects and recycling performance of the alternatives. Potential alternatives and their suppliers should therefore be carefully assessed by Parties before being considered as suitable alternatives. However, it should be noted that polymeric flame retardants (Table 2, entry 1) cannot be easily released from the polymer matrix due to its high molecular weight (US EPA 2014). The risk of unintended release into the environment during the lifecycle of EPS/XPS products is therefore expected to be much lower compared to all other alternatives of HBCD listed in Table 2.

Substitution of HBCD can take place at two levels:

1. **HBCD can be replaced by another flame retardant with similar properties:**

Table 2. Chemical alternatives to HBCD in EPS/XPS (UNEP 2019b)

Chemical	Trade names	Claimed suitability	Availability
Benzene, ethenyl-, polymer with 1,3-butadiene, brominated (brominated co-polymer of styrene and butadiene) Synonym: Polymeric FR CAS No: 1195978-93-8	Bluedge™ Emerald Innovation™ 3000 FR122P GreenCrest® Polymeric FR™	EPS via one-step process, likely also suitable in two-step process XPS	Commercially available. Originally developed by Dow Chemicals Company as a polymeric, high molecular weight flame retardant alternative to HBCD. Exclusive rights for the production, sales and marketing of the pFR have been granted by Dow to three flame retardant manufacturers worldwide: ICL-IP, Chemtura (now LANXESS) and Albemarle. Estimated 50% of the global demand of HBCD substituted in 2017[3] Production capacity in the US: 14 000 MT (LANXESS) Production capacity in Israel: 10 000 MT (ICL-Industrial Products) According to ICL-IP (pers. comm. 2019), total installed capacity of polymeric FR of Bluedge™ technology licensed producers is more than adequate to meet global demand today and into the future.
Benzene, 1,1'-(1-methylethylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)] Synonym: TBBPA-bis brominated ether derivative CAS No: 97416-84-7	Pyroguard SR-130 SR-130 FR-130 AP 1300 S	EPS XPS HIPS Limited testing in the Plastics Europe testing programme and not known to be technically feasible for use in EPS in Europe (Assessment of Alternatives).	Commercially available, but unlikely to be available in sufficient quantities to replace HBCD in the EU in 2014 (Assessment of Alternatives). Japan was expected to replace HBCD with FR130 and polymeric FR (ICL-IP, 2014). Several producers in Europe and China.
Tetrabromobisphenol A bis(2,3-dibromopropyl ether) (TBBPA-DBPE), CAS No: 21850-44-2 with dicumene for XPS and dicumyl peroxide for EPS, as usual synergists	STARFLAME PS SAM 54: masterbatch for XPS STARFLAME PO SAM 55: masterbatch for XPS	EPS XPS	For XPS the alternative is already in use in commercial scale. For EPS only laboratory scale experience, not yet in wide use. All raw materials, however, are worldwide commodities and thus GC SAM 55 E is reported to be immediately available for up-scaling on a commercial scale.

[3] https://lanxess.com/en/corporate/media/press-releases/2017-00049e/ Accessed 23 January, 2019

Chemical	Trade names	Claimed suitability	Availability
	GC SAM 55 E: powder blend for EPS		

Additional details on costs and efficacy of these alternatives are provided in UNEP (2019b).

2. Resin/Material Substitution

Stone wool

Stone wool is made from volcanic rock, typically basalt or dolomite, an increasing proportion of which is recycled material in the form of briquettes. Slag wool is made from blast furnace slag (waste). The stone wool is a subgroup of the mineral wool together with glass wool. Over the last decade, glass wool, rock (stone) wool and slag wool have together met just over half of the world demand for insulation.

After the furnace, droplets of the vitreous melt are spun into fibres. Droplets fall onto rapidly rotating flywheels or the mixture is drawn through tiny holes in rapidly rotating spinners, which shapes it into fibres. Small quantities of binding agents are added to the fibres for adhesion. The structure and density of the product can be adapted to its precise final usage. Inorganic rock or slag is the main components (typically 98%) of stone wool. The remaining 2% organic content is generally a thermosetting resin binder (an adhesive), usually phenol formaldehyde and a little mineral oil.

Glass wool (fibre glass insulation)

For glass wool, the raw materials are sand, limestone and soda ash, as well as recycled off cuts from the production process. The glass wool is a subgroup of the mineral wool.

The raw materials are melted in a furnace at very high temperatures, typically 1300 to 1500 °C. In insulation, fibreglass borates act as a powerful flux in the melt as it lowers glass batch melting temperatures (Floyd et al., 2008). After the furnace, droplets of the vitreous melt fall onto rapidly rotating flywheels or the mixture is drawn through tiny holes in rapidly rotating spinners, which shapes it into fibres for adhesion. Small quantities of binding agents are added to the fibres. Glass wool products usually contain 95% to 96% inorganic material (Eurima 2011).

