Assessment of TBBPA (tetrabromobisphenol-A) according to the “Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances (Annex III) under the RoHS2 Directive”

Part II and Part III assessment

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CONTENTS

ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
ACGIH	American Conference of Governmental Industrial Hygienists
ATH	Aluminium tri-hydroxide
BAT	Best available technique
BBP	Benzyl butyl phthalate
BCF	Bioconcentration factor
BFR	Brominated flame retardant(s)
BREF document	Best available technique reference document
BSEF	Bromine science and environmental Forum
CAA	Clean air act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHCC	Chemical of high concern to children
CLP	Classification, labelling and packaging of substances and mixtures
CSPA	Children's Safe Product Act
DBP	Dibutyl phthalate
DEHP	Bis(2-ethylhexyl) phthalate
DNEL	Derived no effect level
DOPO	9-oxy-10-phosphaphenanthrene-10-oxide
EC10	Effective concentration where 10% of organisms show an effect
ECHA	European Chemicals Agency
EEA	European Environment Agency
EEE	Electric and electronic equipment
EFRA	European flame retardant association
EHC	Environmental health criteria
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt („Swiss Federal Laboratories for Materials Science and Technology")
EPCRA	Emergency Planning and Community Right-to-Know act
EU RAR	European Union Risk Assessment Report
GADSL	Global Automotive Declarable Substance List
GASG	Global automotive stakeholder group
GESTIS	„Gefahrstoffinformationssystem der Deutschen Gesetzlichen Unfallversicherung"; Information system on hazardous substances of the German Social Accident Insurance
GLP	Good laboratory practice
HBCDD	Hexabromocyclododecane
HIPS	High impact polystyrene
IARC	International Agency for Research on Cancer
LOUS	List of Undesirable Substances in Denmark
NOAEL	No observed adverse effect level
NOEC	No observed effect level
MAK	"Maximale Arbeitsplatzkonzentration"; threshold limit value
MS	Member state
OEL	Occupational exposure limit

PAH	Polycyclic aromatic hydrocarbon
OSHA	Occupational Safety and Health Administration
OSPAR	Oslo and Paris conventions
PBT	Persistent, bioaccumulative,and toxic
PC	Polycarbonate
PCDD/F	Polychlorinated dibenzodioxin / -furan
PBDD/F	Polybrominated dibenzodioxin / -furan
PBDE	Polybrominated Diphenyl Ethers
PEL	Permissible exposure limit
PM	particulate matter
PMMA	Poly(methyl methacrylate)
PNEC	Predicted no effect concentration
PNOR	Particles not otherwise regulated
PNOS	Particulates not otherwise specified
POP	Persistent organic pollutant
PPE	Polyphenylene ether
PROC	Process category (descriptor under REACH)
PTFE	Polytetrafluoroethylene
R&D	Research and development
RCR	Risk characterisation ratio
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SCOEL	Scientific Committee on Occupational Exposure Limits
SVHC	Substance of very high concern
TBBPA	Tetrabromobisphenol A
TLV	Threshold limit value
TSCA	Toxic substances control act
TWA	Time weighted average
vPvB	Very persistent and very bioaccumulative
WEEE	Waste of electric and electronic equipment
WHO	World Health Organisation
WSDH	Washington State Department of Health

SUMMARY

In this report the substance tetrabromobisphenol A (TBBPA, CAS no. 79-94-7) has been evaluated according to the RoHS manual as published by the Austrian Umweltbundesamt and an evaluation of data gaps and uncertainties has been conducted.

TBBPA is a flame retardant, that can be used additively and reactively. It is currently not restricted under any legislation.

The evaluation of its hazardous properties for human health showed a low acute toxicity, no reproductive or teratogenic effects and no clear indication for neurotoxicity or endocrine activity. However, recent studies show a carcinogenic potential in rats and mice.

Concerning environmental hazards, TBBPA shows acute and chronic aquatic toxicity (category 1). However, it doesn't meet the PBT no POP criteria.

An exposure assessment related to the treatment of waste has been conducted which has been based on established assumptions and exposure tools as used for the assessment of other substances under RoHS. The assessment came to the result that under the assumptions made no risk for humans or the environment was expected.

Releases of toxic degradation products (e.g. during incineration of WEEE) are possible, but according to literature levels are usually well below the regulatory limit values.

Substitutes for TBBPA are available and even partly in use. However, according to collected information the reliability of other flame retardants e.g. in printed circuit boards has not been proven to be fully comparable to TBBPA, yet. The same applies for possible alternatives for TBBPA in housings, where insufficient data for some end-points was identified and increased costs are expected.

Some of the available substitutes may be toxic for humans or the environment.

In the socio-economic analysis two scenarios, one without a ban of TBBPA and one with a ban of TBBPA, have been compared. The analysis revealed a moderate cost increase concerning the additive use of TBBPA. For reactive use, however, the cost increase is expected to be much higher while advantages are expected to be limited.

Overall the evaluation came to the conclusion that, since under controlled conditions no risk has been identified for humans or the environment during waste treatment and in general no negative impact on waste management was determined, a restriction under RoHS is not necessary.

In the course of the data gap analysis mainly data gaps concerning the exposure scenario and possible alternatives were identified. Concerning hazardous properties no specific data gaps exist; however, it cannot be excluded that new studies will be published which may lead to a change of limit values (DNELs, PNECs) or other substance properties and therefore the outcome of the risk assessment. General discussions on TBBPA such as the CoRAP evaluation are ongoing and their outcome will be a major influence on the result of this evaluation.

INTRODUCTION AND OBJECTIVES

In this report the substance tetrabromobisphenol A (CAS no. 79-94-7) will be evaluated according to the RoHS manual, which was published by the Austrian Umweltbundesamt commissioned by the European Commission, Directorate General Environment, DG, and was in line with the requirements under the RoHS2 Directive. [1].

In a first step, a screening assessment ("part II assessment") has been performed, consisting of a short evaluation of human and environmental toxicological hazards and waste relevance criteria (influence of TBBPA on WEEE treatment, releases, health impacts). As a result, TBBPA has been assigned to one of 12 priority classes which are used to compare substances relevant under RoHS with each other and to decide which have to be assessed further with a higher level of detail in the future. This screening assessment has been summarised in a status report which is laid down in Appendix A.
The screening assessment resulted in the second highest priority class (category 2). Thus, as volumes currently present in WEEE in the EU are mostly comparable to other substances with this priority class and 4 substances with class 1 priority have already been assessed for the European Commission, a more detailed assessment in the near future cannot be excluded. The priority class is also consistent with the previously published list of priority substances [2].

In a second step, a more detailed assessment as described in the RoHS manual ("part III assessment") was performed, in order to predict possible conclusions that may be drawn by the authorities and identify possible data gaps.
In general, the assessment includes an evaluation of identification, classification and labelling as well as the legal status (section 1), a description of the use (section 2), the human health hazard profile (section 3), information about environmental hazards (section 4), a summary of waste treatment processes (section 5), an exposure – and risk assessment for these processes (sections 6 and 7), and a socio-economic analysis (section 9).
As this detailed assessment includes extensions and amendments of the main aspects already shortly summarised in the course of the screening, cross-links have been set in Appendix A to the corresponding sections in the main report part, where more information about human health, environmental toxicology and waste relevance can be found.
Based on the findings of the detailed assessment, a conclusion concerning a possible restriction of TBBPA under RoHS has been drawn which is described in section 10. Overall, there is to our knowledge no current need for the substance to be restricted. Potential risks may be related to uncontrolled treatment. However, under the assumptions made for this assessment, no risk for humans or the environment could be identified.

As a last step, a discussion of uncertainties, data gaps and other possible issues has been provided, that can be found in section 11.

ROHS ANNEX II DOSSIER

Restriction proposal for hazardous substance in electrical and electronic equipment regulated under RoHS

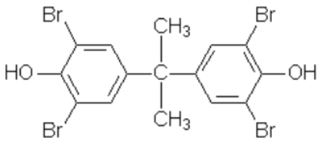
Substance Name:	**Tetrabromobisphenol A (TBBPA)**
EC Number(s):	**201-236-9**
CAS Number(s):	**79-94-7**

1 IDENTIFICATION, CLASSIFICATION AND LABELLING, LEGAL STATUS AND USE RESTRICTIONS[1]

1.1 Identification

1.1.1 Name, other identifiers and composition of the substance

Table 1: Substance identity and composition [3, 4]

Chemical name	2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol
EC number	201-236-9 (EG-Nummer)
CAS number	79-94-7
IUPAC name	2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol
Index number in Annex VI of the CLP Regulation	604-074-00-0
Molecular formula	C15H12Br4O2
Molecular weight range	543.88 g/mol
Synonyms	3,3',5,5'-tetrabromobisphenol-A 2,2',6,6'-tetrabromobisphenol A 2, 2,2-bis(3,5-dibromo-4-hydroxyphenyl) propane 4,4'-isopropylidene-bis(2,6-dibromophenol) 4,4'-isopropylidinebis(dibromophenol) 4,4'-(1-methylethylidene)bis(2,6-dibromophenol) tetrabromodihydroxy diphenylpropane TBBPA TBBP TBBA
Structural formula	

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[1] For basis of the assessment process in this and the following chapters see Ref. 1. Umweltbundesamt Österreich, *Manual: Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances (Annex II) under the RoHS2 Directive*, 2014: 1090 Wien/Österreich Available from: http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/abfall/ROHS/finalresults/Annex1_Manual.pdf.

1.1.2 Physico-chemical properties

Table 2: Overview of physico-chemical properties of TBBPA [3-5]

Property	Value
Physical state at 20°C and 101.3 kPa	solid
Melting/freezing point	178°C; 181-182°C
Boiling point	~316°C (decomposes at 200-300°C)
Vapour pressure	<1.19E-5 Pa at 20°C
Water solubility	pH 5 - 0.15 mg/l at 25°C pH 7 - 1.26 mg/l at 25°C pH 9 - 2.34 mg/l at 25°C pure water - 0.063 mg/l at 21°C and 0.24 mg/l at 25°C (used for risk assessment) 2.8 mg/l
Partition coefficient n-octanol/water (log P_{OW})	Log K_{ow} 3.25-5.9
Acid dissociation constants (pKa)	pKa1= 7.5 pKa2 = 8.5

1.2 Classification and Labelling Status

1.2.1 Classification in Annex VI Regulation No 1272/2008

The regulation [6] on classification, labelling and packaging of substances and mixtures entered into force on 20 January 2009. It aligns existing EU legislation to the United Nations Globally Harmonised System (GHS) and ensures that hazards of chemicals are clearly communicated to consumers and workers within the European Union. For TBBPA there is a harmonised classification and labelling available with the entries Aquatic Acute 1 and Aquatic Chronic 1 (H410: Very toxic to aquatic life with long lasting effects). For more details, see Table 3.

Self-classification(s)

Table 3: Classification according to part 3 of Annex VI, Table 3.1 (list of harmonized classification and labelling of hazardous substances) of Regulation (EC) No 1272/2008 [1]

Index No	**International Chemical Identification**	**EC No**	**CAS No**	**Classification**		**Labelling**			**Spec. Conc. Limits, M-factors**	**Notes**
				Hazard Class and Category Code(s)	**Hazard statement code(s)**	**Pictogram, Signal Word Code(s)**	**Hazard statement code(s)**	**Suppl. Hazard statement code(s)**		
604-074-00-0	tetrabromobisphenol- 4,4’-isopropylidenedip	201-236-9	79-94-7	Aquatic Acute 1 Aquatic Chronic 1	H400 H410	GHS09 Wng	H410	--	--	--

1.3 Legal status and use restrictions

1.3.1 Regulation of the substance under REACH

The production and use of TBBPA was registered by the industry under REACH (1000-10000 t/a) [4]. Up to July 2015 TBBPA was not on ECHA's candidate list of substances of very high concern (SVHC) for authorisation or listed in Annex XVII. [7, 8] .

On 30 October 2014 ECHA published the Draft Community rolling Action Plan [9] (CoRAP) update for the years 2015-2017 to which TBBPA was added. According to the document itself the draft plan has been submitted on 16 October 2014 to the Member State Competent Authorities and the ECHA Member State Committee.

The decision on a compliance check has been published in August 2014 [10]. The Decision asks for further testing concerning the identification of degradation products such as diethyl and dimethyl TBBPA derivatives. A revised environmental hazard assessment is suggested and it is stated that the PBT assessment should be revised under the light of information concerning possible degradation products (bisphenol A, dimethyl- or diethyl ether). It is stated that the transformation products should be taken into account for the exposure and risk assessment. Justification of the release factors into the environment used for the exposure assessment is demanded (see also section 11.5).

In the updated CoRAP published in March 2015 TBBPA is listed as new entry with Denmark being the designated Member state [11]. Initial grounds for concern stated in the document are suspected reprotoxic, potential endocrine disruptor, suspected PBT/vPvB, wide dispersive use, exposure of environment, consumer use, exposure of workers and a high (aggregated) tonnage. Finalisation of the review is scheduled for March 2016.

1.3.2 POPs Regulation, (EC) No 850/2004 amended by (EU) No 756/2010 and (EU) No 757/2010

TBBPA is not listed under POPs Regulation (see also section 4.1).

1.3.3 Montreal Protocol, the Regulation (EC) No 1005/2009 on substances that deplete the ozone layer and the F-gas Regulation (EC) NO 842/2006

TBBPA is not listed under these regulations.

1.3.4 Other legislative measures

OSPAR convention

"OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic". OSPAR is named after the original Oslo and Paris Conventions ("OS" for Oslo and "PAR" for Paris). A list of substances with need for priority action was published which includes TBBPA. [12] An assessment report has been published that also includes suggestions concerning the general proceedings [13]. However, this does not include specific restrictions.

EU WEEE Directive (2012/19/EU) [14]

The Waste of Electrical and Electronic Equipment 2012/19/EU calls for selective treatment of plastics containing brominated flame retardants (applies for additive use of TBBPA) as well as printed circuit boards of mobiles generally and other devices if the surface exceeds the size of 10cm^2 (applies for reactive use of TBBPA), as stated in Annex VII ref. to article 8(2).

Though this is not explicitly stated by the Directive the latter is probably triggered by their metal content which leads to hazardous properties of the boards and their residues.

Commission Recommendation of 3 March 2014 on the monitoring of traces of brominated flame retardants in food (2014/118/EU) [15]

"The European Commission has adopted certain recommendations to the Member States in which MS "should carry out analysis of the different classes of brominated flame retardants in order to detect the presence of […the class of tetrabromobisphenol A and its derivatives…] in the respective food commodities".

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal [16, 17]

The Basel Convention is an international treaty aiming at reducing hazardous waste movements between nations. The regulated waste streams and constituents are listed in Annex I. Category Y39 displays "Wastes containing phenolic constituents". Wastes containing phenolic constituents are therefore considered being hazardous if they possess any characteristics displayed in Annex III or are considered to be hazardous by the respective domestic legislation. In case of TBBPA, point H12 "Ecotoxic" from Annex III is applicable (see section 4). The Basel Convention was implemented by (EEC) No. 259/93 within the European Union. EEC No. 259/93 was replaced by (EC) No.1013/2016 on shipments of waste [18].

USA: TSCA Work Plan for Chemical Assessments: Oct 2014 Update [19]

The TSCA work plan run by the Environmental Protection Agency Office of Pollution Prevention and Toxics was updated in October 2014. The exposure score of TBBPA increased due to either domestic production or higher import quantities and more variable use in consumer and children's products. The classification changed from "moderate" to "high" under Step 2 of the screening process identified in the Methods Document for the TSCA Work Plan for Chemical Assessments.

USA: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-to-Know Act (EPCRA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Section 112® of the Clean Air Act [20]

Chemical substances listed are subjected to reporting requirements under the EPCRA, also known as Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and section 112® of the Clean Air Act (CAA). TBBPA is listed under section 313 (also known as the Toxic Release Inventory).

India [21, 22]

TBBPA was listed in the "Guidelines for Environmentally Sound Management of E-Waste" as of March, 2008, Annex VII. However, these were superseded by the E-Waste (Management and Handling) Rules, 2011 and the subsequent implementation guidelines that were issued in 2011 and in which TBBPA is not mentioned.

Uganda

In August 2012 Uganda adopted the e-waste definition of Basel Convention into its Electronic Waste (E-Waste) Management Policy - a rationale to mitigate the danger of human health and environmental hazards.

Further legislative measures

Further identified documents are the Children and Firefighters Protection Act of 2014 (USA, Proposal on prohibition of Flame Retardants in Children's Products and Furniture, Senate Bill 2811, 2014 [23], the Act on Regulation of Toxic Chemicals (USA / Vermont, Senate Bill 239, Public Act 188 [24]) and the Washington: Children's Safe Products Reporting Rule (Chapter 173-334 WAC, Rule, in force since 22 Aug 2011 [25]). However, the Children and Firefighers Protection Act of 2014 was never reported by the committee and for its 2015 successor the prognosis for being enacted concerning is also low [26]. The Act on Regulation of Toxic Chemicals and the Childrens Safe Products Reporting on the other hand exclude electronic Articles. Thus, those regulations are not considered to be relevant in this context.

1.3.5 Non-governmental initiations / voluntary measures

VECAP

The Voluntary Emissions Control Action Programme (VECAP) was initiated by industry in 2006. The website states "It is a voluntary initiative of members companies of the European Flame Retardant Association (EFRA) together with the industry's global organisation, the Bromine Science and Environmental Forum –BSEF." [27] TBBPA is included in the programme.

Global Automotive Declarable Substance List (GADSL) [28]

The GADSL was introduced on 29 April 2005 as a voluntary industry initiative aiming at ensuring "integrated, responsible and sustainable product development by OEM's and their supply chain" [29].

The GADSL is issued and updated by the GASG-SC. The Global Automotive Stakeholders Group (GASG) is a voluntary organization open to any member of the automotive supply chain. The GASG consists of the Americas, Europe/Africa/Middle East, and Asia/Pacific regions. Regional teams consist of representatives of the automotive, supplier and chemical industries. Each of the three regions nominates six members to sit on the governing body of the GASG, called the Steering Committee (GASG-SC). [28].

TBBPA is listed under No 115, classified as D (= Declarable). "A substance designated "D" must be declared if it exceeds the defined threshold limits [0.1%]" with the Reason Code FI (=For Information).

Substitute It Now (S.I.N.) – List

"The International Chemical Secretariat (ChemSec) is an environmental NGO that has been working with other environmental groups and manufacturers to produce a list of substances that they have identified to meet the criteria of Article 57 of the REACH regulations for Substances of Very High Concern (SVHC). The SIN-List is targeting chemicals that they believe are likely to become legally restricted under REACH. [30] The European Chemical Agency (ECHA) will develop the official list of SVHCs – the so-called "candidate list" over a period of many years and ChemSec's aim is to identify potential SVHCs as soon as possible so that manufacturers can search for alternatives."

The methodology for substance inclusion has been published by ChemSec and is based on screening of other lists (e.g. OSPAR, list of chemicals of possible concern & priority action or the EU Water Framework Directive) but also on literature search and evaluation. [31]

By the mid of December 2014 830 substances are being listed in the SIN list. ChemSec introduced TBBPA to the SIN list already in 2008, since according to their analysis reprotoxic and endocrine disruptive effects have been reported. TBBPA has therefore been categorized by ChemSec as a substance having properties of an equivalent level of concern as PBT or CMR substances.

LOUS – List of Undesirable Substances in Denmark

The Danish LOUS-List [32], published by the Danish Environmental Protection Agency's is a guide for enterprises. Listed substances should be reduced or halted. The aim is to foster substitution of these substances. TBBPA is listed under the group of certain brominated flame retardants.

1.3.6 Summary and conclusions on legal restrictions

The production and use of TBBPA was registered by the industry under the REACH regulation. Up to now, TBBPA has not been restricted under the REACH regulation. It was recently added to the Community Rolling Action Plan (CoRAP) -Draft for the years 2015-2017. The decision on a compliance check has been published in August 2014 [10].

In the U.S., TBBPA is currently regulated under the Emergency Planning and Community Right-to-know-Act (EPCRA) and the Children's Safe Products Reporting which is in force since August 2011. However these regulations do not restrict the production and placing on the market in articles but impose certain notification obligations.

Overall, currently there are no legal restrictions on the use of TBBPA.

2 USE IN ELECTRICAL AND ELECTRONIC EQUIPMENT

2.1 Use and function of the substance

TBBPA can be used as flame retardant or as intermediate (e.g. for the production of other flame retardants).

It can be used reactively, i.e. the substance is chemically bonded to the base material, or additively, i.e. the substance is only mixed with the base material.

According to Gensch et al. ~90% of TBBPA used as flame retardant in general are used reactively, while 10% are used additively. [33]

However, different values exist in literature concerning this fraction. As an example the Canadian assessment of TBBPA estimates a fraction of 10-20% of the overall TBBPA used as a flame retardant to be used additively and a share of TBBPA being used as a reactive flame retardant in epoxy and polycarbonate resins and/or electrical and electronic equipment ranging from 70 to 90%[2].[34]

As a reactive flame retardant TBBPA is mainly used in printed circuit boards [33]. In this case TBBPA is included into the polymer matrix and only minor '"free" substance residues may remain in the material (~0.0004%-0.06% of TBBPA originally used for resin production [5, 36]). According to Covaci et al. [37, 38] the bromine content in printed circuit boards may go up to 20% by weight. This corresponds to approximately 34% original TBBPA content (m/m), leading to free TBBPA residues of ~0.000134-0.0204% in the final epoxy resins.

Approximately 90% of all circuit boards are based on these brominated epoxies while the remaining circuit boards may use synthetic resin bonded paper, PTFE, alternative resins with other brominated or phosphorus based flame retardants (phosphorus based, e.g. DOPO: ~6-7% of circuit boards) [39].

Use as additive flame retardant is mainly relevant for the polymer used for housings. Concerning the affected EEE articles and polymer materials, various sources of information exist.

As an example, Gensch et al indicate ABS resins to be the most relevant material for additive use of TBBPA. [33]

According to EFRA enclosures can be made of High Impact Polystyrene (HIPS), acrylonitrile butadiene styrene (ABS) polycarbonate blends (PC / ABS), PC / PMMA or polyphenylene ether / HIPS blends (PPE / HIPS).[39] TBBPA levels in ABS may go up to 22.0% [3, 5, 37, 40] while lower levels of ~14% have been reported for HIPS by Covaci et al. (2009).

However, use of TBBPA in HIPS could not be confirmed by all sources of information.

Thus, overall ABS is considered to be the main polymer of relevance concerning additive use of TBBPA in housings and shows the highest applicable TBBPA concentration.

Another application is the use of TBBPA as intermediate for the production of other flame retardants (TBBPA derivatives & oligomers, e.g. the bis(2-hydroxyethyl ether) of TBBPA, as a flame retardant for paper and textiles, tetrabromobisphenol-A dimethylether or tetrabromobisphenol-A dibromopropylether for other niche applications) [3, 40, 41]. However, the production of these flame retardants will happen before the actual EEE production step and most likely will include additional purification steps in order to minimise the amount of unreacted TBBPA within the substance. Thus, remaining TBBPA amounts in the final EEE products are considered to be negligible.

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[2] Discrepancies (10-20% or 10-30% used additively) are not further explained by the Canadian risk assessment.

2.2 Quantities of TBBPA in EEE

In general, the tonnage of relevance is represented by the amount of flame retardant in WEEE in the EU, which is not necessarily identical to the amount used in the EU, as articles or half-finished products may be imported into the EU from other countries (e.g. Asia).

In order to estimate this tonnage of TBBPA, the EU risk assessment for TBBPA refers to assumptions concerning import of EEE and EEE components to estimate the release from these articles. However, since the EU risk assessment was published, more detailed numbers about the annual amount of EEE waste produced world-wide and in the EU have become available [42] [43, 44][3] which are considered to be a more reliable option for an estimation of the volumes present in WEEE per year.

Using the reported ~40 million t/a WEEE world-wide and ~9.1-9.2 million t/a WEEE in the EU, this results in ~23% of the global WEEE being generated in the EU. Assuming that the substances are evenly distributed within the WEEE, the amount of chemicals present in the WEEE of EU can be derived using this fraction of WEEE (23%) and the global tonnage of the corresponding substance used in EEE.[4]

Concerning TBBPA tonnages, different values have been published.

The approach implemented in the EU risk assessment [5] uses 6500 t/a import of the substance, assumes 6000 t/a import in partly finished products and 27500 t/a import in finished products, which results in 40000 t/a TBBPA in EEE waste per year (data from 2001).

According to the Oeko-Institute, the European consumption of TBBPA accounts for 1/3 of the worldwide total [45]. In contrast, the Government of Canada calculates a European share of roughly 10 % of the global market volume for the year 2004 [34].

Gensch et al. (2014, [33]) indicate an overall usage of ~5850 t/a as a reactive flame retardant in the EU (based on tonnage information from 2008). As the amount present in EEE / WEEE in the EU also depends on imported parts and articles a higher tonnage of ~40000 t/a present in EEE in the EU is overall estimated (13800 t/a imported as substance, 6000 t/a in partly finished products assumed, 20200 t/a in finished products assumed; estimates from previous evaluation by Oeko-Institute). Thus, the estimated amount of TBBPA used in EEE in the EU is approximately consistent with the EU risk assessment.

According to the German Umweltbundesamt (2008, [46]) ~7000 t/a TBBPA are used in the EU (data source not indicated).

The current use of TBBPA in the EU is at approximately 1000-2500 t/a according to Gensch et al. and the most recent VECAP reports from 2013 and 2014 [33, 47, 48]. For 2008 and 2009 still 2500-5000 t/a were indicated by VECAP, i.e. the amounts used in the EU are clearly decreasing. However, concerning global tonnages, this apparently does not apply according to information published by EBFRIP and Covaci et al., who report TBBPA to be the brominated flame retardant with the highest production volume [35] [49].

The global market volume of TBBPA increased dramatically during the past two decades. From around 40000 t in the early 1990ies, its production in the year 2000 already accounted for roughly 140000 t (+ 350 %) [50, 51]. Environment Canada notes a likely increase for the first decade of the 21st century [34].

According to the German Umweltbundesamt (2008, [46]), 145000 t/a TBBPA are used (data source not indicated).

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[3] See also Eurostat results from accompanying Excel document (http://ec.europa.eu/eurostat). Further details also for non-EU countries can be found in Appendix A.

[4] Assumption: The substances are evenly distributed within the WEEE.

The EU risk assessment refers to ~120000 t/a global consumption (based on data from 2001, see also Morose (2006, [36]), world-wide use of 119700 t/a in 2001) [5].

Updates on the global use of TBBPA published by EBFRIP report volumes between 104000 t/a and 170000 t/a between 1995 and 2004, with 170000 t/a representing 2004 [35]. However, only 139000 t/a of this are used in ABS or laminates for printed circuit boards as a flame retardant, while the remaining 30500 t/a are used for the production of derivatives and oligomers.

Using 139000 t/a TBBPA consumption worldwide as flame retardant (worst case and most recent available volume) in EEE this leads to ~32000 t/a TBBPA in WEEE in Europe. This tonnage will be used for the further risk assessment. The amount TBBPA potentially released into the environment is however much smaller, since the substance is incorporated into the resin in case of reactive application and only minor amounts remain unreacted (see section 5).

3 HUMAN HEALTH HAZARD PROFILE

The toxicity of TBBPA has been reviewed extensively in the last years, i.e. in an EU risk assessment report [3], in an evaluation by EFSA [52], in a Screening assessment report published by Health Canada [34] as well as in a recent toxicological review published by Colnot et al. (2014) [53]. There are also data available from a registration dossier submitted to ECHA. In general, data from these peer-reviewed publications are used for summarising the toxicological characteristics of TBBPA.

Overall the acute toxicity of TBBPA is low.

No significant indication for skin or eye irritation and not potential for skin or respiratory tract sensitisation was identified.

From different studies concerning repeated oral dosing of rats and mice for up to 14 weeks, NOAEL values in the range of about 50 – 1000 mg/kg bw can be derived. For the dermal route the NOAEL value in rabbits after 3-weeks of dosing was 2500 mg/kg bw. The substance shows no reproductive or teratogenic effects.

No clear indication for neurotoxicity or endocrine activity could be shown so far, however, a new study from 2014 [54] showed a carcinogenic potential of TBBPA after oral dosing of rats and mice (NOAELs of 50, 100 and < 250 mg/kg bw).

3.1 Endpoints of concern

The acute toxicity of TBBPA is rather low. The oral LD_{50} values for rats and mice are given with > 50000 mg/kg bw or with > 3200 mg/kg bw, respectively. For an exposure via inhalation the LC_{50} values were > 10920 mg/mg^3 in rats (4-h exposure) or > 50000 mg/m^3 in mice (8-h exposure). The dermal LD_{50} value in rabbits was reported with > 10000 mg/kg bw.

Testing in rabbits demonstrated that TBBPA does not have the potential to cause skin or eye irritation and has no potential for corrosion. The only evidence in relation to irritation of the respiratory tract comes from a 14 day inhalation study. However, these signs are more likely a direct consequence of mechanical rather than chemical-induced irritation. Concerning sensitisation studies with guinea pigs and humans are available which do not indicate a tendency for skin sensitisation. Despite its widespread occupational use there are no case reports of respiratory or sensitisation.

No animal studies have investigated the respiratory sensitisation potential of TBBPA, although the absence of significant skin sensitisation potential and the generally unreactive nature of TBBPA suggest that it would not be a respiratory sensitiser. [3]

The toxicity of TBBPA after repeated exposure was investigated in different studies with rats. mice and rabbits. The individual studies are summarised in the following Table 4. In a subacute inhalation study, groups of male and female rats were exposed (whole body) to 0, 2, 6 or 18 mg/L (as dust) on 4 h/d and 5 d/w over 2 weeks. Apart from signs of local irritation (eyes, upper respiratory tract) seen in all dosed rats, there was no indication for adverse systemic effects even at the highest concentration of 18 mg/L (International Research and Development Corporation, 1975; Cited in: EU RAR [3][5]). From a three-week dermal study with rabbits, a NOAEL of 2500 mg/kg bw was derived. The toxicity after repeated oral dosing was studied in male and female Wistar rats according to OECD GL 407. In this 28-day study, the animals were dosed with 0, 30, 100 or 300 mg/kg bw/d via diet. The only effects were decreased circulating T4 and increased T3 levels in males and non-significant trends for these parameters in females. The BMDL10 was given with 48 and 124 mg/kg bw/d, respectively (Van der Ven et

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[5] International Research and Development Corporation (1975) Fourteen day inhalation toxicity study in rats (unpublished). (cited in EU RAR)

al., 2008; cited in EFSA 2011 [52][6]). In an another study performed according to OECD GL 408, groups of male and female rats were dosed via gavage over 90 days with 0, 100, 300 or 1000 mg/kg bw/d. There was no indication for adverse effects after dosing with up to 1000 mg/kg bw/d (MPI Research, 2002; Cited in: EU RAR). From an older study, where male and female Sprague Dawley rats were dosed with 0, 0.3, 3, 30 or 100 mg/kg bw/d via diet over 90 days, a NOAEL value of 100 mg/kg bw/d can be derived (Dow Chemical Company, 1975; cited in: EU RAR[7]). In a recent three-month study with male and female F344/NTac rats [54], the animals were dosed with 0, 10, 50, 100, 500 or 1000 mg/kg bw/d via gavage. In an additional clinical pathology investigation study groups of male and female rats were administered the same doses for 23 days. After dosing with ≥ 100 mg/kg bw, effects such as dose-related decreases in total thyroxine concentrations or changes in hepatic enzyme values were noted. In addition, after dosing with ≥ 500 mg/kg changes in haematological parameters and organ weights were described (NTP, 2014). In a parallel study with male and female B6C3F1/N mice, changes in organ weights and increased incidences of renal tubule cytoplasmic alteration were found at ≥ 500 mg/kg bw (NTP, 2014) [54].

Concerning mutagenicity, TBBPA was tested negative in a variety of in different in vitro studies (e.g. Ames tests, chromosomal aberration study with human peripheral lymphocytes, intragenetic recombination assay). Also in an in vivo study, TBBPA induced no increases in micronucleated normochromatic erythrocytes in male and female B6C3F1/N mice following three months of administration via gavage.

TBBPA was tested in a two-year study with male and female Wistar Han rats and also with male and female B6C3F1/N Mice [54]. The dose levels in both studies were 0, 250, 500 or 1000 mg/kg bw and the animals were dosed for up to 105 weeks. While in male rats the incidences of interstitial cell adenoma were slightly increased ("equivocal evidence), in females there was a clear evidence of carcinogenic activity based on increased incidences of uterine epithelial tumours. In male B6C3F1/N mice the treatment caused increased incidences of hepatoblastoma and also of large intestine neoplasms and haemangiosarcoma (all organs) (some evidence). In contrast, in female mice there was no indication for an increased tumour incidence caused by TBBPA [54]. Knudsen et al. (2014) as well as Lai et al. (2015) discussed the possible modes of action resulting in increased tumour incidendes in rodents and it was concluded, that this may be due to indirect endocrine disruption caused by high doses of TBBPA. However, the relevance to humans exposed to much lower concentrations of TBBPA is questionable and there are no human data available. Therefore, at present these data do not allow for a classification as carcinogenic [55, 56]. The IARC is planning to review the carcinogenicity risk of TBBPA in more detail in February 2016 [57].

