EUROPEAN COMMISSION
DIRECTORATE GENERAL JRC
JOINT RESEARCH CENTRE ISPRA
Institute for Health and Consumer Protection
Toxicology and Chemical Substances (ECB)

"REVIEW ON PRODUCTION PROCESSES OF DECABROMODIPHENYL ETHER (DECABDE) USED IN POLYMERIC APPLICATIONS IN ELECTRICAL AND ELECTRONIC EQUIPMENT, AND ASSESSMENT OF THE AVAILABILITY OF POTENTIAL ALTERNATIVES TO DECABDE".

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European Chemicals Bureau

Institute of Health and Consumer Protection
Joint Research Centre
European Commission

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EXECUTIVE SUMMARY

In July, 2006 Directorate General Environment (DG ENV) requested from Directorate General Joint Research Centre (DG JRC) that the JRC-IHCP-ECB prepare a report on *"Alternatives to DecaBDE (Deca Bromodiphenyl ether) used in polymeric applications in electrical and electronic equipment"* (EEE). In essence DG ENV requested a report on the substitutes used or that could be used for DecaBDE as a flame retardant in electrical applications and availability of risk information. It is noted that DecaBDE was issued an exemption by which its use was allowed in polymeric applications, according to COM decision 2005/717/EC under "Adaptation to scientific and technical progress under Directive 2002/95/EC" based on the results of a public stakeholder consultation and on the EU Risk Assessment Report on DecaBDE (see http://ecb.jrc.it/). Under normal circumstances the industrial preparation for DecaBDE contains about 3% Nona Bromodiphenyl ether BDE (NonaBDE) which when applied to typical applications (~ 10% concentration) would exceed the limit of 0.1% for NonaBDE, as set by COM decision 2005/618/EC, and thus would also prohibit products containing such polymers being put on the market under Directive 2002/95/EC.

In this study commissioned by DG ENV, the JRC-IHCP-ECB has reviewed the production processes of DecaBDE, in particular its NonaBDE content, and explored the availability of potential DecaBDE alternatives used in polymeric applications for EEE (cost of substitution and recyclability of alternatives was outside the scope of the study).

This Report concludes that substitutes do exist on the market for DecaBDE for the proposed applications and that many large electronic manufacturers claim to have moved to bromine-free alternatives. In addition literature data suggest that potential adverse environmental and human health effects of at least some substitutes may be minimal. However key data and information gaps in comprehensive risk assessments and hazard classification still exist, as well as uncertainties related to the potential impacts of degradation products of both DecaBDE and its substitutes.

Summary responses to the five (5) questions raised by DG ENV are presented as follows:

1. *the reason why DecaBDE is currently required and for which applications it is used and in which quantities?*

Though no longer produced in the EU, 7,600 tonnes of DecaBDE are imported each year in addition to 1,300 tonnes that are included in articles.

DecaBDE is used as an additive flame retardant mainly in plastics (roughly 3/4) and textile (roughly 1/4) applications. The major polymer applications for DecaBDE in EEE is to provide flame retardancy according to the fire safety standard UL94[1] V-0, high impact polystyrene (HIPS), Polyolefins (polyethylene (PE) and polypropylene (PP)), always in conjunction with antimony trioxide. As an example, 2,400 T of DecaBDE were used in TV back casings.

2. *knowledge about the production process of DecaBDE and particularly the possibility to produce DecaBDE with lower contents of NonaBDE?*

[1] industrial standard measurement of flammability refering to Underwriters Laboratories Inc., and to section 94 of the regulations covering "Tests for Flammability of Plastic Materials for Parts in Devices and Appliances".

The EU Risk Assessment Report (RAR) under Regulation (EEC) 793/93 on Existing substances (ESR)[2] describes the production of DecaBDE and the impurities issue, mainly the NonaBDE content. The Bromine Industry has recently developed and is commercialising a new Higher Purity DecaBDE Flame Retardant, SAYTEX 102HP, whose NonaBDE content is not specified.

3. *if the elimination or substitution of DecaBDE via design changes, or different materials and components is currently technically or scientifically impracticable?*

The manufacturers of brominated flame retardants have specifically pointed to difficulties of substituting DecaBDE in the plastics HIPS, ABS, and PBT, citing the lack of suitable alternative flame retardants that can provide good flame retardancy and good mechanical properties. In contrast, the Danish Environmental Protection Agency (EPA) contends that there is no EEE application for which the substitution of DecaBDE is not possible from the scientific or technical point of view. For all EEE materials and components presently using DecaBDE, technically acceptable alternatives are available on the market and have been so for some years. Moreover, the Danish EPA argues that a large number of the world's major manufacturers of EEE have phased out DecaBDE in their products and this demonstrates *ipso facto* that commercially viable DecaBDE-free effective flame retardants are used in many polymeric applications and in EEE components.

4. *if substitutes exist, what are the substitutes, the reason why they are not used and if they have been subject to a risk assessment?*

Many large international electronics companies (Philips, Sony, IBM, Apple) that voluntarily replaced DecaBDE in their products have not specified which flame retardants they have used as substitutes. However by compiling the information received from different sources twenty seven (27) potential substitutes to DecaBDE have been identified, of which 16 are halogenated and 11 are non-halogenated. Of these 27 chemicals, 3 are priority substances under Regulation (EEC) 793/93 on Existing substances and are currently undergoing an EU Risk Assessment. Four other potential substitutes to DecaBDE. have been scrutinised under National Risk Assessment Programmes in the UK. In addition the Danish EPA has assessed six compounds for a range of physico-chemical properties, and environmental and human health impacts according to the EU Technical Guidance Document; these six were found by the Danish EPA to be suitable for use as DecaBDE substitutes. (see details in Chapter 3).

5. *if substitutes exist, if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits?*

The Danish EPA states that “none of six assessed substances in their report appear to have more negative impacts on the environmental, health and/or consumer safety than DecaBDE” and concludes that “it does seem likely that the <u>substitution of DecaBDE by one of the alternatives available today is possible</u>”.

On the other hand, the Bromine Industry points out that <u>none of the potential alternatives to DecaBDE</u> have been <u>subject to a concluded EU risk assessment</u>, in contrast to DecaBDE, whose Risk Assessment Report (RAR), contains no conclusions (iii) [meaning no *need for further risk management measures*]. However, this RAR also emphasises the need for further testing and is surrounded by several uncertainties.

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[2] Council Regulation (EEC) No 793/93 on the evaluation and control of the risks of existing substances.

The present study provides available information on classification and potential (eco)toxicological endpoints. However for most of the possible substitutes such published information is not available. Given those data gaps, it is not possible at this time to determine with any certainty if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits. But the ongoing EU risk assessment process covering several of these substitutes gives already some indication that, at present, there may arise concern, at least for adverse environmental effects.

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PREFACE

In July 2006 Unit G4 of the European Commission Environment Directorate General (Sustainable Production & Consumption) requested the European Chemicals Bureau (ECB) at the Institute for Health and Consumer Protection of the Joint Research Centre, to investigate the availability of technically suitable alternatives to Decabromodiphenylether (hereafter referred to as DecaBDE) in polymers applications for electrical and electronic equipment (EEE), and to give an overview on the current knowledge on the impact of this potential substitution on health, environment and consumer safety. In addition, it has been asked to review the use patterns and production processes of DecaBDE, in particular the possibility of producing DecaBDE with a lower Nonabromodiphenylether (NonaBDE) content.

The present report summarises the findings of this review and presents a list of potential substitutes to DecaBDE. All information stemming from the EU draft Risk Assessment Reports (RAR) on these potential substitutes is provisional, as they are currently under discussion in the Competent Group of Member State experts with the aim of reaching consensus. During the course of these discussions, the scientific interpretation of the underlying scientific information may change, more information may be included and even the conclusions reached in the draft RARs may change. The information contained in those draft RARs does not, therefore, necessarily provide a sufficient basis for decision making regarding the hazards, exposures or the risks associated with the priority substance under consideration therein.

The DecaBDE RAR, though completed in 2002 with an addendum in 2004, has undergone further amendments that have been agreed upon on Technical and Competent Authorities levels, but not yet officially published.

The economic implications of using various alternatives are beyond the scope of this exercise. All conclusions regarding flame retardant capacity and technical feasibility of the alternative options derive from published sources. The European Chemicals Bureau does not guarantee the accuracy of data obtained from other sources, information or know-how supplied or contained in this publication.

ACKNOWLEDGEMENTS

For the purpose of drafting the present report, the ECB, in addition to the EU RARs data, mainly used detailed information received from both Bromine Industry representatives and various regulatory agencies (e.g. Danish Environmental Protection Agency, Environment Agency for England and Wales, Swedish Chemicals Inspectorate, Washington State Departments of Ecology and Health, US Environmental Protection Agency). The ECB would like to thank all contributors for their helpful assistance and in particular for their useful comments to the draft report, especially the EA for England and Wales, the Danish EPA and the EBFRIP[3].

The DecaBDE Review was led by S. Pakalin, with major contributions from T. Cole, H. Steinkellner, R. Nicolas, C. Tissier, S. Munn and S. J. Eisenreich, and with the help of many other ECB staff members, in particular the editing support of O. Cosgrove.

[3] European Brominated Flame Retardant Industry Panel

INTRODUCTION

0.1 BACKGROUND

As of 1st of July 2006 Directive 2002/95/EC (European Commission, 2003)[(1)] (the "RoHS" Directive) restricts the use of i.e. flame retardant chemicals belonging to the group of Polybrominated diphenyl ethers ("PBDEs") in electrical and electronic equipment (EEE). The maximum tolerated concentration for these chemicals is 0.1%, as set in Commission Decision 2005/618/EC.

However, certain applications, materials and components can be exempted from the restrictions if their elimination or substitution via design changes or materials and components is technically impracticable, or if the negative environmental, health and/or consumer safety impacts caused by substitution outweigh the environmental, health and/or consumer safety benefits thereof. These exemptions are to be reviewed periodically.

Based on the results of a stakeholder consultation and the Risk Assessment Report (RAR) on Decabromodiphenylether (DecaBDE) (European Commission, 2002)[(2)] pursuant to Council Regulation (EEC) 793/93 on Evaluation and Control of Existing Substances (European Commission, 1993)[(3)], the Commission has exempted DecaBDE in polymeric applications by Commission Decision 2005/717/EC of 13 October 2005. This Decision has been the subject of legal challenges by the European Parliament and several Member States at the EC Court of Justice.

Recognising that there is little knowledge on substitutes to DecaBDE, and on their impacts, the Environment Directorate General requested in August 2006 the European Chemicals Bureau (ECB) to conduct the current review to provide input to the discussion on the availability of suitable substitutes to DecaBDE.

Industrial-grade DecaBDE is typically accompanied by around 3% of another PBDE, NonaBDE (European Commission, 2002)[(2)]. Therefore, using commercial DecaBDE in typical applications (around 10% by weight are added to plastic materials) may result in ~ 0.3% of NonaBDE in the final product i.e. three times the accepted level. This makes the use of industry-grade DecaBDE practically impossible, despite the exemption.

0.2 OBJECTIVES

The purpose of the report is twofold:

- To identify suitable alternatives to DecaBDE in polymers applications for electrical and electronic equipment, and presenting an overview of the main properties of the potential alternatives with respect to their impact on health and environment. The cost aspect of substitution or any other socio-economic parameter was not considered in this review. Other Life Cycle aspects of the DecaBDE substitutes such as recyclability and associated energy consumption implications have also been left outside the scope of the study.
- To investigate the possibility of producing DecaBDE with a lower NonaBDE content so that final materials could respect the limit value of up to 0.1% set in RoHS Directive.

The review study seeks to answer the following questions raised by DG ENV:

1. *the reason why DecaBDE is currently required and for which applications it is used and in which quantities*
2. *knowledge about the production process of DecaBDE and particularly the possibility to produce DecaBDE with lower contents of NonaBDE*
3. *if the elimination or substitution of DecaBDE via design changes, or different materials and components is currently technically or scientifically impracticable;*
4. *if substitutes exist, what are the substitutes, the reason why they are not used and if they have been subject to a risk assessment.*
5. *if substitutes exist, if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits*

0.3 METHODOLOGY

In order to achieve these objectives, the ECB has obtained information mainly from the following sources:

- EU Risk Assessment Reports available at the ECB website http://ecb.jrc.it and subsequent non finalised working documents;
- The IUCLID database on http://ecb.jrc.it/iuclid/;
- The C&L databases of the ECB on http://ecb.jrc.it/classification-labelling/;
- The publications of the Danish EPA (2006)[(4)] [(5)];
- The Environment RER on EBP (Environment Agency for England and Wales, 2006)[(6)];
- The Swedish Chemicals Inspectorate's Survey of June 2005 on alternatives to DecaBDE in plastics (KEMI, 2005)[(7)]**;**
- The Washington State Departments of Ecology and Health "PBDE Chemical Action Plan" of 2006[(8)]**;**
- Other sources of information have also been reviewed e.g. the US EPA Project Plan on PBDE's (US EPA)[(9)].

1 DecaBDE PRODUCTION, USES AND PROCESSES

Preamble

A Risk Assessment Report (RAR) of bis(pentabromophenyl) ether (generally known as “Decabromodiphenyl ether” or DecaBDE) produced in accordance with Council Regulation (EEC) 793/93 (the Existing Substances Regulation, ESR) was published in 2002 (EC, 2002) and an updated risk assessment was agreed in Spring 2004 at the EU Member State technical and policy level (ECB, 2004). The latter report concluded that further information was required, in particular in relation to the PBT[4] assessment and for the possible risk of secondary poisoning from all sources of DecaBDE (see Section 3.1).

1.1 DecaBDE PRODUCTION VOLUMES

According to the original risk assessment DecaBDE is no longer produced in the EU but is imported at high tonnage levels by at least three importers. The EU consumption of DecaBDE was estimated at 8,210 tonnes/year in the mid-1990s. In 2001, while the world-wide demand for DecaBDE was reported to be 56,100 tonnes, the Danish EPA study mentions a European market demand of 7,600 tonnes.

In addition it is assumed that a further 1,300 tonnes/year of DecaBDE are imported into the EU in finished (or partly finished) articles. This estimate consisted of 500 tonnes/year from DecaBDE present in non-television (TV) consumer electronics produced in Asia, 400 tonnes/year of DecaBDE present in TVs produced in Asia, and 400 tonnes/year of DecaBDE in flame retarded polystyrene produced outside the EU. It should also be noted that products containing DecaBDE could also be exported out of the EU (European Commission, 2002)[(2)].