Phenolic foams

Phenolic foam insulation is made by combining phenol-formaldehyde resin with a foaming agent. When hardener is added to the mix and rapidly stirred, the exothermic reaction of the resin, in combination with the action of the foaming agent, causes foaming of the resin. This is followed by rapid setting of the foamed material (Greenspec 2011). In the process, phenol is polymerized by substituting formaldehyde on the phenol's aromatic ring via a condensation reaction and a rigid thermoset material is formed. Compared to the EPS/XPS and PUR/PIR, the market share of the phenolic foams seems to be small due to higher prices.

Natural fibre-based insulation materials

Various modern insulation materials are based on natural fibres, primarily plant fibres but also sheep wool. Some of these have been known for centuries but have had a renaissance over the last decades with the growing interest for environment friendly building techniques. They are available as loose insulation fill, as insulation batts or/and as rolls.

More detailed information on the known alternatives to HBCD used in XPS and EPS is available in UNEP (2019b).

5. Considerations for identification, screening and labelling of HBCD containing products and articles

Identification and screening

UNEP (2017, 2021a) provides guidance for screening and monitoring in products and articles.

The screening of HBCD in end-of-life products should be done according to the requirements of the Basel Convention and the relevant technical guidelines should be considered (UNEP 2019a, 2015).

Analytical procedures and methods for HBCD can vary depending on the nature of the matrices in which the HBCD is to be found, along given value chains, starting from production over use to waste and disposal. Releases to soil, water and sediment from production and from application/use are likely to be monitored by means of trace analysis, for which a number of methods exist (UNEP 2017).

Regarding HBCD in use, and in particular as flame retardant in polystyrene (PS) matrices such as PS, ABS, HIPS, EPS and XPS, standard operating procedures (SOPs) exist. These methods have been developed to capture the concentrations of HBCD at levels in products fabricated to provide optimum flammability characteristics[4].

The screening of bromine in plastics by means of XRF, in particular in polystyrene plastics containing flame retardants in electrical engineering and foams like EPS and XPS from construction activities, is widely used today as a qualitative method to prove the presence of a flame retardant. DIN EN 62321-3-1: 2013[5] describes how the X-ray fluorescence analysis (XRF) can be used for the screening of total bromine.

A qualitative statement on the presence of HBCD derived from the measurement results for bromine in EPS / XPS foams is possible by applying the HBCD-Rapid test (also called “Fraunhofer extraction method”)[6].

There is currently no standardized method of analysis for HBCD in plastic materials. Since 2015 work has been carried out under the IEC TC111 WG3 for the development of the standard IEC DIN EN 62321-9 (HBCD) related to HBCD in electro technical products and polystyrene foams (validated to 1000 ppm HBCD). The standard is expected to be published soon.

Industry has developed and shared a validated method for the 1000 ppm range of HBCD in PS foams based on Gas Chromatography-Flame Ionization Detector (GC-FID). Presently no validated method exists for measuring HBCD at lower levels in PS material.

The above-mentioned procedures are equally applicable to the use phase as well as to end of life phase of plastic materials containing HBCD.

Labelling

According to Part VII of Annex A to the Stockholm Convention, Parties having registered for the exemption for the production and use of HBCD for EPS and XPS in buildings are required to take necessary measures to ensure that EPS and XPS containing HBCD can be easily identified by labelling or other means throughout its life cycle. The identification is intended to support waste management for the exempted use. Guidance on labelling of products or articles that contain POPs is available in UNEP (2019d).

6. Considerations for the environmentally sound management of contaminated sites

In accordance with the provisions of Article 6(1)(e), Parties shall endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in Annex A, B or C. UNEP (2019c) provides a list of potential HBCD-contaminated sites or hot spots.

The identification and inventory of polluted sites is merely a first step to manage related risks and for final clean-up and rehabilitation. Guidance on the identification and management of POPs contaminated sites is available in UNEP (2021b).

[4] Annex 1-C: HBCD in articles and products, Draft Guidance on Sampling, Screening and Analysis of Persistent Organic Pollutant in Products and Articles (UNEP 2017)

[5] DIN EN 62321-3-1: 2013 - Methods for the determination of certain substances in electrical engineering products – Part 3-1: Screening - Lead, mercury, cadmium, total chromium, and total bromine by X-ray fluorescence spectrometry

[6] Schlummer et al. (2015), WM&R Vol. 33, No. 7, 662 - 670

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Annex: Former / non-exempted uses of HBCD

An overview of former/non-exempted uses of HBCD, that are no longer allowed under the Convention, is provided below (UNEP 2019, ECHA 2009):

Material	Use/Function	End-products (Examples)
Expanded polystyrene (EPS)	Insulation	• Insulation boards against frost heaves of road and railway embankments • Packaging material (non-food packaging, and very minor use and not intended in food packaging)
Extruded polystyrene (XPS)	Insulation	• Insulation boards (against cold or warm) of transport vehicles e.g. lorries and caravans • Insulation boards against frost heaves of road and railway embankments
High impact polystyrene (HIPS)	Electrical and electronic parts	• Electric housings for VCR • Electrical and electronic equipment e.g. distribution boxes for electrical lines • Video cassette housings
Polymer dispersion for textiles	Textile coating agent	• Upholstery fabric • Bed mattress ticking • Flat and pile upholstered furniture (residential and commercial furniture) • Upholstery seating in transportation • Automobile interior textiles • Draperies, and wall coverings • Interior textiles e.g. roller blinds

Expanded polystyrene (EPS) / Extruded polystyrene (XPS) for insulation in other applications than buildings

EPS containing HBCD was used in end-products such as rigid packaging material for fragile equipment or packaging material such as ”chips” and shaped EPS-boards. HBCD-containing EPS was also used in props for theatre, film and for exhibitions.