Concerning reproductive or teratogenic effects of TBBPA, the substance was tested in several studies with oral dosing in rats and mice. Possible effects of TBBPA on reproductive performance and fertility were investigated in a GLP and OECD compliant two-generation study (MPI Research, 2002b, 2003), [cited in EU RAR and EFSA 2011[8]]; Cope et al. 2015 [58]) which also included an assessment of potential developmental neurotoxicity. In this study, groups of 30 male and 30 female Sprague-Dawley rats per group were dosed with 0, 10, 100 or 1000 mg/kg bw/d via gavage. At weaning of the F_2 generation, developmental and neurobehavioral assessments (i.e. detailed clinical examinations, motor activity, learning, memory and auditory startle habituation, assessed in 10 pups/sex/group) were performed in addition to neuropathological evaluations (i.e. brain weight and neuropathological evaluation of the brain, spinal cord and peripheral nerves, assessed in 10 pups/sex/group). Apart from a transient decrease in body weight gain of high-dosed F_1 males during the pre-mating period, no treatment relat-

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[6] van der Ven LTM, Van de Kuil T, Verhoef A, Verwer CM, Lilienthal H, Leonards PEG, Schauer UMD, Cantón RF, Litens S, De Jong FH, Visser TJ, Dekant W, Stern N, Håkansson H, Slob W, Van den Berg M, Vos JG and Piersma AH, 2008. Endocrine effects of tetrabromobisphenol-A (TBBPA) in Wistar rats as tested in a one-generation reproduction study and a subacute toxicity study. Toxicology, 245, 76-89. (cited in EFSA (2011))

[7] The Dow Chemical Company (1975) Results of a 90-day toxicological study in rats given tetrabromobisphenol A in the diet. (cited in EU RAR)

[8] MPI Research, 2002b. An oral two generation reproductive, fertility and developmental neurobehavioural study of tetrabromobisphenol-A in rats (unpublished). As cited in ECB (2006). (cited in EFSA (2011))

ed clinical or pathological effects were observed in F_0 and F_1 animals. Serum T3, T4 and TSH concentrations were determined in F_0 and F_1 animals several days prior to termination. In the F_0 generation the levels of serum T4 were statistically significantly lower in males exposed to ≥ 100 mg/kg bw/d and in females dosed with 1000 mg/kg bw/d. In the F_1 generation statistically significantly lower serum T4 concentrations were observed in both sexes dosed with ≥ 100 mg/kg bw/d. T3 serum levels were significantly lower only in F_0 males dosed with 1000 mg/kg bw/d. In none of the dosed rats, changes in serum TSH levels were observed. The histopathological examination did not show any changes in any of the organs and even at the highest dose level there were no adverse effects on fertility or development incl. neurodevelopment. TBBPA also was investigated in a one-generation reproduction assay with rats. The animals were dosed with 0, 3, 10, 30, 100, 300, 1000 or 3000 mg/kg bw/d via diet starting 70 and 14 days prior to the mating for males and females, respectively, and the dosing continued in dams during pregnancy and lactation (Van der Ven et al., 2008). In F_1 offspring a decrease in circulating T4 was observed in males and females ($BMDL_{10}$: 31 and 16 mg/kg bw/d, respectively), while plasma T3 was increased in F_1 females ($BMDL_{10}$: 2.3 mg/kg bw/d). In F_1 males also an increase in testes weights (BMDL5: 0.5 mg/kg bw/d) and an increase in pituitary weights (BMDL10: 0.6 mg/kg bw/d) was noted, but in both cases there was no clear dose response. In another study, groups of Sprague-Dawley rats were dosed with 100, 1000 or 10000 ppm in a soy-free diet from gestation day 10 until the day 20 after delivery. The calculated doses were given with 9.5 – 23, 87 – 202 or 820 – 2130 mg/kg bw for the dams. At study termination a slight increase in the incidence of diffuse thyroid follicular cell hypertrophy was seen at ≥ 87 mg/kg bw. In male pups dosed with TBBPA a slight, but non dose-related decrease in serum T3 levels was noted at postnatal day 20 without changes in serum T4 and TSH concentrations. In postnatal week 11 there were no changes in any of the thyroid hormones in any dosed rat (Saegusa et al., 2009; cited in EFSA 2011). No adverse effects on average litter size, average litter weight, total number of offspring, and average male or female offspring weights as well as no effects on reproductive organ weights and histopathological changes were noted in ICR mice dosed with 0, 0.01, 0.1 or 1 % of TBBPA from gestation day 0 to postnatal day 27 (Tada et al., 2006; cited in EFSA 2011[9]). In a study focussed on developmental toxicity, groups of 25 female CD® rats [Crl: CD® (SD) IGS BR] were dosed with 0, 100, 300 or 1000 mg/kg bw/day via gavage from gestation days 0 – 19. Observations of the dams included clinical signs, gestational body weights, and food consumption. Females were euthanized on day 20 of gestation and given a postmortem macroscopic examination. Gravid uterine weights and liver weights were recorded and the litters were delivered by cesarean section. The total number of corpora lutea, uterine implantations, early and late resorption, viable and nonviable fetuses, and the sex and individual weights of fetuses were recorded. All fetuses were given a gross external examination for malformations and variations and also were examined for visceral abnormalities and for skeletal/cartilaginous malformations and ossification variations. As no adverse effects were seen in dams and fetuses even at the highest dose level, from this study a NOAEL value of 1000 mg/kg bw/day can be derived (Cope et al. 2015 [58]). In additional studies with limited documentation, the dosing of rats via gavage with TBBPA at doses of 0.03, 0.1, 0.3, 1, 3 or 10 g/kg bw/d during gestation days 6 – 15 caused no teratogenic effects (IRDC, 1978; Velsicol Chemical Corporation, 1978a,b; both cited in EFSA 2011[10]). Also in rats dosed with 0, 0.28, 0.83 or 2.5 g/kg bw

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[9] Tada Y, Fujitani T, Yano N, Takahashi H, Yuzawa K, Ando H, Kubo Y, Nagasawa A, Ogata A and Kamimura H, 2006. Effects of tetrabromobisphenol A, brominated flame retardant, in ICR mice after prenatal and postnatal exposure. Food Chemistry and Toxicology, 44, 1408-1413. (cited by EFSA (2011)

[10] IRDC (International Research and Development Corporation), 1978. Goldenthal EI, Jessup DC and Rodwell DE. Tetrabromobisphenol A (FM BP-4A): Pilot teratology study in rats. TSCATS [Unpublished Health and Safety Studies submitted to EPA]. Microfiche No. OTS0206828. Document No. 878216109. [Study was sponsored by Velsicol Chemical Corporation; see Velsicol Chem. Corp. (1978b). As cited by NIEHS (2002).

Velsicol Chemical Corporation 1978a. Goldenthal EI, Rodwell DE and Morseth SL. Firemaster® PHT4: Pilot teratology study in rats. TSCATS [Unpublished Health and Safety Studies submtted to EPA]. EPA Document No 88-7800185. Microfiche No. OTS0200512. Document No. 8EHQ-0678- 0185D. From the RTK Net database. As cited by NIEHS (2002).

Velsicol Chemical Corporation, 1978b. Goldenthal EI, Jessup DC and Rodwell DE. Pilot teratology study in rats with tetrabromobisphenol A with cover letter dated 041778. TSCATS [Unpublished Health and Safety Studies during gestation days 0 – 19 no adverse effects on birth rate, embryo or foetus, and no skeletal or visceral abnormalities were seen (Noda, 1985; cited in EFSA 2011[11]). In total, the available studies gave no indications for significant adverse effects caused by the treatment with TBBPA.

TBBPA also was tested in vitro and/or in vivo for a possible neurotoxicity or endocrine activity. All of these studies gave no clear indications for significant adverse effects.

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submitted to EPA]. Microfiche No. OTS0200479. Document No. 8EHQ-0478-0130. From the RTK Net database. As cited by NIEHS (2002).

(all cited by EFSA (2011))

[11] Noda T, 1985. Safety evaluation of chemicals for use in household products (VII): Teratological studies on tetrabromobisphenol-A in rats. Annu. Rep. Osaka City Inst. Public Health Environ. Sci. 48:106-121. As cited in WHO/IPCS (1995). (cited by EFSA (2011))

Table 4: Summary of repeated-dose toxicity

Species / Strain	Method	Duration of Dosing	Dose	Results	NOAEL	Reference
Exposure via inhalation						
5 male and 5 female rats per group (not further specified)	Inhalation (whole body) Guideline study: no data GLP compliance: no data	4 h/d, 5 d/w, 2 w	0, 2, 6 or 18 mg/L (as dust)	Some evidence of local irritation (eyes, upper respiratory tract) at ≥ 2 mg/L. No indication for adverse systemic effects.	18 mg/L	International Research and Development Corporation (1975) Fourteen day inhalation toxicity study in rats (unpublished). (1975). Cited in: EU RAR
Oral exposure						
7 – 8 male Crlj:CD1 (ICR) mice per group	Oral via gavage Guideline study: no data GLP compliance: no data	14 d	0, 350, 700 or 1400 mg/kg bw/d	Only effects on the liver were studied. Dose-dependent increase of absolute and relative liver weights (significant at 1400 mg/kg bw). Also some control animals showed an enlargement of hepatocytes, inflammatory cell infiltrations and focal necrosis of hepatocytes. The histological findings were more marked in liver of treated groups at ≥ 350 mg/kg bw compared with controls.	700 mg/kg bw/d	Tada Y, Fujitani T, Ogata A and Kamimura H, 2007. Flame retardant tetrabromo-bisphenol A induced hepatic changes in ICR male mice. Environmental Toxicology and Pharmacology, 23, 174-178.; cited in EFSA 2011
25 male and 25 female rats per group (not further specified)	Oral via diet Guideline study: no data GLP compliance: no data	28 d	0, 1, 10, 100 or 1000 ppm (m: 0, 0.07, 0.7, 7.2 or 75 mg/kg bw/d; f: 0, 0.07, 0.77, 7.4 or 72 mg/kg bw/d)	No indication for significant adverse effects	72 - 75 mg/kg bw/d	International Research and Development Corporation (1972) Twenty-eight day toxicity study in rats (unpublished). Cited in: EU RAR
Male and female Wistar rats (not further specified)	Oral via diet Guideline study: OECD GL 407 GLP compliance: no data	28 d	0, 30, 100 or 300 mg/kg bw/d	The only effects were decreased circulating T4 and increased T3 levels in males and nonsignificant trends for these parameters in females.	$BMDL_{10}$: 48 and 124 mg/kg bw/d	van der Ven LTM, Van de Kuil T, Verhoef A, Verwer CM, Lilienthal H, Leonards PEG, Schauer UMD, Cantón RF, Litens S, De Jong FH, Visser TJ, Dekant W, Stern N, Håkansson H, Slob W, Van den

Species / Strain	Method	Duration of Dosing	Dose	Results	NOAEL	Reference
						Berg M, Vos JG and Piersma AH, 2008. Endocrine effects of tetrabromobisphenol-A (TBBPA) in Wistar rats as tested in a one-generation reproduction study and a subacute toxicity study. Toxicology, 245, 76-89. (cited in EFSA (2011)) cited in EFSA 2011
10 – 15 male and 10 – 15 female rats per group (not further specified)	Oral via gavage Guideline study: according to OECD GL 408 GLP compliance: yes	90 d	0, 100, 300 or 1000 mg/kg bw/d	The study included a detailed functional observational battery at pre-test and at week 12. Also motor activity was assessed at week 12. No indication for significant adverse effects	1000 mg/kg bw/d	MPI Research (2002a) A 90-day oral toxicity study of tetrabromobisphenol-A in rats with a recovery group (unpublished). Cited in: EU RAR
7 – 21 male and 7 – 21 female Sprague Dawley rats per group	Oral via diet Guideline study: no data GLP compliance: no data	90 d	0, 0.3, 3, 30 or 100 mg/kg bw/d	No indication for significant adverse effects	100 mg/kg bw/d	The Dow Chemical Company (1975) Results of a 90-day toxicological study in rats given tetrabromobisphenol A in the diet. Cited in: EU RAR
10 male and 10 female F344/NTAC rats per group	Oral via gavage Guideline study: no data GLP compliance: no data	14 w	0, 10, 50, 100, 500 or 1000 mg/kg bw/d	≥ 100 mg/kg: dose-related decreases in total thyroxine concentrations (m/f); decreased serum activities of alanine aminotransferase and sorbitol dehydrogenase (m/f) ≥ 500 mg/kg: small decreases in haematocrit values, haemoglobin concentrations, and erythrocyte counts (m/f); significant increased liver weights (m/f) and significant decreased spleen weights (m) No treatment-related histopathological lesions were observed.	50 mg/kg bw/d	NTP (2014) [54]

Species / Strain	Method	Duration of Dosing	Dose	Results	NOAEL	Reference
10 male and 10 female B6C3F1/N mice per group	Oral via gavage Guideline study: no data GLP compliance: no data	14 w	0, 10, 50, 100, 500 or 1000 mg/kg bw/d	≥ 500 mg/kg: significantly increased liver weights (m); increased incidences of renal tubule cytoplasmic alteration (m) 1000 mg/kg: significantly increased liver weights (f); significantly decreased kidney weights (m); significantly increased spleen weights (m)	100 mg/kg bw/d	NTP (2014) [54]
50 – 60 male and 50 – 60 female Wistar HAN rats per group	Oral via gavage Guideline study: yes GLP compliance: yes	5 d/w over 104 (m) or 105 (f) w	0, 250, 500 or 1000 mg/kg bw/d	≥ 250 mg/kg: preneoplastic lesion of endometrial atypical hyperplasia ≥ 500 mg/kg: decreased mean body weights (m); significant increased incidences of adenoma, adenocarcinoma, or malignant mixed Müllerian tumours of the uterus; increased incidences of interstitial cell adenoma of the testis; increased incidences of rete ovarii cyst 1000 mg/kg: decreased thymus weights and increased liver weights at 3-month interim evaluation	< 250 mg/kg bw/d	NTP (2014) [54]
50 male and 50 female B6C3F1/N mice per group	Oral via gavage Guideline study: yes GLP compliance: yes	5 d/w over 105 w	0, 250, 500 or 1000 mg/kg bw/d	250 mg/kg: increased incidences of hepatoblastoma and hepatocellular carcinoma/hepatoblastoma (m); increased eosinophilic focus (m); increased incidences of renal tubule cytoplasmic alteration (m); increased incidences of ulcer, mononuclear cell cellular infiltration, inflammation, and epithelium hyperplasia of the forestomach (f) 500 mg/kg: increased incidence of multiple hepatocellular adenomas (m); increased incidences of clear cell focus and eosinophilic focus (m); increased incidences of renal tubule cytoplasmic alteration (m); increased incidences of ulcer, mononuclear cell cellular infiltration, inflammation, and epithelium hyperplasia of the forestomach (m/f) 1000 mg/kg: decreased survival rate (m/f); decreased mean body weights (f) The incidences of adenoma or carcinoma (combined) of the caecum or co-	< 250 mg/kg bw/d	NTP (2014) [54]

Species / Strain	Method	Duration of Dosing	Dose	Results	NOAEL	Reference
				lon and the incidences of hemangiosarcoma (all organs) occurred with significant positive trends (m)		
Dermal exposure						
4 male and 4 female NZW rabbits per group	Dermal (occlusive or non-occlusive not specified) Guideline study: no data GLP compliance: no data	6 h/d, 5 d/w, 3 w	0, 100, 500 or 2500 mg/kg bw/d	No indication for significant adverse effects	2500 mg/kg bw/d	International Research and Development Corporation (1979) Three week dermal toxicity study in rabbits (unpublished). Cited in: EU RAR

3.2 Existing Guidance values (DNELs, OELs)

No acceptable daily intake values or other limit values have been derived by EFSA [52]. However, the Panel of contaminants in the Food Chain identified a lower confidence limit for a benchmark response of 10 % ($BMDL_{10}$) of 16 mg/kg bw following a study of Van der Ven et al. (2008)[12]. A margin of exposure (MOE) approach for the health risk assessment of TBBPA was used.

The EU risk assessment [3] for human health concludes that no health effects of potential concern to adults have been identified and thus, no risk assessment has been performed. For infants an MOE approach on the basis of a NOAEL of 40 mg/kg/day has been used (based on a study by Fukuda et al. (2004)[13]).

TBBPA is listed in GESTIS, ("**Ge**fahr**st**off**i**nformations**s**ystem der Deutschen Gesetzlichen Unfallversicherung"; Information system on hazardous substances of the German Social Accident Insurance) however, no international limit values or OELs are documented there [59].

The substance is not listed by SCOEL (Scientific Committee on Occupational Exposure Limits) [60] and no MAK ("**M**aximale **A**rbeitsplatz**k**onzentration"; threshold limit value) value or OSHA PEL (Permissible exposure limit) are published so far [61, 62].

However, according to NTP [54] as particulates not otherwise regulated (PNOR), the OSHA permissible exposure level time-weighted average (PEL TWA) is 15 mg/m^3 TBBPA and as particulates not otherwise specified (PNOS), the American Conference of Governmental Industrial Hygienists threshold limit value (ACGIH TLV) TWA is 10 mg/m^3 (PNOR, particulates not otherwise regulated).

The REACH dossier in its current form [4] lists the following DNEL values (Derived No Effect Levels):

Table 5: DNEL values as documented in the course of the REACH registration (16.01.2015).

				DN(M)EL related information	
	Hazard assessment conclusion	**Value**	**Most sensitive endpoint**	**Overall assessment factor (AF)**	**Dose descriptor starting point (after route to route extrapolation)[14]**
Workers - Hazard via inhalation route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	705 mg/m³	repeated dose toxicity	25	NOAEC (18000 mg/m^3; from repeated dose inhalation)
Acute/short term exposure	No-threshold effect and/or no dose-response information available				

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[12] van der Ven LTM, Van de Kuil T, Verhoef A, Verwer CM, Lilienthal H, Leonards PEG, Schauer UMD, Cantón RF, Litens S, De Jong FH, Visser TJ, Dekant W, Stern N, Håkansson H, Slob W, Van den Berg M, Vos JG and Piersma AH, 2008. Endocrine effects of tetrabromobisphenol-A (TBBPA) in Wistar rats as tested in a one-generation reproduction study and a subacute toxicity study. Toxicology, 245, 76-89 (cited by EFSA (2011)).

[13] Fukuda N, Ito Y, Yamaguchi M, Mitumori K, Koizumi M, Hasegawa R, Kamata E and Ema M (2004) Unexpected nephotoxicity induced by tetrabromobisphenol A in newborn rats. Toxicology Letters 150, 145-155. (cited by ECB (2006)).

[14] Assignment of studies used for DNEL derivation on basis of REACH dossier as published on ECHA webpage (state of affairs 16.01.2015) 4. ECHA. *REACh Registration Dossier: 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol*. 2011. 20.04.2015]; Available from: http://apps.echa.europa.eu/registered/data/dossiers/DISS-9d928727-4180-409d-e044-00144f67d249/AGGR-6b060dfb-b271-4d97-b245-a8f2c2d93f2a_DISS-9d928727-4180-409d-e044-00144f67d249.html#AGGR-6b060dfb-b271-4d97-b245-a8f2c2d93f2a.

Local effects					
Long term exposure	No-threshold effect and/or no dose-response information available				
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
Workers - Hazard via dermal route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	100 mg/kg bw/day	repeated dose toxicity	100	NOAEL (10000 mg/ day/ kg bw; from Developmental toxicity / teratogenicity No 002)
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
Local effects					
Long term exposure	No-threshold effect and/or no dose-response information available				
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
General Population - Hazard via inhalation route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	174 mg/m³	developmental toxicity / teratogenicity	50	NOAEC
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
Local effects					
Long term exposure	No-threshold effect and/or no dose-response information				
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
General Population - Hazard via dermal route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	50 mg/kg bw/day	repeated dose toxicity	200	NOAEL (10000 mg/day/ kg bw; from Developmental toxicity / teratogenicity No 002)
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
Local effects					
Long term exposure	No-threshold effect and/or no dose-response information available				
Acute/short term exposure	No-threshold effect and/or no dose-response information available				
General Population - Hazard via oral route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	5 mg/kg bw/day	repeated dose toxicity	200	NOAEL (1000 mg/kg bw day, Repeated dose toxicity: oral. No. 001)
Acute/short term exposure	No-threshold effect and/or no dose-response information available				

3.3 Alternative DNELs suggested by the authors

In addition to the summary of already published limit values, an independent derivation of DNEL values has been undertaken by the authors of this report. Results are summarised in Table 6.

Since these values are in most cases lower than the ones published on the ECHA webpage and therefore represent the worst case they will be used for the risk assessment.

Table 6: Alternative DNEL suggestions on basis of the available studies

				DN(M)EL related information	
	Hazard assessment conclusion	**Value**	**Most sensitive endpoint**	**Overall assessment factor (AF)**	**Dose descriptor starting point (after route to route extrapolation)**
Workers - Hazard via inhalation route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	600 mg/m³	repeated dose toxicity	30	NOAEC (18000 mg/m^3; from Exp Key Repeated dose toxicity: inhalation.001)
Workers - Hazard via dermal route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	8.3 mg/kg bw/day	repeated dose toxicity	300	NOAEL (2500 mg/ day/ kg bw; from Exp Key Repeated dose toxicity: dermal.001)
General Population - Hazard via inhalation route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	300 mg/m³	repeated dose toxicity	60	NOAEC (18000 mg/m^3; from Exp Key Repeated dose toxicity: inhalation.001)
General Population - Hazard via dermal route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	4.2 mg/kg bw/day	repeated dose toxicity	600	NOAEL (2500 mg/ day/ kg bw; from Exp Key Repeated dose toxicity: dermal.001)
General Population - Hazard via oral route					
Systemic effects					
Long term exposure	DNEL (Derived No Effect Level)	1.7 mg/kg bw/day	repeated dose toxicity	150	LOAEL (250 mg/kg bw day, from NTP (2014))

4 ENVIRONMENTAL HEALTH HAZARD PROFILE

4.1 Environmental fate properties

Within the frame of the EU risk assessment series a draft in-depth characterization of TBBPA has been published in the year 2007 [5]. There is also a recent screening assessment report available published by the Government of Canada [34].

Based on the REACH criteria according to OSPAR [13] TBBPA only meets the persistence criteria for the PBT assessment and thus, is not considered to meet the REACH PBT criteria [5][15]. Reported half-life values in water/sediment go up to 84 d (natural river water / sediment system) according to the studies listed on the ECHA webpage [4] and in the EU risk assessment report [3].

The authors of the EU risk assessment report also consider the substance to be “P” or “potentially vP” based on its ultimate mineralisation (persistent or very persistent (see EU RAR, [5]).

Half-lifes in soil range between 5.3 and 7.7 days according to the EU risk assessment (disappearance time); however, the mineralisation half-life has been found to be considerably longer (> 6 months). [3].

More recent publications from Chang et al. [63, 64] describe a half-life of 16.6 d in river sediment (anaerobic), of 9-13.1 d in river sediment (50 microgram / g TBBPA, aerobic, up to 26 d for concentrations up to 500 microgram / g TBBPA) and Nyholm et al. found half-lifes of 58-110 (average 65 and 93 d for activated and digested sludge) and 340-600 d (average 430 d activated sludge) in aerobic and anaerobic soil [65][16].

Overall, although TBBPA and its degradation products could be found in the environment in some monitoring studies, TBBPA does not fall under the criteria for bioaccumulation:

The highest BCF value reported so far is 1234 l/kg (total ^{14}C, fish, corresponding to 177 l/kg for TBBPA itself). All BCF factors for the parent compound listed in the current REACH registration and the EU risk assessment report are below 500 (maximum 485 l/kg for parent compound, fish). No accumulation in lipid tissues has been observed [4, 5].

Nyholm et al. [66] report a low tendency for bioaccumulation as well while Morris et al. [67] state that due to its polar nature, the molecule will be subject to metabolism and elimination from organisms.

A logKow of 5.62 is reported on the ECHA webpage [4] while values ranging from 3.25 to 5.9 are reported in the environmental EU risk assessment report [5]. This may suggest a tendency for bioaccumulation; however, as mentioned above the available BCF values do not support this.

Vorkamp and Riget [68] report that TBBPA degrades to dimethyl TBBPA (citing George and Häggblom, 2008[17]) which is less polar and potentially more bioaccumulative. However, they conclude that there is no clear situation with regard to bioaccumulation of TBBPA in the environment. Apart from that, dimethyl TBBPA seems to be less toxic than TBBPA [69].

Possible accumulation in plants was studied by Sun et al. [70], but no BCF factor was derived.

Other possible degradation products are bisphenol A, which has however been considered within the EU risk assessment report for this substance [5], TBBPA allyl ether and TBBPA 2,3-dibromopropyl ether (Qu et al. (2013) [71]). It is however not always clear if all substances are formed in the environment, if they are released separately or if they are a by-product of manufacturing processes in certain cases (see e.g. [71]).

TBBPA may have the potential for long-range transport. However, only a small database is available for this aspect (e.g. measured TBBPA in Norway) according to the EU risk assessment [5]. The EU

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[15] In the OSPAR Framework the PBT criteria are more conservative than those used by the EU and therefore TBBPA is considered as a priority substance under OSPAR; however, for RoHS the REACH definition of PBT substances is applied.

[16] Nyholm et al.: similar to OECD Test Guideline 307 ”Aerobic and Anaerobic Transformation in Soil”

[17] George, K.W., Häggblom, M.M., 2008. Microbial o-methylation of the flame retardant tetrabromobisphenol-A. Environ. Sci. Technol. 42, 5555–5561. (cited by Vorkamp and Riget, 2014)

risk assessment for the environment also discusses this and concludes that the potential for long-range transport is smaller than that of other compounds and depends on the particulates to which it is adsorbed. However, it is not considered to be negligible.

In Table 7 a summary of relevant environmental fate parameters and corresponding PBT and POPs criteria is given.

Table 7: Selected environmental parameters in comparison with PBT and POPs criteria.

Parameter	**Outcome**	**PBT criteria (according to REACH, Annex XIII)**	**POPs criteria (Stockholm convention)**
fresh water (half-life)	maximum 84 d (mixed system river sediment/water) → above limit for water but below limit for sediment. → no clear indication for persistence.	> 40 d (fresh water) > 120 d (fresh water sediment)	> 60 d (water) > 180 d (sediment)
soil (half-life)	maximum 430 d	> 120 d (soil)	> 180 d (soil)
log Kow	3.25-5.9	-	> 5
Log Koc	5.17	-	-
bioconcentration factor	maximum 1234 l/kg (fish, overall ^{14}C, corresponding to 177 l/kg for the parent compound) 30-485 l/kg (overall BCF range for parent compound, fish and invertebrates)	> 2000	>5000
T	no classification as carcinogen toxic for the environment but NOEC > 0.01 mg/L	substance that meets the CMR criteria (categories 1A-1B) NOEC or EC10 < 0.01 mg/L	Toxicity or ecotoxicity data indicating potential to damage human health or the environment

Overall, TBBPA meets neither PBT nor POP criteria, as it does not fulfil the bioaccumulation criterion nor the toxicity criterion under REACH.

4.2 Environmental hazard

Main ecotoxicity studies were summarised on the basis of risk assessment reports.

More recent studies of relevance were not identified.

4.2.1 Eco-Toxicity studies

Concerning aquatic organisms the long-term toxicity of TBBPA was tested in different species such as daphnia, algae or fish and in general the determined NOEC values were > 0.01 mg/L, i.e. the substance is not considered to be toxic following the PBT criteria.

However, according to the REACH registration as documented on the ECHA homepage TBBPA shows acute and chronic aquatic toxicity (category 1) [4, 72].

For microorganisms an EC50 value of 82 mg/l has been determined for tetrabromobisphenol-A for inhibition of respiratory enzyme activity in the parasitic protozoan Giardia lamblia over 0.5-1 minute. In addition a NOEC of ³15 mg/l has been determined for TBBPA using the OECD Guideline 209 activated sludge respiration inhibition test [5] and been used for the PNEC derivation within the EU risk assessment and the currently published REACH registration dossier as published on the ECHA webpage [4] .

For the soil compartment numerous studies are available, including plants, earthworms and effects on microorganisms. The lowest NOEC has been identified for earthworms in a study following OECD Guideline 222 (NOEC = 0.12 mg/kg ww) [5]. The study has been used for PNEC derivation within the EU risk assessment and the currently published REACH registration dossier as published on the ECHA webpage,[4] which leads however to different resulting PNEC values due to a different interpretation of the study (nominal concentration instead of measured concentration, correction for carbon content in EU RAR but not under REACH).

No information concerning toxicity of tetrabromobisphenol A to plants or other organisms exposed via air is available. However, it is also noticed that TBBPA shows a very low vapour pressure and thus, volatilisation to the atmosphere is probably limited. [5]

No clear indications for significant adverse effects concerning endocrine effects were identified. According to the EU risk assessment report most studies related to these effects either showed no effects or only effects above the suggested PNEC values. One study cited by ECB [5] (Kuiper et al. (2008)[18]) has found effects on some reproductive endpoints. However, the study could not be used for the derivation of clear NOEC due to variability and a lack of dose response in some of the studied endpoints and thus, was not considered to be robust enough for the derivation of a PNECs within the EU RAR.

4.2.2 Potential for secondary poisoning and bioaccumulation

Secondary poisoning is a phenomenon related to toxic effects occurring in higher members of the food chain due to ingestion of organisms from lower trophic levels containing accumulated substance. Thus, if a substance has properties indicating potential for bioaccumulation or biomagnification it may pose an additional threat within the food chain.

According to EFSA [52] there are a number of studies of TBBPA in wildlife. As an example, concentrations in herring are reported to be in in the range of 0.5-5 ng/g fresh weight, Northern pike showed 2-4 ng/g fresh weight and moose 1-3 ng/g fresh weight (see also section 5.4.1 for more examples).

However, although the substance is found in the environment BCF factors as reported in section 4.1 do not support a tendency for bioaccumulation.

PNECs for secondary poisoning have been derived in the EU risk assessment as well as in the course of the REACH registration process and are 667 mg/kg food and 222 mg/kg food, respectively.

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[18] Kuiper R V, van den Brandhof E J, Leonards P E G, van der Ven L T M, Wester P W and Vos J G. (2007). Toxicity of tetrabromobisphenol A (TBBPA) in zebrafish (Danio rerio) in a partial life-cycle test. Arch. Toxicol., 81, 1-9. (cited by EU RAR, 2008)

4.3 Existing guidance values

The PNEC (predicted no effect concentration) of a substance is the concentration below which exposure to a substance is not expected to cause adverse effects to species in the environment. PNECs have been derived in the EU risk assessment as well as under the REACH registration.

The following PNECs have been used for the environmental exposure assessment as published in the EU risk assessment reports [3, 5].

	Species	**Method**	**Study result**	**Assessment factor**	**PNEC**	**Reference**
PNEC freshwater	Acartia tonsa (Invertebrates)	No guideline given in EU RAR	5d-EC10 = 0.0127 mg/l	10	1.3 µg/l	Cited in EU RAR: Wollenberger L., Dinan L. and Breitholtz M. (2005). Brominated flame retardants: Activities in a crustacean development test and in an ecdysteroid screening assay. Environ. Toxicol. Chem., 24, 400-407.
PNEC freshwater sediment	C. riparius	Based on OECD 218 28-day study investigating emergence and development rates	NOEC 125 mg/kg dw (=27 mg/kgww)	10	2.7 mg/kg ww (5.5 mg/kg ww suggested for Koc = 147360 l/kg)	Cited in EU RAR: Wildlife International (2005a). Tetrabromobisphenol-A (TBBPA): A 28-day sediment toxicity test with Chironomus riparius using spiked sediment. Wildlife International Ltd., Project Number 439A-130.
PNEC STP	activated sludge	OECD Guideline 209 respiration inhibition test.	NOEC of ^{3}15 mg/l	10	1.5 mg/l	Cited in EU RAR: Wildlife International (2002b). Tetrabromobisphenol-A: An Activated Sludge Respiration Inhibition Test. Wildlife International Ltd., Project Number: 439E-107A.
PNEC marine water	Acartia tonsa (Invertebrates)	No guideline given in EU RAR	5d-EC10 = 0.0127 mg/l	50	0.25 µg/l	Cited in EU RAR: Wollenberger L., Dinan L. and Breitholtz M. (2005). Brominated flame retardants: Activities in a crustacean development test and in an ecdysteroid screening assay. Environ. Toxicol. Chem., 24, 400-407.
PNEC marine sediment	Chironomus riparius (freshwater midge)	Based on OECD 218 28-day study investigating emergence and development rates	NOECs = 27 mg/kg ww	50	0.54 mg/kg ww	Cited in EU RAR: Wildlife International (2005a). Tetrabromobisphenol-A (TBBPA): A 28-day sediment toxicity test with Chironomus riparius using spiked sediment. Wildlife International Ltd., Project Number 439A-130.
PNEC soil	earthworms	OECD Guideline 222	NOEC = 0.12 mg/kg ww	10	0.012 mg/kg ww	Cited in EU RAR: ABC Laboratories (2005). Effect of tetrabromobisphenol A on the reproduction of the earthworm, Eisenia fetida. ABC Laboratories Inc., Study Number 49264.
PNEC secondary poisoning	rat	GLP and OECD compliant 2-generation study	1000 mg/kg bw/day21 (i.e. 20000 mg/kg food)	30	>667 mg/kg food	Cited in EU RAR: MPI Research (2002b) An oral two generation reproductive, fertility and developmental neurobehavioural study of tetrabromobisphenol-A in rats (unpublished). MPI Research (2003) Amendment to the final report.

	Species	Method	Study result	Assessment factor	PNEC	Reference
						An oral two generation reproductive, fertility and developmental neurobehavioural study of tetrabromobisphenol-A in rats (Unpublished report).
	rat	conform with GLP and OECD guidelines 13-week repeated dose study	1000 mg/kg bw/day			Cited in EU RAR: MPI Research (2002a) A 90-day oral toxicity study of tetrabromobisphenol-A in rats with a recovery group (unpublished).

The following PNECs have been published on the ECHA webpage in the course of the REACH registration process [4]. The references have been assigned on basis of the published PNECs and assessment factors, as no detailed derivation procedure nor the specifically used studies are documented in the public dossier version.