1.2 DecaBDE USES

DecaBDE is used as a general purpose flame retardant mainly in plastics and textile applications. It is an additive flame retardant i.e. it is physically combined with the material being treated rather than chemically combined (as in reactive flame retardants). This means that there is the possibility that the flame retardant may diffuse out of the treated material over time depending on conditions and use.

The EU use pattern described in the original RAR showed:

Use as a flame retardant in **polymers**:	6,710 tonnes/year (**81.7%** of total)
Use as a flame retardant in textiles:	1,500 tonnes/year (18.3%)
Total:	8,210 tonnes/year

In 2003, the European Brominated Flame Retardant Industry Panel (EBFRIP) indicated that for 2002 the total EU usage was around 8,300 tonnes/year, with 5,800 tonnes/year (**70%** of the total) being used in **plastic/polymer** applications, mainly for electrical and electronic equipment, and 2,500 tonnes/year (30% of total) being used in textile applications. Chemtura, a major bromine producer estimated DecaBDE sales into Europe in 2005 at ~7800 tons [(20)].

[4] Persistant, Bioaccumulative and Toxic

DecaBDE is used in a variety of polymer applications. The amount of flame retardant used in any given application depends on a number of factors such as the flame retardancy required of the finished product, the effectiveness of the flame retardant and synergist within a given polymer, the physical properties of the end product (e.g. colour, density, stability etc.) and the use of the end product.

Industry information indicates that DecaBDE is used at loadings of 10-15% weight in polymers and is always used in conjunction with antimony trioxide (European Commission, 2002)[(2)].

The major application for DecaBDE in EEE is to provide flame retardancy to high impact polystyrene (**HIPS**) according to the fire safety standard UL94 V-0, in TV back casings, but also for printers, scanners, fax machines, and similar applications. It should be noted that, according to EBFRIP, this is not a major application in the EU.

Other EEE applications involve a large number of other polymers such as:

- Polyolefins **(**polyethylene **(PE)** and polypropylene (**PP**)) in computers, connectors, electrical boxes, wire cable, etc.;
- acetate copolymers, **EVA**[5] and other ethylene copolymers for wire and cable, like **EPDM** and thermoplastic elastomers (for wire and cable) and polyester resins (for electronics);
- styrenic rubbers (**SR**), polycarbonates (**PC**), nylons or polyamides (**PA**), and terphthalates (**PBT/PET,** thermoplastic polyesters);
- small amounts are also reported to be used in hotmelt adhesives;

It was not possible to obtain a breakdown of the amounts of DecaBDE used in each application. However, Stevens and Mann (1999)[(10)] provide indications of the quantities of all brominated flame retardants (thus, including DecaBDE) used in the European E&E industry in 1999:

- 2,400 tonnes were used in TV back casings;
- 400 tonnes were used in printed circuit boards (mainly tetrabromobisphenol-A, TBBPA);
- more than 545 tonnes were used in business machines intended for home use and
- more than 545 tonnes were used in other consumer products (such as vacuum cleaners, plugs, sockets).

Table 1.1 provides data on the volume and percentage of plastics treated with flame retardants in the E&E sector by application.

Table 1.1 Use of Flame Retardants in E&E Equipment

Equipment	% Treated with Flame Retardants	Treated Plastics (t)
Data processing - PCs and monitors	65%	110,000
Office equipment - printers and copiers	20%	18,000

[5] EVA (ethylene-vinyl acetate) and EDPM (ethylene-propylene-diene terpolymer).

Consumer equipment - TVs/audio equipment	55%	74,000
Small household equipment - inner parts	2%	3,000
Large household appliances - inner parts	1%	5,000
Total		210,000

Source APME (2001) (Association of Plastics Manufacturers in Europe)

1.3 DecaBDE PRODUCTION PROCESSES AND NonaBDE CONTENT

1.3.1 Production Processes – DECABDE

Production of DecaBDE is carried out by using bromine as both the reactant and reaction medium. Diphenyl ether is added to the bromine in the presence of a catalyst and the rate of addition of diphenyl ether effectively controls the rate of reaction. The reaction is a batch process and the temperature of the reaction is around the boiling point of the bromine solvent (~ 59°C).

1.3.2 NONABDE content

1.3.2.1 Purity

The EU RAR applies to commercial DecaBDE. The actual composition of the products from different producers/suppliers is regarded as confidential information, but the major global manufacturers committed themselves in 1995 to producing DecaBDE with an average purity of 97% or better. WHO (1994) reported that a typical composition for commercial DecaBDE would be 97-98% pure DecaBDE with 0.3-3.0% of other brominated diphenyl ethers, mainly NonaBDE. Since DecaBDE is used at loadings of 10-15% weight in polymers, EEE may contain NonaBDE at concentrations above the cut-off value of 0.1% mentioned in Directive 2002/95/EC (RoHS). Further information on the composition of the commercial PBDE products can be found in Appendix G of the EU RAR.

1.3.2.2 Production processes with a lower NONABDE content

Albemarle Corporation has investigated the production of a DecaBDE with lower NonaBDE content for the past several months. Albemarle Corp. has recently developed and is commercialising a new Higher Purity DecaBDE Flame Retardant, SAYTEX 102HP, whose NonaBDE content is not specified. (11)

Other bromine producers like ICL-IP and Chemtura, are also currently developing new processes with a lower NonaBDE content but need more time to improve the results and have those validated (12). Chemtura pledges to sell this high purity DecaBDE before mid-2007(20).

2 ALTERNATIVES TO DecaBDE

2.1 SUBSTITUTING DecaBDE

2.1.1 Key Considerations

When assessing the availability of alternatives to DecaBDE in polymer applications for electrical and electronic equipment (EEE), the first question to address is whether substitution of DecaBDE via design changes, or different materials and components is actually feasible. In addition to environmental and human health impacts which will be considered in a second stage, the replacement of DecaBDE by another chemical or an alternative system needs to take into account both the technical suitability of the substitute or alternative, and its capability to meet the required safety standards.

2.1.2 Technical Feasibility

Enclosures for TV-sets are typically made of HIPS, ABS, or copolymers like PC/ABS, PPE/HIPS and PPE/PS, whereas PC monitors are mainly made from ABS and PC/ABS.

Asked about design changes or use of different materials in EEE that might provide alternatives to plastics containing DecaBDE, Albemarle Corporation mentions other thermoplastic polymers that find some application in EEE housings like acrylonitrile-butadiene-styrene polymers (ABS), polycarbonate-ABS alloys (PC/ABS), and polyphenylene oxide-polystyrene alloys (PPO/PS). Also ICL-IP has placed on the EU market FR 245, a Bromine based Flame Retardant for HIPS, and contends that alternatives can replace some polymeric applications, but not all of them. Chemtura, another halogenated flame retardants producer, is of the same opinion. EBFRIP adds that some properties cannot be achieved by those alternatives e.g. for color in polyamide applications (red phosphorus fits only for dark colours) and heat distortion temperature in ABS (TPP in PC/ABS has low heat distortion temperatures).

In contrast, a recent Danish EPA (2006) study [(5)] has not identified any application of DecaBDE in EEE for which substitution is not possible, from the scientific or technical point of view. For all EEE materials and components presently using DecaBDE, technically acceptable alternatives are available on the market, according to this Danish review. The DK study adds that two brominated flame retardants (BFR), namely EBP and EBTPI (see Section 2.2.2), have application spectra very close to the spectrum for DecaBDE, and they have been produced and marketed as general purpose alternatives to DecaBDE by the same companies that produce DecaBDE. For most applications the two compounds have superior technical properties (except for colour) compared to DecaBDE; but are more expensive.

2.1.3 Safety standards

The UL 94 [6]vertical flame test, V-0 grade is typically required for plastic parts in connectors, switches, and other components in contact with current bearing metal parts of EEE. In the USA, V-0 grade plastics are also required for TV-set enclosures, whereas the European standard has less strict requirements i.e.V-1[7]. However the major European producers today use a higher level of flame-retardancy than required by the European standard.

The Bromine Industry claims that only halogenated flame retardants can impart a fire safety standard UL94 V-0 to HIPS and ABS polymers. Besides DecaBDE being the most heavily used in these applications, they mention also a number of others which are used because of particular technical and marketing considerations such as the light stability of light gray HIPS. These other brominated flame retardants include EBP, EBTPI, brominated epoxy oligomer, tris(tribromophenoxy) triazine and Dechlorane Plus. PC/ABS and PPO/PS resins tend to use aromatic phosphate esters as flame retardants. In these applications the treat rate of the phosphate ester is higher than that of DecaBDE in HIPS, and the level of fire safety achieved is generally somewhat lower, i.e. UL V-I rather than UL V-0. To go to V-0 in general, mechanical properties are less performant, according to EBFRIP.

The Danish EPA states that all of the 26 flame retardants cited in their survey can provide a high level of flame retardancy, even when using copolymers with non-halogen organo-phosphorous flame retardants. For ABS polymers, they point out that brominated flame retardants have superior technical properties compared with DecaBDE. However they admit that some of the flame retardants may, in peculiar applications, fail to be a viable substitute for DecaBDE for other technical reasons. In particular, the application of some of the non-halogenated alternatives might change the properties of the flame-retarded plastics.

2.1.4 Actual Use of DECABDE Alternatives

A large number of EEE key players expressly state that they have moved away from BFR’s, and in particular DecaBDE in all of their products. Some of the main driving forces for these commitments have been an industry drive to apply eco-labels, customer requirements (e.g. “green procurement” initiatives) and preparedness for the RoHS Directive and other legislation. Some of the companies replaced DecaBDE already in the 1990s by enforcing specifications prohibiting its use in the products and components supplied by sub-contactors, but they generally have not specified which flame retardants should be used as substitutes. The specific flame retardants used in products are generally considered confidential and proprietary, but a typical replacement scheme seems includes the use of copolymers with halogen-free organo-phosphorous compounds for enclosures and other large parts, and the use of alternative BFR for the small parts (< 25 g) in connectors, switches, etc. In this manner, the products still meet the strictest criteria of eco-labels (Danish EPA, 2006).[(5)]

Furthermore there is some evidence demonstrating that currently available technology allows EEE to be produced without the inclusion of halogenated flame retardants while meeting simultaneously the requirements on fire safety, as presented in **Annex 1**.

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[6] industrial standard measurement of flammability refering to Underwriters Laboratories Inc., and to section 94 of the regulations covering "Tests for Flammability of Plastic Materials for Parts in Devices and Appliances". Materials are tested in a number of different ways to ensure that they pass the UL-94 rating.

[7] See also http://www.cenorm.be/cenorm/businessdomains/businessdomains/index.asp?pClose=0

Major electronics corporations which have voluntarily started to phase out or have already phased out PBDE, including DecaBDE, in the supply chain are listed in **Annex 2** and include Philips, Sony, Toshiba, Epson, Intel, NEC, Samsung, Atlas Copco, Ericsson Network Technologies, Electrolux, Dell, Hewlett-Packard Company (including Compaq), IBM, Apple, Matsushita (including Panasonic) and B&O.

2.1.5 Conclusions

The manufacturers of brominated flame retardants have specifically pointed at difficulties of substituting DecaBDE in the plastics HIPS, ABS, and PBT, citing the lack of extensively tested alternative flame retardants that can provide good flame retardancy and good mechanical properties.
This is contradicted by the Danish EPA who claims that it is possible to use a higher level of flame-retardancy than required by the European standard by using copolymers with **non-halogen** organo-phosphorous flame retardants. It further adds that if a large number of the world's major manufacturers of EEE have phased out DecaBDE in their products, this demonstrates *ipso facto* that commercially viable and suitable alternatives are used in many polymeric applications, and that safe fire retardant EEE components free of DecaBDE are actually available.

2.2 IDENTIFICATION OF POTENTIAL SUBSTITUTES

2.2.1 Introduction

By compiling the information from different sources 27 potential substitutes to DecaBDE have been considered in total, of which 16 are halogenated compounds and 11 are non halogenated. From these 27 chemicals, only 3 are priority substances under Regulation (EEC) 793/93 on Existing Substances (the so called "ESR") and are currently undergoing an EU Risk Assessment: HBCDD, TBBPA and MCCP[8]. It must be noted that the halogenated substitutes are always used with a synergistic substance, namely Antimony Trioxyde (ATO), which is subject to an ongoing EU Risk Assessment of its own. All EU Risk Assessment Reports (RARs) of the afore-mentioned substances are still under discussion, which implies that all information provided here in relation with these ESR substances, is provisional and subject to change. In addition National Risk Assessment Programmes have been carried out in the UK for several chemicals[9].

2.2.2 List of Substitutes

Annex 3 contains **Table A3.1** listing 27 potential Flame Retardant Alternatives to DecaBDE, and summarising their main applications and the types of plastic in which they may be used. Only flame retardants that can be used to obtain plastics meeting the UL 94 vertical flame test, V-0 have been included.

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[8] Respectively Hexabromocyclododecane, Tetrabromobisphenol A and Medium Chained Chloroparaffins (Alkanes, C14-17, chloro)

[9] Bis(pentabromophenyl)ethane (EBP), Resorcinol bis (diphenylphosphate) (RDP), Cresyl diphenylphosphate (CDP), Triphenyl phosphates (TPP);

3 ENVIRONMENTAL AND HUMAN HEALTH EFFECTS OF DecaBDE ALTERNATIVES

3.1 OVERVIEW

In addition to technical issues, of major importance is how the alternatives to DecaBDE compare in terms of environmental and human health impacts.

DecaBDE has been in the market for many years, and a breadth of applications has been under close scrutiny with regard to their effects to the environment and human health. Since the DecaBDE RAR did not show formal Conclusions (iii)[10], one might expect that DecaBDE will compare rather favourably to other flame retardants. However, despite this wealth of information on DecaBDE impacts, there are still significant gaps in knowledge, expressed by Conclusions (i)[11] in the EU Risk Assessment Report (RAR) of 2002.

The Environment section of the RAR concluded that further information was required in relation to the PBT[12] assessment, as DecaBDE is likely to be very persistent (vP), according to the criteria presented in the Technical Guidance Document (European Commission, 2003)[(13)]. The substance has some similarities in its behaviour to a vPvB[13] substance and its breakdown to substances with PBT or vPvB properties could occur in the environment (for example by metabolism in fish).

Additional testing is needed also with respect to secondary poisoning. Furthermore there are uncertainties regarding possible neurotoxic effects by mammals in laboratory studies; and possible formation of more toxic and accumulative products such as lower BDE congeners and brominated dibenzofurans in the environment.

This means that the available assessment methodology might not be applicable to this substance, and in general also not to other BFR's. There is a continued need to monitor environmental contamination for both the substance and its more toxic and bioaccumulative degradation products. This uncertainty surrounding DecaBDE is expected to be clarified through further testing and long term biomonitoring. In the meantime a voluntary program of reducing & controlling emissions to the environment has been put in place. On 18th March 2005, the Scientific Committee on Health and Environmental Risks (SCHER) gave their opinion on the environment risk assessment, and they considered that risk reduction measures should be investigated (SCHER, 2005).