EPS used in packaging does normally not contain any flame retardant additive. According to information from 2008, only in some cases, e.g. when requested by customers to minimize for instance the effect of fires, flame retarded EPS-material was used for non-food packaging applications (European Commission 2008, 2019).

Further, flame retarded expanded polystyrene / extruded polystyrene was also used for prevention of frost damage on roads and in railway embankments. It is assumed that, when flame retardant was used, the concentration of HBCD was XPS was around 0.8-2.5% (European Commission 2008, Posner et al. 2010).

High impact polystyrene (HIPS)

High impact polystyrene was produced either in a batch or continuous polymerization process. The final raw material is homogenized and extruded into HIPS pellets either strand- or face-out. These pellets are the starting material for the production of flame retarded HIPS. Different flame retardant additives are used of which HBCD was used only a small part. In the feeding hopper all ingredients, together with the HIPS pellets, are metered in the extruder for further mixing, homogenization and granulation into pellets.

An alternative route for HIPS production is via an intermediate-compounding route. First, a masterbatch of general-purpose polystyrene pellets and HBCD at a high concentration is prepared, followed by compounding this masterbatch with virgin HIPS material in a conversion step. The process of preparing the HBCD masterbatch is similar to that of the HIPS production but at higher HBCD concentrations (Posner et al. 2010).

After the molten mass at the end of the extruder is pressed through a plate with holes (die/plate), different granulation processes take place, for example:

- face cutting in air; a rotating knife directly after the plate cut the extruded “strands” into pellets cooled by air.
- under water face cutting; a rotating knife directly after the plate in a water bath cuts the extruded strands in pellets cooled by water.
- strand cutting; the molten strands are passed through a water bath to solidify and cool and are cut in a granulator

After the granulation process the HIPS pellets are dried and packed, either in bulk silos/containers or 25 kg bags, ready for conversion into HIPS products. The HBCD masterbatch process normally uses the strand-cutting route.

HIPS materials can be converted into HIPS products using various extrusion techniques and injection moulding. HIPS products can also be manufactured via a compounding route, i.e. mixing virgin HIPS raw material with a HBCD masterbatch during the extrusion or injection moulding process.

Most of the flame retarded HIPS products are used in electrical and electronic appliances. HBCD in HIPS has been used in e.g. (UNEP 2019):

- audio visual equipment cabinets (video and stereo equipment)
- distribution boxes for electrical lines in the construction sector
- refrigerator lining.

Textile coatings

Flame retardant systems are used in textile applications to comply with flame retardant standards. HBCD was formulated to polymer-based dispersions (e.g. acrylic or latex) of variable viscosity in the polymer industry. The dispersions are then processed in the textile finishing industry. When HBCD was used for in this application, the HBCD used for textile back-coating needed to be very small. Therefore micronising was performed before the formulation step.

Textile formulators prepare flame retarded formulations, which are water-based dispersions and can contain a binder system and the flame retardant as well as up to 20 other ingredients. These flame retarded formulations, mostly custom tailored, are supplied as dispersion to back-coaters. In this scenario, formulation is carried out in an open batch system. HBCD was added to a dispersion containing water, a polymer e.g. synthetic latex, acrylates or PVC, thickener and dispersion agent. The chemical preparation can also contain other brominated flame retardants. In addition, synergists, such as antimony trioxide and antimony pentoxide, could also be included in the end-product. According to industry information, the concentration of HBCD in the dispersion ranged from 5 to 48%. However, additional product information indicates that a likely concentration of HBCD in the coated layer could have been about 25% corresponding to 10 - 15% in the final dilution of the dispersion. Water and solvents will leave the preparation when dried and concentrations of flame retardants in the coating layer will likely be higher than in the preparation (Posner et al. 2010).

Applying a back-coating to textile can be carried out in the following ways:

- as paste where a layer is “glued” to the textile and a scratch knife defines the final thickness depending on the flame retardant standard, the textile used and the flame retardant concentration in the dispersion or
- as foam, where a foam layer is pressed on the textile through a rotating screen. Once applied the foam cells will break resulting in a thin coating film.

The coating is dried and fixated in an oven at temperatures between 140 to 180 °C. The formulated product is used on technical textile and furniture fabric, on cotton fabrics and cotton polyester blends. HBCD was usually applied with antimony trioxide as a backcoating in a mass ratio of 2:1 (i.e. about 6-15% HBCD and 4-10% antimony oxide by weight) (National Research Council, 2000).

The textiles with the back-coating containing HBCD were used for e.g. flat and pile upholstered furniture (residential and commercial furniture), upholstery seating in transportation, draperies, and wall coverings, bed mattress ticking, interior textiles e.g. roller blinds, automobile interior textiles and car cushions (UNEP 2019).

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