	Species	Method	Study result	Assessment factor	PNEC	Reference (extrapoluated from information published on ECHA webpage[4])
PNEC freshwater	Pimphales promelas (Fish)	GLP study, with analytical verification of test compound concentrations. However, did not follow standard guidelines (other guideline: Protocol for Conducting Early Life Stage Toxicity Tests with Fathead Minnow (Pimephales promelas) - US EPA's Tetrabromobisphenol-A Final Test Rule (Federal Register, Volume 52, No. 128, 6 July 1987)	35d-NOEC = 0.16 mg/l	10	16 µg/l	Exp Key Long-term toxicity to fish.001 from ECHA webpage. Corresponding reference from EU RAR: Springborn Laboratories (1989b). The toxicity of tetrabromobisphenol A (TBBPA) to fathead minnow (Pimephales promelas) embryos and larvae. Report No 89-2-2937. Springborn Laboratories, Inc., Wareham, Massachusetts.
PNEC marine water		GLP study with analytical verification of test compounds concentration using a protocol approved by the UK under TBBPA's EU risk assessment. No guideline followed.	17 µg/L	50	0.34 µg/L	Exp Key Long-term toxicity to aquatic invertebrates.001 Corresponding reference from EU RAR: Brown R. J., Smyth D. V. and Kent S. J. (2005). TBBPA: Determination of effects on the growth of the common mussel Mytilus edulis. Brixham Environmental Laboratory Study Number 03-0337/A. Study sponsored by ACC-BFRIP, Arlington, USA.
PNEC STP	activated sludge	OECD Guideline 209 activated sludge respiration inhibition test	NOEC of 15 mg/l	10	1.5 mg/L	Exp Key Toxicity to microorganisms.001 Cited in EU RAR: Wildlife International (2002b). Tetrabromobisphenol-A: An Activated Sludge Respiration Inhibition Test. Wildlife International Ltd., Project Number: 439E-107A.

	Species	**Method**	**Study result**	**Assessment factor**	**PNEC**	**Reference (extrapoluated from information published on ECHA webpage**[4]**)**
PNEC freshwater sediment	Chironomus riparius (freshwater midge)	28-day study	NOEC 125 mg/kg dw (=27 mg/kgww)	10	12.5 mg/kg sediment dw (=2.72 mg/kg sediment ww)	Exp Key Sediment toxicity.001 Cited in EU RAR: Wildlife International (2005a). Tetrabromobisphenol-A (TBBPA): A 28-day sediment toxicity test with Chironomus riparius using spiked sediment. Wildlife International Ltd., Project Number 439A-130.
PNEC marine sediment	Chironomus riparius (freshwater midge)	28-day study	NOEC 125 mg/kg dw (=27 mg/kgww)	50	2.5 mg/kg sediment dw (0.543 mg/kg ww)	Exp Key Sediment toxicity.001 Cited in EU RAR: Wildlife International (2005a). Tetrabromobisphenol-A (TBBPA): A 28-day sediment toxicity test with Chironomus riparius using spiked sediment. Wildlife International Ltd., Project Number 439A-130.
PNEC soil	Earthworm	Guideline EPA OPPTS 850.6200 (Earthworm Subchronic Toxicity Test) Guideline OECD Guideline 222 (Earthworm Reproduction Test (Eisenia fetida/Eisenia andrei)) Guideline ISO 11268-2 (Effects of Pollutants on Earthworms. 2. Determination of Effects on Reproduction)	0.31	10	0.031 mg/kg soil dw (=0.0273 mg/kg ww)	Exp Key Toxicity to soil macroorganisms except arthropods.001 Cited in EU RAR: ABC Laboratories (2005). Effect of tetrabromobisphenol A on the reproduction of the earthworm, Eisenia fetida. ABC Laboratories Inc., Study Number 49264.
PNEC secondary poisoning	-	-	1000 mg/kg bw/day; i.e. 20000 mg/kg food	90	222.22 mg/kg food	Several possibilities.

5 WASTE MANAGEMENT OF ELECTRICAL AND ELECTRONIC EQUIPMENT

5.1 Description of waste streams

In order to determine the waste relevance of TBBPA a detailed literature review was conducted. Various assessments of TBBPA have been published in the past in order to determine its hazard potential to the environment and human health, e.g. by the EU [5], Oeko-Institute [45], WHO [40], US EPA [73], Government of Canada [74].

Government of Canada identifies various releases during waste treatment, which have been documented during dismantling, recycling, landfills, incineration, accidental fires and sewage sludge applications for agricultural purposes.

Various waste streams during manufacturing, processing and disposal have, however, been identified as sources of possible releases of TBBPA to the environment [34]. According to BSEF, the entire amount of TBBPA is produced in Israel, the United States, Jordan, Japan and China [75]. Releases from manufacturing in Europe thus can be excluded.

5.1.1 Main materials where the substance is contained

TBBPA as a flame retardant is used either as a reactive or additive component of polymers [76] (see also section 2).

In its most common application as a reactive component TBBPA is chemically reacted with the polymer backbone in order prepare fire-resistant polycarbonates [3], and therefore does not exist anymore as a separate molecule. In contrast, the use as an additive component in plastics accounts for 10 to 20% [34].[19] As additive flame retardant TBBPA is not chemically bonded but rather physically combined with the material being treated. [34].

For this risk assessment it will be assumed that approximately 15% of the TBBPA used as flame retardant are used additively in housings (ABS) and ~85% are used reactively in epoxy resins. Since additively used TBBPA can be found mainly in old CRT monitors where it was used during a short period (2002-2005) as a replacement for OctaBDE, this is considered to be a very worst case estimate. CRT monitors are no longer state of the art concerning TV or PC equipment and additively used volumes of TBBPA have been decreasing over the last years [77].

Of the fraction used reactively, only a maximum of 0.06% of the original TBBPA remain unreacted and can still be released as the substance itself.

5.1.2 WEEE categories containing the substance

As mentioned in earlier sections, the main application area for TBBPA as a flame retardant is reactive use in printed circuit boards.

According to the EU risk assessment, the applications of ABS, which is the most relevant material for additively used TBBPA, are widespread, e.g. in business machines, and telephones , and therefore its

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[19] Heart, S., Environmental Impacts and Use of Brominated Flame Retardants in Electrical and Electronic Equipment. Environmentalist 2008. 28: p348-357. (Cited by the Government of Canada, 2013)

Bromine Science and Environmental Forum. 2009. About Tetrabromobisphenol A (TBBPA). Available online: http://www.bsef.com/our-substances/tbbpa/about-tbbpa/. Accessed 17 May 2009. (Cited by the Government of Canada, 2013) release potential is significant. As described by the EU risk assessment report [5] plastics containing additively bound TBBPA may cover vacuum cleaners, components of professional printers, coffee machines, televisions (CRT monitors), electric plugs, etc. [5].[20]

Concerning additive use, Chen et al. evaluated the presence of brominated flame retardants in cell phone shells, computer and TV housings but it was only identified in computer housings [78] (see also Morose et al [36]: TV housings mostly HIPS, computer monitor housings ABS or PC/ABS blend). Gensch et al. also reported computer monitors to be the article of most relevance [33].

Apart from that, a study about flame retardants in mixed plastics published by EMPA overall supports the estimated TBBPA distribution. According to EMPA [79] ~30% of housings of IT-appliances made of ABS are treated with TBBPA, while the remaining housings use different flame retardants. Within the study TBBPA concentrations in different WEEE articles were measured (see Table 8). Again CRT monitors were identified to be the WEEE article of the highest relevance.

Table 8: TBBPA in WEEE (EMPA, 2010 [79]), study from Switzerland

	Averages				
No TBBPA detected in:	**0.2 g/kg**	**<1 g/kg**	**1 g/kg**	**1-10g/kg**	**10-100 g/kg**
Large household appliances w/o cooling appliances (5 samples)	Small appliances for high-temperature applications (toaster, hair dryer, curler) (1 sample)	Consumer equipment w/o CRT- and flat screens (1 sample)	M2 w/o vacuum cleaners (1 sample)	C2: Small household appliances (2 samples)	CRT (cathode ray tube) monitors (5 samples);
Cooling and freezing appliances (inside lining without drawers) (5 samples)		Small household appliances, tools, toys, leisure and sport equipment (2 samples)	CRT TVs (7 samples)	Small appliances w/o CRT- and flat screens (7 samples)	
Cooling and freezing appliances (all plastics, except foams) (6 samples)				ICT equipment w/o CRT- and flat-screens (2 samples)	
Vacuum cleaners w/o hoses (1 sample)				Small appliances w/o CRT- and flat screens (7 samples)	
				ICT and consumer equipment w/o CRT- and flat screens (2 samples)	
				Flat screens (3 samples);	
				Professional printers (3 samples)	
				ICT and consumer equipment w/o CRT- and flat screens (2 samples)	

Overall, regional differences and variations are obviously present (see e.g. Lassen et al. (1999) for further examples from Denmark [80]: PC monitors, printers, notebooks), however, the most relevant

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[20] Risk and Policy Analysts Limited. 2001. Octabromodiphenyl ether: Risk reduction strategy and analysis of advantages and drawbacks. Draft stage 2 report prepared for Department for Environment, Food and Rural Affairs. RPA, November 2001 (cited in EU RAR 2008).

WEEE categories are relatively constant: they include mainly monitors (PC / TV), and occasionally small equipment such as hair dryers, professional printers etc.

It is also noted that the apparently major use is in cathode ray tubes, which are expected to be produced and discharged of much less in the future than this may have been the case in the past, as they are usually replaced by flat screens. This is supported by additional information provided by the flame retardants industry, indicating that the relevance of additive use of TBBPA in general has been decreasing [77, 81].

In general, TBBPA and other flame retardants are only used where standards concerning flame retardants / fire protection in certain articles apply (although good manufacturers could also go beyond such minimum requirements).

Overall it is therefore decided to use WEEE categories 3 and 4 (IT and telecommunications equipment, Consumer equipment) for statistical considerations concerning housings / additive use and all categories for printed circuit boards / reactive use, since these are present in almost all pieces of equipment.

Thus, Table 9 summarizes the possibility of TBBPA occurrence in WEEE categories.

Table 9: Most relevant WEEE categories

	Occurrence of TBBPA	
WEEE category	Reactive used	Additive use
1. Large household appliances	x	
2. Small household appliances	x	
3. IT and telecommunications equipment	x	x
4. Consumer equipment	x	x
5. Lighting equipment	x	
6. Gas discharge lamps	x	
7. Electrical and electronic tools	x	
8. Toys, leisure and sports equipment	x	
9. Medical devices	x	
10. Monitoring and control instruments	x	
11. Automatic dispensers	x	

Apart from this general information there are additional publications available describing the different fractions which contribute to the specific relevant WEEE article categories.

As documented by Lee et al. (2004) [82], one printed circuit board contains approximately 15% (w/w) epoxy resin, while the weight content of printed circuit boards within EEE can vary greatly (6, 14, 42% in PC, monitor, keyboard). The weight fraction of the housing for the PC and the monitor were indicated to be 43 and 17%.

Schlummer and Mäurer [83] investigated screen housing materials at a shredding site and found that these consist of approximately 4% ABS, 16 % ABS (+ brominated flame retardants) and 14% ABS/PC blends, i.e. overall ~30% of all IT screen housings may contain TBBPA as flame retardant.

According to Duan et al., 2011 [84] the weight fraction of circuit boards within TV equipment, CRT/LCD screens, PC control units, laptops and mobile phones ranges from 5.5 to 21.3 %, depending on type of equipment and study.

According to the Austrian Umweltbundesamt, the fraction of plastic in relation to the whole monitors is ~12% (6-16%) [85].

However, these details will not be used for the exposure assessment and are only listed for general information.

5.1.3 General WEEE streams

Using information derived from EUROSTAT (see attached Excel document ref. [86]), the following average distribution of WEEE over different waste streams in Europe can be identified:

Table 10: Average WEEE streams in the EU (information taken from Eurostat)

	Waste amounts		**Waste fractions**	
Overall WEEE in EU	9224248	t/a		
WEEE collected	3572821	t/a	39	% of overall WEEE
			27	% of collected WEEE (average, range 16–38 %)
WEEE exported from EU	964662	t/a	10	% of overall WEEE (average)
WEEE recycled and reused			27	% of overall WEEE
WEEE recycled and reused	2496100	t/a	70	% of collected WEEE
WEEE treated in the EU (overall)			30	
IT and consumer equipment				

These numbers are also consistent with other published values related to waste export from the EU (e.g. Premalatha et al. [44]: ~18% export from EU; Evaluation of the WEEE directive [43]). They can however be refined using WEEE category specific information using information from Eurostat (Table 11). This is done in section 5.4 for the exposure assessment.

Concerning the fraction of landfilled WEEE, different assumptions can be made (e.g. 90% of the waste stream being landfilled is stated in Tange & Drohmann, 2005 [87]).

According to the Oeko-Institut EEE waste is predominantly disposed of to landfills, while a smaller extent is incinerated [45].

According to Premalatha et al., WEEE can represent up to 8% by volume of municipal waste. Operations such as landfilling, storage or incineration (% of overall) are applied to 16% of WEEE and domestic recovery to 66 % of the overall WEEE (Premalatha et al., 2014 [44]).

PlasticsEurope reports ~38% of all plastics to be landfilled within EU27+Norway+Switzerland in 2012 [88].

However, for the purpose of risk assessment it will be assumed that all WEEE which is separately collected will be treated via recycling / recovery and only WEEE in municipal solid waste may be landfilled. It is furthermore assumed that ~1/3 of the collected municipal waste and the corresponding WEEE is landfilled while ~2/3 is incinerated [89].

Table 11: Extract from Eurostat: Amounts of WEEE in t/a Yellow background: percentage of overall WEEE. (see separate Excel table; data from RoHS manual refers to 2010).

WEEE waste categories		**WEEE products put on market in tonnes**	**WEEE waste collected**	**WEEE waste collected from households**	**WEEE waste collected from other sources**	**WEEE waste treated in the member state**	**WEEE waste treated in another member state of EU**	**WEEE waste treated outside EU**	**WEEE waste reused**	**WEEE waste recovery**	**WEEE waste total recycling and reuse**
1	Large household appliances	4622969	1535115	1473414	61702	1295924	81500	6098	24382	1049637	967392
			33.21	31.87	1.33	28.03	1.76	0.13	0.53	22.70	20.93
2	Small household appliances	895595	236319	225354	10967	213069	10769	615	2436	176141	155302
			26.39	25.16	1.22	23.79	1.20	0.07	0.27	19.67	17.34
3	IT and telecommunications equipment	1297209	666425	591243	75182	548980	31677	4984	39219	396900	360377
			51.37	45.58	5.80	42.32	2.44	0.38	3.02	30.60	27.78
4	Consumer equipment	742828	656289	639956	16333	532334	44104	1738	3585	508916	468060
			88.35	86.15	2.20	71.66	5.94	0.23	0.48	68.51	63.01
5	Lighting equipment	442682	28414	18287	10128	22621	3788	987	103	24063	21460
			6.42	4.13	2.29	5.11	0.86	0.22	0.02	5.44	4.85
	Gas discharge lamps	71053	35796	27436	8361	29716	3673	126	2	0	27476
			50.38	38.61	11.77	41.82	5.17	0.18	0.00	0.00	38.67
6	Electrical and electronic tools	666553	88677	80846	7830	81528	4098	1358	353	63852	57064
			13.30	12.13	1.17	12.23	0.61	0.20	0.05	9.58	8.56
7	Toys, leisure and sports equipment	213895	18444	15120	3327	15779	674	57	550	12984	11954
			8.62	7.07	1.56	7.38	0.32	0.03	0.26	6.07	5.59
8	Medical devices	96460	8503	2843	5659	7118	420	70	219	6454	5816
			8.82	2.95	5.87	7.38	0.44	0.07	0.23	6.69	6.03
9	Monitoring and control instruments	107070	10992	7299	3695	9008	740	288	93	8829	8033
			10.27	6.82	3.45	8.41	0.69	0.27	0.09	8.25	7.50
10	Automatic dispensers	67938	21201	7436	13765	19232	458	84	1150	16326	15495
			31.21	10.95	20.26	28.31	0.67	0.12	1.69	24.03	22.81
	Total	**9224248**	**3572821**	**3089233**	**483590**	**2775311**	**209688**	**72308**	**72091**	**2693299**	**2496100**
			38.73	**33.49**	**5.24**	**30.09**	**2.27**	**0.78**	**0.78**	**29.20**	**27.06**

Growth prediction for e-waste

Hischier et al. (2005) [90] predict a growth rate for e-waste in Europe of 3 to 5% per annum. This leads to two scenarios, a best and a worst case. Table 12 illustrates the development of collected WEEE waste until 2050 according to these numbers.

Table 12: Development of collected WEEE waste until 2050

	Unit	**2012**	**2020**	**2030**	**2040**	**2050**
Best case	t	3572821	4525943	6082489	8174356	10985651
	% of 2012 tonnage	100	127	170	229	307
Worst case	t	3572821	5278684	8598420	14005920	22814167
	% of 2012 tonnage	100	148	241	392	639

Export of e-waste

Many authors have indicated that the documented number of e-waste exports from Europe (72308 tons in 2012 according to Eurostat) is by far too low. A common alternative for the shipping of e-waste without any reporting duties is the declaration as used products. In this context, the European Environment Agency refers to an estimated number of unreported cases between ~550000 and ~1300000 tons of used products/WEEE being shipped out of the EU every year [86].

This corresponds to approximately 16–38 % of the collected WEEE in the EU and approximately 6-15% of the overall produced WEEE in the EU.

WEEE in municipal waste

Numbers of WEEE fractions being discarded to municipal waste are hardly found. EEE products ending up in waste bins are rather small devices. Nevertheless, according to the numbers presented by Hirschier et al. (2005) [90] their amount is likely to rise. Since these applications are either incinerated or landfilled they might present a considerable threat for release. Further research is needed in order to provide concrete numbers. However, in the meantime it will be assumed that everything that is not collected separately according to information from Eurostat will be discarded via municipal waste.

5.2 Applied waste treatment processes

A general overview of WEEE recycling / recovery options is given in Figure 1. Details related to TBBPA specific applications will be discussed in the next subsections.

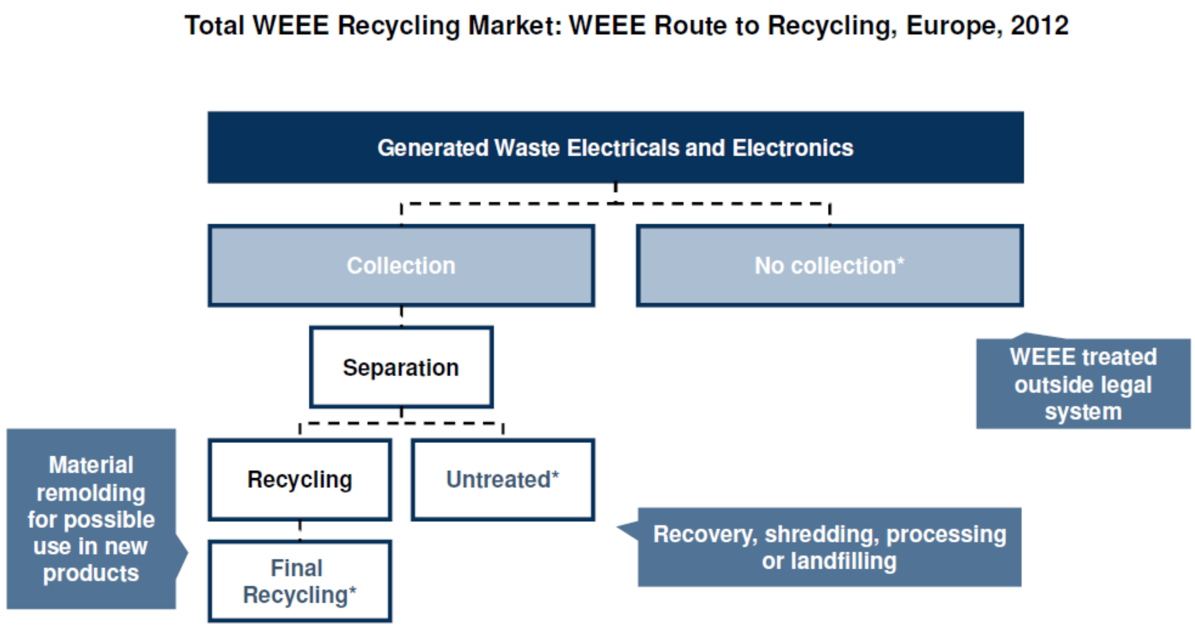

Figure 1: Total WEEE recycling market: WEEE route to recycling, Europe, 2012 [91]

5.2.1 Initial treatment processes

As discussed above, in the context of EEE products, TBBPA is predominantly incorporated into printed circuit boards and plastic housings. While being bound reactively in printed circuit boards, the substance is integrated additively in plastics such as ABS.

General handling processes of WEEE waste are dismantling, recycling, recovery, shredding, processing, incineration or landfilling.

In general, during the WEEE treatment, some components have to be removed from WEEE, including circuit boards larger than 10 cm^2 and plastics containing brominated flame retardants (see e.g. [80]). Removal may happen before further treatment or after an initial shredding / crushing process. [43]

Generally, WEEE waste is dismantled after its collection (EU RAR [3]). The Oeko-Institute indicates that recyclers for computers and electronic equipment mostly apply manual dismantling [45].

5.2.1.1 Housings

Only internal parts of WEEE are usually recycled, while plastics are either incinerated or landfilled [92] [80]. Examples from France as presented in [43] suggest that for plastic mechanical recycling and recovery through oxidative thermal methods such as pyrolysis / gasification are most common. It is however noted at a later point that data from literature seems to confirm that at present plastic output streams from WEEE recycling operations are mostly not recovered, but are landfilled together with other residue streams, as opposed to the apparent preference for the recycling option concluded from the earlier responses to the enquiry exercise. BSEF members also indicated, that to their knowledge most for the ABS or HIPS with BFRs are processes by energy recovery [93].

Thermal treatment in general may include e.g. rotary kiln furnace (widely used for hazardous waste, however, according to personal communication from industry this is typically not done for WEEE plastics [94]), mass burning on grate (first choice for municipal waste), fluidised bed reactors (cofiring of refuse derived fuels), or different pyrolysis techniques with plant sizes up to 150000 t/a (example from Japan). [95]

As an example, according to the Austrian Umweltbundesamt [85] in 2006 display screen equipment (approximately 12000 tonnes) was treated by manual disassembling in 16 facilities in Austria, resulting in an average treatment tonnage of 750 t/a and site.

Typical treatment of these display screens includes:

- Transport
- Sorting of functioning machines for sale
- Fixing of broken monitors (only very small amount of monitors, not relevant)
- Manual disassembling: removal of housing, sometimes with extraction ventilation for dust removal

The most relevant practice in Austria seems to be the pressing and export of housing plastic from monitor equipment [85]. However, this may not be representative for other countries.

Recycling processes other than energy recovery have not been reported as relevant for plastic housings containing TBBPA, although it is in general possible to recycle ABS containing TBBPA (see section 7).

ABS recycling in general usually also includes shredding, separation from other fractions (e.g. metals) and mixing with virgin ABS. Thus, even if releases from recycling facilities may happen occasionally those facilities are probably very rare and releases are assumed to be covered by shredding processes related to thermal treatment [96, 97].

5.2.1.2 Printed circuit boards

Concerning the dismantling, a UK study published by WRAP [98] describes different types of techniques used for the separation of the board from the equipment, depending on the type of circuit board, including fully manual segregation, fully manual segregation + reuse, semi-automated dismantling with commercial shredding and semi-automated with commercial smashing (see Table 13 for more details).

Table 13: Overview of techniques [98].

Technique	Description	WEEE Category	Typical grades of circuit boards
Fully manual segregation	Manual segregation from other streams, followed by manual dismantling of equipment. Grading of printed circuit boards.	IT and Communications Equipment (Category 3) FPDs and CRTs (Displays, Category 11)	Grades 1,2,3, and 4
Fully manual segregation, including re-use	As above but incorporates the recovery of specific printed circuit boards/processor chips for re- use – visual checks and functionality testing is used. This is followed by cleaning and packaging ready for sale, being stored and advertised for sale on electronic auction sites or sold in bulk to a third party retailer	IT and Communications Equipment (Category 3) FPDs and CRTs (Displays, Category 11)	Grades 1,2 and 4

Semi-automated with commercial shredding	Mechanical shredding of WEEE for size reduction and separation of saleable ferrous and non-ferrous metals, with manual downstream picking operations to recover printed circuit boards and other components. This process is best suited for recovering printed circuit boards from items which are not cost effective to manually sort or items where the printed circuit boards are physically attached, e.g. welded, and cannot be manually removed.	Large domestic appliances (Category 1) Small mixed WEEE (Category 2) Carcasses remaining (after manual segregation) from separately collected I.T and communications equipment	Grades 3 and 4
Semi-automated with commercial smashing	Manual removal of streams requiring manual recovery. Spinning and smashing of the remaining WEEE into smaller components followed by magnetic separation and finally manual picking lines. QZ 2000 (MeWa) tool used by respondents.	Small mixed WEEE Large domestic appliances	Grades 3 and 4

In general, three recycling techniques of printed circuit boards are described by Lee et al. [82], physical separation, copper smelting and scraping.

Copper smelting plants and physical separation processes are also described by the Austrian Umweltbundesamt [85] as main treatment techniques.

Epoxy resins used in the printed circuit boards cannot be recycled by re-melting, however, particle down cycling and re-use of epoxy resins is possible. This is done on a limited scale in Germany: Waste from laminate and printed circuit board are grinded and separated into metal and plastic fractions. The plastic fraction can then be used as a supplement or filler in other products made from flame-retarded thermosetting resins. (Oeko Institute, 2008 [45]).

Copper smelting method:

The board is sent to a smelting plant to recover its copper. During the smelting process, the epoxy resin can be incinerated.

Because of PXDD/F and other emissions many smelters have installed and adapted gas-cleaning devices to keep emissions of dioxins well below European emission limits. Landfilling of the products from these gas-cleaning units is minimal, as metal values are sufficiently important (Tange & Drohmann, 2005 [87]). This method is stated to be the usual one by the review of the WEEE directive published in 2008 [43].

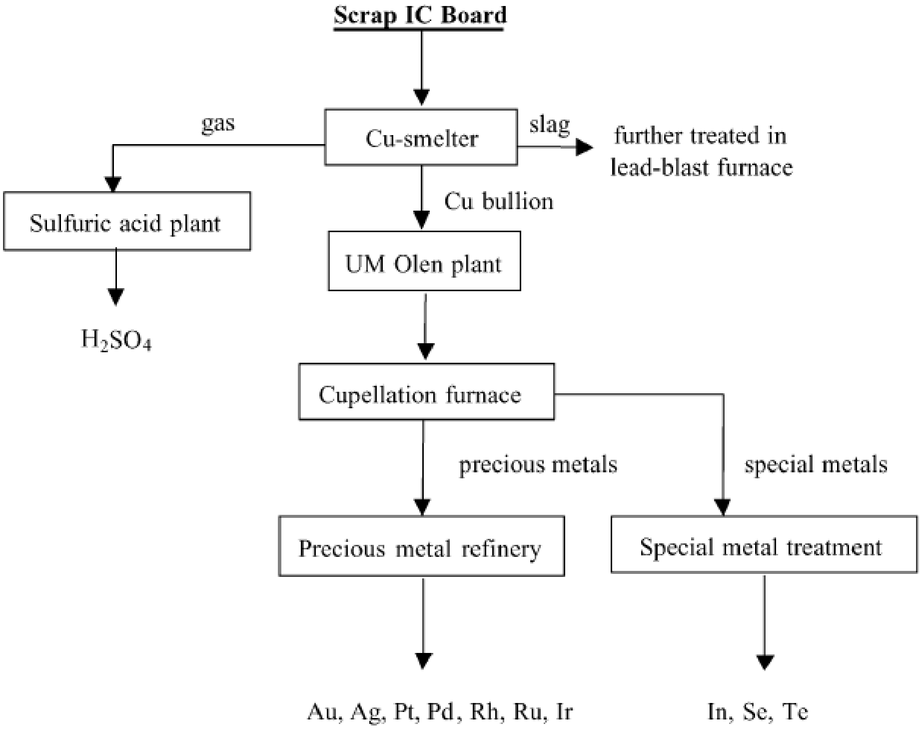

Figure 2: Example for copper-smelting flow sheet for recycling of scrap IC board. (see Lee et al., 2004 [82])

Physical separation method:

This type of separation technique usually includes a series of physical treatment units such as crushing, grinding, screening, magnetic separation, air classification, eddy-current separation, electrical-conductivity separation etc. As a result, different fractions of varying particle size and composition are obtained. [82]

Various types of shredders exist, e.g. large-scale metal shredders, combined shredders with automated material sorting, horizontal cross-flow shredders, plants for treatment of screens. Within the shredding process TBBPA will most likely end up in the plastics fraction, while only little amounts remain in the metal section.

As described by Duan et al, this also represents the usual process in European countries such as Germany (Duan et al., 2011 [84])**.** The following typical techniques are described by Duan et al.:

- boards are crushed directly without further dismantling,
- then magnetic separation
- vortex separation and air separation.

Another example as published by Lee et al. [82] is shown in Figure 3.

Scraping method [82]:

The board is heated to melt the solder. Afterwards the electronic parts can be removed mechanically and processed separately. It is not known to which extent this method is practiced in the EU.

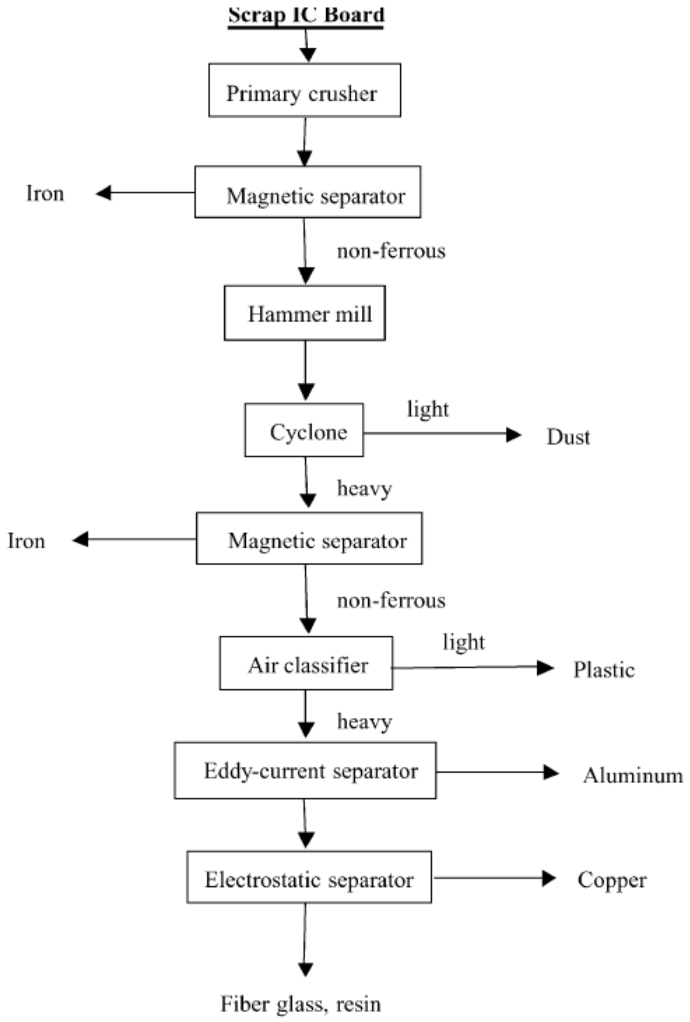

Figure 3: Example for physical separation flow sheet for recycling of scrap IC boards (see Lee et al., 2004 [82])

5.2.1.3 WEEE treatment in third countries

E-waste recycling or waste handling in developing countries may also include other, less controlled processes. The following processes are, as an example, summarised by Premalatha et al., 2014 [44]:

- Open burning of printed circuit boards and cables
- Burning of boards for component separation or for solder recovery
- Toner sweeping, plastic chipping and melting, burning wires to recover copper, heating, and acid leaching of boards
- Gold recovery from boards with cyanide salt leaching or nitric acid and mercury amalgamation
- Manual dismantling of cathode ray tubes and open burning of plastics

As a further example, in China recycling is done by heating and manual removal of components from printed circuit boards, open burning to reduce waste volumes and facilitate recovery of metals, and open acid digestion of e-waste to recover precious metals (Premalatha et al. (2014) [44], citing Yang et al., 2012[21]). Solder is melted from printed circuit boards over makeshift coal grills. Workers toil without goggles, masks, or gloves (Premalatha et al. (2014) [44], citing Fu et al., 2011[22]).

Further details and examples are given e.g. by Duan et al., 2011 and Lee et al., 2004 (Refs. [82, 84] [99]).

A summary of general treatment techniques and possible risks for the environment is given in Figure 4. However, most of the techniques are not commonly practiced in the EU or only with corresponding safety measures.

5.2.2 Subsequent treatment processes

As recycled fractions are considered to be negligible, the main subsequent treatment processes refer to shredder residues.

Usually these fractions are either land-filled or incinerated, while recycling of epoxy resins or ABS containing TBBPA is not practiced or only in isolated cases.