On the other hand there is even less information on most of the alternatives listed in **Annex 3**, especially as far as their breakdown products are concerned. So far few BFRs have been investigated to the same extent as DecaBDE. Some potential alternatives, such as TBBPA, MCCP or HBCDD, are currently undergoing a comprehensive EU Risk Assessment, and EBP has been scrutinised in the UK under a National Risk Evaluation Programme. However these are rather the exception than the rule.

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10 need for further risk management measures

11 further testing needed

12 Persistant, Bioaccumulative and Toxic

13 very Persistant, very Bioaccumulative

3.2 HEALTH AND ENVIRONMENT PROPERTIES OF DecaBDE SUBSTITUTES

3.2.1 Hazardous properties

Table A4.1 in **Annex 4** outlines, where available, the Hazard Classification of the earlier mentioned chemicals. Only 3 out of 27 substances, TBBPA, MCCP and Red Phosphorus) are classified according to Directive 67/548/EEC (EEC, 1967)(14). The 24 remaining chemicals have not yet been classified because their data set might be incomplete, and/or they have not been considered as hazardous or apparently toxic.

Table A5.1 in **Annex 5** presents the assessment of the CMR[14] characteristics of the same listed potential substitutes (+ for DecaBDE).

3.2.2 PBT assessment

PBT assessment may be considered as an extension of conventional environmental risk assessment based on the principle of local/regional scale exposure/effect estimation, comparing compartmental predicted effect concentrations (PEC) with predicted no effect concentrations (PNEC). PBT assessment estimates potential risk to ecosystems where exposure/effect may be diffuse, relevant to chemicals that have tendency to persist, bio-accumulate, or show chronic toxicity, particularly in the aquatic environment. PBT assessment therefore accounts for uncertainty in predicting exposure/effect concentrations. Substances are considered as PBT, eligible for risk reduction measures, when all three properties are fulfilled. For instance, DecaBDE, which fulfils only the P criterion, is not considered as a PBT. A subsidiary category, vPvB (i.e. very persistent, very bio-accumulating) has also been defined. The TGD (European Commission, 2003)(13) has defined the following criteria:

Persistence, P, is quantified by determination of half-life longevity of a substance under environmental conditions (e.g. freshwater thresholds for P and vP are > 40 days and > 60 days, respectively) usually obtained from experimental ready/inherent biodegradation testing.

Bio-accumulation, B, is estimated as bio-concentration factor (BCF, where thresholds for B and vB are > 2,000 and > 5,000, respectively) obtained either from standard method uptake studies (e.g. into fish) or inferred from physical-chemical properties (e.g. octanol-water partition coefficient, Log K_{ow}). Log K_{ow} gives an indication of lipophilic tendency (i.e. affinity of a substance for tissue fat in living material) (e.g. LogK_{ow} > 4.5 represents a screening threshold for B).

Toxicity, T, may be measured as an acute or chronic effect in a variety of organisms. For example, a substance which is found to be persistent and bio-accumulative may have potential chronic toxicity to aquatic organisms. In this case, long-term no observed effect concentration (NOEC) is relevant (NOEC < 0.01 mg/l represents a screening threshold for T).

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14 Carcinogenic, Mutagenic, or Toxic to reproduction, as laid down in Annex VI of Council Directive 67/548/EEC[14].

Table A6.1 in **Annex 6** provides an overview of the PBT properties for 27 (including DecaBDE) envisaged Flame retardants.

There is substantial information on which to consider the PBT status, but little systematic review of the quality of such data. Few of the listed alternatives could be viewed as PBTs using the EU criteria. Many of the potential DecaBDE substitutes are P's (**TBBPA** is even vP, but does not meet all of the PBT criteria), some are B's (although less data are available for this criterion), and some are T's. The potential impact of breakdown products has not been envisaged in the present study.

3.2.3 Risk Assessment

Looking to the present status of the ESR risk assessment process, which is only partially completed, the following preliminary conclusions may be drawn:

- **HBCDD**: the RAR (European Commission, 2006)[15] is not yet finalised. However its Environmental part suggests concerns for aquatic and terrestrial compartments (for local site-specific and generic scenarios), together with effects on the food chain (secondary poisoning). The PBT assessment is still ongoing, but HBCDD fulfils the vB criterion and the T-criterion. Thus it is sufficiently persistent to behave like a PBT/vPvB substance, i.e. it accumulates in predators even in remote areas. On the Human Health side, there is a need for further information and/or testing in order to address the uncertainties relating to potential for bioaccumulation, potential excretion of HBCDD to breast milk, and indications of developmental neurotoxicity.
- Tetrabromobisphenol A (**TBBPA, n° 6** in the Annex 3 Table): the not yet finalised draft Environment RAR (European Commission, 2006)[16] indicates concerns for water and terrestrial compartments.

  For surface water and sediment, this conclusion applies to compounding sites and combined compounding/conversion sites where TBBPA is used as an additive flame retardant in ABS.

  For the terrestrial compartment, this conclusion applies to the use of TBBPA as an additive flame retardant in ABS from compounding, conversion and combined compounding/conversion sites. For the use of TBBPA as a reactive flame retardant in the manufacture of epoxy and polycarbonate resins at sites where sewage sludge is applied to agricultural land, discussion is ongoing at EU technical level, and it is recommended that this is investigated as part of any subsequent risk management activities

  The substance has been shown to break down in marine sediments to another substance (bisphenol-A) that is known to be toxic and shows effects on the endocrine system. Thus this indicates that TBBPA may have the potential to cause long-term adverse effects on marine ecosystems if sufficient exposure occurs. The effects of bisphenol-A on aquatic organisms are currently being investigated further. In addition, another possible metabolite/degradation product of TBBPA (i.e TBBPA bis(methyl ether) appears to possibly meet the screening criteria for a PBT substance using mainly estimated data.

  No health effects of concern have been identified by the TBBP-A published Human Health RAR (European Commission, 2006)[17].
- Alkanes, C14-17, Chloro (**MCCP, n° 14** in the Annex 3 Table)**:**

The finalised Environment RAR (European Commission, 2006)[18] has identified secondary poisoning through the earthworm food chain for all scenarios**.**

The National Environmental Risk Evaluation Report on **EBP** (Environment Agency for England and Wales, 2006)[6], has flagged the need to investigate the identity of degradation products in more detail, despite a low hazard potential, and seek additional data on the partitioning behaviour in the environment.

3.3 CONCLUSIONS

The Danish EPA states that "none of the six substances"[15] (**EBTPI, TBBPA, TBBPA carbonate oligomer, TPP, Red phosphorus and Diethylphosphinic acid, aluminium salt**) presented in their health and environmental assessment "appear to have more negative impacts on the environmental, health and/or consumer safety than DecaBDE". These six compounds were assessed for a range of physico-chemical properties, environmental and human health properties, according to the EU TGD (European Commission, 2003)[13]. They conclude that "it does seem likely that the substitution of DecaBDE by one of the alternatives available today is possible".

On the other hand, the Bromine Industry[19] points out that none of the potential alternatives to DecaBDE, either brominated or non-brominated, have been subject to a concluded EU risk assessment. They add that in the case of DecaBDE, no **Conclusions (iii)** (need for further risk management measures) have been drawn from the Risk Assessment process.

As a matter of record the ongoing EU risk assessment process covering some of these substitutes (**HBCDD, TBBPA** and **MCCP)** shows that, at present, there are some reasons for concern for the Environmental effects. **MCCP** is already subject to risk management based on the PEC/PNEC approach for secondary poisoning. Concerns for the breakdown products of some of these alternatives have been raised.

15 in Annex 3 Table, respectively n° 2, 6, 8, 19, 20, and 24.

4 CONCLUSIONS

In this study commissioned by DG ENV, the European Chemicals Bureau has reviewed the production processes of DecaBDE, in particular its NonaBDE content, and explored the availability of potential DecaBDE alternatives used in polymeric applications for electrical and electronic equipment (EEE), without considering any cost aspect of that substitution.

The review sought to answer the following questions raised by DG ENV:

1. *the reason why DecaBDE is currently required and for which applications it is used and in which quantities*

Though no longer produced in the EU, 7,600 tonnes of DecaBDE are imported each year in addition to 1,300 tonnes that are included in articles.

DecaBDE is used as an additive flame retardant mainly in plastics (roughly 3/4) and textile (roughly 1/4) applications.

The major polymer applications for DecaBDE in EEE is to provide flame retardancy to the fire safety standard UL94 V-0, high impact polystyrene (HIPS), Polyolefins (polyethylene (PE) and polypropylene (PP)), always in conjunction with antimony trioxide. As an example, 2,400 tonnes of DecaBDE are annually used in TV backcasings (Stevens and Mann, 1999)[(10)].

2. *knowledge about the production process of DecaBDE and particularly the possibility to produce DecaBDE with lower contents of NonaBDE*

The EU Risk Assessment Report describes the production of DecaBDE and the impurities issue, mainly the NonaBDE content. The Bromine Industry has recently developed and is commercialising a new Higher Purity DecaBDE Flame Retardant, SAYTEX 102HP, whose NonaBDE content is not specified.

3. *if the elimination or substitution of DecaBDE via design changes, or different materials and components is currently technically or scientifically impracticable*

The manufacturers of brominated flame retardants have specifically pointed at difficulties of substituting DecaBDE in the plastics HIPS, ABS, and PBT, citing the lack of suitable alternative flame retardants that can provide good flame retardancy and good mechanical properties.

In contrast, the Danish EPA contends that there is no EEE application for which the substitution of DecaBDE is not possible from the scientific or technical point of view. For all EEE materials and components presently using DecaBDE, technically acceptable alternatives are available on the market for years. Moreover, the Danish EPA sustains that the fact that a large number of the world's major manufacturers of EEE have phased out DecaBDE in their products demonstrates *ipso facto* that commercially viable DecaBDE-free effective flame retardants are used in many polymeric applications and in EEE components.

4. *if substitutes exist, what are the substitutes, the reason why they are not used and if they have been subject to a risk assessment.*

The big companies (listed in Annex 2) that voluntarily replaced DecaBDE in their products have not specified which flame retardants they have used as substitutes.

However by compiling the information received from different sources 27 potential substitutes to DecaBDE have been considered in total, of which 16 are halogenated and 11 non-halogenated. From these 27 chemicals, 3 are priority substances under Regulation (EEC) 793/93 on Existing substances and are currently undergoing an EU Risk Assessment: HBCDD, TBBPA and MCCP. Four other potential substitutes to DecaBDE have been scrutinised under National Risk Assessment Programmes in the UK. In addition the Danish EPA has assessed six compounds for a range of physico-chemical, environmental and human health properties, according to the EU Technical Guidance Document.

5. *if substitutes exist, if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits*

The Danish EPA states that “none of six assessed substances in their report appear to have more negative impacts on the environmental, health and/or consumer safety than DecaBDE” and conclude that “it does seem likely that the substitution of DecaBDE by one of the alternatives available today is possible”.

On the other hand, the Bromine Industry points out that none of the potential alternatives to DecaBDE, either brominated or non-brominated, have been subject to a concluded EU Risk Assessment, in contrast to DecaBDE, whose Risk Assessment Report (RAR), contains no conclusions (iii) [meaning no *need for further risk management measures*]. However, this RAR also emphasises the need for further testing and is surrounded by several uncertainties.

For most of the potential substitutes such published information is not available. Given those data gaps, it is not possible at this time to determine with any certainty if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits.

However the ongoing EU risk assessment process covering several of these DecaBDE substitutes (**HBCDD, TBBPA** and **MCCP**) gives already some indication that, at present, there may arise concern, at least for adverse environmental effects. Concerns for the breakdown products of some of these alternatives have also been raised. In addition, the Environmental Risk Evaluation Report carried out on **EBP** by the Environment Agency for England and Wales [(6)] has highlighted the need for further investigation i.e. in relation to degradation products.

5 REFERENCES

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(11) Letter from Albemarle Corp. to S. Eisenreich, ECB of January 26, 2007.

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(20) Chemtura letter to ECB of December 19, 2006

Annex 1 Technical feasibility for the production of halogen-free EEE

Plastics contribute to an especially extensive domain of applications in the sector of electronic and electrical equipments (EEE), as these materials offer considerable advantages in terms of equipment weight and robustness, electrical insulation as well as design and aesthetics.

Taking the specific physicochemical requirements on the polymeric material for each application into consideration, very different polymers are in fact present in these equipments. In practice, the group essentially consists of ABS-, polyamide-, polyester-, -epoxy-, HIPS-, PVC- and polyolefin-based plastics.
For an efficient protection of EEE against fire, a universal flame retardant solution is not available, and the selection of the flame retardant strategy has to be considered individually for each polymeric component.

In an effort to develop halogen-free flame retardant options for the sector of electronics and electrical goods, three main approaches have been commercially applied:

- Selection of the flame retardant

The development of alternative flame retardant solutions for plastics generally implies the design of formulation strategies for an optimised protection against fire, involving for instance synergistic flame retardant mechanisms, with minimised smoke generation during the fire.(1) The processes for the incorporation of the flame retardant components into the polymer matrix may also be deleterious for the performance of these additives.(2) In this respect, a great deal of improvements is also achieved so as to preserve the full flame retardant properties of the formulations.
For polymers like polyamides, certain polyolefins (polyethylene and polypropylene), and to a lesser extent polyesters, and as mentioned in the Danish EPA (2006) report,(3) several non-halogenated additives providing UL94 V-0 rating already exist and are used commercially.
Noteworthy is the case of epoxy resins, the material of choice for the encapsulation of electronic components such as printed circuit boards, for which development of non-halogenated fire retardant concept has been the Research topic of recent interest. Although the flame retardant market for this thermosetting material is still strongly dominated by reactive tetrabromobisphenol-A compounds, sustainable alternatives have been developed and commercially adopted, as listed in a recent review.(4)

- Modification/substitution of polymer matrix

On the other hand, for certain polymers such as HIPS and ABS, two matrices used for enclosure applications, halogen–free flame retardant alternatives providing an efficient protection against fire do not exist. To overcome this restriction, one approach consists in the substitution of the polymer matrix by polymer alloys based on more expensive polymers such as polycarbonate, polyphenylene oxide, polyphenylene sulfide, possibly in the presence of a fluorinated polymer (as synergist) so that "halogen-free" flame retardant options also become possible, and provided compromises in terms of processability and recycling properties at the end of the life cycle are acceptable.(3), (5) Substitution of HIPS and ABS enclosures with inherently flammable polymers,(6) or even with metal,(7) has also been commercially adopted.

- Design approach

Design-based solution to fire safety requirements has been considered as a mean to minimize the requirements on the flame retardant additive performance and loading. This is for instance achieved by maintaining safety distance or introducing physical barriers between the equipment's high voltage components and the flammable parts.

From a careful selection of the plastic materials and the flame retardant additive, while keeping in mind the impact of the equipment design on its propensity to burn, a wider section of flame retardant may be considered for an efficient protection of EEE against fire. A scientific illustration is for instance the fact that the production of flame-retarded electrical and electronic devices without the inclusion of halogenated flame retardants can be technically achieved.

References

(1) See for instance the CASICO^{TM} flame retardant concept for polyethylene wire and cable applications

(2) See for instance "Compounding with ammonium polyphosphate.based flame retardants", Plastic Additives & compounding, April 2002.

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(6) Polyphenylene sulphide is an inherently flame resistant plastic used by Toshiba for casings of electronics.

(7) Apple has for instance been using metal casing for its laptops.

Annex 2 Major electronics corporations which have voluntarily started to phase out PBDE, including DecaBDE, in the supply chain

Philips

DecaBDE appears in a list of substances which Philips has restricted in production worldwide (Philips, 2002)[(1)] unless no alternatives are available (Philips, 2002a)[(2)].

Sony

Since April 2002, the Sony Corporation has put in place a global policy which bans the application of PBDEs, including DecaBDE, in its products. This is documented in Sony Standard 55-00259, which is the basis for their Green Partner Program[(3)]. On 26 July 2006, Sony informed the Commission that it has taken appropriate measures to comply with requirements of the Directive 2002/95/EC (RoHS), and hence does not need any exemption neither for DecaBDE nor commercial DecaBDE.

Toshiba

Applying a restrictive use of DecaBDE to its products and to its suppliers' ones, Toshiba, in common with Sony and several other Japanese producers such as Matsushital Panasonic and NEC, has shown some product models with non-halogenated alternatives.

Epson

In January 2003 Seiko Epson Corporation established its Green Purchasing Standard for Production Materials and scheduled later on the elimination of six chemicals (i.e. PBDE) from its electrical and electronic products, in accordance with the RoHS Directive (Epson, 2003)[(4)].

Intel

According to the Intel website, Intel does not use PBBs or PBDEs and works with its suppliers to ensure that these compounds are not used in raw materials supplied to Intel (2003) [(5)]. It is still unclear if Intel has now completely replaced DecaBDE.

Matsushita Electric Group (Panasonic)

Matsushita has developed Chemical Substances Management Rank Guidelines aimed at prohibiting the use of DecaBDE contained in the parts, devices and materials used in products manufactured and sold by Matsushita Electric. These Guidelines apply also to its suppliers (Matsushita, 2002) [(6)].

NEC

In January 1999, NEC Computers International BY adopted a set of requirements banning PBDEs from plastic used in NEC products (NEC, 2002) [(7)].

NEC Corporation and Sumitomo Dow Ltd. have developed a transparent version of their flame retardant and *"environmentally conscious* NuCycle™ plastic, used for PC casings and other electronic products.

According to NEC, NuCycle™ consists of po1ycarbonate resin with a special silicone compound newly developed as a flame retardant that eliminates the need to use halogen compounds, for a high degree of safety, strength and recyclability, as well as high flame retardance characteristics (NEC, 2000) [8]. No further information could be obtained from NEC on the applicability of NuCycle™ to products relevant to DecaBDE

Samsung

Samsung Electronics is switching from halogen flame-retardants to **phosphoric** flame retardants. It is unclear if this will apply to electronics relevant to DecaBDE. Samsung claims that the performance of its ha1ogen- free multilayer printed circuit boards (for use in notebook computers) is superior to competitive products (note that DecaBDE does not find applications to printed circuit boards) (Samsung, 2001) [9].

In addition, a survey conducted in 2005 by the Swedish Chemical Inspectorate KEMI (2005) [10] showed the following findings:

Hewlett Packard

declared that they had already phased out PBDEs, including DecaBDE, in 1994, in all their products. This statement remains to be ascertained, especially in view of a Greenpeace study (2006) [11] concluding that a HP laptop, contained DecaBDE at a concentration of 0.165% and NonaBDE at a concentration of 0.204%, as well as being the only laptop fan containing the banned Octa BDE, though at much lower levels.

Atlas Copco

stated that they have a strict policy towards their suppliers not to use flame retardants restricted in the RoHS –directive.

Ericsson Network Technologies

declared that they only use halogen free flame protected materials in their products beside PVC and fluoropolymers.

Electrolux

declared that they have an ongoing process to phase out PBDEs, including DecaBDE, from products ending up on the European market.

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Table A3.1 Flame Retardant Alternatives- Uses Summary

No	Substance Name	CAS No	Source References	Trade Names/(Marketing Companies) for HIPS	Other polymer-type applications	Total Production or Import Volume in EU (in 1,000 tonnes-IUCLID)
0	Decabromodiphenylether (DecaBDE)	1163-19-5	EU ESR finalised RAR and addendum EBFRIP		HIPS, ABS, PA, PBT, PP, PE Minor applications: PC/ABS, HIPS/PPO	< 10
1	Bis(pentabromophenyl) ethane (DBDE, EBP)	84852-53-9	ENV Agency for England and Wales (EA) WS Ecol Health 2006 DK EPA Report August 2006 EBFRIP	SAYTEX 8010 (Albemarle Corp.), Firemaster 2100 (Great Lakes Chemical Corp.)	HIPS, ABS, PA, PBT, PP, PE Minor applications: PC/ABS, HIPS/PPO	No IUCLID sheet Assessed under a UK National programme EA estimate: > 1 (CONFIDENTIAL)
2	Ethylene bistetrabromo phthalimide (EBTPI)	32588-76-4	DK EPA Report July 2006 WS Ecol Health 2006 DK EPA Report August 2006 EBFRIP	SAYTEX BT-93 and BT-93W (Albemarle Corp)	HIPS, ABS, PBT, PP, PE Minor applications: PC/ABS, HIPS/PPO	EA estimate: >5
3	Tetrabromobisphenol A epichlorohydrinpolymer	40039-93-8	WS Ecol Health 2006 DK EPA Report August 2006	Starex (Cheil Industries, Korea)	ABS, PC/ABS,	No IUCLID sheet
4	Bis(tribromophenoxy) ethane	37853-59-1	WS Ecol Health 2006 DK EPA Report August 2006	FF-680 (Great Lakes Chemical Corp.)	typical use: ABS	No IUCLID sheet

Table A3.1 continued overleaf

Table A3.1 continued Flame Retardant Alternatives- Uses Summary

No	Substance Name	CAS No	Source References	Trade Names/(Marketing Companies) for HIPS	Other polymer-type applications	Total Production or Import Volume in EU (in 1,000 tonnes- IUCLID)
5	Hexabromocyclododecane (HBCDD)	3194-55-6 25637-99-4	EU ESR on going RAR WS Ecol Health 2006 DK EPA Report August 2006	SAYTEX HP-900 and 9006L (Albemarle Corp.) SP-75 and CD-75P (Great Lakes Chemical Corp.)	HIPS	EU consumption estimated at: ~10
6	Tetrabromobisphenol A (TBBPA)	79-94-7	EU ESR on going RAR DK EPA Reports, July and August 2006 WS Ecol Health 2006	SAYTEX CP-2000 (Albemarle Corp.), BA-59P (Great Lakes Chemical Corp.)	ABS	EU consumption estimated at: ~ 6,5
7	Tetrabromobisphenol A bis (2,3-dibromopropyl ether)	21850-44-2	WS Ecol Health 2006 DK EPA Report August 2006	SAYTEX HP-800 A; HP-800 AG and HP-800 AGC (Albemarle Corp.), PE-68 (Great Lakes Chemical Corp.), 403AF (LG Chem)	PP	No IUCLID sheet
8	Tetrabromobisphenol A carbonate oligomer	94334-64-2 71342-77-3	DK EPA Reports, July and August 2006		PC/ABS, PPO/HIPS, PBT/PET	No IUCLID sheet
9	Brominated polystyrene	88497-56-7	DK EPA Report August 2006		PA, PBT/PET,	No IUCLID sheet
10	Poly(dibromostyrene)	148993-99-1	DK EPA Report August 2006 EBFRIP		PA,PBT/PET	No IUCLID sheet
11	Poly (pentabromobenzyl acrylate) fr 1025	59447-57-3	DK EPA Report August 2006 EBFRIP		PA,PBT/PET	No IUCLID sheet
12	2,4,6-Tris(2,4,6-tribromo phenoxy) -1,3,5 triazine	25713-60-4	DK EPA Report August 2006 EBFRIP ENV Agency for England and Wales (EA)		HIPS, ABS	Notified Substance (CONFIDENTIAL)

Table A3.1 continued overleaf

Table A3.1 continued Flame Retardant Alternatives- Uses Summary

No	Substance Name	CAS No	Source References	Trade Names/(Marketing Companies) for HIPS	Other polymer-type applications	Total Production or Import Volume in EU (in 1,000 tonnes-IUCLID)
13	Brominated epoxy oligomer	68928-70-1	DK EPA Report August 2006 EBFRIP		ABS, PC/ABS, HIPS	No IUCLID sheet
14	Chloroparaffins; Chloroparaffins;(Alkanes, C14-17, chloro), MCCP	63449-39-8 85535 85-9	DK EPA Report August 2006 EU ESR on going RAR EBFRIP		Not V-0 PP	10-50 100-500
15	Dodecachlorododecahydro-dimethanodibenzocyclooctene (Dechlorane Plus)	13560-89-9	DK EPA Report August 2006 EBFRIP		PA, PBT/PET, PE	No IUCLID sheet (> 1 in the US)
16	Resorcinol bis (diphenylphosphate) (RDP)	57583-54-7 125997-21-9	WS Ecol Health 2006 DK EPA Report August 2006 ENV Agency for England and Wales (EA)	Fyrolflex RDP (Akzo Nobel), Reofos RDP (Great Lakes Chemical Corp.)	HIPS/PPO, PC/ABS,	Assessed under a UK National programme
17	Bisphenol A diphenyl phosphate (BAPP,BPADP); Bisphenol A (diphenyl phosphate) (BDP)	181028-79-5 5945-33-5	WS Ecol Health 2006 DK EPA Report August 2006 ENV Agency for England and Wales (EA)	Reofos BAPP (Great Lakes Chemical Corp), Fyrolflex BDP (Akzo Nobel), NcendX P-30 (Albemarle Corp.)	HIPS/PPO, PC/ABS	Notified substance Tonnage figures CONFIDENTIAL

Table A3.1 continued overleaf

Table A3.1 continued Flame Retardant Alternatives- Uses Summary

No	Substance Name	CAS No	Source References	Trade Names/(Marketing Companies) for HIPS	Other polymer-type applications	Total Production or Import Volume in EU (in 1,000 tonnes-IUCLID)
18	Cresyl diphenylphosphate (CDP)	26444-49-5	WS Ecol Health 2006 DK EPA Report August 2006 ENV Agency for England and Wales (EA)	Kronitex CDP (Great Lakes Chemical Corp.), Phosflex CDP (Akzo Nobel), Transol (Chemiehandel GmbH)	PC/ABS	Assessed under a UK National programme
19	1.Triphenyl phosphates (TPP); 2.Triaryl phosphates butylated (alternative name: tert-butylphenyl diphenyl phosphate)	115-86-6 68937-40-6 (alternative CAS no.: 56803-37-3)	DK EPA Reports, July and August 2006 WS Ecol Health 2006 (TPP) EBFRIP ENV Agency for England and Wales (EA)	TPP: Reofos TPP (Great Lakes Chemical Corp.), Phosflex TPP (Akzo Nobel)	HIPS/PPO, PC/ABS	Assessed under a UK National programme Tonnage figures CONFIDENTIAL (used in very low volumes)
20	Red phosphorus	7723-14-0	DK EPA Reports, July and August 2006		PA	Not given
21	Melamine polvphosphate	218768-84-4	DK EPA Report August 2006		PA	No IUCLID sheet
22	Melamine cyanurate	37640-57 -6	DK EPA Report August 2006 EBFRIP		PA	No IUCLID sheet
23	Ammonium polyphosphate	14728-39-9 68333-79-9	DK EPA Report August 2006 EBFRIP		PP	10-50
24	Diethylphosphinic acid, aluminium salt	225789-38-8	DK EPA Reports, July and August 2006 EBFRIP		PBT/PET, PE	No IUCLID sheet
25	Aluminium trihydroxide	21645-51-2	DK EPA Report August 2006 EBFRIP		PE	> 1,000

Table A3.1 continued overleaf

Table A3.1 continued Flame Retardant Alternatives- Uses Summary

No	Substance Name	CAS No	Source References	Trade Names/(Marketing Companies) for HIPS	Other polymer-type applications	Total Production or Import Volume in EU (in 1,000 tonnes-IUCLID)
26	Magnesium dihydroxide	1309-42-8	DK EPA Report August 2006 EBFRIP		PA, PP, PE	100-500
27	*Brominated epoxy resin end-capped with tribromophenol*	*135229-48-0*	EBFRIP	*CONFIDENTIAL information from BIT (German Company)*	HIPS, ABS (only for the lower molecular weight BEO) PBT (higher molecular weight BEO)	No IUCLID sheet

HIPS High impact polystyrene (e.g. TV enclosures, accounting for 45-85% of DecaBDE use in USA)
PPO Polyphenylene oxide
ABS Acrylonitrile butadiene styrene
PC Polycarbonate
PA Polyamide; nylon
PBT Polybutylene terephtalate
PET Polyethylene terephtalate
PE ?
PP Polypropylene
ATO Antimony trioxide used as synergist

References

EU RAR	Decabromodiphenylether (DecaBDE)
EU RAR	Hexabromocyclododecane (HBCD)
EU RAR	Tetrabromobisphenol A (TBBPA)
EU RAR	Chloroparaffins;(Alkanes, C14-17, chloro) MCCP
ENV RER	Environmental Risk Evaluation Report: 1’1-(Ethane-1,2-diyl)bis[penta-bromobenzene] CAS no. 84852-53-90 Draft for Peer Review . Environment Agency for England and Wales, Rio House, Water Side Drive, Aztec West, Almondsbury, Bristol, BS32 4 UD Tel: 01454 24400 Fax: 01454 62 4409 www.environment-agency.gov.uk; Author: S. Dungey
WS Ecol Health 2006	Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Final Plan, January 19, 2006 Department of Ecology Publication No. 05-07-048, Department of Health Publication No. 334-079 http://www.ecy.wa.gov/biblio/0507048.html, PO Box 47600, Olympia WA 98504-7600, ecypub@ecy.wa.gov
DK EPA Report July 2006	Danish Environmental Protection Agency Health and Environmental Assessment of Alternatives to Deca-BDE in Electrical and Electronic Equipment
DK EPA Report August 2006	Danish Environmental Protection Agency Deca-BDE and Alternatives in Electrical and Electronic Equipment Carsten Lassen and Sven Havelund, COWI A/S, Denmark Andre Leisewits, Oeko-Recherche GmbH, Germany, Peter Maxson, Concorde East/West Sprl, Belgium
EBFRIP	European Brominated Flame Retardant Industry Panel