5.2.3 Treatment processes applied to wastes derived from WEEE containing the substance of concern and substance flows

For the relevant TBBPA tonnage per year a value of 32000 t/a is used (see section 2.2) in combination with the worst case concentration for TBBPA remaining in epoxy resins.

	housings	**epoxy resins**
t/a in application	4800	27700
Concentration TBBPA in final article (max.)	22%, 100 % of originally used	0.0204%, 0.06% of originally used
Remaining tonnage (t/a)	4800	16.32

Consistency check:

*It is known, that printed circuit boards represent ~8% of WEEE collected from small appliances and 3% of overall global WEEE. This results in an overall amount of ~277000 t/a scrap printed circuit boards per year in the EU (9.22 Mio t/a * 0.03), which would be equivalent to ~83000 t/a epoxy resin (30% of organics in boards [100], assumption: all boards contain epoxy resin with TBBPA) and, with 34% original TBBPA content assumed, to ~28200 t/a TBBPA. This number is consistent with the estimated amount of 27200 t/a TBBPA used in boards, considering the fact that a small fraction of boards is already manufactured with alternative flame retardants / resins.*

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[21] Yang, H., Zhuo, S., Xue, B., Zhang, C., and Liu, W. (2012). Distribution, historical trends and inventories of polychlorinated biphenyls in sediments from Yangtze River Estuary and adjacent East China Sea. Environmental Pollution 169, 20–26. (cited by Premalatha)

[22] Fu, J., Wang, Y., Zhang, A., Zhang, Q., Zhao, Z., Wang, T., and Jiang, G. (2011). Spatial distribution of polychlorinated biphenyls (PCBs) and polybrominated biphenyl ethers (PBDEs) in an e-waste dismantling region in Southeast China: Use of apple snail (Ampullariidae) as a bioindicator. Chemosphere 82, 648–655. (cited by Premalatha)

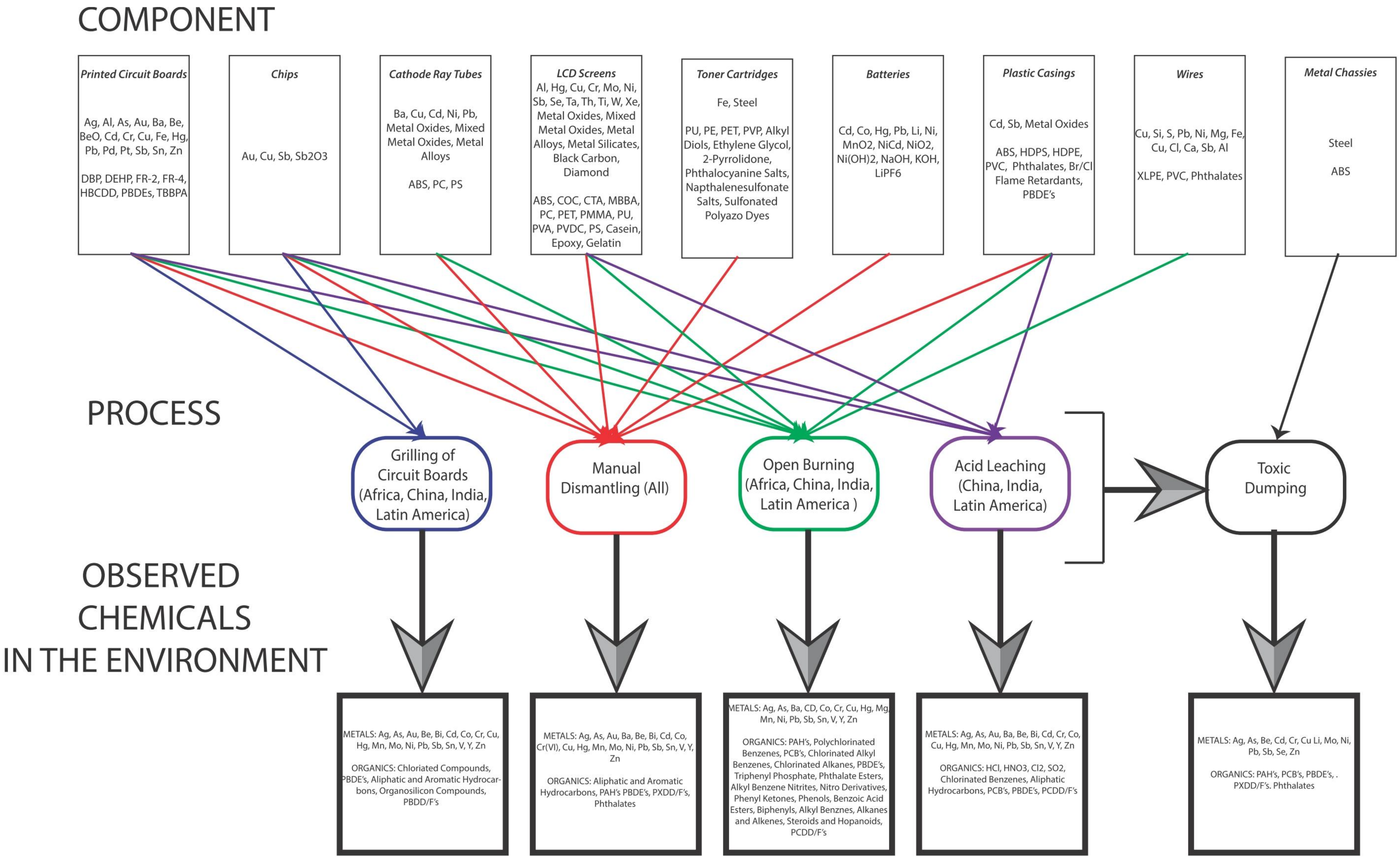

Figure 4: Comparison between chemicals found in 9 selected components and chemicals measured in the environment at informal waste sites as a result of the 5 major processes [99]

Table 14: Waste streams for TBBPA in WEEE.

		WEEE separately treated						WEEE in municipal waste (assumption: everything that is not collected)			
	relevant TBBPA tonnage (based on overall tonnage 32000 t/a use as flame retardant)	thereof in collected WEEE		TBBPA in WEEE which is treated in EU		shipped to other countries (mostly uncontrolled)		in municipal waste		incinerated (assumption 1/3, based on EEA, 2013 [89])	landfilled (assumption: 2/3 EEA, 2013)
ABS housings (waste category 3 and 4 used for derivation of fractions)	4800*	69.86	% of overall WEEE	61.18	% of overall WEEE			1446.6	t/a TBBPA in this fraction	428.2 t/a TBBPA in this fraction	964.4 t/a TBBPA in this fraction
				87.48	% of collected WEEE	8.75	% of collected WEEE				
		3353.37	t/a TBBPA in this fraction	2933.6	t/a TBBPA in this fraction	419.8	t/a TBBPA in this fraction				
printed circuit boards (all waste categories used for derivation of fractions)	16.32**	38.73	% of overall WEEE	32.36	% of overall WEEE						
				83.55	% of collected WEEE	6.37	% of collected WEEE	10	t/a TBBPA in this fraction	3.33 t/a TBBPA in this fraction	6.67 t/a TBBPA in this fraction
		6.32	t/a TBBPA in this fraction	5.28	t/a TBBPA in this fraction	1.04	t/a TBBPA in this fraction				

** 15% of overall TBBPA used as flame retardant is assumed to be used additively*

*** 85% of overall TBBPA used as flame retardant is assumed to be used reactively, only 0.06% of original TBBPA remain unreacted and can still be released as the substance itself.*

A small fraction of WEEE is reused according to Eurostat data (~1%); however, will be neglected during the risk assessment.

5.3 Waste treatment processes relevant for assessment under RoHS

In order to focus on processes where risks for workers or the environment are most likely to be expected, the following processes were selected for a risk assessment according (see RoHS manual [1]):

- Treatment of WEEE in shredders (including housings or circuit boards), as it is applied to TBBPA containing parts of WEEE at several stages of the overall treatment chain at a large number of installations.

The following processes are not assessed:

- Collection and transport, storage: Because the substance is not a gas or volatile in any form in the resulting products (neither additive nor reactive use).
- Manual dismantling: Because there is not extended manual or thermal treatment that may lead to emissions into the environment via vapour or dust.
- Landfilling / leaching: An estimated share of 0.0004 to 0.06% of the originally used TBBPA remains unreacted in case of printed circuit boards and thus, may theoretically leach from the product [5]. This corresponds to a maximum concentration of 0.02% TBBPA in the resin. In case of housings, i.e. additive use, the remaining TBBPA concentration in the polymer is higher (100% unreacted, corresponding to concentrations of 17.6 to 22.0% TBBPA in polymer [5, 40]). However, a recent extraction study by Zhou et al. [70] did not show any detectable TBBPA after extraction of printed circuit boards with acidic solutions and only small extracted fractions with other extraction liquid (pH ~8.5)). With alkaline solutions (0.01 M NaOH) small TBBPA amounts could be extracted (see section 6); however, a pH of 12 does not represent typical leaching conditions [71]. Moreover, WEEE or WEEE residues (e.g. incinerator ash) in general only represents a small fraction of municipal waste <<80%.
- Processing of circuit boards in copper smelters: Because the whole circuit boards are processed and the epoxy resin is usually incinerated in the smelter. Furthermore, concentrations of TBBPA in the circuit boards are very low.
- Scraping of circuit boards, recycling / further processing of separate parts: Because there is no evidence that this technique is relevant in EU countries. Furthermore, TBBPA concentrations in circuit boards are very low and recycling is only practiced on a very limited scale.
- Incineration: Because WEEE only represents a very small fraction in municipal solid waste and for WEEE dedicated incineration processes emission controls are usually in place in order to reduce both TBBPA and degradation product emissions. As described in the EU risk assessment report a mass balance for a WEEE treatment plant in Japan also showed that the amount of tetrabromobisphenol-A leaving the incinerator (as bottom ash, flue gas and fly ash) was around 1/500 to 1/9000 of that entering the incinerator [5].
- Any derivatives of TBBPA which are produced from TBBPA: According to the EU RAR residual TBBPA concentration in derivatives are < 0.005% and thus negligible.
- Uncontrolled treatment: As also discussed for other substances previously assessed under RoHS (e.g. DBP), WEEE is usually not the main source of release for TBBPA. Other steps of the lifecycle ((uncontrolled) manufacture of BFRs or EEE) may lead to higher releases, although not all information on this is consistent (see estimated release for WEEE treatment in EU risk assessment report vs. estimated release within this assessment, section 10).

  In case of uncontrolled WEEE treatment not only the release of TBBPA but also degradation products or other substances may be of relevance. Techniques may include open burning, shredding and a number of other processes (see section 5.2.1.3).

  A general comparison of processes in developed and developing countries has been summarised by Tsydenova et al. (see Table 15).

Publications by Tsydenova et al. and Sepúlveda et al. [101] [102] suggest that high levels of heavy metals, PBDEs, PCDD/Fs and PBDD/Fs in bottom ash, dust, soil, water, sediments, in WEEE recycling areas of India and China, where substandard, “informal” WEEE recycling plays a larger role than in Europe, may be found.

However, it is difficult to assess such processes in a quantitative way, as, due to their uncontrolled nature, not much information is available concerning release and exposure scenario, especially concerning degradation products. Thus, although it is obvious that illegal shipping and uncontrolled treatment of WEEE may lead to negative impacts, overall no quantitative exposure assessment will be performed.

Table 15: Comparison of the typical e-waste management scenarios and associated hazards in developed and developing countries.[102]

	Developed countries	**Developing countries**
Typical recycling and waste disposal processes	Manual dismantling	Manual dismantling
	Semi-automatic separation	Manual separation
	Recovery of metals by state-of-the art methods in smelters and refineries	Recovery of metals by heating, burning and acid leaching of e-waste scrap in small workshops
	Incineration with MSW	Open burning
	Landfill disposal	Open dumping
Occupational exposure hazard	Not well documented, apparently low	High
	Concentrations of PPBDEs in blood of electronics dismantlers:	Levels of PPBDEs in blood of informal e-waste workers:
	15–75 ng/g lw (Sweden[23])	140–8500 ng/g lw (Guiyu, China[24])
	3.8–24 ng/g lw (Norway[25])	77–8452 ng/g lw (China[26])
Workplace contamination hazard	Not well documented, apparently low	High
	Indoor air concentrations of PPBDEs at recycling facilities:	Outdoor air concentrations of PPBDEs in Guiyu town, China:
	510 ng/m^3 (TV recycling plant, Japan[27])	21.5 ± 7.2 ng/m^3[28]
	96; 98; 260; 310 ng/m^3 (four measurements near a shredder at an electronics recycling plant, Sweden[23])	*NB: No data on air concentrations in e-waste processing workshops were available for the comparison. However, the high outdoor concentrations are indicative of still higher concentrations in the e-waste workers’ immediate environment*
Environmental contamination hazard	Not well documented	High

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[23] Sjödin, A., Hagmar, L., Klasson-Wehler, E., Kronholm-Diab, K., Jakobsson, E., Bergman, Å., 1999. Flame retardant exposure: polybrominated diphenyl ethers in blood from Swedish workers. Environmental Health Perspectives 107 (8), 643–648. (Cited by Tsydenova et al)

[24] Bi, X., Thomas, G.O., Jones, K.C., Qu, W., Sheng, G., Martin, F.L., Fu, J., 2007. Exposure of electronics dismantling workers to polybrominated diphenyl ethers, polychlorinated biphenyls, and organochlorine pesticides in South China. Environmental Science and Technology 41 (16), 5647–5653 (cited by Tsydenova et al.)

[25] Thomsen, C., Lundanes, E., Becher, G., 2001. Brominated flame retardants in plasma sample from three different occupational groups in Norway. Journal of Environmental Monitoring 3, 366–370. (cited by Tsydenova et al.)

[26] Yuan, J., Chen, L., Chen, D., Guo, H., Bi, X., Ju, Y., Jiang, P., Shi, J., Yu, Z., Yang, J., Li, L., Jiang, Q., Sheng, G., Fu, J., Wu, T., Chen, X., 2008. Elevated serum polybrominated diphenyl ethers and thyroid-stimulating hormone associated with lymphocytic micronuclei in Chinese workers from an e-waste dismantling site. Environmental Science and Technology 42 (6), 2195–2200 (cited by Tsydenova et al.)

[27] Takigami, H., Hirai, Y., Matsuzawa, Y., Sakai, S., 2006. Brominated flame retardants and brominated dioxins in the working environment and environmental emission – a case study at an electronics recycling plant. Organohalogen Compounds 68, 2190–2193. (cited by Tsydenova et al.)

[28] Deng, W.J., Louie, P.K.K., Liu, W.K., Bid, X.H., Fu, J.M., Wong, M.H., 2006. Atmospheric levels and cytotoxicity of PAHs and heavy metals in TSP and PM2.5 at an electronic waste recycling site in southeast China. Atmospheric Environment 40, 6945–6955 (cited by Tsydenova et al.)

5.4 Releases from (relevant) WEEE treatment processes

Various approaches concerning releases of TBBPA and its degradation products during waste treatment or other lifecycle stages have been published (e.g. in the EU risk assessment [3, 5]). However, quantitative exposure estimations for WEEE treatment are rarely found and mainly based on a limited number of monitoring data.

Recycling processes, especially metal recycling of parts from printed circuit boards, require high temperatures. The same applies obviously to the incineration of plastic housings. The Oeko-Institute thus identifies a potential for the formation of dibenzo-p-dioxins and furans if TBBPA containing material enters the recycling process. However, according to the Oeko-Institut a quantification of the amounts and assessment of environmental significance of these products cannot be undertaken [45] (see section 5.4.3 for more details).

For epoxy resins of printed circuit boards, where TBBPA is incorporated reactively, recycling by remelting is not possible although they can be processed in a metal smelter which allows for the possible formation of degradation products. Apart from that, only re-use and downcycling remain as alternatives, although only rarely being applied. Releases therefore are mainly due to shredding activities in the course of WEEE processing.

According to EFRA, in EEE products TBBPA is either reacted within the circuit board or encapsulated in casings. When being treated according to standards, only a minor risk exists for releases to the environment as there will be no contact with water during the end of life phase [74].

According to the Government of Canada (2013) [34] release of TBBPA into the environment may occur during all stages of Product Life Cycle of the substance itself or products containing TBBPA, i.e. manufacturing phase, processing phase, and disposal phase. However, no quantitative release estimation is described.

It is stated that though water solubility is assumed to be low under neutral conditions, free TBBPA could be released from printed circuit boards in landfills that come into contact with basic leachate of pH 12 ([34], see also EU RAR [103]). However, more recent studies show that the tendency of the remaining TBBPA residues from the boards is quite low under acidic conditions (< 4.4E-3 microg/L) (Zhou et al., 2013 [104]) and basic pH values commonly found in leachate (pH ~8.5, maximum leaching rate 1 % of TBBPA after 100 days). Higher concentrations in leachate may be possible if housings, i.e. material with additively incorporated TBBPA is extracted or disposed of via landfilling (see section 6.2.3 for further leaching studies). However, Environment Canada [34] concludes that due to strong adsorption to particulates and degradation under anaerobic conditions the potential for leaching into groundwater is reduced.

According to the EU RAR there are indications that materials in landfills release TBBPA particulates or polymer-associated TBBPA into soil, water and air. Based on the findings in EU RAR 2008 that TBBPA has some solubility in water the EU risk assessment concludes that leaching over an extended time period is a possibility. [34] Release estimations for WEEE treatment activities are provided, however, it is stated that they should be used with care since they are based on only one example site.

TBBPA has been detected in various environmental compartments partly related to the disposal phase (e.g. indicated by US EPA, Chemtura & ICL-IP [103] and Covaci et al. [37], see section 6.2.3 and 6.2.2).

5.4.1 Shredding of WEEE

An estimation of the release of TBBPA to air has been done using the approach and defaults as suggested in the available official Annex II assessment reports for DEHP, HBCDD, BBP and DBP [105-108].

One main scenario, the shredding of WEEE, is considered

The most important release factor for TBBPA during shredding of WEEE is considered to be the emissions via dust.

For emissions from shredders typically abatement technologies are in place in order to remove dust (e.g. via cyclone and wet scrubber). According to the BAT reference document for Waste Treatment Industries [109] generic emission levels for dust (PM) associated to the use of BAT are in the range of 5-20 mg/m^3. Information on the actual dust emission from shredders under current operational conditions is scarce[29]. For the risk assessment therefore the upper border of the given range (i.e. 20 mg/m^3) will be used. Measurements concerning TBBPA in WEEE recycling plants including shredding operations as presented in section 6.1 indicate that this is a highly conservative assumption which is not expected to lead to any underestimations of the risk.

Additional information from the European Comission[30] indicates an overall annual release of PM10 from European car shredders of 2100 tonnes resulting from manipulation of fluff and fines. This is based on an assumption 18% generation of fines/ dust from materials treated in a shredder and an emission factor of the dry material of 1 g/kg.

In order to estimate TBBPA releases via diffuse emission of dust during manipulating material streams at sites where WEEE are shredded therefore the following assumptions were made (see ref. [105]):

Table 16: Diffuse emissions via PM10: Assumptions

100	% of TBBPA transferred to fluff/fines/dust[31]
0.1	% of fluff etc. will be emitted diffusely via PM10
250	t/d WEEE shredder capacity

To estimate the annual as well as the daily release per site of TBBPA due to diffuse release via PM10 the shredder capacity has been combined with the release factors and an average concentration of 522 mg/kg WEEE[32].

This value is between the worst case (housings 220000 mg/kg) and printed circuit boards (220 mg/kg). However, the scenario is considered to be a reasonable worst case concerning TBBPA concentrations in dust for the following reasons:

- The concentration of unreacted TBBPA in printed circuit boards is lower, i.e. the shredding of circuit boards alone is covered in all cases.
- not all housings contain TBBPA (~30% of them according to Schlummer [110]).
- The transfer factor to dust has been neglected.
- sometimes housings are not shredded but only pressed before further processing (e.g. incineration), which probably leads to less particle and dust formation than shredding, [85], i.e. the overall release is already overestimated by this approach
- manual dismantling may happen before the shredding, but this is not necessarily the case, i.e. whole pieces of equipment may be put into a shredder as well[33]

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l Monitoring 3, 366–370. (cited by Tsydenova et al.)

[30] Yuan, J., Chen, L., Chen, D., Guo, H., Bi, X., Ju, Y., Jiang, P., Shi, J., Yu, Z., Yang, J., Li, L., Jiang, Q., Sheng, G., Fu, J., Wu, T., Chen, X., 2008. Elevated serum polybrominated diphenyl ethers and thyroid-stimulating hormone associ

ated with lymphocytic micronuclei in Chinese workers from an e-waste dismantling site. Environmental Science and Technology 42 (6), 2195–2200 (cited by Tsydenova et a

l.)

[32] Takigami, H., Hirai, Y., Matsuzawa, Y., Sakai, S., 2006. Brominated flame retardants and brominated dioxins in th

- concentrations of TBBPA in dust in recycling facilities found by Morf et al. [111] (95-1210 mg/kg) and other sources of information (see section 6, 80.4-950 ng/g dust) suggest that 522 mg/kg is a representative concentration.
- A typical throughput of 250 t/day/site has been assumed for the daily release estimation referring to a large scale metal shredder (no reference given in [105], assessment report for BBP refers to end-of-life vehicles shredders). It is considered to be very likely that end-of-life vehicle shredders are at the upper end of possible shredder capacities (see e.g. Ref. [112] for other example, or example plants in Ref. [113] **</**= 3 t/h throughput overall). As an example, Lee et al. [82] report a weight of ~ 2 kg for the shell of a cathode ray tube monitor, which would result in 250000 monitors to be shredded per day at a facility to reach the used shredder capacity for housings alone.

Table 17: Diffuse release via PM10

total input of TBBPA into shredders (t/a) (see Table 14)	**TBBPA in fluff and fines (t/a)**	**TBBPA released via PM10 (t/a)**	**TBBPA in 250 t/day site WEEE**	**TBBPA released via PM10 (kg/d/site)**
2938.8	2938.86	2.93886	0.131	0.131

In addition, the release from de-dusting has been estimated using the upper limit of the dust levels documented in the BAT document, an exhaust air flow of 20000 m^3/h and a treatment quantity of 60 t WEEE/h[34]. The shift duration was assumed to be 7 h per day.

Table 18: Release of TBBPA via de-dusting.

dust concentration (BAT) max	20	mg/m^3
exhaust	20000	m^3/h
Shift duration	7	h/day
WEEE treated per hour	60	t/h
resulting WEEE per day	420	t/d
TBBPA in this WEEE	219.3	kg
released dust per day (exhaust • shift duration)	2.8	kg/day
TBBPA in this fraction	0.5712	kg
Resulting release factor for TBBPA from de-dusting (fraction released via dust in exhaust air / TBBPA in complete WEEE) (suggested release factor in RoHS manual: 0.1)	0.00666667	g/kg
Resulting release via de-dusting	0.00087	kg/d TBBPA

Together with diffuse releases this results in a maximum daily release of ~131.4 g/day/site for shredding of WEEE.

As another example, the EU risk assessment report [5] describes releases from a WEEE recycling site as being 183 mg/day of TBBPA to air before the incinerator (exhaust air is also led to incinerator) and a maximum of 1.4 mg/day of TBBPA after the incinerator. This indicates that the currently used assumptions are highly conservative, although obviously one exemplary study should not be used for a general exposure assessment.

It is recognised in the EU RAR that the available amount of data is limited and thus, can only give indicative results. However, it is not completely inconsistent with values that can be derived from other monitoring data:

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e working environment and environmental emission – a case study at an electronics recycling plant. Organohalogen Com

pounds 68, 2190–2193. (cited by Tsydenova et al.)

[34] Deng, W.J., Louie, P.K.K., Liu, W.K., Bid, X.H., Fu, J.M., Wong, M.H., 2006. Atmospheric levels and cytotoxicity of PAHs and heavy metals in TSP and PM2.5 at an ele

The highest identified TBBPA concentration in air in a recycling company is 20.8 µg/m^3. When this value is combined with an exhaust air output of 20000 m^3/h and a 7 h shift this leads to a release of 2.9 g TBBPA per day and site and a release fraction of 22 mg/kg TBBPA (average concentration of TBBPA in WEEE and 250 t WEEE /day throughput used as reference for the estimation).[35]

Concentrations in dust go up to 653 mg/kg dust, [111] which would together with a maximum dust concentration of 20 mg/m^3 result in 1.8 g TBBPA release per shift and a release factor of 14 mg/kg TBBPA.

Although these values will not be used for the risk assessment they may be seen as an indication, that the release estimated before (0.13 kg/day and site) and the release factor of overall 1007 mg/kg TBBPA (0.13 kg per day divided by average TBBPA throughput of 250 t/day shredder) is at the very high upper end of possible local release factors.

5.4.2 Further considerations

Workplace description mechanical treatment of WEEE (see Austrian Umweltbundesamt (2008) [85] and available assessment reports for DEHP, BBP, DBP, DEP)

In general mixed shredder residues are usually further processed with the intention to recover valuable metals and also to achieve legally binding recycling targets.

In case of monitors a partial separation e.g. of cathode ray tubes from the housing is often practiced before the remaining fractions are further processes (i.e. pressing or shredding in case of housing)[36].

In case of mixed shredding residues, in order to obtain recyclable metal-rich concentrates, several automated sorting techniques are used, such as various types of mechanical treatments, such as shredding, milling, etc., where dust is generated. It is assumed that not all of those installations are equipped with efficient dust prevention techniques (-> upper limit of applicable dust concentrations has been used, 20 mg/m^3).

Emissions to water and soil from shredding are considered to be negligible (see also RoHS manual).

Treatment of WEEE in large-scale metal shredders is usually an automated process, where workers handle the material outdoors with different machines. In addition, the employees are partly sitting in closed cabins

However, for other processes (e.g. horizontal flow shredders or special drums) the treatment may be completed by manual sorting of disintegrated appliances along a conveyor belt. Ventilation conditions may vary. Dust masks are usually worn.

Further handling and processing of the mixed shredder residues may differ. As an example, both outdoor and indoor processing in partly encased places may be possible. Fully encapsulated grinding and sorting aggregates are also possible.

It is assumed that two thirds of the shredder residues are landfilled, while one third is incinerated (see section 5.1).

5.4.3 Releases of toxic degradation products

Various studies are available on the release of toxic degradation products, especially polybrominated dibenzo-p-dioxins and dibenzofurans during pyrolysis or other processes.

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ctronic waste recycling site in southeast China. Atmospheric Environment 40, 6945–6955 (cited by Tsydenova et al.)

[36] See e.g. https://www.youtube.com/watch?v=ZeN2gMM31lE, https://www.youtube.com/watch?v=grwY42EeP8o,

Luijk & Gover (1992) [114] analysed the formation of polybrominated dibenzo-p-dioxins and dibenzofurans during pyrolysis of polymer blends containing brominated flame retardants. They came to the result that for systems of ABS TBBPA mono- to penta-brominated dibenzofurans at ppb levels are formed during pyrolysis.

Bozi et al. (2007) [115] also identified brominated phenols when polycarbonate with 4% TBBPA was processed by pyrolysis while Barontini et al., 2004 [116] investigated decomposition pathways of TBBPA and identified amongst others bisphenol A and its derivatives.

A study performed at the TAMARA test plant and published by Vehlow et al. (ref. [117], also discussed by Borgnes and Rikheim [118]) discussed the influence of brominated flame retardants on the emission of polybrominated dibenzo dioxins and – furans using test fuels with 70% organic/green waste and 30% of WEEE test mixes (e.g. TV housings, printed circuit boards). It was concluded that the dioxin and furan emission were always below the most stringent regulatory limit and overall emissions of PCDDs/Fs were not increased by higher bromine load in the WEEE. PXDD/F loads in raw gas up to ~ 200 ng/m^3 or 2.3 ng(TE)/m^3 were detected. Apart from that, abatement efficiencies of scrubbers usually showed removal efficiencies above 90% (69-99%). Similar conclusions were drawn by Tange & Drohmann (2004 and 2005) [87, 119] who in addition concluded that corrosion of municipal waste incinerators was mainly due to chlorine and not to bromine. Overall, it was concluded that small WEEE fractions containing brominated flame retardants in municipal waste incinerators do not pose a hazard for humans or the environment.

A similar study discussed by Borgnes and Rikheim [118][37] evaluated the formation of brominated dioxins from co-incineration of household waste and BFRs in another pilot scale incineration plant. In contrast to the TAMARA plant the results showed that the formation of halogenated dioxins was higher when adding BFRs than when only chlorine was present. It was concluded that batch incineration of wastes containing BFRs should be avoided.

Concerning full-scale plants Borgnes and Rikheim are citing measurements from 2002 carried out at a plant in Norway incinerating wastes from households and small industries (normal waste composition). 0.003 ng/m^3 tetrabrominated dibenzo-p-dioxins were found while concentrations of other single compounds were lower than the detection limit (< 0.0001-0.02 ng/m^3). Measurements from 1999 at other plants in Sweden (incineration of municipal waste) indicated emissions of chlorinated dioxins below 0.1 ng/m^3 and emissions of brominated dioxins below the LOD (< 0.05 ng/m^3). Further measurements from 2002 showed PBDD/F and PCDD/F levels between ~0 and ~0.11 ng/m^3 TEQ.

Flue gas cleaning is stated to be applied at all these plants and measurements represent concentrations in cleaned flue gas.

Borgnes and Rikheim concluded that more incineration tests and studies of dioxins in full scale plants would be needed in order to decide concentrations in flue gas before and after cleaning at different levels of bromine content in the waste. Further information about bottom ash, fly ash, water from scrubbers should also be gathered.

As a consequence incineration tests at three Norwegian plants were carried out. At plant 1 tests were performed using waste without bromine, a mix with 5% brominated waste (~0.05% (w/w) bromine content overall) and a mix with 10% brominated waste (~0.1% (w/w) bromine content overall). Plant 2 provided measurements without addition of BFRs, while at the third plant incineration studies using a mix with 0 and 20% bromine containing waste (i.e. ~0.2% (w/w) bromine content in the total mix). Measured levels of chlorinated, brominated and chlorinated / brominated dioxins were between ~0.6 and 1.8 ng/m^3 (all dioxins together). The values (transformed into Nordic toxic equivalents) are at least a factor of 3 below the EU threshold value of 0.1 ng/TE(Nordic)/m^3. Increasing the content of BFRs in the waste did not lead to a significant increase in the emissions of chlorinated dioxins, or either brominated and chlorinated / brominated dioxins, whereas the emission level for brominated dioxins is

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[37] cited by Borgnes and Rikheim: Söderström et al. (2000) (no further information concerning Reference available)

overall lower than for chlorinated or mixed halogenated dioxins. Overall it is concluded that the incineration efficiency and operating conditions of the flue gas treatment systems are of greater importance than the bromine content of the incinerated waste. Concerning the flue gas treatment removal efficiencies of 93% and >99% for chlorinated and chlorinated / brominated dioxins were determined, whereas the removed dioxins remain in the fly ash and are treated as hazardous waste.

A study published by PlasticsEurope (2006) [120] used metal-rich WEEE plastics as feedstock for integrated metal smelters and showed no increase in air emissions from dioxin/furan like compounds from chlorine or bromine containing flame retardants at the levels present in the used household WEEE (6% WEEE with plastics in test fuel).

Boerrigter (2000) [121] evaluated 4 different plants with thermal processes for feedstock recycling of bromine from plastics waste of electrical and electronic equipment and came to the result that all companies claim their that emissions of dioxins and furans meet the current legislation limits. Different abatement techniques were used to reach this goal.

A study published by Wichmann et al. (2002) [122] investigated the thermal formation of PBDD/F from TBBPA used as reactive and additive flame retardant. It was shown that in both cases PBDD/Fs were formed (e.g. 18.1 mg/kg in case of epoxy resins, equalling 0.042 mg TE /kg).

Concerning printed circuit boards various studies investigating thermal processes and their influence on emissions are published [123-126]. Identified substances range from brominated benzenes, phenols, bisphenol A derivatives, PBDD/Fs to dioxin like polychlorinated biphenyls and hydrogen bromide. However, for most of these substances also the temperature range and exact conditions are of relevance. As an example, brominated aromatic compounds are exclusively formed between 270 and 400°C, while bromine is released at higher temperatures only in the form of hydrogen bromide [123] and PBDD/Fs were only formed if oxygen is present [124].

Studies listed in the Annex of the EU risk assessment report suggest that some contaminants are already present in purchased TBBPA. Contaminant levels in the air of recycling sites and circuit boards are low (< 1 µkg board, < 1 ng/m3 in air dibenzo-p-dioxins and furans).

Levels of brominated dibenzofurans and dibenzo-p-dioxins in ABS containing TBBPA before and after recycling show sometimes increasing concentrations (depending on the substance); however, general orders of magnitude for the sum of all substances stayed the same.

According to a series of combustion experiments performed by the US EPA (2014) [127] with different printed circuit board laminates / resins TBBPA retarded boards release more PAHs during combustion than those treated with DOPO or without flame retardants. The total smoke release is higher as well in some cases (less difference if samples with other board components are incinerated). Particulate matter emissions are highest for a variant of DOPO resin, while for incineration with components differences are again less defined. CO/CO_2 emissions are highest for samples without flame retardants, whereas again the differences are less clear if other board components are also incinerated.

According to the EU risk assessment [5] TBBPA can contribute to the formation of halogenated dibenzo-p-dioxins and furans generated during such processes but it is not possible to quantify the amounts or assess the environmental significance of these products. However, studies listed above seem to suggest that emitted levels are usually low and available and commonly practiced abatement techniques are able to keep their concentrations below legal limit values.

No or little increase of the amounts of brominated dibenzofurans and dibenzo-p-dioxins during recycling processes (granulate, remoulded ABS) has been shown [5]. As apart from this recycling seems to be hardly practiced this is therefore assumed to be irrelevant concerning human and environmental exposure.

In conclusion it can be said that there is the possibility that toxic decomposition products are formed when WEEE containing TBBPA is incinerated or otherwise heated.

However, the studies closest to real life situations (e.g. TAMARA test plant, UMICORE smelter, incineration tests performed by Borgnes and Rikheim) suggest that the emissions are well controllable with established abatement techniques and emissions are below the applicable limit values.

In addition, according to the EU RAR tetrabromobisphenol-A will only constitute a small proportion of the total halogenated material present in an accidental fire and thus, will probably not significantly affect the total release of toxic products from fires.

6 EXPOSURE ESTIMATION DURING WEEE TREATMENT

6.1 Human exposure estimation

As TBBPA is only used as intermediate or as flame retardant in WEEE, these are the main exposure pathways for the general population as well as employees. Within the scope of this assessment the focus will lie on exposure due to processing / recycling of WEEE, however, a short discussion of consumer exposure will be done.

6.1.1 General population

An evaluation of the daily intake of TBBPA via food has been undertaken by EFSA [52] and resulted in a maximum daily exposure of 2.6 ng/kg bw/d for an adult high fish consumer. The intake has been estimated on the basis of the highest reported LOQ (= 1 ng/g ww), since TBBPA could not be identified in the evaluated food samples.

For toddlers one scenario using concentrations in cow milk (LOQ = 0.65 ng/g ww, as TBBPA could not be quantified) resulting in an exposure value of 55.7 ng/kg bw /d. An additional scenario for daily consumption of human milk (0.06-37.3 ng/g fat reported via cross-references, see also Appendix B) led to a maximum intake of 0.41-257 ng/kg bw/d for infants with a high consumption.

This is roughly consistent with the assessment published by Canada [34] which suggests an exposure of 1 ng/kg bw for formula fed infants or 195 ng/kg bw for breast fed infants to TBBPA and its derivates (TBBPA bis(2-hydroxyethyl ether), TBBPA bis(allyl ether)).

On the basis of house dust ingestion and inhalation as documented by RIVM (2008) [128] and the identified maximum concentration of TBBPA in house dust (1480 ng/g, Table 21) the following daily exposure via dust has been estimated:

Table 19: Parameters used for exposure estimation

Child	100	mg/day dust ingestion
Child	0.8	mg/day dust inhalation
Adult	50	mg/day dust ingestion
Adult	2	mg/day dust inhalation
body weight adult consumer	60	kg (as used in the ECETOC TRA v.3 model)
body weight child	10	kg (as used in the ECETOC TRA v.3 model)

Table 20: Worst case exposure to TBBPA via house dust (ingestion + inhalation).

Population	**Exposure**
Child	0.015 mg/day/kg
Adult	0.0013 mg/day/kg

It is noted that the used contamination of house dust represents a worst case and there is a high fluctuation depending on location and sampling point with a range from not detected up to 1480 ng/g dust and all values except the one used being below 600 ng/g dust.

There is no limit value for combined uptake. However, since the inhalation DNEL proposed in section 3.3 is fairly high (300 mg/m^3) and the oral DNEL is 1.7 mg/kg/day, i.e. clearly above the estimated exposure values, under the used assumptions no risk is expected for consumers / general population.

Apart from that TBBPA has been detected in human serum (nd–12 ng/g lw) and whole blood (up to 330 ng/kg whole blood).

Exposure may be increased by additional factors not related to waste, e.g. employment in EEE manufacturing or a BFR manufacturing (see also Appendix B).

A recent study published by Puype et al. showed small concentrations of TBBPA in equipment (also non-electrical) use for the preparation of food. Several brominated flame retardants were measured, however, only overall concentrations of bromine were given which are summarised in Table 52 in Appendix B [129].

If it is assumed that all detected bromine has been caused by TBBPA as a worst case scenario, relative concentrations between 0 (n.d.) and 1% TBBPA in the material can be derived as a worst case estimate. If it is furthermore assumed that the relevant plastic parts have a weight of ~50 g per piece and a maximum fraction of 1% is released into food per day, a maximum dose of 0.022 mg/kg/day TBBPA can be estimated (sample 9). This is considered to be a worst case estimate since leaching studies (see section 6.2) show that 1% release is a maximum value which is reached after a larger timespan than one day. Furthermore 1% refers to extraction liquid with a pH value above 7, whereas most beverages show pH values below 7, in particular tea and coffee, which are mostly used in thermos-cups [130, 131]. Eggs may have slightly higher pH values (7.6-8) [132][38] but an egg cutter (sample 1) will have much less contact area and contact time than cups or glasses. The same applies to apple cutters (sample 3).

Overall this publication therefore gives no indication that a risk may be present for the general population from TBBPA contained in equipment with contact to food or beverages, even if the uncertainties of the approach are compensated via highly conservative assumptions (whole bromine content caused by TBBPA).

According to the EU RAR [3] in experimental animals, toxicokinetic data are available in the rat only. Following oral exposure, 100% of the administered dose of TBBPA was absorbed from the gastrointestinal tract.

Quantitative measurements in blood indicate very little of the administered TBBPA and/or its metabolites are present from 4 hours onwards following oral administration. However, it is indicated that there is a significant gap about what is known of the fate of TBBPA between being absorbed and appearing in the faeces.

This is supported by the assessment published by EFSA (2011) [52] which suggests > 70% absorption after oral administration followed by a rapid distribution in different tissues. The results published by EFSA indicate that TBBPA is conjugated, mainly to glucuronic acid, prior to excretion. Some minor other metabolites have been identified, including TBBPA sulphate, TBBPA diglucuronide, TBBPA glucuronide sulphate, and free and conjugated tribromobisphenol A.

Regarding dermal exposure, results of the EU RAR for human health suggest that dermal absorption would be low (< 10%). This is supported by a study published on the ECHA webpage corresponding to the TBBPA REACH registration which indicates dermal absorption below 1%. [4]

According to the EU risk assessment there is no evidence to suggest that it has the potential to bioaccumulate. One toxicokinetic study in pregnant animals is available which indicates no significant transfer of TBBPA or its metabolites to the foetus.

Table 21: Human TBBPA exposure not related to WEEE treatment

medium	location	minimum	maximum	unit
House dust	USA, UK, Japan, Belgium, Germany, China, 8 EU countries	nd	1480	ng/g
Human milk	F, China, France, Faroe Islands, Norway, Germany, UK	nd	37.34	ng/ g fat
Blood serum	Norway, Japan	< 0.1	12	ng/g lw
adipose tissue	US	0.0033	0.464	ng/g lw

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[38] Handbook of Chemistry and Physics, CRC Press (cited by E. Farnworth; no further information concerning Edition etc. given).

Dermal exposure	Sweden (furniture workshop, cikrcuit board factory)		< 0.09	ng/cm^2
			<2	ng/hands
Hair	US, TBBPA manufacturing facility		2	µg/kg

6.1.2 Exposure of workers of EEE waste processing plants

6.1.2.1 Exposure modelling

Exposure estimations performed in this section are based on assumptions as summarised in section 5. The ECETOC TRA tool has been used for occupational exposure modelling. However, a refinement of the concentration implementation has been undertaken as previously published by the Austrian Umweltbundesamt in the available assessment reports under RoHS [105-108]. Details of the model algorithm used in the ECETOC TRA tool are published in ECETOC technical reports (TR114 and TR107) [133, 134]. The model is most frequently used under REACH for Tier 1 exposure estimates; however, it is also suggested by the RoHS manual for assessment reports in this context.

One scenario, shredding of WEEE, has been selected as relevant for a quantitative risk assessment (see section 5.3):

Due to its origin as a REACH based exposure model, that is mainly used for formulation and manufacturing processes, ECETOC TRA does not explicitly include waste treatment processes such as shredding. However, the implemented descriptor system [135] allows for a scenario based on “PROC24: high (mechanical) energy work-up of substances bound in materials and/or articles”, which has been selected as a surrogate for shredding of WEEE. The further description of this process category refers to “substantial thermal or kinetic energy applied to substance by hot rolling / forming, grinding, mechanical cutting, drilling or sanding. Exposure is predominantly expected to be to dust).”

As mentioned before, further handling of WEEE (e.g. during dismantling) is not assessed quantitatively. However, it is noted that these processes can be described as a worst case via PROC21 (low energy manipulation of substances bound in materials and/or articles) which leads to identical exposure results as PROC 24 within the ECETOC TRA algorithm.

In the previously published assessment reports under RoHS, all PROC24 subcategories (a, b, c) have been estimated. However, as can be seen in the glossary within the model and the available technical reports (TR107 and TR114 [133, 134]), the sub-categories a, b and c refer to different temperatures in relation to the articles or substance’s melting point. These categories are used to define the fugacity instead of dustiness for PROCs 22-25 within ECETOC TRA:

Process temperature **<** melting point: Low fugacity
Process temperature **≈** melting point: Moderate fugacity
Process temperature **>** melting point: High fugacity

It is not further explained in the available RoHS assessment reports if this context was known to the authors or why high temperatures should be assessed in the context of shredding. However, it is not considered to be reasonable to shred a material that is already melting, therefore, PROC24a (process temperature < melting point) is assumed to be the only relevant sub-category of this process.

Apart from that, the following input parameters have been selected for the scenario:

- full shift activity (> 4 h)
- professional setting
- outdoors, since shredding equipment is assumed to be either completely outdoors or in large, partially open halls
- no respiratory equipment or gloves
- The concentration of the preparation has been set to 100% within ECETOC TRA. However, it has been corrected in a second step with a concentration as used in section 5.4 (0.0522 %, see section 5.4 and environmental exposure assessment).

This leads to the following exposure values and risk characterisation ratios (RCR = exposure divided by limit value, see section 3):

Table 22: Exposure estimates (ECETOC TRA v3), shredding of WEEE

Process Category (PROC)[39]	Long-term Inhalative Exposure Estimate (mg/m^3) c= 100%	Long-term Dermal Exposure Estimate (mg/kg/day) c= 100%	Long-term Inhalative Exposure Estimate (mg/m^3) c= 0.0522 %,	Long-term Dermal Exposure Estimate (mg/kg/day) c= 0.0522 %,
PROC 24a	2.10E+00	2.83E+00	1.1E-3	1.5E-3

Table 23: Risk characterisation ratios (RCR = exposure / DNEL)

Process Category (PROC)	DNEL inh (mg/m^3)	DNEL derm (mg/kg/day)	RCR inh	RCR derm	RCRges
PROC 24a	600	8.3	1.8E-6	1.8E-4	1.8E-4

The comparison between estimated exposure and identified limit value shows that for this scenario no risk is expected for workers.

Since the RCR values are several orders of magnitude below 1, it is also ensured that small uncertainties such as non-average contents of the shredder contents are still covered.

Moreover, usually dust masks and sometimes gloves are worn during the work, thus, actual exposure may be lower than the predicted value which does not take into account these measures.

6.1.2.2 Monitoring of occupational exposure due to WEEE recycling / treatment

In this section a short summary about available monitoring data related to WEEE recycling / treatment is given. More details are summarised in Table 49, Table 50 and Table 51.

Monitoring of recycling plant employees:

Location	**Sampled medium**	**results**	**unit**
Norway, Sweden	Electronics dismantling site employees; Serum concentration	0.64–4	ng/g lw

TBBPA concentrations in indoor dust at recycling facilities:

Location	**results**	**unit**
China, Switzerland, Sweden	0.08-653	µg/g

Air concentrations of TBBPA at recycling sites:

Location	**results**	**unit**
Finland, Sweden, UK	(nd)/0.007-20.8	µg /m^3

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[39] Process temperature* in relation to melting point (mp) vs. Fugacity

PROC24a: Process temp < mp: Low

PROC24b: Process temp ≈ mp: Moderate

PROC24c: Process temp > mp: High

Additional studies concerning levels of degradation products of TBBPA are available (see e.g. section 5.4.3, [99]), however, have not been evaluated in detail, since concentrations cannot be directly related to TBBPA as their origin in most cases.

Concerning the dust samples it is surprising that the order of magnitude is for most samples roughly similar to concentrations found in other, general dust samples collected in offices or as domestic house dust, although the maximum value found is higher for WEEE treatment facilities (see Appendix B for details). However, it has already been described in previous chapters that also at recycling sites, not all treated equipment will contain TBBPA in significant amounts. On the other hand, there may be offices or other locations where several parts of equipment using additively bonded TBBPA are contained. An exposure estimation based on this dust concentrations has not been undertaken since it is no domestic dust and uptake fractions, especially for the oral uptake which is the dominant exposure pathway for house dust exposure, are most likely lower than has been concluded by RIVM [128] for domestic dust. However, concentrations of TBBPA in dust suggest, that the scenario modelled with ECETOC TRA in the previous section will probably lead to highly conservative results. Measured data are from Switzerland and China, but similar orders of magnitudes were determined.

Concerning the air measurements, sampling strategies differed between personal and stationary sampling. Other parameters related to the scenarios such as protective measures, ventilation and exact processes varied as well; however, at least some of the samples also included personal exposure sampling of shredding operations. Measurements were done in Sweden, UK and Finland. The highest results were found in one of the UK samples; however, the size of the database does not allow for a general differentiation between countries. Measured air concentrations are at least a factor of ~100 smaller than those estimated with ECETOC TRA, again suggesting a conservative modelling approach.

Partly it was indicated that dust masks were worn during parts of the workday. However, sampling was done without taking into account these protective measures, i.e. outside the masks.

All measured concentrations are clearly below the DNEL for inhalation exposure.

One study by Mäkinen et al. evaluated dermal exposure to TBBPA due to WEEE recycling and other activities, resulting in an exposure range of 2.0-6.7 ng/cm^2 (potential exposure, above clothing) which however did not include sampling points at the hands.

The available monitoring data can also be used to estimate release factors for an exposure assessment (see section 5.4).

6.1.3 Exposure of neighbouring residents of EEE waste processing plants (WPP)

No information could be identified in the course of this project about measured TBBPA concentrations related to neighbouring residents of WEEE processing plants.

6.2 Environmental exposure estimation

6.2.1 Exposure modelling

For the environmental exposure modelling releases as described in section 5 have been used.

Two risk assessments have been carried out for different Koc values as suggested in the EU risk assessment report in order to take into account variability and uncertainty within the assessment parameters: 49726 l/kg and 147360 l/kg.

For the freshwater sediment two PNECs have been discussed in the EU RAR: 2.7 (see section 4.3) and 5.5 mg /kg ww, whereas the higher value is proposed for the Koc of 147360. However, for the sake of simplicity in both cases the PNEC of 2.7 mg/kg ww has been used.
In general, the PNECs from the EU risk assessment have been used since they represent the worst case in most compartments.
Furthermore, different BCF values have been discussed for earthworms in the EU risk assessment. However, since the concentrations estimated are very low and the RCR values shown in later sections several orders of magnitude below 1, this has not been done in the course of this assessment.

The following parameters have also been adapted according to the changed adsorption coefficients (see EU RAR for details):

Table 24: Adsorption coefficients used in the environmental risk assessment (see EU RAR)

Partition coefficient	**Symbol**	**Values used**	
Organic carbon - water partition coefficient	Koc	49726	[147360 l/kg]
Solids – water partition coefficient for soil	Kp_{soil}	3321 l/kg	[2947 l/kg]
Solids – water partition coefficient for sediment	Kp_{sed}	4813 l/kg	7368 l/kg
Solid - water partition coefficient for suspended matter	Kp_{susp}	7299 l/kg	[14736 l/kg]
Soil - water partition coefficient	$K_{soil\text{-}water}$	4982 m^3/m^3	[4420 m^3/m^3]
Sediment - water partition coefficient	$K_{sed\text{-}water}$	2407 m^3/m^3	3680 m^3/m^3
Suspended matter – water partition coefficient	$K_{susp\text{-}water}$	1826 m^3/m^3	[3680 m^3/m^3]
Solids – water partition coefficient for raw and settled sewage sludge	$Kp_{raw\ sewage\ sludge}$ $Kp_{settled\ sewage\ sludge}$	17245 l/kg	[44200 l/kg]
Solids – water partition coefficient for activated and effluent sewage sludge	$Kp_{activated\ sewage\ sludge}$ $Kp_{effluent\ sewage\ sludge}$	20725 l/kg	[54500 l/kg]

Table 25: Summary of estimated ultimate biodegradation rate constants for use in the EUSES model

Compartment		**Reaction rate constant**	**Half-life**
Waste water treatment plant		0 d^{-1}	Infinite
Surface water		$4.7x10^{-3}$ d^{-1}	150 days
Soil	Kpsoil = 3000 l/kg	$2.31x10^{-5}$ d^{-1}	30000 days
	Kpsoil >3000 l/kg	$2.31x10^{-6}$ d^{-1}	300000 days
Sediment	Kpsoil = 3000 l/kg	$2.31x10^{-5}$ d^{-1}	30000 days
	Kpsoil >3000 l/kg	$2.31x10^{-6}$ d^{-1}	300000 days

Some further selected EUSES parameters which have been used for the assessment are listed in Table 26 and have been chosen on the basis of the RoHS manual and available assessment reports under RoHS.

Table 26: Selected EUSES parameters

Descriptor	input
Assessment mode	Interactive
Assessment type	Local scale
Additional:	Predators exposed via the environment
Biodegradability	not biodegradable
Chemical class for Koc -QSAR	Phenols, benzonitrils
Industry category	4: Electrical/Electronic engineering industry
Use category	22: Flame retardants and fire preventing agents
Use pattern	Waste treatment
Fraction of the main local source	0.02
Number of emission days per year	220

Descriptor	input
Production volume	2939
Fraction of the EU production volume in the region	10
Fraction of tonnage released to air	0.001*
Local emissions to air during episode	0.13 kg
Local STP input	Bypass STP

**the suggested value for the release fraction is 1, however, this is not considered to be reasonable since it is already assumed for the local release that not all substance will be released to air. This would only be the case for substances with a very high volatilisation rate. For TBBPA this would only be the case if the complete WEEE was processed to fine dust and directly blown into the atmosphere without anything left to process, sort or incinerate. Obviously this will not happen in reality, the release factor has therefore been adapted according to the assumptions already described in earlier chapters.*

PREDATOR EXPOSURE			
Bioconcentration factor for earthworms	9.53E+03	[l.kgwwt-1]	S
HUMAN AND PREDATOR EXPOSURE			
Bioconcentration factor for fish	1.23E+03	[l.kgwwt-1]	S

Details of the assessment are given in Appendix C as EUSES report files including all defaults and input parameters.

The following concentrations in the environmental compartments and for secondary poisoning have been estimated:

Table 27: Environmental PECs for Koc = 49726 l/kg

AIR		
Concentration in air during emission episode	3.61E-05	[mg.m-3]
Annual average local PEC in air (total)	2.18E-05	[mg.m-3]
WATER, SEDIMENT		
Local PEC in surface water during emission episode (dissolved)	3.90E-07	[mg.l-1]

Annual average local PEC in surface water (dissolved)	3.90E-07	[mg.l-1]
Local PEC in fresh-water sediment during emission episode	6.20E-04	[mg.kgwwt-1]
Local PEC in seawater during emission episode (dissolved)	5.06E-08	[mg.l-1]
Annual average local PEC in seawater (dissolved)	5.06E-08	[mg.l-1]
Local PEC in marine sediment during emission episode	8.04E-05	[mg.kgwwt-1]
SOIL, GROUNDWATER		
Local PEC in agric. soil (total) averaged over 30 days	6.97E-03	[mg.kgwwt-1]
Local PEC in agric. soil (total) averaged over 180 days	7.02E-03	[mg.kgwwt-1]
Local PEC in grassland (total) averaged over 180 days	9.12E-03	[mg.kgwwt-1]
Local PEC in pore water of agricultural soil	2.39E-06	[mg.l-1]
Local PEC in pore water of grassland	3.11E-06	[mg.l-1]
Local PEC in groundwater under agricultural soil	2.39E-06	[mg.l-1]
SECONDARY POISONING [WASTE TREATMENT]		
Concentration in fish for secondary poisoning (freshwater)	4.82E-04	[mg.kgwwt-1]
Concentration in earthworms from agricultural soil	0.0151	[mg.kg-1]
Concentration in fish for secondary poisoning (marine)	6.25E-05	[mg.kgwwt-1]
Concentration in fish-eating marine top-predators	6.25E-05	[mg.kgwwt-1]

Table 28: Environmental PECs for Koc = 147360 l/kg.

AIR		
Concentration in air during emission episode	3.61E-05	[mg.m-3]
Annual average local PEC in air (total)	2.18E-05	[mg.m-3]
WATER, SEDIMENT		
Local PEC in surface water during emission episode (dissolved)	1.03E-07	[mg.l-1]
Annual average local PEC in surface water (dissolved)	1.03E-07	[mg.l-1]
Local PEC in fresh-water sediment during emission episode	3.31E-04	[mg.kgwwt-1]
Local PEC in seawater during emission episode (dissolved)	1.93E-08	[mg.l-1]
Annual average local PEC in seawater (dissolved)	1.93E-08	[mg.l-1]
Local PEC in marine sediment during emission episode	6.17E-05	[mg.kgwwt-1]
SOIL, GROUNDWATER		
Local PEC in agric. soil (total) averaged over 30 days	3.54E-03	[mg.kgwwt-1]
Local PEC in agric. soil (total) averaged over 180 days	3.58E-03	[mg.kgwwt-1]
Local PEC in grassland (total) averaged over 180 days	5.60E-03	[mg.kgwwt-1]
Local PEC in pore water of agricultural soil	1.38E-06	[mg.l-1]
Local PEC in pore water of grassland	2.15E-06	[mg.l-1]
Local PEC in groundwater under agricultural soil	1.38E-06	[mg.l-1]

SECONDARY POISONING [WASTE TREATMENT]		
Concentration in fish for secondary poisoning (freshwater)	1.27E-04	[mg.kgwwt-1]
Concentration in earthworms from agricultural soil	6.91E-03	[mg.kg-1]
Concentration in fish for secondary poisoning (marine)	2.38E-05	[mg.kgwwt-1]
Concentration in fish-eating marine top-predators	2.38E-05	[mg.kgwwt-1]

6.2.2 Monitoring data: remote regions

A summary of general monitoring data of TBBPA in various compartments is given in Table 29 (more details including data for biota can be found in Appendix B). Although TBBPA is a frequently sampled substance, concentrations are usually lower than those of other brominated flame retardants (see e. g. Morris et al., 2004 [67]).

Moreover, the available monitoring data suggest that main release sources of TBBPA are not necessarily WEEE treatment facilities, but, as an example, manufacturing plants (BFR manufacturing or EEE manufacturing) (see also following section for comparison).

In addition, potential transformation products were monitored (e.g. dimethyl TBBPA), but they were not found in all cases and the results have not been evaluated in detail (see EU RAR [3]).

More monitoring data can be found, as an example, in the evaluation report published by the Government of Canada [34].

All water samples are below the PNECs for fresh and marine water (0.0013, 0.00025 mg/l).

However, for soil and sediment some values are found which are above the corresponding limit values (sediment 12.4 mg/kg dw (freshwater), 2.48 mg/kg dw (marine water), 0.055 mg/kg dw (soil)). Again the covered range is large for all compartments, going over several orders of magnitude.

For sediment, two values are above the PNEC (see details in Table 54): One measured in 1977 in the US near a BFR manufacturing site (330 mg/kg dw) and one from the UK (9.8 mg/kg dw), all other values are below 1 mg/kg dw.

For soil also two values are affected: One from Israel measured near a contaminated site (450 mg/kg dw) and one from China, measured near a BFR manufacturing site (0.672 mg/kg dw). All other values are below the PNEC.

Again this indicates that safe use, including manufacture of TBBPA, is in general possible. However, under uncontrolled conditions without appropriate safety measures a risk, in particular for the soil and / or sediment compartment, may be possible.

Table 29: Environmental exposure / monitoring not related to waste treatment.

	minimum	maximum	unit
STP sludge			
Italy, Korea, Spain, Sweden, Germany, NL, UK, Ireland, Finland, Canada	<0.01	617	ng /g dw
Sediment			
Arctic environment, china, Norway, Czech republic, Germany, Japan, UK, NL, Asia (general), US	nd	330000	ng /g dw
Air			
Arctic environment, Sweden, Russia, Northeast Atlantic, Sweden, US, Japan, Germany, "8 EU countries"	< LOD	1800	ng/m^3
Soil			
Israel, US, China, Switzerland	25.2	45000	ng/g
	0.12		ng/g ww

	< 0.1	2.3	ng/g dw
Water			
France, Germany, Japan, Finland, NL, UK, Canada, China, Belgium, Sweden	< LOD	130	ng/l

6.2.3 Monitoring data: waste management

A summary of available monitoring data of TBBPA in environmental compartments near waste treatment / landfilling sites can be found in below and in more detail in Appendix B, Table 30 [101] [102].

Overall most concentrations are not significantly higher than the range of values found at other points of the environment (see section 6.2.2). One concentration in water could be found (68 pg/l), concentrations in sediment between 0 and 21 ng/g dw (up to 44.4 ng/g ww) and concentrations in soil in the range from < 0.025 – 1800 ng/gdw.

Thus, most values for environmental compartments are below the postulated PNEC values as described in section 4.3.

There are however some exceptions for the soil compartment, where the concentration reaches 1.8 mg/kg dw. All sampling points related to waste treatment for the soil compartment are located in China where substandard waste treatment is more common than in the EU (see section 5). It is furthermore noted the values span a huge range of up to 5 orders of magnitude (soil), indicating that disposal and treatment of WEEE is possible without high release of TBBPA. However, the increased values at some points indicate that uncontrolled waste dumping or treatment should be avoided [101] [102].

Available leaching studies (see Table 31, extraction of housings and printed circuit boards) show that the leaching rate of TBBPA is depending on the pH of the extracting liquid, with higher pH values obviously giving higher leaching rates. However, all studies indicate comparably low leaching rates of usually less than 1 %.

Concentrations in extraction liquid go up to 0.012 mg/l which is above the PNECs for fresh and marine water as suggested by the EU RAR (0.0013 and 0.00025 mg/l). However, concentrations in laboratory extraction studies on only one product type (printed circuit boards, housings) are not representative for actual concentrations found in leachate.

Concentrations found in landfill leachate go up to 0.00062 mg/l. This is still above the PNECs, however, the measured concentrations include values before waste water treatment, which usually happens before leachate is released into a water compartment (see ECHA guidance R18 [136]). After on-site treatment and dilution happening during the release concentrations are expected to be below the applicable PNECs.

Particulate, “leachate sediment”[40] and sludge concentrations are in the ng/g region and thus, all below the PNECs for soil and sediment.

Table 30: TBBPA in environmental compartments, exposure related to waste treatment.

Compartment	Location	minimum	maximum	unit
Water	China		68	pg/l
Sediment	Czech republic, China, Finland, Norway, Japan	< loq	44.4	ng/g dw
Soil	China	< 0.025	1800	ng/g dw

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[40] No further explanation of wording given in publication, probably settled particles from leachate.

Table 31: Leaching potential of TBBPA

Reference	Cross reference	Location	Sampled medium	results	unit
Extraction studies					
EU RAR [5]	Ulla Sellström and Bo Jansson, Chemosphere, Vol. 31, No. 4, pp. 3085-3092, 1995		Extraction of printed circuit boards with 0.01 M NaOH (i.e. pH 12)	TBBPA could be extracted with this solution	
Zhou et al., 2013 [104]		China	Extraction of crushed waste printed circuit boards with leachate from landfill site (pH = 8.59 (raw), 8.43 (treated))	untreated mean max concentration 12270; treated 3570 (saturation after 100 days)	ng/l
Zhou et al., 2013 [104]		China	Extraction of crushed waste printed circuit boards with leachate from landfill site (pH = 8.59 (raw), 8.43 (treated))	1 (raw landfill leachate), 0.45 (treated leachate)	% leaching
Zhou et al., 2013 [104]		China	Leaching studies / extraction of crushed waste printed circuit boards: TCLP method and SPLP method, The extracts were acetic acid for TCLP and nitric and sulfuric acid solution for SPLP	Not detectable	
Choi et al., 2009 [137]		Korea	Extraction of TV housings with distilled water (HIPS with 8100 ng/g TBBPA)	~5	ng/l
Choi et al., 2009 [137]		Korea	Extraction of TV housings with dissolved humic matter (HIPS with 8100 ng/g TBBPA)	~10	ng/l
Monitoring studies: landfill leachate					
Kajiwara et al., 2014 [138]		lysimeter study, waste samples contained 1400 ng/g TBBPA (composite) and 2600000 ng/g (plastic), municipal waste from developing countries was simulated	leachate from simulated waste landfill, 3.5-year experiment	0.003 (aerobic); 0.001 (semi-aerobic); 0.002 (anaerobic)	% leaching
Kajiwara et al., 2014 [138]		lysimeter study, waste samples contained 1400 ng/g TBBPA (composite) and 2600000 ng/g (plastic), municipal waste from developing countries was simulated	Concentration of TBBPA in leachate	5-45 (aerobic/anaerobic/semiaerobic together)	ng/l

Reference	Cross reference	Location	Sampled medium	results	unit
EU RAR [5]	Morris S., Allchin C. R., Zegers B. N., Haftka J. J., Boon J. P., Belpaire C., Leonards P. E., Van Leeuwen S. P. and De Boer J. (2004). Distribution and fate of HBCD and TBBPA brominated flame retardants in North Sea estuaries and aquatic food webs. Environ. Sci. Technol., 38, 5497-5504.	UK, Ireland	landfill leachates (dissolved)	< 15	ng/l
Zhou et al., 2013 [104]		China	leachate from landfill site with 10000 t of garbage per day, leachate is treated by a combined process of oxidation ditch/Fenton advanced oxidation and the capacity of the process is ~1200 t/day	15.41 (raw), < 4.5 (treated)	ng/l
Suzuki et al., 2006 [139]		Japan	leachate from landfill	0.3-540	ng/l
Osako et al., 2004 [140]		Japan (7 landfills)	leachate of waste landfill, raw and treated leachate samples as far as possible.	raw 1-620; treated 0.5-11.0	ng/l
Monitoring studies: landfill particulate					
EU RAR [5]	de Boer J., Allchin C., Zegers B., Boon J. P., Brandsma S. H., Morris S., Kruijt A. W., van der Veen I., van Hesselingen J. M. and Haftka J. J. H. (2002). HBCD and TBBPA in sewage sludge, sediments and biota, including interlaboratory study. RIVO Report No. C033/02. September 2002.	NL	landfill leachates (particulate)	43-320 (3 of 9 landfill sites) (dimethyl TBBPA also not found)	ng/g dw
EU RAR [5]	Morris S., Allchin C. R., Zegers B. N., Haftka J. J., Boon J. P., Belpaire C., Leonards P. E., Van Leeuwen S. P. and De Boer J. (2004). Distribution and fate of HBCD and TBBPA brominated flame retardants in North Sea estuaries and aquatic food webs. Environ. Sci. Technol., 38, 5497-5504.	UK, Ireland	landfill leachates (particulate)	< 3.9	ng/g dw
EBRC 2011 [103]	Borgnes, D. & Rikheim, B. (2004). Emission measurements during incineration of waste containing Bromine. Final report on behalf of the Nordisk Ministerråd, Statens Forurensningstilsyn, Norsk Renholdsverks-forening, Elektronikkretur AS, Hvitevareretur AS, Stena Miljø AS, RENAS AS.	-	sediments from landfill leachate	1-440	ng/g
Sewage sludge from plants receiving landfilling leachate					

Reference	Cross reference	Location	Sampled medium	results	unit
EU RAR [5]	de Boer J., Allchin C., Zegers B., Boon J. P., Brandsma S. H., Morris S., Kruijt A. W., van der Veen I., van Hesselingen J. M. and Haftka J. J. H. (2002). HBCD and TBBPA in sewage sludge, sediments and biota, including interlaboratory study. RIVO Report No. C033/02. September 2002.	NL	sewage sludge from landfills	< 0.3-0.4	ng/g dw
EU RAR [5]	Sellström U. and Jansson B. (1995). Analysis of tetrabromobisphenol A in a product and environmental samples. Chemosphere, 31, 3085-3092.		sludge from plant receiving leachate from landfilling site (including TBBPA using plastics factory waste)	56	ng/g dw
EU RAR [5]			sludge from plant receiving leachate from landfilling site (no source of TBBPA known)	31	ng/g dw

Table 32: TBBPA in other waste residues

Medium	Location	minimum	maximum	unit
flue ash	Japan		0.0013	mg/kg
Flue gas from incinerator	Norway	<5	22	ng/m^3
scrubber water	Norway	0	0.01	mg/l
Filter dust	Norway	0	0.04	mg/kg
air emission	Japan		8	ng/m^3
Pyrolysis residue / oil from pyrolysis of printed circuit boards		0	0.013	%
automobile shredder residues	Japan		15	mg/kg

7 IMPACT AND RISK EVALUATION

7.1 Impacts on WEEE management as specified by Article 6 (1) a

Classification of waste relevance according to RoHS

The RoHS2 Directive (Article 6) defines a set of three criterions that determine the waste relevance of a substance. The following subsection thus analyses, if these specifications apply to TBBPA.

Criterion a) describes the impacts of the substance on WEEE management:

a) *Substances / substance groups that "could have a negative impact during EEE waste management operations, including on the possibilities for preparing for the reuse of waste EEE or for recycling of materials from waste EEE"*

According to the RoHS manual published by the Austrian Umweltbundesamt [1] criterion a) is fulfilled if one of the following facts is true:

1. There is evidence that the substance hinders recycling or recovery as it has adverse effects on recycling / recovery processes (examples are Pb in glass fractions, halogenated polymers in fractions to be used for energy recovery).
2. There is evidence that large proportions of the substance remain in the recycling loop and are not discharged during the treatment processes and collected for subsequent safe disposal. As a consequence the hazardous substance / substance group may be distributed across various types of recycled materials such as metals, plastics, glass or building material and finally in the environment.

Concerning point 1 it has already been discussed in section 5.4.3 that in general, toxic degradation products such as dibenzo-p-dioxins and dibenzofurans may be formed during incineration or other thermal treatment options for WEEE containing TBBPA. However, the most elaborate studies using test reactors and monitoring data suggest that emissions are well controllable by available risk mitigation measures. Moreover, it is not completely clear from the definition of this criterion if toxic degradation products are even a part of its definition, since these are also covered under other waste criterions in article a (see Appendix A).

In general, the formation of HBr during waste incineration may contribute to corrosion of waste incinerators in case of municipal waste incinerators. However, as previously discussed (see section 5.4.3) corrosion in municipal waste incinerators is mainly due to chlorine and not to bromine within the incinerated waste mixture (typical chlorine concentration in waste 0.6-0.7%, bromine concentration 65-100 ppm) [141]. It is concluded, that the amounts of WEEE, that can be mixed and co-fired with Municipal Solid Waste is up to 3%, which is according to the authors 10 to 15 times more than what is normally present in the household waste.

However, information concerning the possible content of WEEE in municipal waste varies between different authors, e.g. according to Premalatha et al., WEEE can represent up to 8% by volume of municipal waste (Premalatha et al., 2014 [44]).

According to Tohka, the use of recycled ABS (acrylonitrile-butadiene-styrene) as a blend with PC (polycarbonate) is not possible because the BFR causes the PC to depolymerise, resulting in poor quality of the recyclate [95]. According to DEPA (2010) [81] presence of additively used TBBPA housings may hinder recycling of the corresponding plastic. However, the stated reasons for this are indirect ones: It is discussed that recycling may be hindered because standard procedures may not be able to distinguish TBBPA from other, already restricted, brominated flame retardants like OctaBDE (a POP under the Stockholm Convention), especially in black ABS. Thus, recycling would become increasingly challenging.