Table A4.1 Flame Retardant Alternatives – Classification of Hazard Properties

No	Substance Name	CAS No	Einecs No	Classification[(1)] (Annex I to Directive 67/548/EEC & IUCLID)	References
0	Decabromodiphenylether (DecaBDE)	1163-19-5	214-604-9	None	EU ESR RAR
Halogenated alternatives					
1	Bis(pentabromophenyl) ethane (DBDE, EBP)	84852-53-9	284-366-9	None	RER ENV Agency for England and Wales WS Ecol Health 2006 DK EPA Report August 2006
2	Ethylene bistetrabromo phthalimide (EBTPI)	32588-76-4	251-118-6	None	DK EPA Report July 2006 WS Ecol Health 2006 DK EPA Report August 2006
3	Tetrabromobisphenol A epichlorohydrinpolymer	40039-93-8	500-107-7	None	WS Ecol Health 2006 DK EPA Report August 2006
4	Bis(tribromophenoxy) ethane	37853-59-1	253-692-3	None	WS Ecol Health 2006 DK EPA Report August 2006
5	1,2,5,6,9,10-Hexabromocyclododecane; Hexabromocyclododecane (HBCDD)	3194-55-6 25637-99-4	221-695-9 247-148-4	None None	WS Ecol Health 2006 DK EPA Report August 2006 EU ESR *On going RAR*

Table A4.1 continued overleaf

Table A4.1 continued Flame Retardant Alternatives – Classification of Hazard Properties

No	Substance Name	CAS No	Einecs No	Classification[1] (Annex I to Directive 67/548/EEC & IUCLID)	References
6	Tetrabromobisphenol A (TBBPA)	79-94-7	201-236-9	N; R 50/53[2] (Draft list 31st ATP)	EU ESR *On going RAR* DK EPA Report July 2006 DK EPA Report August 2006 WS Ecol Health 2006
7	Tetrabromobisphenol A bis (2,3-dibromopropyl ether)	21850-44-2	244-617-5	None	WS Ecol Health 2006 DK EPA Report August 2006
8	Tetrabromobisphenol A carbonate oligomer	94334-64-2 71342-77-3	Not in EINECS		DK EPA Report July 2006 DK EPA Report August 2006
9	Brominated polystyrene	88497-56-7	Not in EINECS	None	DK EPA Report August 2006
10	Poly(dibromostyrene)	148993-99-1	Not in EINECS		
11	Poly (pentabromobenzyl acrylate) fr 1025	59447-57-3	Not in EINECS	None	DK EPA Report August 2006
12	2,4,6-Tris(2,4,6-tribromo phenoxy) -1,3,5 triazine	25713-60-4	Not in EINECS		
13	Brominated epoxy oligomer	68928-70-1	Not in EINECS	None	DK EPA Report August 2006
14	Chloroparaffins; Chloroparaffins;(Alkanes, C14-17, chloro), MCCP	63449-39-8 85535-85-9	264-150-0 287-477-0	R64 R66 N; R50-53[3] (Draft list 30th ATP)	DK EPA Report August 2006 EU ESR *On going RAR*

Table A4.1 continued overleaf

Table A4.1 continued Flame Retardant Alternatives – Classification of Hazard Properties

No	Substance Name	CAS No	Einecs No	Classification[1] (Annex I to Directive 67/548/EEC & IUCLID)	References
15	Dodecachlorododecahydrodimethanodibenzocyclooctene (Dechlorane Plus)	13560-89-9	236-48-9	None	DK EPA Report August 2006
Non-halogenated alternatives					
16	Resorcinol bis (diphenylphosphate) (RDP)	57583-54-7 125997-21-9	260-830-6 Not in EINECS	None	WS Ecol Health 2006 DK EPA Report August 2006
17	Bisphenol A diphenyl phosphate(BAPP,BPADP); Bisphenol A (diphenyl phosphate) (BDP)	181028-79-5 5945-33-5	Not in EINECS Not in EINECS	None	WS Ecol Health 2006 DK EPA Report August 2006
18	Cresyl diphenylphosphate (CDP)	26444-49-5	247-693-8	None	WS Ecol Health 2006 DK EPA Report August 2006
19	Triphenyl phosphates (TPP); Triaryl phosphates butylated	115-86-6 68937-40-6	204-112-2 273-065-8	None	WS Ecol Health 2006 (TPP) DK EPA Report August 2006
20	Red phosphorus	7723-14-0	231-768-7	F; R11, R16, R52-53[4]	DK EPA Report July 2006 DK EPA Report August 2006
21	Melamine polvphosphate	218768-84-4	Not in EINECS	None	DK EPA Report August 2006
22	Melamine cyanurate	37640-57 -6	253-575-7		
23	Ammonium polyphosphate	14728-39-9 68333-79-9	Not in EINECS 269-789-9	None	DK EPA Report July 2006 DK EPA Report August 2006

Table A4.1 continued overleaf

Table A4.1 continued Flame Retardant Alternatives – Classification of Hazard Properties

No	Substance Name	CAS No	Einecs No	Classification[(1)] (Annex I to Directive 67/548/EEC & IUCLID)	References
24	Diethylphosphinic acid, aluminium salt	225789-38-8	Not in EINECS	None	DK EPA Report July 2006 DK EPA Report August 2006
25	Aluminium trihydroxide	21645-51-2	244-492-7	None	DK EPA Report August 2006
26	Magnesium dihydroxide	1309-42-8	215-70-3		
Further alternatives					
27	*Brominated epoxy resin end-capped with tribromophenol*	*135229-48-0*	*Not in EINECS*	*None*	*CONFIDENTIAL information from BIT (German Company)*

ATO Antimony trioxide (CAS: 1309-64-4 EC 215-175-0) is used as synergistic additive in halogenated flame retardants (n° 0 to 15).
Legally binding classification/labelling of ATO in Annex I to Dir. 67/548/EEC at concentrations of ≥ 1%:
Xn; Harmful Carc. Cat. 3; Carcinogenic Category 3
R40; Limited evidence of a carcinogenic effect
S2 - S22 -S36/37; Keep out of the reach of children. Do not breathe dust. Wear suitable protective chlothing/gloves.

(1) Classification listed in Annex 1 to Dir. 67/548/EEC is legally binding. However, manufacturers, distributors and importers have a legal obligation to self-classify substances not listed in Annex I should relevant data exist.

(2) Tetrabromobisphenol A (CAS: 79-94-7 EC: 201-236-9) Classification in the draft Annex I list for the 31st ATP to Dir. 67/548/EEC
N; R50-53; Dangerous for the environment; Very toxic to aquatic organisms. May cause long-term effects in the aquatic environment.
S60-61; This material and its container must be desposed of as hazardous waste. Avoid release to the environment. Refer to special instructions/Safety data sheet.

(3) Chloroparaffins (Alkanes, C14-17, chloro) (CAS: 287-477-0) Classification in the draft Annex I list for the 30th ATP to Dir. 67/548/EEC at concentrations of ≥ 25%:
R64; May cause harm to breastfed babies
R66; Repeated exposure may cause skin dryness and cracking
N; R50-53; Dangerous for the environment; Very toxic to aquatic organisms. May cause long-term effects in the aquatic environment.
S (2-)24-60-61; Keep out of the reach of children. Avoid contact with skin. This material and its container must be desposed of as hazardous waste. Avoid release to the environment. Refer to special instructions/Safety data sheet.

(4) Red phosphorus (CAS: 7723-14-0) Legally binding classification/labelling in Annex I to Dir. 67/548/EEC
F; R 11; Highly flammable;
R16 ; Explosive when mixed with oxidizing substances.
R52-53 (at concentrations of ≥ 25%)
S2 - S7 - S43 - S61; Keep out of the reach of children. Keep container tightly closed. In case of fire, use (indicate in the space the precise type of fire-fighting equipment. If water increases risk, add - `Never use water`). Refer to special instructions/Safety data sheet

References

RAR Decabromodiphenylether (DecaBDE)	European Union Risk Assessment Report Volume 17 Bis(Pentabromophenyl)Ether CAS No: 1163-19-5 Einecs No: 214-604-9 Luxembourg Office for Official Publications of the European Communities, 2002
RAR Hexabromocyclododecane (HBCD)	European Union Risk Assessment Report 1st DRAFT Hexabromocyclododecane (HBCD) CAS No: 25637-99-4 Einecs No: 247-148-4
RAR Tetrabromobisphenol A (TBBPA)	European Union Risk Assessment Report Volume 63 Tetrabromo-4,4', 6,6'-Isopropylidenediphenol (Tetrabromobisphenol-A-aTBBP-A) CAS No: 79-94-7 Einecs No: 201-236-9 Luxembourg Office for Official Publications of the European Communities, 2006
RAR Chloroparaffins;(Alkanes, C14-17, chloro)	European Union Risk Assessment Report Volume 58 Alkanes, C14-17, chloro (MCCP) CAS No : 85535-85-9 Einecs : 287-477-0. Luxembourg Office for Official Publications of the European Communities, 2005
ENV RER	Environmental Risk Evaluation Report: 1'1-(Ethane-1,2-diyl)bis[penta-bromobenzene] CAS no. 84852-53-90 Draft for Peer Review, 2006. Environment Agency for England and Wales, Rio House, Water Side Drive, Aztec West, Almondsbury, Bristol, BS32 4 UD Tel: 01454 24400 Fax:1454 62 4409 www.environment-agency.gov.uk; Author: S. Dungey.
WS Ecol Health 2006	Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Final Plan, January 19, 2006 Department of Ecology Publication No. 05-07-048, Department of Health Publication No. 334-079 http://www.ecy.wa.gov/biblio/0507048.html PO Box 47600, Olympia WA 98504-7600, ecypub@ecy.wa.gov
DK EPA Report July 2006	Danish Environmental Protection Agency Health and Environmental Assessment of Alternatives to Deca-BDE in Electrical and Electronic Equipment
DK EPA Report August 2006	Danish Environmental Protection Agency Deca-BDE and Alternatives in Electrical and Electronic Equipment Carsten Lassen and Sven Havelund, COWI A/S, Denmark Andre Leisewits, Oeko-Recherche GmbH, Germany, Peter Maxson, Concorde East/West Sprl, Belgium

Table A6.1 PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
0	Decabromo Diphenylether (DecaBDE)	1163-19-5	EU RAR (1)	Although photodegradation has been observed in laboratory, DecaBDE is not readily biodegradable based on a single test. In such cases the TGD[2] recommends that a simulation test for environment degradation should be performed to establish a half-life in marine water and/or sediment. Since no degradation was seen in an anaerobic freshwater sediment study, DecaBDE is not expected to degrade biotically at a significant rate in the environment. Therefore it is considered to meet the very persistent (vP) criterion. The degradation of DecaBDE into lower brominated congeners can occur under certain conditions.	Based on fish data DecaBDE does not meet the (B) criterion. Although it meets the *screening* criterion (Log K_{OW}) for being potentially very bioaccumulative (vB) it does not meet the actual confirmatory criteria based on bioconcentration factor (BCF) data from aquatic tests. Its presence in the tissues of top predators might indicate a biomagnification process, but routes of exposure are still unknown. There is limited evidence for the formation of lower brominated congeners from the metabolism of DecaBDE in fish. Further information on trends in environmental levels of both the parent substance and its metabolites would be useful. Levels in the environment are likely to be correlated with the continuing release of these substances from articles still in use for some time into the future. New data show that DecaBDE is bioavailable from food and can be taken up by earthworms from soil and aquatic worms from sediment.	DecaBDE is not considered to meet the T criterion. However there is some indication that it can cause behavioural disturbances in mice when they are exposed at a sensitive stage of brain development (possibly via a metabolite). This apparent toxicity makes the presence of DecaBDE in the eggs of top predators a serious finding that is relevant in any assessment of long-term risk. It should be noted that the normal PEC/PNEC comparison methods described in the TGD do not apply to this situation. *In vitro* information indicates that DecaBDE has a very low potential for causing endocrine disrupting effects. In relation to the secondary poisoning assessment, recent data indicate that DecaBDE may be more toxic to mammals than assumed in the original risk assessment report. A more detailed evaluation of the recent mammalian toxicity data is currently being carried out. A NonaBDE (a main impurity in commercial DecaBDE) has been shown to cause neurotoxic effects in mice. However, the method used was subject to uncertainties.
				In conclusion, although the actual bioaccumulation potential of DecaBDE cannot be quantified and so it cannot be concluded that the substance is a vPvB substance, it is clear that the substance has some similarities in its behaviour to a vPvB substance. The second aspect for the PBT assessment of DecaBDE ether is the possible formation of PBT or vPvB substances in the environment from breakdown of DecaBDE.		

			WS[3]	Half life of DecaBDE in water, soil or sediments > 60 days. Half-lives of lower brominated congeners also > 60 days.	Log K_{OW} = 5.24; BCF = 3.16. BCF of potential breakdown products, e.g. Penta-BDE, are substantially higher (27,400 for Penta-BDE)	Potential degradation to more toxic Penta, Octa-BDEs. Environmental ecosystem buildup and potential toxicity.

Table A6.1 continued overleaf

(1) European Commission (2004) Addendum of May 2004 to the European Union Risk Assessment Report Volume 17 Bis(Pentabromophenyl)Ether CAS No: 1163-19-5 Einecs No: 214-604-9 Luxembourg Office for Official Publications of the European Communities, 2002, as last amended in January 2007 (as to the date of publication of the present report, this version has not yet been officially agreed).

(2) European Commission (2003) Technical Guidance Document in support of Commission Directive 93/67/EEC on Risk Assessment for new notified substances, Commission Regulation (EC) No 1488/94 on Risk Assessment for existing substances and Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market. European Communities, 2003

(3) Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Final Plan, January 19, 2006 Department of Ecology Publication No. 05-07-048, Department of Health Publication No. 334-079 http://www.ecy.wa.gov/biblio/0507048.html, PO Box 47600 Olympia WA 98504-7600, ecypub@ecy.wa.gov

(4) Danish EPA (2006) Danish Environmental Protection Agency Health and Environmental Assessment of Alternatives to Deca-BDE in Electrical and Electronic Equipment, July 2006

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
1	Bis(pentabromophenyl) ethane (DBDE, EBP)	84852-53-9	WS	Half-life in all media unknown, but is stable halogen	Log K_{OW} = 3.2 and BCF < 1,000; not detected in food web, low water solubility.	Rat LD50 > 5,000mg/kg; Rabbit LD50 > 2,000mg/kg, NOAEL = 1000mg/kg. Low toxicity.
	Bis(pentabromophenyl)ethane (DBDE, EBP)	84852-53-9	RER(5)	Available evidence indicates EBP as potentially P EBP is not susceptible to abiotic degradation (e.g., hydrolysis) and is not readily biodegradable under aerobic conditions in the aquatic environment (*viz*: 2% according to OECD 301C). Persistence is linked to low water solubility (0.72 µg/L).	Measured BCF not significant (e.g., < 25 L/kg at 0.05 mg/L) but not reliable due to, e.g.: flow through, not dietary, study water solubility limit exceeded dispersant used Assuming aquatic conc^{n} = 0.72 ug/L (i.e., solubility limit) then worst case BCF would be 1600 (i.e, < 2,000 threshold criterion for B). Measured Log K_{ow} = 3.55 (i.e., < 4.5 threshold criterion for B (but considered an estimate only, due to analytical uncertainties) QSAR prediction of BCF (modelled on Log K_{ow}) in the range 100-200. B potential for EBP: low (not bioaccumulating)	Aquatic acute/chronic toxicity studies not available. In view of low water solubility and low bioaccumulation potential, EBP not expected to meet threshold criterion for T (i.e., chronic NOEC < 0.01 mg/L).

Table A6.1 continued overleaf

(5) Environment Agency for England and Wales (2006) Environmental Risk Evaluation Report: 1'1-(Ethane-1,2-diyl)bis[penta-bromobenzene] CAS no. 84852-53-90 Draft for Peer Review . Published by Environment for England and Wales Agency, Rio House, Water Side Drive, Aztec West, Almondsbury, Bristol, BS32 4 UD Tel: 01454 24400 Fax: 1454 62 4409 www.environment-agency.gov.uk Environment Agency for England and Wales; Author: S. Dungey

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
2	Ethylene bistetrabromo phthalimide (EBTPI)	32588-76-4	EU PBT WG[16]	EBTPI is considered to be very persistent (vP).	EBTPI is not considered to meet the B criterion based on molecular properties of the substance (MW = 951.5 g/mol, molecular dimensions: 1.1 – 1.68 nm for most stable conformers, 0.55 – 2 nm for the least stable; measured octanol solubility = 0.45 – 0.6 mg/l < 0.002 x MW). Therefore the substance was delisted as the PBT/vPvB criteria were not fulfilled.	
			WS	Potential PBT/vPvB; further data required halogenated stable compound	Log K_{OW} = 9.8; threshold => 5. BCF < 0.3 - < 3.0	Low toxicity for lab animals
			DK EPA	EBTPI is not readily biodegradable based on the results of a single test. In such cases, the TGD recommends that a simulation test for environmental degradation should be performed, but no such data are available. Considered to meet the very persistent (vP) criteria.	Based on the estimated log Kow value (9.80) EBTPI meets the screening criterion for consideration as bioaccumulative (B) and very bioaccumulative (vB) (log Kow > 4.5). Little uptake of EBTPI has been seen in fish exposed via water (BCF < 3.3). Based on the single bioaccumulation study available, the bioaccumulation criterion is not fulfilled. In support of the results from the bioaccumulation study, the high molecular weight of EBTPI (951.5 g/mol) indicates that EBTPI is unlikely to bioaccumulate significantly regardless of the log Kow value due to possible steric hindrance of passage of gill membranes or cell membranes of respiratory organs (the TGD states that certain classes of chemicals with a molecular mass > 700 are not readily bioaccumulable in fish).	The only available study of the aquatic toxicity of EBTPI indicates that acute toxic effects occur at levels much hiqher than the estimated water solubility. Long-term NOEC values are not found in the literature. More ecotoxicology data are required for assessment of the toxicity (T) criterion.
				DK EPA SUMMARY : EPBTI is considered to be very persistent (vP), is not considered to meet the B criteria and is not acutely toxic at concentrations up to the water solubility limit, but further data is required for assessment of the T criteria for EBTPI.		
3	Tetrabromobisphenol A epichlorohydrin polymer	40039-93-8	WS	unknown	unknown	Not acutely toxic; few animals data, none human; carcinogenicity untested
4	Bis Tribromophenoxy ethane	37853-59-1	WS	T1/2 in water 150-1700 days	BCF +8.7-27.1 (measured in *Cyprinus carpio* in the Great Lakes); K_{OW} = 3.14 - 9.15 measured, 9.14 modelled	Low acute toxicity in mammals (10 g/kg), low subchronic toxicity LOAEL 800-900 mg/kg; relatively low ecotoxicity. Not mutagenic, low reproductive, teratogenic potential

Table A5.1 continued overleaf

16 Technical Committee of New and Existing Chemical Substances (TCNES) Subgroup on PBT, 14-15 November, 2006, Ispra (Italy); *Summary of the* factsheet *conclusions*

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
5	Hexabromocyclododecane (HBCDD)	3194-55-6 and 25637-99-4 (ESR)	WS	60 day half-life in water (EPA PBT Profiler)	BCF > 100 (DK EPA) BCF = 6,210 Log K_{OW} = 5.81 (calculated), 7.59 (calculated) (DK EPA, 2000). Log K_{OW} = 7.74	RfD = 0.2 mg/kg/day based on increase liver weight EPA RfD = 0.002 mg/kg/day and ATSDR MRL = 0.0002 mg/kg/day. HBCDDD is predicted to be toxic to aquatic organisms.
			EU RAR(6)	The new enhanced ready test on CDT shows that the substance is biodegradable. Nevertheless the PBT WG in November 2006 has proposed that HBCDD has PBT like properties due to the increasing concentration in biota and the environment	log Kow : 5.6 HBCDD meets the vB criterion (BCF 18100). HBCDD is subject to biomagnification and long range transport. Levels in marine mammals and in birds are increasing.	Chronic NOEC *Daphnia* survival, reproduction, growth 3.1 µg/l Chronic LOEC *Daphnia* reduced length 5.6 µg/l HBCDD meets the the T-criterion
6	Tetrabromobisphenol A (TBBPA)	79-94-7	EU RAR(7)	vP	TBBPA is not B, but may degrade in the environment to produce increased levels of the plastics intermediate Bisphenol A, TBBPA bis (methyl ether), a possible metabolite/degradation product, possibly meets the PBT screening criteria. Need for investigation of ▪ The sources of TBBPA bis (methyl ether) to the environment ▪ The presence of TBBPA bis (methyl ether) in anaerobic transformation in freshwater aquatic sediment and anaerobic and aerobic soil transformation ▪ Measurement of the water solubility and Log Kow of TBBPA bis (methyl ether) in order to better predict its toxicity and bioaccumulation .	TBBPA may have the potential to cause long-term adverse effects on marine ecosystems Need for further toxicity data. T may change following new endocrine data from the EU FIRE project on Endocrine Disrupters.

Table A6.1 continued overleaf

(6) European Commission (2006) European Union DRAFT Risk Assessment Report Hexabromocyclododecane (HBCDD) CAS No: 25637-99-4 Einecs No: 247-148-4, as last amended in October 2006

(7) European Commission (2006)EU Draft Risk Assessment Report Tetrabromo-4,4’, 6,6’-Isopropylidenediphenol (Tetrabromobisphenol-A, TBBP-A) CAS No: 79-94-7 May, 2006, to be updated in 2007

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
6	Tetrabromobisphenol A (TBBPA)	79-94-7	WS	180 days (water), 320 days (soil), 1600 days (sediments) (EPA PBT Profiler)	Log K_{OW} = 4.5 – 5.3 (DK EPA, 2000). Log K_{OW} = 5.90 (measured) (EU RAR, 2005)	Toxic to aquatic organisms (EPA used an acute toxicity value of 0.4 mg/L)
			DK	TBBPA is not readily biodegradable. Simulation type studies in water/sediment and soil show half-lifes ranging from 48-84 days and indicate only partial degradation of TBBPA. Studies in soil under aerobic and anaerobic conditions likewise indicate partial degradation of TBBPA, but no half-lives were reported for these studies. Based on the above studies, TBBPA is considered to fulfil the P and vP criteria (half-life > 40 days and > 60 days in freshwater, respectively)	The maximum BCF for TBBPA has been obtained in *Chironimus tentans* (range 650-3200 in low organic carbon sediments) whereas BCF in studies with three different fish species attained a maximum of 1200. The large BCF range stated for *Chironimus tentans* indicates some uncertainty in the BCF estimate, and the studies conducted with fish are considered more representative. Thus, TBBPA is not considered to fulfil the B criteria (BCF > 2,000) as the validity of the results obtained for *Chironimus tentans* can be questioned.	TBBPA is toxic towards aquatic organisms (L(E)C50 < 1 mg/L). Chronic NOEC values of 0.16 mg/L and 0.30 mg/L has been obtained in embryo-larvae test with fish and in a reproduction study with *Daphnia magna,* respectively. Based on these data, TBBPA does not meet the T criterion (long-term NOEC < 0.01 mg/L in freshwater or marine organisms)
				DK *Summary* of *PBT assessment* Based on the available data, TBBPA is considered to be very persistent (vP), but NOT to fulfil the B or T criteria.		
7	Tetrabromobisphenol A bis (2,3-dibromopropyl ether)	21850-44-2	WS	Insufficient data; low degradability	Log K_{OW} = 11.52 (estimated, K_{OW}Win)	Low acute toxicity (LD50 = 20g/kg, oral); relatively low sub-chronic NOAEL = 200 mg/kg ; mutagenic NTP thinks it has carcinogenic potential.
8	Tetrabromobisphenol A carbonate oligomer	94334-64-2 and 71342-77-3	DK	DK *Summary* of *PBT assessment* No data regarding the environmental properties of TBBPA carbonate oligomer have been found. The PBT assessment of TBBPA carbonate oligomer is thus based on the monomer TBBPA (#6, above). Thus, TBBPA carbonate oligomer is considered to be very persistent (vP), but not the vB criterion. TBBPA is not considered to fulfil the B or the T criteria.		
9	Brominated polystyrene	88497-56-7		No data	No data	no data
10	Poly(dibromostyrene)	148993-99-1	(8)	Only the data on persistence of dibromostyrene monomer available: overall persistence of dibromostyrene is predicted to be ca. 49 days using the default emission scenario of the EPWIN v3.11 Level III multimedia model	Only the data on bioaccumulation of dibromostyrene monomer available: dibromostyrene is not expected to bioaccumulate in the food chain, since the estimated BCF of the monomer is 790 (EPWIN v3.11)	Insufficient data.
11	Poly (pentabromobenzyl acrylate) fr 1025	59447-57-3	(9)	No data	BCFn< 12.0 (8weeks)	Acute toxicity to fish 48h LC50 > 250mg/l (orange-red killifish)

Table A6.1 continued overleaf

(8) IUCLID Data Set 201-14931 on dibromostyrene (CAS[125904-11-2]

(9) MSDS, ICL Industrial Products

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
12	2,4,6-Tris(2,4,6-tribromo phenoxy) - 1,3,5 triazine	25713-60-4	(10)	The substance is considered not inherently biodegradable (OECD guideline 302D)	The substance was considered to be not bioaccumulative in the food chain: BCFs were determined to be < 0.8-9 and < 8-18 for level 1 and 2 concentrations, respectively (8 weeks, carps, Test methods for new chemical substances, Kanpogyo No5, Yakuhatsu No 615, 49 Kikyoku No 392, 1974)	Practically not toxic to fish up to its limit of water solubility (OECD TG 203 Fish, Acute Toxicity Test- Statistic Conditions; EC directive 92/69/EEC C.1 Acute Toxicity for Fish). Practically not toxic to daphnia up to its limit of water solubility (OECD TG 202 Daphnia sp.. Acute Immobilisation Test and Reproduction Test- Static conditions.
13	Brominated epoxy oligomer	68928-70-1	(11)	No data	No data	No information available
14	Chloroparaffins Alkanes, C14-17, Chloro (MCCP)	63449-39-8 and 85535-85-9	EU RAR(12)	considered to be not biodegradable	High log Kow values indicate a high potential for bioaccumulation. BCF of 1,087 l/kg and an accumulation factor from food of between 1 and 3 on a lipid basis for the fish food chain risk assessment. Further modelling of Kow and/or BCF testing is needed. Uptake from soil : BCF of 0.034. Further evaluation of some constituents of the technical product (C14, 45% wt. Cl and /or 52% wt. Cl) is necessary.	High acute toxicity towards aquatic organisms
15	Dodecachlorododecahydro-dimethanodibenzocyclooctene (Dechlorane Plus)	13560-89-9	(13) (14)	believed to be persistant	In one study, equilibrium of tissue accumulation was reached after 7 days of exposure with accumulated concentration in tissues of up to 8.8 ppm. Because of limited water solubility, BCFs were estimated from the octanol-water partition coefficient, water solubility, and the sediment-water partition coefficient, instead of study data. The BCFs were in poor agreement: 7.02 at 48 hours and 1.97 at 96 hours. Dechlorane Plus was found to bioaccumulate in fish after subacute or subchronic administration.	Acute toxicity to fish: 96h LC50 > 100mg/l (bluegill sunfish fish

Table A6.1 continued overleaf

(10) Full Study Report, File No:STD/1132, NICNAS, July 2006
(11) MSDS, ICL Industrial Products
(12) European Commission (2005) Alkanes, C14-17, Chloro (MCCP), Part I – Environment, CAS No: 85535-85-9, EINECS No: 287-477-0, Final Risk Assessment Report, 2005, UK.
(13) MSDS OxyChem
(14) Dechlorane Plus, High Production Volume (HPV) Chemical Challenge Program, Test Plan, EHSI, August 2004

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
16	Resorcinol bis(diphenylphosphate) (RDP)	57583-54-7 or 125997-21-9	WS	In water (at 20 deg C; pH 7) = 7-17 days (EFRA). In water, 11 days at 20 deg C at pH 4; 17 days at 20 deg C at pH 7; 21 days at 20 deg C at pH 9 (HPV submission IUCLID Data Set, 2001).	Log K_{OW} (estimated) = 7.41; BCF (estimated) = 3000 (EPA PBT Profiler). BCF = 316 (calculated) based on measured K_{OW} = 3.9-4.8	Low for lab animals, medium aquatic toxicity. Negative mutagenicity studies; no carcinogenicity studies.
17	Bisphenol A bis(diphenyl phosphate) (BDP, BAPP)	181028-79-5 and 5945-33-5	WS	Half –life (T½) at pH 4.0 > 1 year @ 25 deg C, T½ at at pH 7.0 > 1 year @ 25 deg C, T½ at pH 9.0 > 1 year at 25 deg C. T1/2 also reported to be between 1 day and 1 year.	Log K_{OW} => 6 at 25 deg C (measured). Experimentally derived Log K_{OW} = 4.5 with a calculated BCF = 3.16 (Supresta LLC, 2002; Akzo Nobel, 2002). Ecology criterion > 5.	Low acute toxicity (> 2,000 mg/kg rat). Low subchronic toxicity NOAEL ~ 2,000 mg/kg ; not mutagenic Ames test. No chronic bioassays.
18	Diphenyl cresyl phosphate (DCP)	26444-49-5	WS	T1/2 = 4.86 years in water	BCF 980 (calculated with K_{OW} = 4.5)	Low acute oral toxicity in multiple species; inhalation toxicity relatively high (sheep); not mutagenic; has reproductive and developmental toxicity, moderate aquatic toxicity.