However, this does not seem to be of relevance currently, since ABS / housings are usually not recycled but energy recovery is practiced (Recycling is not economical due to low volumes) [93].

It is not known how the absence of TBBPA in housings would possibly influence this current status and if recycling would be practiced more often without TBBPA.

Moreover, it is in general possible to recycle plastics containing brominated flame retardants and recycling properties of ABS / TBBPA or ABS / brominated epoxy oligomer have been even shown to be superior to halogen free plastics (PC/ABS or PC/HIPS + organic phosphate ester), i.e. less deterioration of mechanical properties was observed after recycling and in contrast to halogen free plastics fire safety ratings could still be achieved after recycling [142].

Concerning point 2 it has already been described that plastics recycling is infrequently practiced for the components containing TBBPA. Some plastic recycling studies evaluating degradation products are published in the EU risk assessment report (human health), indicating that although dioxins/ furans may be present, the levels are not substantially increasing over recycling processes. Initial levels may already be present in the purchased TBBPA and not only be formed during further processing of WEEE.

ABS in general is used for a variety of products, including computer housings and a variety of other products [143, 144]. If ABS including TBBPA is recycled without removing the flame retardant prior to further processing, it may remain in the recycling loop and be spread over these product categories. Although there are indications that TBBPA can be found in articles where it is not commonly used as a flame retardant (e.g. thermos-cups, egg cutters), resulting amounts and concentrations are very small (< 0.3%, in case of the electrical frying pan sampled by Puype et al. BFRs have probably been used intentionally (EEE)). [129]) and do not seem to pose a risk for human health (see section 6).

According to Comission decision 2000/532/EC [145] wastes which contain one or more substances that are classified as aquatoxic are classified as hazardous waste. TBBPA is aquatoxic [72] and according to the ECHA webpage there are two cases of classification[41] which lead to a hazard class of at least aquatic chronic 2 for a mixture of 22% TBBPA in ABS [146]. This still applies if it will be taken into account that only ~30 % of all monitor housings are made of ABS and thus, may be treated with TBBPA (~6.6% resulting concentration)[42].

The residual TBBPA concentration in circuit board resins is low (</= 0.02%) and thus, TBBPA does not contribute to its classification (although the content of heavy metals may nevertheless lead to a classification). The same applies to leachate concentrations as listed in section 6.2.3.

Considering that a maximum of ~4800 t/a TBBPA is assumed to be present in WEEE housings (see section 5.4) and the maximum concentration of 22% this results in a minimum of 21818 t/a hazardous waste induced by the use of TBBPA. This amount may be higher if other components are mixed with the ABS/TBBPA housings (e.g. other housings / shredded materials). However, considering the fact that the amount of additively used TBBPA has been decreasing over the last years also the amount of produced hazardous waste will further decrease.

Waste plastic without further hazardous substances (waste code 02 01 04) is not classified as hazardous waste.

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[41] a) Aq. Acute 1, Aq. Chronic 1, M chronic = 0 (M=1 used for mixture toxicity since M=0 would mean that even 99% a hazardous substance in a mixture would not classify the mixture as hazardous and this is not considered to be reasonable.)

b) Aq. Chronic 1, M chronic = 10

[42] Sum(Chronic 1 * M * 10 * conc.)+ Sum (Chronic 2) >/= 25% (see CLP guidance document published by ECHA (Guidance on the Application of the CLP Criteria, Guidance to Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures, Version 4.0, November 2013)

7.2 Risks for workers and neighbouring residents

Shredding has been identified as the most relevant treatment procedure regarding TBBPA exposure.

The comparison between estimated exposure and identified limit value shows that for this scenario, under the assumed conditions, no risk is expected for workers, especially considering the fact that the concentration of TBBPA has been set to 22%. However, usually not all shredded material is consisting of housings and not all housings have been treated with TBBPA as a flame retardant.

RCR values are derived in section 6 are given in Table 33.

Table 33: Risk characterisation ratios (RCR = exposure / DNEL)

Process Category (PROC)	RCR inh	RCR derm	RCRges
PROC 24a	1.8E-6	1.8E-4	1.8E-4

The EU risk assessment report concludes that no health effects of concern have been identified for TBBPA. In the meantime, indications have been found that TBBPA may cause cancer, however, this more recent study has been taken into account for the derivation of DNELs and still RCR values are clearly below 1.

For third countries, increased exposure to TBBPA and its decomposition products may be higher.

However, concentrations of TBBPA measured in dust in a recycling facility in China suggest, that at least TBBPA concentrations in air will not reach levels of concern, i.e. above 600 mg/m^3.

An assessment of dermal exposure is not possible due to a lack of measured data originating from third countries.

The formation of toxic degradation products during open burning or other operations is possible, however, cannot be assessed quantitatively.

Available literature suggests, that, as an example, residents or workers in regions around electronics dismantling facilities in China may show higher levels of PCDD/F which exceed the WHO 1998 tolerable daily intake limit of 1-4 pg of W-TEQ kg^{-1} day^{-1} [147]. Hormone levels of children from these areas have been found to be abnormally changed. [148] However, it cannot be assessed to which extent TBBPA contributes to these exposures. In general residents of the corresponding areas may be exposed to a number of chemicals including different flame retardants, metals and a number of other potentially hazardous substances and their degradation products, therefore health effects will probably be caused by more than one single substance..

7.3 Risks for the environment

Risk characterisation ratios for environmental compartments are listed in Table 34 and Table 35. As can be seen all values are clearly below 1, indicating that no risk could be identified for this scenario.

In particular for the exposure to predators all RCRs are several orders of magnitude below 1, i.e. even with the lower PNEC of 222 mg/kg food as suggested in the REACH registration no risk is expected. Apart from that, different BCF values have been discussed in the EU risk assessment (BCFfish = 1234 l/kg, BCFfish = 485 l/kg). For this assessment report only the BCF value of 1234 l/kg has been used, however, results reported in the EU risk assessment report show that differences between the two approaches will not exceed one order or magnitude with BCF = 1234 l/kg giving higher RCR values, thus, it is not expected that one of the RCR values would be above 1 for a BCF value of 485 l/kg.

Table 34: Risk characterisation environmental compartments for Koc = 49726 l/kg

LOCAL	
RISK CHARACTERIZATION OF [WASTE TREATMENT]	
WATER	
RCR for the local fresh-water compartment	3.00E-04
RCR for the local marine compartment	2.03E-04
SEDIMENT	
RCR for the local fresh-water sediment compartment	2.30E-04
RCR for the local marine sediment compartment	7.44E-05
SOIL	
RCR for the local soil compartment	0.581
PREDATORS	
RCR for fish-eating birds and mammals (fresh-water)	7.22E-07
RCR for fish-eating birds and mammals (marine)	9.37E-08
RCR for top predators (marine)	9.37E-08
RCR for worm-eating birds and mammals	2.26E-05
REGIONAL	
WATER	
RCR for the regional fresh-water compartment	3.00E-04
RCR for the regional marine compartment	2.03E-04
SEDIMENT	
RCR for the regional fresh-water sediment compartment	4.57E-04
RCR for the regional marine sediment compartment	2.94E-04
SOIL	
RCR for the regional soil compartment	0.246

Table 35: Risk characterisation environmental compartments for Koc = 147360 l/kg

Local	
WATER	
RCR for the local fresh-water compartment	7.93E-05
RCR for the local marine compartment	7.70E-05
SEDIMENT	
RCR for the local fresh-water sediment compartment	1.22E-04
RCR for the local marine sediment compartment	5.71E-05
SOIL	
RCR for the local soil compartment	0.295
PREDATORS	
RCR for fish-eating birds and mammals (fresh-water)	1.91E-07

RCR for fish-eating birds and mammals (marine)	3.56E-08
RCR for top predators (marine)	3.56E-08
RCR for worm-eating birds and mammals	1.04E-05
REGIONAL	
WATER	
RCR for the regional fresh-water compartment	7.93E-05
RCR for the regional marine compartment	7.70E-05
SEDIMENT	
RCR for the regional fresh-water sediment compartment	2.43E-04
RCR for the regional marine sediment compartment	2.25E-04
SOIL	
RCR for the regional soil compartment	0.041

For third countries, as for human exposure, the situation may be less controlled and exposure to TBBPA and its decomposition products may be higher. Available monitoring data suggest that soil will probably be the most critical compartment for TBBPA exposure in these cases. Concerning degradation products information cited in the previous section concerning PCDD/F levels as well as further information published e.g. by Hu et al. [149] also suggests that other environmental compartments will show increased concentrations of these contaminant. However, it is not possible to quantify the influence of TBBPA on the overall exposure to these potential decomposition products.

8 ALTERNATIVES

8.1 Availability of substitutes / alternative technologies

The flame retardant TBBPA is mainly used as a reactive flame retardant in epoxy resins which are used in printed circuit boards (printed circuit boards, ~90% of use). The remaining 10% are used as additive flame retardant, mainly in ABS (Acrylonitrile butadiene styrene) which can be used for electric and electronic equipment housing.

8.1.1 Printed circuit boards / reactive use of TBBPA

In reactive applications, substitution of TBBPA as a flame retardant is usually done via organic phosphorus compounds.

In printed circuit boards DOPO (9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide) can be used as a substitute. However, the majority of the FR-4 printed wiring boards currently on the market is still TBBPA based. [33] This is at least partly due to the higher costs of DOPO (~ 4 times as much as TBBPA [73]), although these costs can be reduced with ATH or silica as fillers or by using it together with less costly substances (e.g. metal phosphinates). Because it is monofunctional, there is more potential for release compared to TBBPA, which is difunctional (US EPA, 2014 [127]).

Low moisture absorption is a desirable laminate property for environmental stability and enhanced reliability. However, according to Morose, phosphorus based laminates absorb more than two times as much moisture as conventional laminates [4][43].

Phosphorus resins can be used in combination with metal oxides such as Aluminium Tri-hydroxide (ATH), Aluminium Oxide-hydroxide (AOH), Magnesium hydroxide or silicium dioxide. These formulations have good thermal stability but tend to lead to a variety of technical challenges, such as higher water uptake or increased brittleness, while with printed wiring boards, the interaction of metal hydroxides with fire can lead to the presence of water in the laminate during soldering operations, potentially increasing the assembly failure rate and affecting electrical properties. As a consequence, aluminium tri-hydroxide is essentially used in intrinsically less-flammable flexible wiring boards for smaller devices like mobile phones or cameras [4][46].
Silicium dioxide cannot be used without other flame retardants. Moreover silica affects drilling operation during the circuit board manufacturing process. [73]

ATH without other flame retardants requires high loadings and therefore cannot be used in applications where the high loadings may affect critical polymer processing and physical properties. The same applies to magnesium hydroxide. Due to the comparably low decomposition temperature of ATH, it can only be used for processing temperatures below 180 °C. [4] [73]

Gensch et al. also mention nitrogen components to obtain halogen free systems for printed circuit boards [46]. This is supported by some melamine polyphosphate based products mentioned by EPA [73] in their evaluation of flame retardants in printed circuit boards. Another alternative, Melamine cyanurate, is relatively cheap and highly available, however, it is a poor flame retardant and requires high dosage.

This recently published evaluation of flame retardants in circuit boards published by US EPA [73] also covers and evaluates a number of further possible alternatives which have already been pointed out by other authors (DOPO, (phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol), Aluminium hydroxide, aluminium diethylphosphinate, silicium dioxide, magnesium hydroxide).

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[43] Rajoo, R., Wong, E.H., Moisture Characteristics and Performance of Halogen-Free Laminates, International Conference on Electronics Packaging, Japan, 2002. (cited by Morose, 2006)

Silicium dioxide and metal phosphinates such as aluminium diethylphosphinate cannot be used alone [73] but only in combination with other flame retardants.

In addition the reactive flame retardant resins Brominated Bisphenol A Type Epoxy Resin (Phenol, 4,4-(1-methylethylidene)bis([2,6-dibromo-, polymer with (chloromethyl)orxirange and 4,4'-(1-methylethylidene)bis[phenol]), Dow XZ-92547 (Reaction product of an epoxy phenyl novolak with DOPO) and a representative fyrol resin (reaction product of (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol) with bisphenol A, polymer with epochlorohydrin), which can then be used for laminate manufacture.

Morose [36] describes amongst others an alternative brominated compound (2,4,6-tribromophenol) in circuit boards.

Replacement of the resins with less flammable polymers such as polyetherimid or polyethersulfon has recently been evaluated [46] but is only applicable for the high end market due to its pricing [150].

According to Morose [36] for low-end applications of circuit boards, less expensive resins such as phenolics, melamines, vinyl esters, and polyesters may be used while for high frequency applications, poly(tetrafluoroethylene) (PTFE) are applicable. For high temperature applications, PTFE, other fluoropolymers, cyanates and epoxy-PPE blends or even ceramics are an alternative whereas cyanates, PTFE, and inorganic substrates are usually inherently flame retardant.

Further alternatives for TBBPA in epoxy resins are discussed by Vik (zinc borate, [151]) and Mariappan and Wilkie (poly(m-phenylene methyl phosphonate) = (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol); 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO, see above); red phosphorus, aluminium diethylphosphinate [152]).

On the other hand other evaluations state red phosphorus is not recommended for electronic applications, because it can form phosphine (PH3) and acidic oxides under hot and humid conditions. The oxides can lead to metal corrosion, and hence electric defects can occur. [73]

Estimations made by Bergendahl et al. suggest, that costs will increase about approximately 35-50% during manufacture of printed circuit boards if a switch to halogen free resins is performed. In addition, the cycle time may increase [153].

8.1.2 Housings / additive use of TBBPA (mainly ABS)

Blends of ABS with styrenic and polycarbonate or polyphenylene oxide, flame retarded with organophosphorous compounds or brominated flame retardants in combination with antimony trioxide can substitute ABS [33, 46].

Depending on the type of equipment the housing is needed for, other polymer systems with alternative (partly brominated) flame retardants are in use [4], in particular for ABS housings brominated epoxy oligomers (BEO) are mentioned.

It is not documented to which extent housing materials used for other equipment could be used to substitute ABS / TBBPA systems (e.g. HIPS, Polycarbonate/ Polystyrene, PPO/HIPS) [4].

For applications using HIPS several possible flame retardants (halogenated and halogen free) have been listed by Posner, however, since HIPS seems to be of negligible relevance concerning TBBPA applications, this is not expected to have a large influence on the overall TBBPA market. [154]

Posner also lists decabromodiphenylether, decabromodiphenylethane, ethylenebis(tetrabromophtalimide) and brominated epoxies with small amounts of antimony trioxide used as synergist for use in ABS, however, no halogen free comercially available alternative flame retardants are described. [155]

As alternative polymer blends PPE11/PS blends or PC/ABS blends with organic phosphorous compounds such as resorcinol bis (biphenyl phosphate), Bisphenol A bis (biphenyl phosphate) and triphenyl phosphate are listed. [154]

DEPA (2010) [81] also mentions antimony trioxide (not to be used without other flame retardants), bis(tribromophenoxy)ethane, 1,2-bis(tetra-bromophtalimido)ethane, resorcinol bis (diphenylphosphate), bisphenol A diphosphate or bisphenol A bis(diphenylphosphate), diphenyl cresyl phosphate and triphenyl phosphate co-polymers (e.g. PC/ABS, PS/PPE, HIPS/PPO) with phosphate esters.

8.2 Hazardous properties of substitutes

In this section the results of a short screening for hazardous properties of the possible alternative flame retardants mentioned above are summarised.

Information has been extracted mainly from the evaluation published by Morose (2006, [4]), the draft evaluation published by US EPA [73] for flame retardants in printed circuit boards and its revised version as published in December 2014 [127], which is partly based on estimated data. While the evaluation from US EPA categorises the various categories of potential concern into “low”, “moderate” and “high” the revised version uses 5 categories (“very low”, “low”, “moderate”, “high” and “very high”).

A summary of the results is given in Table 36.

8.2.1 Printed circuit boards / reactive use of TBBPA

2,4,6-tribromophenol

According to Morose, 2, 4, 6-tribromophenol is considered a toxic substance by the oral route of administration, but not considered toxic by the dermal or inhalation routes. [4][44]

Organic phosphorus compounds (DOPO, (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol), aluminium diethylphosphinate)

According to Morose [4] no significant health or environmental issues were identified for the phosphorus based FR-4 laminates, however, aquatic toxicity is a likely problem for certain other phosphorus compounds.

According to the entry for DOPO concerning the REACH registration on the ECHA webpage [4] DOPO may cause allergic skin reactions. The revised evaluation as published by US EPA in 2014 identifies moderate hazard concerning carcinogenicity, developmental and neurological effect and skin sensitation (mostly estimated), moderate concern for aquatic toxicity (estimated) and a high tendency for persistence (estimated).

According to case study from Japan as described by Döring et al. [156] DOPO does neither generate phosphine gases in combustion nor dioxins and furans. Furthermore, after burning DOPO, there are good prospects that the resulting phosphorus components can be recycled into an industrial raw material or into fertilizer. Further, when halogen compounds are turned into gases by burning, this can cause destruction of the ozone layer in the stratosphere, but this does not apply to DOPO.

For (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol) no information concerning its toxicity could be identified. A high tendency for persistence is estimated by US EPA (2008) [73], while the revised report version identifies moderate hazard for reproductive, developmental, neurological and repeated dose effects (estimated), high concerns for acute/chronic toxicity (aquatic, estimate) and a very high tendency for persistency (estimated).

Aluminium diethylphosphinate is not registered under REACH, however, some information has been collected by EBRC. [103] According to this summary report, diethyl phosphinic acid was excreted almost quantitatively via the urine within 12 hours after oral application, the acute dermal and oral toxicity is greater than 2000 mg/kg bw and the repeated dose toxicity (oral) results in a NOAEL greater than

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[44] Great Lakes Chemical, HPV Challenge, Test Plan and Robust Summaries for 2, 4, 6, tribromophenol. (cited by Morose, 2006)

1000 mg/kg/day. No mutagenicity was observed and no data indicating carcinogenicity or toxicity for reproduction has been identified.

Available ecotoxicity data indicate NOECS of at least 2.2 mg/l (chronic toxcitiy for algae and reproduction toxicity for invertebrates) and EC0 and LC0 values (invertebrates and fish) of 100 mg/l [157].

The revised assessment by US EPA (2014) indicated moderate concern for developmental, neurological and repeated dose effects for human health (estimated), moderate concern for aquatic toxicity (empirical data) and a high tendency for persistence (estimated).

Metal oxides (Aluminium Tri-hydroxide (ATH), Aluminium Oxide-hydroxide, siliciumdioxide, magnesium hydroxide)

No significant environmental or health issues were identified for ATH or magnesium hydroxide. [4] However, a concern based on the inhalation of small particles was identified by US EPA [73] for silicium dioxide. Though no generally accepted approach on the persistency assessment for metals is available metal ions stay in the environment in some form.

The updated assessment report by EPA indicates moderate concern for neurological and repeated dose health effects (ATH, partly estimated) and moderate skin sensitation concern for Magnesium hydroxide, while for both salts a high tendency for persistence is estimated.

Replacement of the resins (e.g. with polyimid resins such as polyetherimid, PTFE)

Following information summarised by Morose[45], most polyimide resins do not present a health hazard under conditions of normal use. However, one of the raw materials used for some polyimide resins is methylenedianiline which is listed by the International Agency for Research on Cancer (IARC) as a Group 2B, possible human carcinogen.

According to Morose, perfluorooctanoic acid (PFOA) salts and tetrafluoroethylene are used in the production of PTFE whereas tetrafluoroethylene is listed as “reasonably anticipated to be a human carcinogen”.

Red phosphorus

As explained by Morose [4], red phosphorus powder is highly flammable and is difficult to handle until it is incorporated into the plastic. Contact with moisture generates traces of phosphine and corrosive phosphorus acids. Moreover, red phosphorus is toxic to aquatic organisms. Although unlikely, red phosphorus can be acutely toxic if contaminated with yellow phosphorus[46].

Zinc borate

The use of this substance is not recommended for high temperature applications. According to Morose, zinc borate is toxic to aquatic organisms, but is not expected to bioconcentrate, however, at high concentrations, it can be harmful to boron sensitive plants. There is little published information on the human toxicity of zinc borate[47].

Melamine phosphate

According to the evaluation published by US EPA this substance may show moderate concerns for human health effects (estimated) and high concerns for reproductive effects (estimated). A high tendency for persistence is estimated.

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[45] Ring, Koon-Ling, Polyimides, Chemical Economics Handbook, Plastics and Resins, 580.1400, March 2004. (cited by Morose, 2006)

[46] Weil, Edward D., and Levchik, Sergei, A Review of Current Flame Retardant Systems for Epoxy Resins, Journal of Fire Sciences, Vol. 22, January 2004 (cited by Morose, 2006)

[47] HDP User Group International, Inc., Design for Environment – Phase II, January, 2004; Gardner, Donald, et al, Toxicological Risks of Selected Flame-Retardant Chemicals, National Academy Press, Washington D.C., 2000 (cited by Morose, 2006)

Reactive flame-retardant resins Brominated Bisphenol A Type Epoxy Resin, Dow XZ-92547 and resin of (phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol)
Partly these products may act as skin sensitizer [73] and are suspected to cause reproductive and developmental damage. They are further suspected to be persistent.
Moderate hazard is suspected for human health by US EPA (2014) and potential bioaccumulation tendencies have been set to high.

8.2.2 Housings / additive use of TBBPA (mainly in ABS)

Information has been mainly taken from DEPA (2010) [81].

Other brominated flame retardants in combination with antimony trioxide

No specific alternatives are suggested by Gensch et al., therefore a substance specific discussion is not possible.

In general, some brominated flame retardants of priority class 1 or 2 are included in the most recent priority list for RoHS relevant substances as published by the Austrian Umweltbundesamt and thus, show hazardous properties for human health or the environment (dibromo-neopentyl-glycol, 2,3-dibromopropan-1-ol; 2,3-dibromo-1-propanol, hexabromocyclododecane). Other, less hazardous brominated flame retardants exist in general. However, some of them, such as dibromoneopentyl glycol and HBCD, are not a suitable replacement for TBBPA. Thus a general statement concerning the applicability of other brominated flame retardants as substitutes for additively used TBBPA is not possible. [158]

Brominated epoxy oligomers
No information concerning toxicity could be identified, however, these flame retardants are at least partly manufactured from TBBPA, therefore the advantages of a substitution are expected to be limited [159].

Antimony trioxide [81]
According to DEPA antimony trioxide shows potential for skin irritation, local pulmonary toxicity and carcinogenicity. It is not used alone but only in combination with other brominated flame retardants as a synergist.

bis(tribromophenoxy)ethane [81]
Concerning human health, the toxicity potential is considered to be low, whereas the potential for ecotoxicity is classified as low or moderate. The substance is persistent and bioaccumulative according to WSDH criteria, which are more strict than the EU REACH criteria (TBBPA itself is also considered to be a PBT substance according to WSDH criteria) [160].

1,2-bis(tetra-bromophtalimido)ethane [81]
Concerning human health the substance shows low toxicity. Concerning environmental effects it is also not toxic, however, it is probably persistent (insufficient information indicated).

Resorcinol bis (diphenylphosphate) [81]

Concerning human health the substance is indicated to show low toxicity, although no sufficient information concerning cancerogenicity could be identified. The substance is not persistent or bioaccumulative but of moderate/ high ecotoxicity.

bisphenol A diphosphate or bisphenol A bis(diphenylphosphate) [81]
Low toxicity concerning human health was identified, however, no sufficient information related to potential carcinogenicity was found. Low / moderate ecotoxicity is indicated, the substance is peristent according to WSDH criteria but no sufficient information concerning bioaccumulation could be identified.

Diphenyl cresyl phosphate [81]

No sufficient information was found related to the cancerogenicity of this substance. Concerning non-cancer effects moderate toxicity was indicated. Ecotoxicity is categorised as moderate / high and the substance is indicated to be persistent and bioaccumulative according to WSDH criteria.

Triphenyl phosphate [81]

Low / moderate human toxicity was identified for this substance. The ecotoxicity was categorised as moderate / high, however, the substance is not considered to be persistent or bioaccumulative according to WSDH criteria.

Table 36: Alternative flame retardants used in the production of printed circuit boards and housings.

	CAS	**Human hazard**	**Environmental hazard**	**Classification (harmonised (HC) or self-classification (SC) [161]**
DOPO	35948-25-5	low hazard identified (US EPA 2008, [73] estimated data) partly moderate hazard (US EPA 2014, estimated)	High hazard for aquatic toxicity identified ([73] partly estimated), moderate tendency for persistence [73], revised report from 2014 indicates moderate hazard for aquatic toxicity and a high tendency for persistence.	no HC; SC: Skin Sens. 1B Skin Irrit. 2, Eye Irrit. 2
Poly(m-phenylene methyl phosphonate) / (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol)	63747-58-0	low hazard identified ([73]mostly estimated data)	high tendency for persistence estimated [73] high hazard estimated for aquatic toxicity and bioaccumulation [127]	no entry
Aluminium diethylphosphinate	225789-38-8	immunotoxicity, developmental effects and neurological effects were estimated [73] moderate hazards [127]	The substance is estimated to be persistent and shows medium concern for aquatic toxicity [73]	no entry
2,4,6-tribromophenol	118-79-6	toxic substance by the oral route, not considered toxic by the dermal or inhalation routes [4]	biodegradable but not classifiable as readily biodegradable, concern for environment indicated [162]	no HC; SC: Skin Sens. 1, Eye Irrit. 2, Aquatic Acute 1, Acute Tox. 4, Skin Irrit. 2, Acute Tox. 3, STOT SE 3, Aquatic Chronic 2, Acute Tox. 3, Skin Sens. 1, Repr. 2 , STOT SE 2, STOT RE 2 , Aquatic Chronic 1
Aluminium Trihydroxide (ATH)	21645-51-2	low toxicity [4] moderate concern for neurological and repeated dose health effects (partly estimated) (US EPA 2014)	low toxicity [4] high tendency for persistence is estimated.by US EPA (2014)	no HC; SC: Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Eye Irrit. 2, Skin Irrit. 2, Eye Irrit. 2
Aluminium Oxide-hydroxide	24623-77-6	probably low toxicity (see ATH)	probably low toxicity (see ATH)	no HC; SC: Aquatic Chronic 4
Siliciumdioxide	7631-86-9	Low toxicity,	Low toxicity, high tendency for persistence is estimated.by US EPA (2014)	no HC; SC: Skin Irrit. 2, STOT SE 3, Acute Tox. 4, Eye Irrit. 2, STOT SE 2, STOT RE 2, STOT SE 1, Skin Irrit. 2, Skin Corr. 1C, STOT RE 1, Aquatic Chronic 3, Flam. Liq. 2, Asp. Tox. 1, Muta. 1B, Carc. 1A, Carc. 1B

	CAS	Human hazard	Environmental hazard	Classification (harmonised (HC) or self-classification (SC) [161]
	1317-95-9			no HC; SC: STOT RE 2, Eye Irrit. 2, Acute Tox. 4, STOT RE 1
Magnesium hydroxide	1309-42-8	Low toxicity [4] moderate skin sensitation concern (US EPA, 2014)	low toxicity [4] high tendency for persistence is estimated.by US EPA (2014)	no HC; SC: Skin Irrit. 2, Acute Tox. 4, Eye Dam. 1, Eye Irrit. 2, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, STOT RE 1
Red phosphorus	7723-14-0	flammable, acutely toxic if contaminated with yellow phosphorus [4]	toxic to aquatic organisms [4]	HC: Flam. Sol. 1 , Aquatic Chronic 3; SC: Acute Tox. 1, Acute Tox. 2, Self-heat. 1, Acute Tox. 1, Skin Corr. 1A, Eye Dam. 1, STOT SE 1, STOT RE 2, Pyr. Sol. 1, Skin Corr. 1A, Acute Tox. 2, Acute Tox. 4, Acute Tox. 2, Flam. Sol. 1, Aquatic Acute 1, Aquatic Chronic 3
Zinc borate	1332-07-6	high concern for developmental and reproductive toxicological effects [163]	high concern for persistence and aquatic chronic toxicology [163]	no HC; SC: Aquatic Acute 1, Aquatic Chronic 1, Repr. 2, Aquatic Chronic 2, Eye Irrit. 2, Skin Irrit. 2, STOT SE 3, Aquatic Chronic 3,
	138265-88-0			no HC; SC: Aquatic Acute 1, Aquatic Chronic 1, Aquatic Chronic 2,
antimony trioxide	1309-64-4	potential carcinogen and reproductive toxicant (see RoHS report HBCDD)	not readily biodegradable, low to moderate bioaccumulation potential.	HC: Carc. 2 , SC: Carc. 2; Eye Dam. 1; Acute Tox. 4; Aquatic Chronic 2; Repr. 1A; STOT RE 2; Aquatic Chronic 3; Skin Irrit. 2; Eye Irrit. 2
Melamine polyphosphate	218768-84-4	moderate hazard for systemic tox and genotox estimated [73] otherwise low hazard expected	moderate tendency for persistence estimated [73]	no entry
Polyphosphoric acid	8017-16-1	low hazard expected ([73] partly estimated)	low hazard expected ([73] partly estimated)	no HC, SC: Met. Corr. 1, Skin Corr. 1B, Eye Dam. 1, Acute Tox. 4, Skin Corr. 1A, Acute Tox. 3, Skin Corr. 1C, STOT SE 3
Melamine	108-78-1	moderate hazard for systemic tox and genotox estimated [73], otherwise low hazard expected	moderate tendency for persistence estimated [73]	no HC; SC: Acute Tox. 4, Skin Sens. 1, Eye Irrit. 2, STOT RE 2, Eye Irrit. 2, Skin Corr. 1C, Aquatic Acute 1, Aquatic Chronic 1, Carc. 2, Acute Tox. 4, Skin Irrit. 2, STOT SE 3,
Brominated Bisphenol A Type Epoxy Resin	26265-08-7	moderate hazard ([73], mostly estimated)	moderate tendency for persistence estimated [73]	no HC; SC: Skin Irrit. 2, Skin Sens. 1, Eye Dam. 1
Dow XZ-92547	N.N.	moderate hazard ([73] mostly estimated)	high tendency for persistence estimated [73]	no entry
Resin of (phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol)	N.N.	moderate hazard ([73] mostly estimated)	high tendency for persistence estimated [73],	no entry
Bis(tribromophenoxy)ethane [81]	37853-59-1	low toxicity	low or moderate ecotoxicity. persistent and bioaccumulative according to WSDH criteria	not classified
1,2-bis(tetrabromophtalimido)ethane [81]	32588-76-4	low toxicity.	not toxic, probably persistent (insufficient information indicated	no HC; SC: Eye Irrit. 2
Resorcinol bis (diphenylphos-	57583-54-7	Concerning human health the substance	moderate/ high ecotoxicity. not persistent or bi-	no HC; SC: Aquatic Chronic 3, Aquatic Chronic 2

	CAS	Human hazard	Environmental hazard	Classification (harmonised (HC) or self-classification (SC) [161]
phate) [81]		is indicated to show low toxicity, although no sufficient information concerning cancerogenicity could be identified.	oaccumulative,	
Bisphenol A diphosphate or bisphenol A bis(diphenylphosphate) [81]	181028-79-5; 5945-33-5	Low toxicity concerning human health was identified, however, no sufficient information related to potential carcinogenicity was found	Low / moderate ecotoxicity is indicated, the substance is peristent according to WSDH criteria but no sufficient information concerning bioaccumulation could be identified.	no HC; SC: Aquatic Chronic 4, Aquatic Chronic 2; no HC; SC: Aquatic Chronic 4
Diphenyl cresyl phosphate [81]	26444-49-5	No sufficient information was found related to the cancerogenicity of this substance. Concerning non-cancer effects moderate toxicity was indicated.	Ecotoxicity is categorised as moderate / high and the substance is indicated to be persistent and bioaccumulative according to WSDH criteria	no HC; SC: Aquatic Acute 1, Acute Tox. 4, Aquatic Chronic 1, Aquatic Chronic 2, STOT SE 2
Triphenyl phosphate [81]	115-86-6	Low / moderate human toxicity was identified for this substance.	The ecotoxicity was categorised as moderate / high, however, the substance is not considered to be persistent or bioaccumulative according to WSDH criteria	no HC; SC: Aquatic Chronic 4, Aquatic Chronic 1, Aquatic Chronic 2, Eye Irrit. 2, Aquatic Acute 1

8.3 Conclusion on alternatives

Several criteria have to be fulfilled in order to allow for a substitution of a flame retardant. As summarised by Morose these can be described as follows:

- Equal or better flame retardance for the product/part
- Equal or better performance and physical properties for the product/part
- Less risk to environment and human health
- Cost
- Commercial availability

Additional criteria are obviously the hazardous properties of the various substances.
Within this report no in-depth evaluation of these criteria was made, however, the general impression is that, although a number of alternatives exists, often these have other disadvantages which limit the number of applications where they can actually be used.

Concerning printed circuit boards, according to Rakotomala [164] currently the largest volume share of flame retardants is occupied by inexpensive additives such as ATH, although the high loading may lead to negative repercussions. Combinations of nitrogen-based flame retardants such as melamine polyphosphate and metal phosphinates also are also possible, as well as phosphorus compounds.

Unlike other halogen-free alternatives, for phosphorus compounds relatively low loadings are necessary, regardless of their mode of addition. However, the chemical addition of DOPO may be problematic for lead-free soldering. Hence, new multifunctional reactive DOPO derivatives, phosphorus containing oligomers and phosphorus-based curing agents are subject to extensive research. [164]

Concerning printed circuit boards, O’Connel et al. [165] conclude that there aluminium hydroxide and magnesium hydroxide may be more recommendable based on hazard assessments, however, no complete assessment of the technical feasibility was done.