Table A6.1 continued overleaf

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
19	Triphenyl phosphate (TPP)	115-86-6	WS	T1/2 =12 hours atmospheric; T1/2 hydrolysis < 5 days – 366 days (pH 9 – pH 3); criterion is > 60 days.	BCF = 113 – 1,743; criterion is > 1,000; KOW < 4.77; Criterion = >5.	Low oral rat 3,500-20,000mg/kg; HOWEVER aquatic toxicity is high, not mutagenic Ames test; low repro, low teratogenic toxicity, low neurotoxicity.
			DK	TPP is inherently biodegradable and has been found to biodegrade extensively under both aerobic and anaerobic conditions in various test systems. Half-lives in water/sediment simulation tests range from 3-12 days in river water/sediment and pond sediment, whereas halflives ranging from 50-60 days are obtained in pond hydrosoil. No data have been found on ready biodegradability. Based on the available data, TPP is not considered to meet the P or vP criteria (half-life > 40 days and > 60 days in freshwater, respectively and half-life > 120 days and > 180 days in freshwater sediment, respectively)	TPP does not meet the B criterion as the experimentally determined BCF values (range 84-364) are < 2,000.	It is questionable whether TPP meets the T criterion, as the validity of the chronic NOEC values reported (range 0.087-0.23 mg/L) are uncertain. The acute L(E)Cso values are typically < 1 mg/L but higher than 0.1 mg/L, which is the screening level assignment of potentially toxic substances.
				DK *Summary* of *PBT assessment* TPP is not considered persistent or bioaccumulable according to the PBT criteria.		
	Triaryl phosphates butylated	68937-40-6				

Table A6.1 continued overleaf

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
20	Red phosphorus	7723-14-0	DK	Red phosphorus is an inorganic compound, and biodegradation is thus not a relevant parameter. In the aquatic environment, red phosphorus will slowly undergo abiotic transformation to phosphoric acid via intermediates such as hypophosphorus acid, phosphorus acid and phosphine. Phosphine is transformed to phosphates under oxidising conditions. Reaction rates have not been reported, but experimental determination of hydrolysis products of red phosphorus have shown that soluble reaction products accounted for up to 2.7% of the nominal concentration of solid red phosphorus after 4 months, indicating that the reactivity of red phosphorus is low in water. Red phosphorus is thus considered to meet the persistent (P) and very persistent ~ vP) criteria.	No data describing bioaccumulation of red phosphorus are available.	Red phosphorus has a relatively high aquatic toxicity with L(E)C5o values of < 1-1.3 mg/L, based on measured concentrations of total P in the solutions. As red phosphorus is insoluble in water, the aquatic toxicity exceeds the solubility limit of red phosphorus. The toxicity may be related to decomposition products of red phosphorus in aquatic solutions. Chronic NOEC values are not available. As a screening assignment of the T criterion, a substance is considered potentially toxic if the acute I.(E) *C50* to aquatic organisms is less than 0.1 mg/L. Based on the available data, red phosphorus does not meet the T criteria at a screening level, as the lowest L(E)C50 value report.ed is 0.63 mg/L *(Daphnia* magna, measured concentrations of total P), but further data are required for assessment of the T criterion.
				DK *Summary* of *PBT assessment* Based on the available data, red phosphorus is considered to meet the P and vP criteria due to the inorganic nature of the substance. The data are insufficient for evaluation of the Band T criteria. At a screening level, red phosphorus does not meet the T criteria.		
21	Melamine polvphosphate	218768-84-4	(15)	No data	Log Pow not applicable	Acute toxicity to Algae EC50 > 3.0mg/L (above the solubility of the compound in water), OECD 201, EEC C 3
22	Melamine cyanurate	37640-57 -6	(16)	Limited data: inherently biodegradable	Log Pow< 0	Acute toxicity to fish LC50 > 100mg/L (96h, estimated) Acute toxicity to daphnia EC50 > 100mg/L (48h, Daphnia magna, estimated) Note: water solubility (22°C): 2.2mg/L

Table A6.1 continued overleaf

(15) MSDS Melapur 200, Ciba SC
(16) MSDS Melapur MC25, Ciba SC

Table A6.1 continued PBT Assessment of Flame retardant alternatives

No	Substance Name	CAS No	Ref	P	B	T
23	Ammonium polyphosphates	14728-39-9 68333-79-9	(17)	Biodegradation, typically > 95% within 28 days	No data	Acute toxicity to fish: - 96h LC50 > 500mg/l (Brachydanio rerio (fish, fresh water), OECD guideline 203) - 96h LC50 > 500mg/l (Brachydanio rerio (fish, fresh water, Chimikaliengesetz) - 96h LC50 > 100mg/l (rainbow trout) - 48h EC50 > 100mg/l (Daphnia magna) - 72h EC50 > 100mg/l (algal growth inhibition)
24	Diethylphosphinic acid, aluminium salt	225789-38-8	DK	The commercial product Exulit OP 1230 is not biodegradable based on the results of a single test for inherent biodegradability. In such cases, the TGD recommends that a simulation test for environmental degradation should be performed, but no such data are available. Exolit OP 1230 is thus considered to meet the persistent (P) and very persistent (vP) criteria until otherwise proved.	Based on the estimated log Kow value (-0.44) Exolit OP 1230 does not meet the screening criterion for consideration as bioaccumulative (B) and very bioaccumulative (vB). No experimental BCF values have been found in the literature.	The results of the aquatic toxicity tests with Exolit OP 1230 indicate that toxic effects occur at levels much higher than the estimated water solubility with L(E)Cso values > 100 mg/L, corresponding to measured concentrations between 11-33.7 mg/L. Based on these data, Exolit OP 1,230 does not meet the toxicity (T) criterion.
				DK *Summary* of *PBT assessment* Based on the available data, Exolit OP 1230 is considered to be very persistent (vP). Exolit OP 1230 is not considered to meet the criteria for bioaccumulation. The available data indicate that Exolit OP *1230* is not acutely toxic at concentrations up to the water solubility limit, and has a low acute toxicity towards aquatic organisms.		
25	Aluminium trihydroxide	21645-51-2	(18)	No environmental issues identified		Ecotoxicity is low, reported in the literature as LC50 > 10g/l (fish) and EC50 > 10g/l (daphnia). Acute toxicity data is limited, but indicates that risk is low. One study reports LD50 > 5,000 mg/kg (rat)
26	Magnesium dihydroxide	1309-42-8	(18)	No environmental issues identified		Generally considered as non-toxic. May be harmful to fresh-water crustaceans LC50 = 64.7 mg/l.

(17) Frank Stuer-Lauridsen, COWI A/S, Comments on report on alternatives to brominated flame retardants, Working Report No. 18 2001, Arbejdsrapport fra Miljøstyrelsen.
(18) Environmental Assessment of Halogen-free Printed Circuit Boards, HDP User Group International, Inc January 15, 2004

Table A5.1 CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
0	Decabromodiphenylether (DecaBDE)	1163-19-5	EU RAR	Classification for carcinogenicity is not proposed. But a LOAEL of 1,120 mg/kg/day is stated based on the increased incidence of liver neoplastic nodules. (1) Due to remaining uncertainties additional studies needed on current concentrations in humans(2)	Negative bacterial mutagenicity tests. DecaBDE does not exhibit cytogenetic effects and does not present a mutagenic risk.	Not toxic to the reproduction. A recent study raised concern about the potential of DecaBDE to cause developmental neurotoxicity and a new study is expected.
			DK			May cause minor developmental defects and abortions..
			WS	Cancer review: Mice and rats (NTP, 2 year carcinogenicity study, via diet): LOAEL (non neoplastic lesions in spleen and forestomach, and in liver and lymph nodes at higher dose) = 25,000 ppm (in rats equivalent to approx. 1100 mg/kg/day). (EU Risk Assessment, 2002). Liver, pancreas and thyroid cancers have been reported in rodents at high doses (2500-5000 mg/kg) (NAS, 2000) U.S. EPA classified in Group D: insufficient evidence in humans and animals (U.S.EPA, 1995). IARC classification Group 3: not classifiable (IARC, 1991).	Mutagenicity Negative results in Salmonella mutagenicity tests (EU Risk Assessment, 2002) Gene mutation DecaBDE is not mutagenic in mouse lymphoma L 5178 Y/TK +/- assay for gene mutation with or without metabolic activation. (EU Risk Assessment, 2002). Chromosome abnormalities DecaBDE did not induce sister chromatid exchanges or chromosomal aberrations in Chinese hamster ovary cells in vitro. (EU Risk Assessment, 2002). Other genotoxic effects (no data)	Reproductive toxicity (no data) Teratogenicity Mice (single dose on post-natal day 3): LOAEL (neurobehavioral effects) = 20.1 mg/kg (Viberg et al., 2003). Embryotoxicity (no data)

Table A5.1 continued overleaf

(1) European Commission (2002) European Union Risk Assessment Report BIS(PENTABROMOPHENYL) ETHER CAS No: 1163-19-5 EINECS No: 214-604-9 Volume 17 EUR 20402 EN. Office for Official Publications of the European Communities, 2002, Luxembourg;

(2) Update of the Risk Assessment Addendum, Human Health Draft, 27th May 2005

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
1	Bis(pentabromophenyl) ethane (DBDE, EBP)	84852-53-9	WS	Cancer review: No studies available (German Report, 2001)	Mutagenicity Negative Ames tests, with and without metabolic activation. (IUCLID Dataset, 2005). Gene mutation (no data) Chromosome abnormalities Negative in in vitro chromosome aberration test, with and without metabolic activation (with Chinese Hamster lung cells) (IUCLID Dataset, 2005). Other genotoxic effects (no data)	Reproductive toxicity (no data) Teratogenicity NOAEL > 1,250 mg/kg bw (for maternal toxicity and teratogenicity; rats, gavage during gestational days 6-15). NOAEL > 1,250 mg/kg bw (for maternal and teratogenicity; rabbits, gavage during gestational days 6-18). (IUCLID Dataset, 2005). Embryotoxicity (no data)

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
2	Ethylene bistetrabromo phthalimide (EBTPI)	32588-76-4	WS	Cancer review: (no data)	Mutagenicity Negative Ames assay in a variety of salmonella strains, with and without activation (IUCLID Dataset, 2000). Gene mutation (no data) Chromosome abnormalities (no data) Other genotoxic effects (no data)	Reproductive toxicity (no data) Teratogenicity Sprague Dawley rats, given increasing doses once daily by gavage from gestation to days 6-15, NOEL: > 1,000mg/kg bw. Neither maternally toxic nor teratogenic when administered to pregnant rats at a dosage as high as 1000 mg/kg. (IUCLID Dataset, 2000). Repeated results in New Zealand white rabbits. (IUCLID Dataset, 2000). Embryotoxicity (no data)
			DK	There was no information on the carcinogenicity of EBTPI. No mutagenic activity was observed when EBTPI was tested in Salmonella typhimurium, Saccharomyces cerevisiae, or Escherichia coli with and without metabolic activation. EBPTI does not seem to pose a mutagenic risk. Based on results in rats and rabbits EBPTI does not seem to be toxic to the reproduction.		

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
3	Tetrabromobisphenol A epichlorohydrin polymer	40039-93-8	WS	Cancer review: (no data)	Mutagenicity For tetrabromobisphenol A epoxy resin (a related compound): mutagenic in S. typhimurium strain TA 100 without metabolic activation only, but not in strains TA 98, TA 1535, TA 1537 and TA 1538 (Gardiner et al., 1992). Gene mutation For tetrabromobisphenol A epoxy resin (a related compound): induced chromosomal aberration in cultured Chinese hamster ovary cells with and without metabolic activation. Did not induce morphological transformation in the BALB/C-3T3 cell system. Daily dermal doses of 1000 mg/kg for 5 days did not induce chromosomal aberrations in bone marrow of rats (Gardiner et al., 1992). Chromosome abnormalities (no data) Other genotoxic effects (no data)	Reproductive toxicity (no data) Teratogenicity (no data) Embryotoxicity (no data)

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
4	Bis(tribromophenoxy) ethane	37853-59-1	WS	Cancer review: (no data)	Mutagenicity Nonmutagenic in Ames Test and in yeast Saccharomyces cerevisiae tester strain DR. (HSDB). Gene mutation (no data) Chromosome abnormalities (no data) Other genotoxic effects (no data)	Reproductive toxicity Rat (90 feeding study): NOAEL (parental) = 8329 – 9364 mg/kg (males and females) (10%). Effects on reproductive organs. (Great Lakes Chemical Corp, 2002). Teratogenicity Rat (gest. Day 6-15, by gavage): NOAEL (maternal) = 1000 mg/kg bw; NOAEL (fetal) = 10000 mg/kg bw. Rat (gest. Day 6-15, by gavage): NOAEL = 10000 mg/kg bw (both maternal and fetal) (Great Lakes Chemical Corp, 2002). Embryotoxicity (no data)
5	Hexabromocyclododecane (HBCDD)	3194-55-6 and 25637-99-4	WS	Cancer review: NAS reported that there was inadequate carcinogenicity data from any route of exposure to make any conclusions about the potential carcinogenicity of HBCDD (NAS, 2000).	Mutagenicity Negative in mutagencitiy assays in yeast and Salmonella (NAS, 2000). Gene mutation (no data) Chromosome abnormalities Negative for chromosomal aberrations in human peripheral blood lymphocytes (NAS, 2000). Other genotoxic effects Not genotoxic (NAS, 2000).	Reproductive toxicity (no data) Teratogenicity Rats (gestational day 0-20, diet) NOAEL ~ 500 mg/kg-day. Rats (gestational day 0-20, by gavage) NOAEL = ~ 1,000 mg/kg-day (NAS, 2000). Embryotoxicity (no data)
			EU RAR(3)	No concern	No genotoxic potential	An indicative LOAEL of 0.9 mg/kg/day can be deduced from a recent study indicating that neonatal HBCDD exposure may cause developmental neurotoxic effects, but the results need to be confirmed.

Table A5.1 continued overleaf

(3) European Commission (2006) European Union DRAFT Risk Assessment Report Hexabromocyclododecane (HBCDD) CAS No: 25637-99-4 Einecs No: 247-148-4, as last amended in October 2006

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
6	Tetrabromobisphenol A (TBBPA)	79-94-7	WS	Cancer review: (no data)	Mutagenicity Negatives in Ames Salmonella test) (HPV Data Summary, 2004). Gene mutation (no data) Chromosome abnormalities Negative in in vitro chromosome aberration test) (HPV Data Summary, 2004). Other genotoxic effects (no data)	Reproductive toxicity Rat two generational reproduction study, NOEL = 1000 mg/kg/day. (HPV Data Summary, 2004). Teratogenicity Rat developmental study, (dose 0 – 19 days of gestation): NOAEL = 1000 mg/kg/day). (HPV Data Summary, 2004). Embryotoxicity (no data)
			EU RAR(4)	No studies available. From the available *in vitro* mutagenicity data and from repeated exposure studies, there is no indication of concerns for carcinogenicity.	Negative *in vitro* studies, and no structural indications for any genotoxic potential	Overall, the data do not provide strong evidence of the potential for TBBP-A to act as a developmental toxicant or neurotoxicant. Some Member States expressed a minority opinion that an effect on neurobehavioural development was observed and that a NOAEL of 50 mg/kg/day could be derived.
			DK	Cf. EU RAR	Negative results in a range of *in vitro* mutagenicity tests using bacterial strains and yeast. No in vivo data are available.	TBBPA has no toxicologically significant effects on fertility or reproduction at doses of up to 1000 mg/kg and no developmental effects was seen at doses up to 10,000 mg/kg.

Table A5.1 continued overleaf

(4) European Commission (2006)EU Risk Assessment Report Volume 63 Tetrabromo-4,4', 6,6'-Isopropylidenediphenol (Tetrabromobisphenol-A, TBBP-A) CAS No: 79-94-7 Einecs No: 201-236-9 Luxembourg Office for Official Publications of the European Communities, 2006, EUR 22161 EN

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
7	Tetrabromobisphenol A bis (2,3-dibromopropyl ether)	21850-44-2	WS	Cancer review: "Tetrabromobisphenol A bis(2,3-dibromopropyl ether) (TBBPA-DBPE) was nominated for toxicological characterization by the National Institute of Environmental Health Sciences (NIEHS) based on studies of 2,3- dibromo-1-propanol (DBP) and the DBP-based flame retardant tris(2,3-dibromopropyl)phosphate (TBP) that showed clear evidence of carcinogenicity in all sex-species combinations in two-year dermal and feed studies, respectively, conducted by the National Toxicology Program (NTP). Out of 32 compounds identified with the DBP substructure, only TBBPA-DBPE was found to be currently in production and use." (NIEHS, 2002).	Mutagenicity Positive for mutagenic activity with and without metabolic activation in Salmonella typhimurium strains (NIEHS, 2002). Gene mutation (no data) Chromosome abnormalities (no data) Other genotoxic effects Negative in a rat unscheduled DNA synthesis assay. Did not induce sister chromatid exchanges in Chinese hamster ovary cells with or without metabolic activation (NIEHS, 2002).	Reproductive toxicity (no data) Teratogenicity (no data) Embryotoxicity (no data)
8	Tetrabromobisphenol A carbonate oligomer	94334-64-2 and 71342-77-3	DK	There are no studies available on carcinogenicity. BC-52 and BC-58 gave negative results when tested in 5 strains of *Salmonella typhimurium* at doses ranging from 100 to 10,000 µg/plate. There are no studies available on reproduction toxicity of TBBPA oligomers.		
9	Brominated polystyrene	88497-56-7	(5)	No data	Non mutagenic (salmonella). Note: Contaminants in commercial product (solvent, monomer) may give positive results in-vitro	Reproductive toxicity: NOAEL = 150mg/kg/day (maternal tox in rats)

Table A5.1 continued overleaf

(5) Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Octabromodiphenyl Ether, RPA, June 2002

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
10	Poly(dibromostyrene)	148993-99-1	(6)	No data	Only the data on of dibromostyrene monomer available: dibromostyrene has been tested for mutagenicity in S. typhimurium strains TA98, TA100, TA1535, TA1537 and TA1538 as well as in the CHO/HGPRT mammalian cell gene mutation assay in the absence and presence of a metabolic activation system. Results of both studies were negative.	Only the data on of dibromostyrene monomer available: reproductive toxicity: NOAEL=400mg/kg/day (two-generation reproduction study, decreased mean testes weights) Neonatal toxicity. NOAEL for adults < 100 mg/kg/day (parental toxicity was apparent in the 400mg/kg/day treated groups)
11	Poly (pentabromobenzyl acrylate) fr 1025	59447-57-3	(7)	No data	Not mutagenic by the Ames Test (Salmonella & E. coli)	No data
12	2,4,6-Tris(2,4,6-tribromo phenoxy) -1,3,5 triazine	25713-60-4	(8)	No data	Not mutagenic (OECD TG 471: bacteria reverse mutation) Not clastogenic (OECD TG 473: in vitro chromosome aberration test; OECD TG 476: in vitro gene mutation test)	No data
13	Brominated epoxy oligomer	68928-70-1	(9)	No data	Not mutagenic by the Ames Test	No data
14	Chloroparaffins Alkanes, C14-17, Chloro (MCCP)	63449-39-8 and 85535-85-9	EU RAR(10)	No genotoxic activity	Carcinogenicity cannot be completely ruled out in male and female rats through a non-genotoxic mode of action. NOAEL of 23 mg/kg/day is derived for risk characterisation	The majority opinion of the Technical committee is that there is no developmental toxicity. However, three Member States disagreed with this interpretation and pointed to increased sensitivity in the human foetus during the last trimester. The effect would further imply classification for developmental toxicity.
15	Dodecachlorododecahydro-dimethanodibenzocyclooctene (Dechlorane Plus)	13560-89-9	(11)	No data	The substance did not show a mutagenic response in the following tests: Standard Ames Assay (with and without activation), Ames Assay on Urine from rats treated with the flame retardant, and Mouse Lymphoma Forward Mutation Assay (with and without activation).	No data

Table A5.1 continued overleaf

(6) IUCLID Data Set 201-14931 on dibromostyrene (CAS[125904-11-2]
(7) MSDS, ICL Industrial Products
(8) Full Study Report, File No:STD/1132, NICNAS, July 2006
(9) MSDS, ICL Industrial Products
(10) DRAFT RAR OF JULY 2006, not yet agreed.
(11) OxyChem Dechlorane Plus Manual, (http://www.oxy.com/oxychem/Products/dechlorane_plus/literature/dechlorane_plus.pdf)

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
16	Resorcinol bis(diphenylphosphate) (RDP)	57583-54-7 or 125997-21-9	WS	Cancer review: No rodent chronic bioassay.	Mutagenicity Negative in Ames Test (with salmonella typimurium and Escherichia coli) (HPV submission IUCLID Data Set, 2001). Gene mutation (no data) Chromosome abnormalities Negative in chromosomal aberration test (cultured human lymphocytes) with and without metabolic activation (HPV submission IUCLID Data Set, 2001). Other genotoxic effects Negative in mouse micronucleus assay (HPV submission IUCLID Data Set, 2001). Other genotoxic effects Negative in mouse micronucleus assay (HPV submission IUCLID Data Set, 2001).	Reproductive toxicity Rat (2-generational diet study); concentration in food administered: 1000, 10000, and 20000 ppm. NOAEL of F1 and F2 offspring > 20,000 ppm. Study reported no adverse effects on reproductive performance or fertility parameters (Henrich et al., 2000; HPV submission IUCLID Data Set, 2001). Teratogenicity Rabbit (exposure period gestational days 6-28, by gavage). NOAEL (maternal and developmental toxicity) > 1,000 mg/kg bodyweight (HPV submission IUCLID Data Set, 2001). Embryotoxicity (no data)

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
17	Bisphenol A bis(diphenyl phosphate) (BDP, BAPP)	181028-79-5 and 5945-33-5	WS	Cancer review: (no data)	Mutagenicity Not mutagenic in bacteria (Australian Gov., 2000). Not mutagenic in Ames test (Great Lakes Chemical Corp. MSDS). Non-mutagenic in reverse mutation assay (Salmonella typhimurium TA1535, TA1537, TA98 and TA100, and Escherichia coli WP2uvrA; +/- metabolic activation). (Australian DHA, 2005). Gene mutation (no data) Chromosome abnormalities Did not increase incidence of chromosomal aberrations in Chinese hamster lung cells (Australian Gov., 2000). Non-clastogenic in in vitro Chinese hamster ovary (CHO) cell assay with and without metabolic activation. Nonclastogenic in mice bone marrow cells (at 2000 mg/kg at 0 and 24 hours by oral gavage) (Australian DHA, 2005). Other genotoxic effects (no data)	Reproductive toxicity (no data) Teratogenicity Rat (exposed gestational days 6-19; by gavage): NOAEL (for maternal and developmental toxicity) = 1000 mg/kg bodyweight (highest dose tested). Test material was product CN-1985 listed as having 98.5% purity. Rat (exposed gestational days 8-19, by gavage): NOAEL (for maternal and developmental toxicity) = 1000 mg/kg bodyweight (IUCLID data set, 2004). Embryotoxicity (no data)

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
18	Diphenyl cresyl phosphate (DCP)	26444-49-5	WS	Cancer review: (no data)	Mutagenicity Evaluated for mutagenicity in the Salmonella/microsome preincubation assay using a standard protocol approved by National Toxicology Program. Doses of 0, 100, 333, 1000, 3333, and 10000 ug/plate were tested in four Salmonella typhimurium strains (TA98, TA100, TA1535, and TA1537) in the presence and absence of Aroclor-induced rat or hamster liver S9. These tests were negative and the highest ineffective dose level tested without formation of a precipitate in any Salmonella tester strain was 1000 ug/plate. (Zeiger et al., 1987). Negative in Ames test (IUCLID Dataset, 2000) Gene mutation (no data) Chromosome abnormalities (no data) Other genotoxic effects (no data)	Reproductive toxicity NOEL(rat) reproductive toxicity Parental: 60mg/kg (UNEP, IPCS, 1997) NOEL(rat) reproductive toxicity F1 generation: 300mg/kg (UNEP, IPCS, 1997) Teratogenicity (no data) Embryotoxicity (no data)

Table A5.1 continued overleaf

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
19	Triphenyl phosphate (TPP)	115-86-6	WS	Cancer review: Overall carcinogenic concern LOW, based on modeling results (EPA, 2005) A4; Not classifiable as a human carcinogen (ACGIH, 2005)	Mutagenicity Low concern, negative Ames assay mouse lymphoma cells. (EPA, 2005) Gene mutation Negative in mitotic gene conversion assay (EPA, 2005) Chromosome abnormalities (no data) Other genotoxic effects (no data)	Reproductive toxicity Low concern, 91-112d repro/developmental study (incomplete) rats, diet, no reproductive effects, NOAEL= 690 mg/kg/d (EPA, 2005). Teratogenicity Low concern, 91-112d repro/developmental study (incomplete) rats, diet, no reproductive effects, NOAEL= 690 mg/kg/d (EPA, 2005). Embryotoxicity (no data)
			DK	There are no studies available from which a conclusion on the carcinogenic potential of triphenyl phosphate can be drawn. However, no mutagenic effect was found in any of the *in vitro* genotoxicity studies available although the studies included tests with and without metabolic activation. *In vivo* genotoxicity is not tested. In a well performed and reported study no effects on reproduction and no teratogenic potential was found of daily doses up to and including 690 mg/kg bw administered before and during mating and throughout gestation.		
	Triaryl phosphates butylated	68937-40-6				
20	Red phosphorus	7723-14-0	DK	There are no studies available on carcinogenicity, mutagenicity or reproduction toxicity.		
21	Melamine polvphosphate	218768-84-4		No data	No data	No data
22	Melamine cyanurate	37640-57 -6	(12)	No data	Not mutagenic (bacterial systems)	No data

Table A5.1 continued overleaf

(12) MSDS Melapur MC25, Ciba SC

Table A5.1 continued CMR Assessment of Flame Retardant alternatives

No	Substance Name	CAS No	Ref	C	M	R
23	Ammonium polyphosphates	14728-39-9 68333-79-9	(13)	No data	Ames test: not mutagenic (Salmonella typhimurium; E.Coli)	No data
24	Diethylphosphinic acid, aluminium salt	225789-38-8	DK	There is no information on the carcinogenicity of diethylphosphinic acid, aluminium salt. No mutagenic activity was observed when tested in Salmonella typhimurium or in a cytogenetic assay in vitro with and without metabolic activation. Diethylphosphinic acid does not seem to pose a mutagenic risk. There was no information on the effects of diethylphosphinic acid, aluminium salt on reproduction.		
25	Aluminium trihydroxide	21645-51-2	(14), (15)	not carcinogenic in animal tests. There is no human data available	No specific information available for mutagenicity. No further research is needed for assessing the health risks	When administered orally to animals, has not produced harmful effects for teratogenicity and embryotoxicity. No human data available.
26	Magnesium dihydroxide	1309-42-8		Limited data available. No further research is considered to be needed for assessing the health risks from the substance		

(13) IUCLID dataset
(14) Environmental Assessment of Halogen-free Printed Circuit Boards, HDP User Group International, Inc January 15, 2004
(15) Toxicological Risks of Selected Flame-Retardant Chemicals, NATIONAL ACADEMY PRESS, Washington, D.C., 2000

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Review on production processes of Decabromodiphenyl Ether (DecaBDE) used in polymeric applications in electrical and electronic equipment, and assessment of the availability of potential alternatives to DecaBDE.

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ABSTRACT

In this study commissioned by DG ENV, the JRC-IHCP-ECB has reviewed the production processes of DecaBDE, in particular its NonaBDE content, and explored the availability of potential DecaBDE alternatives used in polymeric applications for EEE (cost of substitution and recyclability of alternatives was outside the scope of the study).