According to Morose further research of TBBPA alternatives could also include a more detailed comparison of the flame retardancy as well as other key performance requirements. It should be noted that TBBPA is used in some mission critical printed circuit board applications such as military, aerospace, medical equipment, and telecommunications. Therefore, sufficient reliability data should be obtained for these alternatives before their use is recommended. [36]

US EPA [127] has made an extensive review of possible flame retardants in printed circuit boards, however, does not give clear recommendations but lists advantages and disadvantages of single alternatives and gives a general recommendation on which areas should be considered when searching for a flame retardant for printed circuit boards (e.g. technical applicability, toxicological hazard).

According to Posner [154], no halogen free commercially available alternative flame retardants for ABS available.

DEPA (2010) [81] concludes on the application in ABS housings, that a number of alternatives is available, however, data are missing for critical end-points. An additive use of TBBPA is not considered to be essential since alternatives exist, in particular alternative co-polymers in combination with phosphate esters. It is stated that phosphate esters have been identified as promising alternatives for deca-BDE, however, a closer evaluation may not lead to the same result for TBBPA which was – at the point this reference was published – not considered to be a carcinogen. It is also recognised that costs of these alternatives are higher (10-50%).

Overall it can be summarised that substitutes for TBBPA are available and even partly in use. However, according to the collected information as described above the reliability of other flame retardants e.g. in printed circuit boards has not been proven to be fully comparable to TBBPA, yet. A shorter service life could be the consequence of such a substitution, which would in turn lead to a higher production of electronic waste. Higher costs are also to be expected as the production chains would have to be adapted.

The same applies for possible alternatives for TBBPA in housings, where insufficient data for some end-points was identified and increased costs are expected.

Partly, the available substitutes are also toxic for humans or the environment [36].

9 DESCRIPTION OF SOCIO-ECONOMIC IMPACTS

9.1 Approach and assumptions

The socio-economic analysis is, according to the RoHS manual and ECHA (2011) [1, 166] based on two scenarios:

- In Scenario A the present legislation is not changed and additively or reactively used TBBPA may continue to be used (no ban of TBBPA in EEE)
- In Scenario B the use of TBBPA in EEE is banned (additive and reactive use):
    - For additive use, TBBPA/ATO in ABS plastics is replaced by ABS with other brominated flame retardants and ATO or co-polymers with phosphate esters (e.g. HIPPS/PPO).
    - For reactive use it is assumed that TBBPA is replaced by DOPO or other non-halogen flame retardants.

The data presented in this socio-economic analysis of additively used TBBPA are mainly taken from DEPA (2010) [81] as already practiced in other available assessment reports under RoHS.

Information about reactive use of TBBPA has been published by Bergendahl [153] and been amended by other sources of information as far as possible. However, for the assessment for the reactive use more data gaps exist and thus, the result is more uncertain.

Some of the assumptions used in the socio-economic analysis are valid for both scenarios and provide the frame assumptions of this analysis.

The following assumptions were made:

1) The substitution of additively used TBBPA by other brominated flame retardants or co-polymers with phosphate esters is assumed to have no effect on the life time of the EEE or its usability (DEPA (2010)). The same assumption was made for reactive use by the authors of this report.
2) DEPA (2010) estimates the total amount of additively used TBBPA in EEE marketed in EU to be 8.000 t/a (20% of overall tonnage of 40000 t/a incorporated in EEE in the EU). However, as described in section 5.1 and 5.2, this amount is most likely too high and **4800 t/a** (32000 t/a overall, 15% use as additive flame retardant as used for environmental exposure assessment, see section 6.2) are considered to be more realistic. Thus, both the values derived by DEPA and within this risk assessment will be given for comparison (new values in bold letters). No TBBPA is produced domestically within the EU.
3) The tonnage of reactively used TBBPA is assumed to be 27200 t/a as described in section 5.1. (32000 t/a present in EEE in EU, 85 % reactively used). No TBBPA is produced domestically within the EU.

Table 37 summarises the described frame assumptions.

In the following the impact of Scenario B (ban of TBBPA) is compared to Scenario A (no ban of TBBPA) from the point of view of the different stakeholders along the life cycle before summing up the difference of the two scenarios' socio–economic impacts.

Table 37: Framework assumptions of the Socio Economic Analysis regarding a ban of TBBPA as additive and reactive flame retardants for plastics used in EEE (electrical and electronic equipment) Updated tonnages for im-

*ported fractions (bold letters) have been estimated using the fraction derived by the EU risk assessment and the more recent tonnage of 32000 t/a (e.g. 20200 / 40000 * 32000 for TBBPA imported in finished products).*

Parameter	Assumption
Effect on life time of EEE	Negligible effect
Additively used TBBPA in EEE in the EU in t/y	**4800**-8000
Reactively used TBBPA in EEE in the EU in t/y	**27200**
TBBPA imported in finished products in t/y (reactive and additive use)	**16160**-20200
TBBPA imported into the EU as the substance itself t/y (reactive and additive use)	**11040**-13800
TBBPA imported in in partly finished products itself t/y (reactive and additive use)	**4800**-6000

9.2 Impact on chemicals industry

TBBPA is globally produced in USA, Japan, Jordan, China and Israel. The total European consumption of TBBPA from the demand for EEE is estimated around **32000** (40000) t/y. **11040** (13800)t/y of the substance TBBPA itself were imported. **4800** (6000) t/y were imported in partly finished products and **16160** (20200) t/y were imported in finished products and components (see DEPA, 2010 and section 5.1 for updated tonnage values) [81].

Concerning reactively incorporated TBBPA 27200 t/a are overall used while for additive application **4800 t/a** (8000 t/a) have been estimated (see above).

Concerning potential alternatives for additively used TBBPA, according to DEPA, three large companies with headquarters in the USA and Israel, but production facilities in Europe dominate bromine production globally and produce a range of brominated compounds. They also manufacture different halogen-free flame retardants like organo-phosphorous compounds and magnesium hydroxide. These companies are vulnerable to changes in the demand for BFRs (DEPA, 2010) [81].

The manufacturers of alternative flame retardants would benefit from a restriction of additive use of TBBPA in EEE, although the impact in the short term may be moderate. Halogen-free alternative flame retardants that may serve as alternatives to additively used TBBPA in EEE are manufactured primarily by 6 European companies, of which 5 have headquarters within the EU (DEPA (2010) [81], citing Lassen et al., 2006)[48].

According to DEPA (2010) [81] the substitution costs of additively used TBBPA in ABS enclosures are comparable to replacement of octa-BDE in ABS. A risk reduction strategy for octa-BDE from Corden and Postle (2002)[49] included a detailed assessment of the cost of substituting octa-BDE in ABS. The price of ABS with TBBPA is mentioned to be slightly lower than the price of ABS with octa-BDE. Total costs of substitution of the octa-BDE was nearly the same whether ABS with an alternative BFR, 1,2-bis(pentabromophenyl) ethane, or an alternative polymer with halogen-free flame retardant were used. The total polymer/flame retardant cost increase was estimated at 10% - compared to an ABS/TBBPA system the price increase would be slightly higher (DEPA, 2010) [81].

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[48] Lassen C., A. Leisewitz and P. Maxson. 2006. Deca-BDE and alternatives in electrical and electronic equipment. Environmental Project no. 1141, 2006. COWI, Öko-Recherche and Concorde East/West for the Danish Environmental Protection Agency. www.mst.dk (cited by DEPA, 2010)

[49] Corden, C. and M. Postle. 2002. Risk Reduction Strategy and analysis of advantages and drawbacks for octabromodiphenyl ether. RFA for U.K. Department for Environment, Food and Rural Affairs (DEFRA). (cited by DEPA, 2010)

As described by DEPA (2010) the total price increase of changing ABS with TBBPA by copolymers with halogen free flame retardants can be estimated at **0.3-0.7€/kg ABS** including R&D costs distributed over 5 years. The price increase is based on European Prices. As much of the TBBPA is imported with EEE from Asia the actual price difference may be lower, but European prices are used here for indication of the incremental costs.

For the estimated amount of ~8000 t/a TBBPA in ABS used by DEPA (resulting in 36364 t/a ABS with ~22% TBBPA content) this would result in 11-25 million € additional costs per year.

If the lower tonnage of ~4800 t/a is used, which has been derived for the purpose of the exposure assessment on the basis of the fraction of WEEE produced in the EU, this would result in **6.5-15.3 million € per year** (see section 5.4).

Both ranges can be seen as indicative values which may vary from year to year but can give a general idea of the expected costs.

It is not known where the main production facilities related to DOPO or other alternative flame retardants for reactive use of TBBPA (e.g. in printed circuit boards) are located and how many manufacturers are on the market. Thus, it is not known where possible changes will be located.

Estimations made by Bergendahl et al. suggest, that costs will increase about approximately 35-50% during manufacture of printed circuit boards if a switch to halogen free resins is performed, resulting in an increase of between 0 and 10 € per panel. [41, 153].

No information could be identified concerning the average weight of one printed circuit board or current manufacturing costs with TBBPA as a flame retardant. However, information about sold units is published in the review of the WEEE directive [43]. There are some WEEE categories where no information about sold items in the EU is available. Therefore it is assumed that the overall amount of items is up to ~2 times the sum of all known items.

It is furthermore assumed that in each sold item one printed circuit board is incorporated. This leads to ~1300-2800 Mio items sold in the EU.

Together with an estimated cost increase of <0.1-10 Euro per board this leads to a global increase of <130-28000 Mio € per year in case of a ban of reactively used TBBPA. It is obvious from this large range that a number of uncertainties still exist. However, a general impression on the possible influence of a ban of TBBPA is possible.

As an alternative approach, the market research published by Frost and Sullivan estimates ~2700 Mio items (boards) sold globally per year and an average price of 0.80 € per item, which would result in 174-250 Mio € additional costs per year for reactive use of printed circuit boards (35-50% increased costs, 23% WEEE in EU). This is a similar order of magnitude. However, the predicted range is much smaller.

Table 38: EEE items sold in the EU (data mostly from 2005 or more recent). [43].

WEEE category	**mio items sold in EU per year**
cat1	
Refrigerators and Freezers, Washing Machines, Dishwashers and Clothes Dryers	41.5
Electric Cookers, Ovens and Hobs	17.4
Microwaves	12.2
cat2	
Vacuum Cleaners	20
Other Items	no EU sales data
cat3	
Computers	99
Printers, Copying Equipment and Facsimile Equipment	29.613

Telephones	345
cat 4	
Televisions	36.5
Other Items	no EU sales data
cat 5: lamps	776
cat 6: Electrical and Electronic Tools (with the exception of large-scale stationary industrial tools)	no EU sales data
cat 7: Toys, Leisure and Sports Equipment Toys	no EU sales data
cat 8: Medical Devices (with the exception of all implanted and infected products)	no EU sales data
cat 9: Monitoring and Control Instruments	no EU sales data
cat 10: Automatic Dispensers	no EU sales data

As also discussed for other substances assessed under RoHS (e.g. BBP) the increased turnover in the flame retardant / plastic industry will probably lead to some additional jobs. According to DEPA health effects related to TBBPA will also decrease in case of a ban, however, since no complete risk assessment had been carried out by DEPA this conclusion may only be of limited value. Results of this study (see sections 6 and 7) indicate that under the assumptions used for the exposure assessment no risks are expected although under uncontrolled conditions (third countries) this cannot be excluded.

9.3 Impact on EEE value change / Impact on EEE producers

According to DEPA plastic resins using TBBPA as additive flame retardant are produced and formulated by relatively few large companies in Europe. The resins are mixed with additives to form compounds, which are the raw material for further processing. Compounding may take place by the resin manufacturer, by specialised compounders or by the company manufacturing the plastic parts (DEPA, 2010) [81].

For printed circuit boards the main market participants have been identified as Panasonic, Omron, TE Connectivity, Teledyne Relays, IDEC Corp, and Standex International Corp. [167]

As described by DEPA, production of EEE is substantial in the EU. However a large part of the total end-user consumption of EEE is imported as finished goods from outside the EU. This is notably the case for small household appliances, consumer electronics, IT equipment, and toys etc., but also for other EEE groups.

For EU based EEE producers, TBBPA containing parts may be produced by themselves or by subcontracting polymer processing or non-polymer formulator companies in the EU as well as on the world market (DEPA, 2010). Whereas the market for compounds is dominated by relatively few large actors, the market for plastic parts is characterized by many small and medium sized enterprises (SMEs). Around 55000 companies produce rubber and plastics within the EU whereas the average enterprise size was given as 25 employees (DEPA, 2010; information given for additively used TBBPA) [81].

According to DEPA, studies have clearly indicated that SMEs are affected to a greater degree by compliance with the RoHS legislation compared to their larger competitors. The relatively larger burden for SMEs holds for total costs to comply with RoHS in general. As most of the SMEs involved in the manufacturing of flame retarded plastics for EEE already have procedures in place for RoHS compliance, the differences between the SMEs and larger companies is probably not as large as seen by the initial implementation of the RoHS Directive. The companies offering the alternative flame retardants for additive use of TBBPA are large companies, and they serve as general customer advisers when it comes to adjusting polymer formulations and production setup, however, the burden of identification of suitable alternatives and R&D by introduction of new substances must still be expected to place a larger burden on SMEs than on larger companies (DEPA, 2010) [81].

The total incremental costs can be roughly estimated using the following assumptions:

1) Total volume of additively used TBBPA in EEE in EU: **4800** - 8000 t/a.
2) Total volume of reactively used TBBPA in EEE in EU: 27200 t/a
3) Total volume of ABS polymer assuming an average TBBPA load of 22%: **21820** - 36000t/y.
4) Total number of printed circuit boards sold in EEE: 1400-2800
5) Total incremental costs assuming that all TBBPA that is used in ABS in the EU is replaced by copolymers with non-halogenated flame retardants: **6.5-15.3** (11-25) Mio €/a (DEPA, 2010) [81].
6) Total incremental costs assuming that all TBBPA that is used in printed circuit boards in the EU is replaced by other flame retardants: ~130-28000 (*174-250 based on data from Frost and Sullivan)* Mio € per year

Considering the uncertainties related to the assumptions the total incremental costs for additively used TBBPA are roughly estimated to be in the range of **3-20** (5-30) million €/year - the costs may decrease over the years as a result of larger market for the alternatives (DEPA, 2010) [81].

For reactively used TBBPA the cost increase is accordingly estimated to be 70-35000 Mio € per year.

Probably not all TBBPA is used in ABS or printed circuit boards, but the incremental costs for other uses of TBBPA are assumed to be close to the same range and would have a small influence on the estimated total (DEPA, 2010) [81].

Additional costs which need to be covered by the EEE producers in addition to the above discussed material costs when banning the use of TBBPPA may include:

- Costs for proving that the components of the EEE-products are TBBPA free
- Costs for developing, testing and approving alternative flame retardants (DEPA, 2010).

To some extent the costs for proving TBBPA freeness are taken into account by the administrative costs, discussed in chapter 9.6.

As compared to the turnover of the EU electrical equipment industry of 279 billion € in 2010 (Eurostat 2013), the additional (worst case) costs of max. **20**-30 Mio € (+0.01%) is small but the possible influence on the market, especially on SMEs needs to be further assessed.

In contrast to this, potential additional costs for substitution of reactively used TBBPA (130-28000 Mio € per year) may reach a comparably high fraction (0.05-10%), which is probably also due to the fact that printed circuit boards are needed for almost all types of electrical equipment and reactive use of TBBPA represents a higher fraction of the overall TBBPA use than additive use. It seems however advisable to gather more data concerning actual manufacturing costs for printed circuit boards (per kg) or reliable numbers of printed circuit boards produced globally and the distribution of prize increase per board and refine the estimated range in order to allow for a clearer indication of the relevance of this cost increase.

9.4 Impact on EEE users

According to DEPA (2010)[50] [81] the estimated percentage increase in the average price of products would be between 0.19% and 0.30%, if the increased costs for a replacement of TBBPA in ABS were passed on to the consumer.

No similar information for reactive use of TBBPA could be identified.

It cannot be concluded that the main consumer may benefit from lower health risk of alternative flame retardants as there are no comparative assessments concerning health and environment available focusing on alternatives to TBBPA (DEPA (2010)).

However, concerning the reactive use of TBBPA the influence is considered to be minimal, since the concentration remaining in boards is very small and the consumer is rarely in direct contact with the usually encapsulated printed circuit boards.

9.5 Impact on waste management

For details on the impacts of TBBPA contained in EEE on waste management please refer to Chapter 5.

The considerations regarding waste management published by DEPA are identical to the considerations for HBCDD (DEPA, 2010) [81].

In total, the benefits of banning additively used TBBPA in EEE can be summarized as:

- Reduced environmental and health impacts:
    - Concerning additive use, DEPA refers to antimony trioxide (carcinogen), with which TBBPA is used in case of additive application and aquatic toxicity of TBBPA itself. However, under the assumptions used for the risk assessment (section 7) no risk was identified for human health or the environment due to exposure to TBBPA. A general improvement of human health or environmental conditions may nevertheless be possible in some cases, however, this will probably be mainly relevant for situations with uncontrolled conditions, which should be avoided in the first place and are usually not practiced in developed countries. Since antimony trioxide was not evaluated in detail in this assessment report, no further statements are made concerning risks related to this substance. DEPA (2010) did not perform an exposure assessment; therefore all conclusions concerning human health and environment are only hazard based.
    - Concerning reactive use, release of TBBPA during WEEE recycling /handling is estimated to be very low.
- Possible increased recycling potential: Refers mainly to ABS (see also section 7).
    - According to DEPA considerations are identical to HBCDD, i.e. it is not possible to distinguish the substance from other substances which are already restricted under RoHS or the Stockholm Convention by the use of simple screening methods and therefore in practice plastics containing the substance are not recycled. However, this does not seem to be of relevance currently, since ABS / housings are usually not recycled but energy recovery is practiced (Recycling is not economical due to low volumes) [93]. It is not known how the absence of TBBPA in housings would possibly influence this current status and if recycling would be practiced more often without TBBPA.

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[50] Corden, C. and M. Postle. 2002. Risk Reduction Strategy and analysis of advantages and drawbacks for octabromodiphenyl ether. RFA for U.K. Department for Environment, Food and Rural Affairs (DEFRA). (cited by DEPA, 2010)

  - Epoxy resins in printed circuit boards (reactively used TBBPA) are usually not recycled anyway.
- Reduction in the generation of hazardous waste: Mainly ABS.
  - Comparably high concentration of TBBPA in ABS (see section 7)
  - In case of printed circuit boards hazardous properties are mainly caused by other components such as metals.

For the waste management sector there are no substitution costs, as bromine-free plastics can be treated with the existing equipment.

9.6 Impact on administration

According to DEPA (2010) [81] extra compliance costs related to the addition of one new substance under RoHS are expected to be minimal for companies which have already implemented RoHS. TBBPA is typically used additively in parts where deca-BDE or octa-BDE have traditionally also been used and compliance documentation would usually be required for such parts. Similar reasons can be found in case of reactively used TBBPA: printed circuit boards may include a number of substances. As an example, in the past lead, which is restricted under RoHS, has often been used in solder. This cost element is therefore not included further in the assessment made.

The main extra costs are estimated by DEPA to be related to controls; both by the manufacturers, importers and the authorities. The presence of TBBPA cannot be determined by simple XRF screening, therefore sampling, extraction and laboratory analysis is required. As the parts that may contain TBBPA typically also may contain other RoHS substances the extra costs would mainly comprise the costs of analysis, as the sampling and sample preparation would in any case be undertaken for control of the PBDEs in the parts.

- DEPA (2010) [81] estimates that the additional costs for proving that the produced plastics is TBBPA free, assuming that the sample is already analyzed for PBDE and thus, sampling and sample preparation are practiced anyway and will not cause additional costs, is 40€. Other information (S. Schuchardt, personal communication, 03. 2015) suggests overall costs between 150 and 500 €, depending on the availability / level of standardisation of the technique and requirements such as good laboratory practice [168]. It is assumed that costs are approximately the same for reactive use of TBBPA.
- When assuming that for the EU as a whole 7000 tests per year (that is 250 tests per EU Member State and year) are sufficient to control a ban of additively used TBBPA ban, the costs for the EU as a whole would be 0.28 Mio € annually using the estimated 40€ per test as suggested by DEPA. [81] Since the estimation published by DEPA is based only on additive use, additional 7000 tests for reactively used TBBPA may be needed, resulting in an overall amount of 0.56 Mio € annually. Using estimated costs of ~300 € per test as suggested by internal information (see above), costs of approximately 2.1 Mio € for additive and reactive use each, i.e. overall 4.2 Mio € are derived.

The administrative costs, however, are not lost costs, as they increase the turnover of the EU chemical analysis industry (DEPA, 2010) [81].

9.7 Total socio-economic impact

This socio-economic analysis is a kind of “worst-case” analysis. The upper boundaries for prices are taken for calculation.

According to DEPA (2010) [81] the cost considerations for replacing additively used TBBPA in ABS are quite comparable to earlier considerations (Corden and Postle, 2002, cited in DEPA, 2010[51]) regarding the replacement of octa-BDE in ABS. The estimated percentage increase in the average price of products if passed on to the consumer would be between 0.19% and 0.30%. At the time of study the price of ABS with octa-BDE was about 1.4 €/kg and the price of alternatives about 1.6 €/kg.

The total price increase of changing ABS with TBBPA by copolymers with halogen free flame retardants can be estimated at 0.3-0.7 €/kg ABS including R&D costs distributed over 5 years

The total socio-economic impact of a ban of TBBPA and replacement by copolymers is in a worst case scenario estimated to lead to incremental costs of **20-**30 million€/year (DEPA 2010).

No similar study for reactively used TBBPA could be identified, however, since printed circuit boards are implemented in basically all EEE products on the market, the overall effect on the consumer may be even larger. A general increase of manufacturing costs for boards of 35-50% in combination with an assumed weight percentage of ~10% in relation to the whole piece of equipment would lead to ~3.5-5% increase in costs of the whole product. Depending on the type of product and the corresponding weight fraction also higher or lower values may be possible.

Regarding the ban of additively used TBBPA DEPA (2010) expect the following developments:

- A neutral effect on the EUs chemical industry resulting from increased administrative effects but increased turnover from chemical analysis industry.
- The higher price of EEE consumer products of 0.30% is expected to have no major influence on the demand.
- There might be a reduction in the generation of hazardous waste
- Possibly increased recycling potential (DEPA (2010), however, currently no recycling due to other reasons [93].

Regarding the ban of reactively used TBBPA we expect the following developments:

- A neutral effect on the EUs chemical industry resulting from increased administrative effects but increased turnover from chemical analysis industry.
- A higher price of EEE consumer products of 3.5-5% may have more influence than in case of additively used TBBPA, resulting in less EEE items purchased or as an alternative, in lower quality of the equipment if it is tried to compensate the costs with other measures.

Table 39: Scenario Management Tableau of the Socio Economic Analysis of a ban of additively and reactively used TBBPA as flame retardant for materials in EEE (electrical and electronic equipment).

	Scenario A – no ban of additively used TBBPA	**Scenario B – ban of additively used TBBPA and substitution by copolymers with non-halogenated flame retardants**	**Scenario B – ban of reactively used TBBPA and substitution by copolymers with non-halogenated flame retardants**
Additional raw material costs of flame retardant in €/kg ABS	0	0.2	-

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[51] Corden, C. and M. Postle. 2002. Risk Reduction Strategy and analysis of advantages and drawbacks for octabromodiphenyl ether. RFA for U.K. Department for Environment, Food and Rural Affairs (DEFRA). (cited by DEPA, 2010)

Additional investment costs for changing to other flame retardant in €/kg ABS	0	0.5	-
Additional raw material + investment costs for TBBPA or its alternative €/kg ABS	0	0.7	-
Additional costs for EEE producer in Mio €/a	0	**20**-30	**130-28000**
Additional costs for waste treatment in €/a	0	0	0
Additional administrative costs in Mio €/a	0	0.28-2.1	0.28-2.1
Total additional costs for final consumers in Mio €/a	0	**22.1**-32.1	**132.1-28002.1**
Benefits		Possible increase of recycling potential (see discussion in section 9.5)	(Possible increase of recycling potential – unknown influence)
		Reduction in the generation of hazardous waste	Reduced environmental and health impacts during the manufacture of boards possible, use and waste phase less relevant concerning TBBPA
		Reduced environmental and health impacts during the use and the waste phase (mainly third countries)	

10 EVALUATION WHETHER THE SUBSTANCE MEETS THE CRITERIA FOR INCLUSION IN ANNEX II OF ROHS

10.1 Hazardous potential

TBBPA shows carcinogenicity potential in animal studies, however, has not been classified as carcinogenic for human health according to CLP. The corresponding study has been used for DNEL derivation and thus be included into the risk assessment. No clear indication concerning endocrine activity is available, however, this is discussed in the context of TBBPA's carcinogenicity [54].

10.2 Releases during WEEE treatment

10.2.1 Comparison with other waste treatment processes

The main release path during WEEE treatment is assumed to be into air due to shredding of TBBPA containing WEEE material.

The approach described in earlier sections led to a release estimation of **~131.4 g/day/site** for shredding of WEEE. A model study performed on a WEEE plant in Japan that has also been used in the EU risk assessment process to give a rough idea of possible releases estimates (183 mg/day TBBPA to air before the incineration) (see section 5.4).

No quantitative exposure assessment for other treatment techniques such as landfilling or incineration has been done.

However, the previously studied plant in Japan also includes an incinerator which leads to a maximum of 1.4 mg/day TBBPA release at this site, which is obviously lower than the estimated release from shredders. However, only one site may not be representative for incineration processes in general.

Other monitoring values for incineration / pyrolysis residues indicate low residual concentrations in flue ash, flue gas, scrubber water, pyrolysis residue / oil and filter dust at recycling plants (see Table 32).

Leaching of TBBPA from plastic is in general possible, but concentrations found in monitoring studies of landfill leachates (mixed waste) and after extraction of printed circuit boards and TV housings with solutions of different pH values are low (see section 6.2.3). The overall tonnage probably present in landfilling in the EU is ~971 t/a, spread over ~8400 landfilling sites in Europe (see ECHA Guidance R18).

10.2.2 Comparison with total releases

A summary of releases as estimated by the EU risk assessment report is given in Table 40.

The table also contains the release indicative release estimation for WEEE recycling which leads to even lower releases than the scenario discussed in this report.

The release per day to air estimated in this report for WEEE shredding is high when compared to these releases, although the release estimation for WEEE recycling described in the EU RAR report is low when compared to other releases. On the other hand, no risk mitigation measures have been implemented in the exposure assessment in this report, thus, the developed scenario may possibly overestimate the release.

Releases into other compartments such as water are possible from other steps of the lifecycle and may have potentially larger impact considering the individual ecotoxicological data.

Additional releases from uncontrolled treatment cannot be completely excluded but cannot be assessed.

Table 40: Releases into the environment as estimated in the EU risk assessment report [5].

Lifecycle step	Comment		Estimated release										
			Local scenario (kg/day)			Regional scenario (kg/year)				Continental scenario[a] (kg/year)			
			Air	Waste water	Number of days	Air	Waste water	Surface water	Industrial/ urban soil	Air	Waste water	Surface water	Industrial/ urban soil
Production of tetrabromobisphenol-A	Example calculation		0	13.6	300	e	e	e	e	e	e	e	e
Use as an intermediate in the production of derivatives	Example calculation		0.025	17.5	200	e	e	e	e	e	e	e	e
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.027	0.027	300	5.9	4.7	1.2	0	52.6	42.1	10.5	0
	Processing of epoxy resins[d]		5×10^{-5}	5×10^{-5}	32	0.070	0.056	0.014	0	0.61	0.49	0.12	0
	Processing of polycarbonate resins[d]		5×10^{-5}	5×10^{-5}	28								
Additive flame retardant use	ABS	Compounding[c]	0.010	1.1	171	13.8	124.8	31.2	0	124.2	1120	279.9	0
		Conversion[d]	0.050	0.050	171								
Volatile loss over service life of product	Reactive flame retardant use					0.017	0	0	0	0.15	0	0	0
	Additive flame retardant use					3.2				28.8			

“Waste remaining in the environment”	Particulate loss over life-time of products				0.008	0	2	6	0.072	0	18	54
Release during recycling and disposal	Collection, separations and shredding/regrinding of plastic	*$1.0x10^{-6}$* *$1.83x10^{-4}$*		*300*	*0.042-5.48*				*0.38-49.3*			
Use of tetrabromo-bisphenol-A derivatives as flame re-					0[f]	0[f]	0[f]	0[f]	0[f]	0[f]	0[f]	0[f]
Total					23.0-28.5[g]	130	34.4	6	207-256[g]	1,163	309	54

a) Continental emissions = total EU emissions - regional emissions.

b) An 80% connection rate to waste water treatment plants is assumed in the regional and continental model. Therefore 20% of the total emissions to waste water is assumed to be released directly to surface water.

c) Emissions at a compounding site include the raw materials handling emissions as well as emissions from the compounding step.

d) No fume elimination equipment is assumed during conversion. Emissions from conversion sites with fume elimination equipment would be ten times lower than these values.

e) No contribution to regional or continental emissions, no site is currently considered to exist in the EU.

f) Emission is considered to be negligible compared with other sources.

g) The upper limit of the figures has been used in the PEC calculations.

10.3 Identified exposure and risk

10.3.1 Human health

Workers are expected to be exposed to TBBPA at WEEE recycling facilities; however, no risk has been identified.

Based on an estimated number of 450 installations (as done in other available assessment reports), and taking into account an average of 5-15 workers per installation, the estimated range for exposed workers ranges between 2250 and 6750.

10.3.2 Environment

Based on the assumptions made in this assessment, the exposure values are expected to be below the corresponding PNECs for all compartments. The highest RCR values have been identified for soil.

Monitoring data from China suggest that at least without proper risk management measures increased exposure to TBBPA in soil and RCR values above 1 are possible for WEEE dismantling / recycling sites. Corresponding monitoring data for soil near WEEE treatment sites in European countries have not been identified.

10.3.3 Main influencing factors within the risk assessment

For the human risk assessment the main influencing factor of the estimated exposure value is assumed to be the actual concentration of TBBPA in dust, since the substance is not volatile. Refinements of the exposure assessment with other models may lead to lower exposures, since ECETOC TRA is a Tier 1 tool and designed in order to give conservative predictions of the possible exposure.

For the environmental risk assessment, one main influencing factor of the estimated PEC is the actual tonnage of TBBPA present in WEEE and the fractions which are collected separately, shipped to third countries, landfilled or treated otherwise. Of high relevance is also the fraction of TBBPA which is used in additive applications, since this is the main entry way of TBBPA into the environment from WEEE. For the purpose of the risk assessment 15% have been assumed for this fraction, however, the use of TBBPA in this area seems to be decreasing [77].

Measured data on release factors or TBBPA into air (or other compartments) are hardly available and no standard scenario for waste treatment is implemented in EUSES which has been used for the exposure assessment, therefore some assumptions have been made in order to provide estimates for the shredding scenario. The few measured data available suggest that emissions are usually much lower than estimated; however, these data are not sufficient to derive a refined scenario.

10.4 Impact on waste management

As describe in earlier sections, neither ABS housings nor epoxy resins are recycled in relevant fractions due to economical and practical reasons. Thus, although the presence of brominated flame retardants may theoretically hinder recycling of ABS in some cases (see section 7.1), it does not influence the recycling fraction in reality because it is already very low due to other reasons.

TBBPA traces found in articles (see Puype et al. [129]) indicate that small amounts of polymer including the substance may be recycled anyway, however, the concentrations are extremely low and are not expected to pose a risk for human health or the environment even under worst case assumptions.

Energy recovery processes do not seem to be negatively influence by the presence of TBBPA under realistic conditions.

The same applies for recovery processes such as smelters applied to printed circuit boards, which are designed in order to recover the precious metal fractions and incinerate the remaining expoxy resin in the process.

ABS is classified as hazardous waste since it still contains TBBPA in significant concentrations (see section 7, Comission decision 2000/532/EC and CLP guidance [145, 146]). This leads to an additional amount of at least ~22000 t/a hazardous waste induced by the use of TBBPA.
TBBPA used in printed circuit boards does not lead to an additional production of hazardous waste.

10.5 Available alternatives

A number of potential alternatives are available for TBBPA; however, they are often not technically feasible, not less toxic / less ecotoxic and more expensive.

An alternative within printed circuit boards is, as an example, DOPO, which is already practiced but only to a small extent.

For ABS co-polymers with phosphate esters seem to be the most suitable alternative.

However, for most possible alternatives additional research would be necessary in order to close data gaps on toxicological and ecotoxicological data and fix technical problems during application.

10.6 Socio-economic impact analysis

The analysis of socio-economic impacts is based on a worst case scenario which shows the costs of replacing TBBPA in a scenario where substantial amounts of TBBPA are used in European EEE.

Socio-economic impacts clearly differ between the two possible applications of TBBPA.

While costs for a substitution in housings seem to be moderate (~20 Mio Euro per year), although higher than for other RoHS relevant substances such as BBP or DEHP, costs for the substitution in printed circuit boards can possibly be high and are difficult to estimate due to data gaps (130-28000 Mio Euro per year).

The overall impact on jobs / employment cannot be predicted, since the possible range of cost increase is quite high. If only use in ABS is restricted, effects are possibly small, due to the lower additional costs. While a few jobs are expected to be lost in industries where EEE is used (due to a marginal increase in prices for EEE), some new jobs are likely to be created in the production of alternative flame retardants and in the environmental (chemical analysis) sector. However, a restriction in printed circuit boards may have much larger impacts.

The following benefits were identified for a possible TBBPA ban (as compared to a scenario where considerable amounts of TBBPA continue to be used in EEE):

- Potential increase in the competitive position of a more environmentally friendly industry. However, some data gaps exist concerning potential alternatives, therefore a final conclusion is not possible (see also DEPA (2010) and sections 7 and 8 [81]).
- Global reduction of environmental and health impacts from TBBPA and possible degradation / decomposition products for additive use of TBBPA, mostly in third countries.
- Possible increased recycling potential (mainly ABS / additive use of TBBPA, see section 9.5): According to DEPA [81] it is not possible to distinguish the substance from other substances which are already restricted under RoHS or the Stockholm Convention by the use of simple screening methods, therefore in practice plastics containing the substance are not recycled. However, currently ABS is not or almost not recycled due to economic reasons and it is not known how the situation will develop in the future [93].
- Reduction in the generation of hazardous waste (mainly ABS / additive use of TBBPA)

10.7 Conclusion

According to the RoHS manual the aim of this step is to finally decide whether a restriction of TBBPA group under RoHS would be the most appropriate measure to combat negative impacts on WEEE management operations and on human health and the environment during waste processing.

To reach this decision a case-by-case approach has to be applied where the following aspects shall be considered:

A recommendation for restricting a substance under RoHS should be considered where either

- a risk for the environment during WEEE treatment or
- a risk for human health during WEEE treatment or
- a negative impact on waste management

has been identified or can be assumed based on related estimates [1].

For TBBPA no risk for the environment or the human health has been identified under the assumed conditions, although some exposure cannot be excluded. Releases according to the scenario for environmental exposure developed in the course of this assessment are higher than releases for other lifecycle steps documented in the EU risk assessment report. However, already the mentioned EU risk assessment report suggests much lower release fractions for the WEEE treatment process, therefore there may still be some refinement potential concerning the actual releases of TBBPA into environmental compartments.

The presence of TBBPA may influence the recycling pathways of ABS (see also sections 7 and 9). However, there is nevertheless currently no negative impact of TBBPA on waste management since housings are usually not recycled anyway due to economic reasons.

Alternatives for TBBPA are available, but are only to a certain extent technically feasible and may lead partly to high increases of costs, especially for the reactive application of TBBPA. Toxicological and ecotoxicological properties differ between substances. Partly data gaps prevent a full evaluation of the hazardous properties of potential substitutes.

Overall it can be concluded that, although under uncontrolled conditions (“informal waste treatment” in third countries) a risk for the environment or humans due to TBBPA and its decomposition products may happen, under controlled conditions no risks have been identified within this risk assessment. It is therefore considered to be reasonable not to restrict the general use of TBBPA but to avoid uncontrolled treatment in order to minimise possible risks.

11 DATA GAP ANALYSIS / UNCERTAINTIES OF THE EVALUATION

In the following paragraphs identified data gaps and other uncertainties of the assessment process are summarised and discussed.

11.1 Human health hazard, environmental health hazard

Concerning toxicological or ecotoxicological studies there are no specific data gaps. However, a recent publication [55, 56] discusses endocrine activity of TBBPA. Although the currently available information may not be sufficient for a final conclusion it cannot be excluded that further information may be published which may lead to a categorisation of TBBPA as endocrine disruptor.

Although the available BCF values do not suggest a tendency for bioaccumulation, bioaccumulative potential is discussed occasionally due to its presence in various environmental compartments and the formation of potentially more bioaccumulative decomposition products. It is indicated that no sufficient data for a conclusion is available so far.

There is always some uncertainty related to the derivation of limit values such as DNELs and PNECs. This includes the choice of studies as well as the assessment factors used for the derivation. For the human health an alternative set of DNELs has been derived that is generally lower than the DNELs published in the REACH dossier on the ECHA webpage.

11.2 Waste treatment processes and exposure assessment

There is information available on commonly practiced treatment techniques; however, this information is rarely specific enough to be the basis of a detailed and refined exposure assessment.

Thus, a number of assumptions have been made in order to allow for the estimation of a release factor to the environment while for the human exposure assessment ECETOC TRA has been used, which is an accepted Tier 1 exposure assessment tool under REACH that has been designed in order to provide conservative exposure estimates.

Additional information, which may be used for a refined exposure assessment are, as an example, the following points:

- Actual concentration of TBBPA in shredder content or in general more recent concentrations of TBBPA in different EEE articles.
- Fraction of additively used TBBPA: The current assumption for risk assessment is that 15% of overall TBBPA used as flame retardant are additively used. Since additive use is the main source of environmental exposure and other lifecycle steps of this application area have been identified as potential risk in the EU risk assessment, a reduction of this fraction may have a large impact on the outcome of the overall assessment of TBBPA (waste stage and possibly other lifecycle stages).
- In general: release fractions from treatment techniques into air, water, soil
- Further monitoring data of environmental compartments around WEEE facilities and air/dust in facilities
- Realistic throughput of one shredder – volume used (250 t/a) is for ELV shredders, possibly not applicable for monitors or other, small equipment

Overall, there are a number of options to refine exposure scenarios. However, experience shows that it can be difficult and time consuming to gather a sufficient amount of high quality information that can be used to derive a refined, generic scenario. To be acceptable in all European countries the scenarios would have to be representative, i.e. all measured values or other kinds of information should cover several countries from different regions.

Another uncertainty during the environmental exposure assessment may be the absence of other lifecycle steps. For environmental exposure there is always a certain background level that is calculated by EUSES on the basis of all releases (PECregional). If only one lifecycle step is estimated, this level will be lower than for all lifecycle steps together. Thus, final RCR values may change if the shredding scenario is incorporated into the full lifecycle.

A general data gap is the release due to uncontrolled treatment as well as TBBPA's influence on the concentrations of possible decomposition products, especially for third countries.

11.3 Impact on WEEE recycling

Under current circumstances, the impact of TBBPA on WEEE recycling and recovery seems to be negligible. It may however be interesting to observe changes in the future. As an example, TBBPA does not seem to influence the emission of dioxins / furans when incinerated together with other waste, as well as the corrosion within treatment plants (e.g. via HBr). However, the composition of average waste may change over time, e.g. because other halogenated flame retardants or other compounds are restricted or introduced for other reasons.

11.4 Alternatives and socio-economic impact

For some possible alternative flame retardants toxicological data gaps are existing (e.g. phosphate esters) or (eco)toxicological hazards are already known which may pose a risk during use and disposal (see e.g. Morose [36]).

Apart from that, technical feasibility seems to be the main issue for most applications.

The socio-economic impact of a replacement of TBBPA in printed circuit boards could only be coarsely estimated due to a lack of data about manufacturing costs. No detailed information on producers of alternative flame retardants such as DOPO, i.e. their number and location, was available. It is considered to be reasonable that the financial impact of a substitution in printed circuit boards will be higher than that of a substitution in ABS, however, the derived numbers are probably quite uncertain and cover a large range.

It cannot be concluded that the main consumer may benefit from potential lower health risk of alternative flame retardants as there are no comparative assessments available concerning health and environmental impact focusing on alternatives to TBBPA, especially for additive use.

11.5 Other considerations and summary

Additional documents published on the ECHA webpage are the “Risk management options analysis” by the Danish Ministry of the Environment, and the “Decision on a compliance check of a registration pursuant to article 41(3) of regulation (EC) No 1907/2006” [10, 169]. They reflect recent developments and the CoRAP process for TBBPA.

The “Risk management options analysis” mentions, based on COM communication 2008/C 152/02, a need for additional further testing regarding the aquatic and the terrestrial ecosystem and risk reduction strategies for compounding and conversion of ABS, where the EU risk assessment report concluded a risk. However, implementation of specific measures and measures in the COM recommendation (emission values are to be laid down by competent authorities, local emissions should where necessary be controlled by national rules) are expected to sufficiently reduce the concentration in the ecosystem. Denmark is planning to conduct a study on the possibility of assessing the hazard of brominated flame retardants as a group and subsequently, if warranted, consider restriction of the whole group under RoHS [169].

The Decision on a compliance check asks for further testing concerning the identification of degradation products such as diethyl and dimethyl TBBPA derivatives. Concerning the chemical safety assessment a revised environmental hazard assessment is suggested and it is stated that the PBT assessment should revised under the light of information concerning possible degradation products (bisphenol A, dimethyl- or diethyl ether). It is stated that the transformation products should be taken into account for the exposure and risk assessment. Justification of the release factors into the environment used for the exposure assessment is demanded.

Although these documents are not directly related to RoHS, the outcome of the demands made in them may also influence the RoHS assessment:

If TBBPA were to be categorised as endocrine disruptor (cat. 1) or as a PBT substance, this would result in a higher priority class and thus, make an official part III assessment more likely.

Revised environmental fate data will influence the predicted environmental concentration (PEC) and thus the risk assessment. The same applies for an implementation of exposure to decomposition products of TBBPA (bisphenol A, dimethyl/diethyl TBBPA).

The assessment was already derived on the basis of the lower PNECs from the EU risk assessment, therefore revised PNECs will not necessarily influence the outcome of the risk assessment. However, new end-point studies (e.g. endocrine activity, PNECs of transformation products) may still lead to lower RCR values.

Overall, there are some data gaps related to TBBPA, its alternatives and the various assessment steps described in this report. However, the main influence on the acceptance of this assessment by other parties will probably the outcome of currently running events, such as the CoRAP evaluation, as these evaluations will influence not only single aspects but the basis of the assessment (PBT properties, limit values etc.).

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APPENDIX A: STATUS REPORT 12.12.2014

Assessment of TBBPA (tetrabromobisphenol-A) according to the “Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances (Annex III) under the RoHS2 Directive”

Part II assessment: Priorisation of substances

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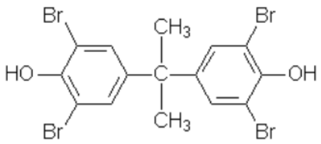
STEP P 1) EVALUATION OF THE LEGAL RESTRICTION STATUS[52]

See section 1 for details and further refinements.

Identification

Name, other identifiers and composition of the substance

Table 41: Substance identity and composition

Chemical name	3,3',5,5'-Tetrabrombisphenol A 2,2',6,6'-Tetrabrom-4,4'-isopropylidendiphenol 2,2',6,6'-Tetrabrombisphenol A 2,2-Bis(3,5-dibrom-4-hydroxyphenyl)propan 4,4'-Isopropylidenbis(2,6-dibromphenol) TBBPA TBBP TBBA
EC number	201-236-9 (EG-Nummer)
CAS number	79-94-7
IUPAC name	
Index number in Annex VI of the CLP Regulation	604-074-00-0
Molecular formula	C15H12Br4O2
Molecular weight range	543.88 g/mol
Synonyms	
Structural formula	

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[52] For basis of the assessment process in this and the following chapters see Ref. 1. Umweltbundesamt Österreich, *Manual: Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances (Annex II) under the RoHS2 Directive*, 2014: 1090 Wien/Österreich Available from: http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/abfall/ROHS/finalresults/Annex1_Manual.pdf.

Degree of purity	
Remarks	--

Physico-chemical properties

Table 42: Overview of physico-chemical properties of TBBPA [5]

Property	Value
Physical state at 20°C and 101.3 kPa	solid
Melting/freezing point	178°C; 181-182°C
Boiling point	~316°C (decomposes at 200-300°C)
Vapour pressure	<1.19E-5 Pa at 20°C
Water solubility	pH 5 - 0.15 mg/l at 25°C pH 7 - 1.26 mg/l at 25°C pH 9 - 2.34 mg/l at 25°C pure water - 0.063 mg/l at 21°C and 0.24 mg/l at 25°C 2.8 mg/l
Partition coefficient n-octanol/water (log P_{OW})	Log K_{ow} 3.25-5.9 [5]
Acid dissociation constants (pKa)	pKa1= 7.5 pKa2 = 8.5

Classification and Labelling Status

Classification in Annex VI Regulation No 1272/2008

The regulation [6] on classification, labelling and packaging of substances and mixtures entered into force on 20 January 2009. It aligns existing EU legislation to the United Nations Globally harmonised System (GHS) and ensures that hazards of chemicals are clearly communicated to consumers and workers within the European Union. For TBBPA there is a harmonised classification and labelling for Aquatic Acute and Aquatic Chronic Category (H410: Very toxic to aquatic life with long lasting effects). For more details, see Table 3.

Self-classification(s)

-

Table 43: Classification according to part 3 of Annex VI, Table 3.1 (list of harmonized classification and labelling of hazardous substances) of Regulation (EC) No 1272/2008 [1]

Index No	**International Chemical Identification**	**EC No**	**CAS No**	**Classification**		**Labelling**			**Spec. Conc. Limits, M-factors**	**Notes**
				Hazard Class and Category Code(s)	**Hazard statement code(s)**	**Pictogram, Signal Word Code(s)**	**Hazard statement code(s)**	**Suppl. Hazard statement code(s)**		
604-074-00-0	tetrabromobisphenol-A; 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol	201-236-9	79-94-7	Aquatic Acute 1 Aquatic Chronic 1	H400 H410	GHS09 Wng	H410	--	--	--

Legal status and use restrictions

Regulation of the substance under REACH

TBBPA is currently (Dec 2014) not on ECHA's candidate list of substances for authorisation or listed in Annex XVII. [7] TBBPA was also not considered in the EU Member State's latest proposals for inclusion to the SVHC list [8]. On 30.10.2014 ECHA proposed to the Member States the Draft Community rolling Action Plan [9] (CoRAP) update for the years 2015-2017 to which TBBPA was added. The draft plan has been submitted on 16 October 2014 to the Member State Competent Authorities and the ECHA Member State Committee.

POPs Regulation, (EC) No 850/2004 amended by (EU) No 756/2010 and (EU) No 757/2010

TBBPA is not regulated under POPs Regulation.

Montreal Protocol, the Regulation (EC) No 1005/2009 on substances that deplete the ozone layer and the F-gas Regulation (EC) NO 842/2006

TBBPA is not covered by these regulations.

Other legislative measures

OSPAR convention

"OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic". OSPAR is named after the original Oslo and Paris Conventions ("OS" for Oslo and

"PAR" for Paris). A list of substances with need for priority action was published which includes TBBPA.[12, 13]

EU WEEE Directive (2012/19/EU) [14]

The Waste of Electrical and Electronic Equipment 2012/19/EU53 calls for selective treatment of plastics containing brominated flame retardants, as stated in Annex II ref. to Art. 8(2).

Commission Recommendation of 3 March 2014 on the monitoring of traces of brominated flame retardants in food (2014/118/EU) [15]

“The European Commission has adopted certain recommendations to the Member States in which MS “should carry out analysis of the different classes of brominated flame retardants in order to detect the presence of […the class of tetrabromobisphenol A and its derivatives…] in the respective food commodities”.

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal [16, 17]

The Basel Convention is an international treaty aiming at reducing hazardous waste movements between nations. The regulated waste streams and constituents are listed in Annex I. Category Y39 displays “Wastes containing phenolic constituents”. Waste containing TBBPA is therefore regarded as being “hazardous waste”. The Basel Convention was implemented by (EEC) No. 259/93 within the European Union. EEC No. 259/93 was replaced by (EC) No.1013/2016 on shipments of waste [18].

USA: TSCA Work Plan for Chemical Assessments: Oct 2014 Update [19]

The TSCA work plan run by the Environmental Protection Agency Office of Pollution Prevention and Toxics was updated in October 2014. The exposure score of TBBA increased due to either domestic production or higher import quantities and more variable use in consumer and children’s products. The classification changed from “moderate” to “high” under Step 2 of the screening process identified in the Methods Document for the TSCA Work Plan for Chemical Assessments.

Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-to-Know Act (EPCRA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Section 112® of the Clean Air Act [20]

Chemical substances listed are subjected to reporting requirements under the EPCRA, also known as Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and section 112® of the Clean Air Act (CAA). TBBPA is listed under section 313 (Also known as the Toxic Release Inventory).

India

"The Indian Government has published its proposals for legislation on the disposal of waste electrical and electronic equipment. This includes what is referred to as reduction in the use of hazardous substances." [22] TBBPA is listed. The Indian Government established the e-waste (Management and Handling) Rules, 2011 which came into effect from 1st May 2012.[54]

Non-governmental initiations / voluntary measures

VECAP

The Voluntary Emissions Control Action Programme (VECAP) was initiated by industry in 2006. The website states "It is a voluntary initiative of members companies of the European Flame Retardant Association (EFRA) together with the industry's global organisation, the Bromine Science and Environmental Forum –BSEF." [27] TBBPA is included in the programme.

Global Automotive Declarable Substance List (GADSL) [28, 29, 170]

The Global Automotive Stakeholders Group (GASG) is a voluntary organization open to any member of the automotive supply chain. The GASG consists of the Americas, Europe/Africa/Middle East, and Asia/Pacific regions. Regional teams consist of representatives of the automotive, supplier and chemical industries. Each of the three regions nominates six members to sit on the governing body of the GASG, called the Steering Committee (GASG-SC). The Global Automotive Declarable Substance List (GADSL) is issued and updated by the GASG-SC.

The GADSL was introduced on 29 April 2005 as a voluntary industry initiative aiming at ensuring "integrated, responsible and sustainable product development by OEM's and their supply chain".

TBBPA is listed under No 115, classified as D (= Declarable). "A substance designated "D" must be declared if it exceeds the defined threshold limits [0.1%]" with the Reason Code FI (=For Information).

Substitute It Now (S.I.N) – List

"The International Chemical Secretariat (ChemSec) is an environmental NGO that has been working with other environmental groups and manufacturers to produce a list of substances that they claim meet the criteria of Article 57 if the REACH regulations for Substances of Very High Concern (SVHC). [The SIN-List is targeting chemicals that they believe are likely to become legally restricted under REACH. [30]] The European Chemical Agency (ECHA) will develop the official list of SVHCs – the so-called "candidate list" over a period of many years and ChemSec's aim is to identify potential SVHCs as soon as possible so that manufacturers can look for alternatives." By the mid of December 2014 830 substances are being listed. ChemSec introduced TBBPA to the SIN (Substitute Now List) already in 2008, snce according to their analysis reprotoxic and endocrine disruptive effects have been reported,. TBBPA has been categorized by ChemSec as a substance having properties of equivalent concern to PBT or CMR.

LOUS – List of Undesirable Substances in Denmark

The Danish LOUS-List [32], published by the Danish Environmental Protection Agency's is a guide for enterprises. Listed substances should be reduced or halted. The aim is to foster substitution of these substances. TBBPA is listed under the group of certain brominated flame retardants.

Voluntary Industry Commitment by the US and European Producers of Selected Brominated Flame Retardants covered under OECD's Risk Reduction Programme

On 30 June 1995 major global producers of selected brominated flame retardants signed a voluntary commitment to further reduce the potential risk to the environment.. Institutions involved were "U.S. Chemical Manufacturers Association (CMA) Brominated Flame Retardant Industry Panel (BFRIP) and the CEFIC European Brominated Flame Retardant Industry Panel (EBFRIP) as they present the major global manufacturers of brominated flame retardants." [171]

Uganda

In August 2012 Uganda adopted the e-waste definition of Basel Convention into its Electronic Waste (E-Waste) Management Policy - a rationale to mitigate the danger of human health and environmental hazards.

Summary and conclusions on legal restrictions

The production and use of TBBPA was registered by the industry under the REACH regulation. Up to now, TBBPA has not been restricted under the REACH regulation. It was recently added to the Community Rolling Action Plan (CoRAP) -Draft for the years 2015-2017. The decision on a compliance check has been published in August 2014 [10].

In the U.S., TBBPA is currently regulated under the Emergency Planning and Community Right-to-know-Act (EPCRA) and the Children's Safe Products Reporting which is in force since August 2011. However these regulations do not restrict the production and placing on the market in articles but impose certain notification obligations.

Overall, currently there are no legal restrictions on the use of TBBPA.

Step P 2) Prioritization of substances

Hazardous properties

11.5.1.1 Human health

11.5.1.1.1 Available data

For details and refinement see section 3.

The toxicity of TBBPA has been reviewed extensively in the last years, e.g. in an EU risk assessment report [3], in an evaluation by EFSA [52] and a Screening assessment report published by Health Canada [34]. In general, data from these peer-reviewed publications are used for summarising the toxicological characteristics of TBBPA.

The **acute toxicity** of TBBPA is low. The oral LD50 values for rats and mice are given with > 50000 mg/kg bw or with 3200 mg/kg bw, respectively. For an exposure via inhalation the LC50 values were > 10920 mg/mg^3 in rats (4-h exposure) or > 50000 mg/m^3 in mice (8-h exposure). The dermal LD50 value in rabbits was reported with > 10000 mg/kg bw.

There is no indication that TBBPA has a significant potential to cause **skin or eye irritation**, corrosion, irritation of the respiratory tract or skin and respiratory tract sensitisation.

The toxicity of TBBPA after **repeated dosing** was investigated in different studies with rats and mice. From a 14-day gavage study with mice, a NOAEL of 350 mg/kg bw was derived. At the higher tested doses (700 or 1400 mg/kg bw) effects such as enlargement of hepatocytes, inflammatory cell infiltration and focal necrosis of hepatocytes or increased liver weights were noted. No such effects were seen in rats dosed with 250 mg/kg bw via gavage over 28 days. The dosing of Wister rats via diet with up to 300 mg/kg bw over 28 days caused no adverse effects upon hepatic mRNA or microsomes. In a recent three-month study with male and female F344/NTac rats [54], the animals were dosed with up to 1000 mg/kg bw via gavage. Additional special study groups of male and female rats were administered the same doses for 23 days. Dose-related decreases in total thyroxine concentrations occurred on day 4 and at week 14 at dose levels of >= 500 mg/kg bw in males and females. This effect was less consistent in the high-dose group. A haematological examination on day 23 showed small decreases in haematocrit values, haemoglobin concentrations, and erythrocyte counts at >= 500 mg/kg bw in both sexes. At study termination, there was some amelioration in the severity of the erythron decreases in these groups. .. At necropsy, significant increased liver weights in both sexes and significant decreased spleen weights in males were seen at >= 500 mg/kg bw. A histopathological examination gave did not reveal any significant treatment related effects. In a parallel study with male and female B6C3F1/N mice with a comparable dosage regimen [54], significantly increased liver weights were seen at >= 500 mg/kg bw in males and at 1000 mg/kg bw in females. Kidney weights were significantly decreased and spleen weights were significantly increased in 1000 mg/kg bw males. In the kidney, incidences of renal tubule cytoplasmic alteration were significantly increased in males dosed with >= 500 mg/kg bw. From two other three-month studies with rats, oral NOAEL values of 100 mg/kg bw or 1000 mg/kg bw were derived. In the study with dosing up to 1000 mg/kg bw, there were no effects observed in either the functional observational battery or motor activity tests, no adverse histopathological changes in liver, thyroid, parathyroid or pituitary and no changes in serum levels of T3 or TSH. Although there was a significant decrease in serum T4 in both sexes, in the absence of any other relevant thyroid-related effects, this was not considered adverse. In an inhalation study with rats, apart from a local irritation in the upper respiratory tract no significant adverse systemic effects were observed after exposure to 18000 mg/m^3 on 4 hrs per day over 14 days. From a three-week dermal study with rabbits, a NOAEL of 2500 mg/kg bw was derived [54].

Concerning **mutagenicity**, TBBPA was tested negative in a variety of in different in vitro studies (e.g. Ames tests, chromosomal aberration study with human peripheral lymphocytes, intragenetic recombination assay). Also in an in vivo study, TBBPA induced no increases in micronucleated normochromatic erythrocytes in male and female B6C3F1/N mice following three months of administration via gavage.

TBBPA was tested in a two-year study with male and female Wistar Han rats and also with male and female B6C3F1/N Mice [54]. The dose levels in all studies were 0, 250, 500 or 1000 mg/kg bw and the animals were dosed for up to 105 weeks. While in male rats the incidences of interstitial cell adenoma were slightly increased ("equivocal evidence), in females there was a clear evidence of **carcinogenic activity** based on increased incidences of uterine epithelial tumours. In male B6C3F1/N mice the treatment caused increased incidences of hepatoblastoma and also of large intestine neoplasms and haemangiosarcoma (all organs) (some evidence). In contrast, in female mice there was no indication for an increased tumour incidence caused by TBBPA [54]. As there are no human data, overall these data indicate that TBBPA is a carcinogenic of category 2.

Concerning **reproductive or teratogenic effects** of TBBPA, the substance was tested in several studies with oral dosing in rats and mice, which in total gave no indications for significant adverse effects caused by the treatment with TBBPA.

TBBPA also was tested in vitro and/or in vivo for a possible **neurotoxicity or endocrine activity**. All of these studies gave no clear indications for significant adverse effects.

11.5.1.1.2 Conclusion: categorisation according to RoHS criteria

Overall the current available data on human health hazard can be summarised as detailed in the following table, resulting in human health hazard group II.

Table 2: Human Health Hazard Groups

Human Health Hazard – Group I
carcinogenic OR reprotoxic OR mutagenic [Categories 1A]
carcinogenic OR reprotoxic OR mutagenic [Categories 1B]
Endocrine activity – (Category 1*)
respiratory sensitization (Category 1)
STOT-SE, STOT-RE (specific target organ toxicity at single and repeated exposure) (Category 1)
Acute toxic (Category 1)
Human Health Hazard – Group II
skin sensitization (Category 1,2)
skin corrosion/irritation (Category 1A,1B,1C,2)
serious eye damage/eye irritation (Category 1,2)
carcinogenic OR reprotoxic OR mutagenic [Category 2]
acute toxic (Category 2)
respiratory sensitization (Category 2)
STOT-SE, STOT-RE (specific target organ toxicity at single and repeated exposure) (Category 2)
Endocrine disruptor (Category 2*)
Human Health Hazard – Group III
STOT-SE (specific target organ toxicity at single exposure Category 3)
acute toxic (Category 3 and 4)
Endocrine disruptor (EU ED strategy list)- (Category 3*)

11.5.1.2 Environment

11.5.1.2.1 Available data

For details and refinements see section 4.2.

Within the frame of the EU risk assessment series a draft in-depth characterization of TBBPA has been published in the year 2007 [5]. There is also a recent Screening assessment report available published by Health Canada [34].

Based on the REACH criteria, TBBPA only meets the **persistence** criteria for the PBT assessment and thus, is not considered to meet the REACH PBT criteria [172][55].

Reported half-life values in water/sediment go up to 84 d (natural river water / sediment) according to the studies reported on the ECHA webpage [4] and the EHC [40]. It is also considered to be "P" or "potentially vP" (persistent or very persistent (see EU RAR, [5]).

More recent publications from Chang et al. [63, 64] and Nyholm et al. [65] describe half-lifes of 16.6 d in river sediment, up to 26 d in river sediment and up to 600 d in anaerobic soil (activated sludge).

However, although it could be found in the environment in some monitoring studies, TBBPA does not fall under the criteria for **bioaccumulation**:

The corresponding EHC about TBBPA [40] describes BCF values between 20 and 170 in aquatic species for the parent species, although higher values were reported for total ^{14}C (1200). All BCF factors listed in the current REACH registration and the EU risk assessment report are below 500. No accumulation in lipid tissues has been observed [4, 5, 172].

Nyholm et al. [66] report a low tendency for bioaccumulation as well while Morris et al. [67] state that due to its polar nature, the molecule will be subject to metabolism and elimination from organisms.

The long-term toxicity of TBBPA was tested in different species such as daphnia, algae or fish and in general the determined NOEC values were > 0.01 mg/L, i.e. the substance is not considered to be toxic following the PBT criteria.

However, according to the REACH registration as documented on the ECHA homepage TBBPA is classified for the aquatic environment due to its acute and chronic aquatic toxicity (category 1).

No clear indications for significant adverse effects concerning **endocrine effects** were identified.

11.5.1.2.2 Conclusion: categorisation according to RoHS criteria

Overall the available data on environmental hazard can be summarised as detailed in the following table, resulting in environmental hazard group II.

Table 3: Environmental Hazard Groups (categories applicable to TBBPA are marked red)

Environmental Hazard Group I
PBT (persistent, bioaccumulative, toxic) according SVHC criteria REACH
vPvB (very persistent and very bioaccumulative) according SVHC criteria REACH
Endocrine Disrupter (Category 1*)

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[55] In the OSPAR Framework the PBT criteria are more conservative than those used by the EU and therefore TBBPA is considered as a priority substance under OSPAR, however, for RoHS the REACH definition of PBT substances is applied.

Environmental Hazard Group II
PB (persistent and bio-accumulative)
Hazardous to the aquatic environment (Chronic Category 1,2)
Hazardous to the aquatic environment (Acute Category 1)
Endocrine Disrupter (Category 2*)
Environmental Hazard Group III
Hazardous to the aquatic environment (Chronic category 3, 4)
Persistent (REACH criterion)
Bioaccumulative (REACH criterion)
Endocrine disrupter (Category 3*)

11.5.1.3 Hazard group (human + environment)

TBBPA can be assigned to human and environmental hazard group II, resulting in the overall hazard group II.

Table 4: Hazard Groups: Derived from Human health and environmental hazard groups (categories applicable to TBBPA are marked red)

Hazard Group (Human Health & Environment) I
Properties of the substance/substance group are allocated either to Human Health Hazard – Group I or to Environment Hazard – Group I
Hazard Group (Human Health & Environment) II
Properties of the substance/substance group are allocated either to Human Health Hazard – Group II or to Environment Hazard – Group II (none to Group I)
Hazard Group (Human Health & Environment) III
Properties of the substance/substance group are allocated either to Human Health Hazard – Group III or to Environment Hazard – Group III (none to Group I or II)

Waste relevance

For details and refinement see section 7.1.

The market volume of TBBPA increased dramatically during the past two decades. From around 40000 t in the early 1990ies, its production in the year 2000 already accounted for roughly 140000 t (+ 350 %) [50, 51]. Environment Canada notes a likely increase for the first decade of the 21st century [34]. Today's production volume adds up to 170000 t/a. Thus TBBPA is globally considered one of the most important flame retardants [49]. According to the Oeko-Institute, the European consumption of TBBPA accounts for 1/3 of the world-wide total [45]. In contrast, Environment Canada calculates a European share of roughly 10 % of the global market volume for the year 2004 [34].

TBBPA is used either as a reactive or additive component of polymers [76]. In its most common application as a reactive component TBBPA is chemically reacted with the polymer backbone in order prepare fire-resistant polycarbonates [3], and therefore does not exist anymore as a separate molecule. The Canadian screening assessment estimates a share of TBBPA being used as a reactive flame retardant in epoxy and polycarbonate resins and/or electrical and electronic equipment ranging from 70 to 90%.[34] In contrast, the use as an additive component in plastics accounts for 10 to 20% [34].[56] As additive flame retardant TBBPA is not chemically bonded but rather physically combined with the material being treated.[34]

TBBPA is widely used in electrical and electronic equipment as both reactive and additive flame retardant. According to the Oeko-Institute, it is primarily applied in printed circuit boards (PCB) as a reactive flame retardant [45]. After the phase-out of Octa-BDE, TBBPA claimed its place temporarily as the flame retardant of choice in ABS monitors and heating equipment [174]. Due to its chemical reaction with the epoxy resin low levels of unreacted TBBPA remain in the PCBs [73]. This estimated share of 0.0004 to 0.06% may thus leach from the finished product and potentially cause harm to the environment or human health [5].[57]

Additional applications as additive flame retardant in polymeric material in housings and packaging, e.g. ABS, HIPS and phenolic resins, are documented [40, 45] Additively incorporated TBBPA does not chemically react with the polymer and is thus considered more likely to leach from the polymer matrix [40]. The share TBBPA being additively (unreacted) bond to ABS may account for 17.6 to 22.0%, for HIPS 14% are recorded [5, 40]. Since these applications are widespread, e.g. ABS among others in pipes and fittings, automotive parts, refrigerators and telephones, its release potential is significant. Plastics containing additively bond TBBPA cover vacuum cleaners, components of printers, coffee machines, televisions, electric plugs, etc. [5].[58]

In order to determine the waste relevance of TBBPA a detailed literature review was conducted. Various assessments of TBBPA have been published in the past in order to determine its hazard potential to the environment and human health, e.g. by the EU, Oeko-Institute, WHO, US EPA, Environment Canada [74].

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[56] 173. Heart, S., *Environmental Impacts and Use of Brominated Flame Retardants in Electrical and Electronic Equipment.* Environmentalist 2008. **28**: p. 348–357. (cited by Government of Canada)

Bromine Science and Environmental Forum. 2009. About Tetrabromobisphenol A (TBBPA). Available online: http://www.bsef.com/our-substances/tbbpa/about-tbbpa/. Accessed 17 May 2009. (cited by Government of Canada)

[57] Sellström U. 1999. Determination of some polybrominated flame retardants in biota, sediment and sewage sludge. Doctoral dissertation. Department of Environmental Chemistry and Institute of Applied Environmental Research. Stockholm University, Sweden. (cited by Government of Canada)

[58] Risk and Policy Analysts Limited. 2001. Octabromodiphenyl ether: Risk reduction strategy and analysis of advantages and drawbacks. Draft stage 2 report prepared for Department for Environment, Food and Rural Affairs. RPA, November 2001 [cited in EU RAR 2008].

Environment Canada identifies various releases during waste treatment have been documented during dismantling, recycling, landfills, incineration, accidental fires and sewage sludge applications for agricultural purposes.

Various waste streams during manufacturing, processing and disposal have, however, been identified as sources of possible releases of TBBPA to the environment [34]. According to BSEF, the entire amount of TBBPA is produced in Israel, the United States, Jordan, Japan and China.[75] Releases from manufacturing in Europe thus can be excluded from examination.

11.5.1.4 Releases

For details and refinement see section 5.4.

According to Environment Canada (2013) [34] release of TBBPA into the environment may occur during all stages of Product Life Cycle of the substance itself or products containing TBBPA. Releases hereby mainly occur through various waste streams in the Product Life Cycle, i.e. manufacturing phase, processing phase, and disposal phase. The treatment processes during disposal phase are manifold and range from incineration, dismantling and recycling to landfills or accidental fires for agricultural purposes through sewage sludge applications [34].

There is evidence that materials in landfills release TBBPA particulates or polymer-associated TBBPA into soil, water and air. However, no experiments have been conducted on the leachability of TBBPA from polymers in landfills so far. Based on the findings in Ref. [5] (EU RAR 2008) that TBBPA has some solubility in water it is concluded that leaching over extended time period is a possibility [34]. EBRC [103] states that though water solubility is assumed to be low under neutral conditions, free TBBPA could be released from PCBs in landfills that come into contact with basic leachate [103]. In the case of TBBPA leaching from plastics in landfills Environment Canada 2013 [34] concludes that due to strong adsorption to particulates and degradation under anaerobic conditions the potential for leaching into groundwater is reduced.

The emissions of PCBs occurring in electronic waste impose no risk to the environment under controlled conditions [103].

Trace level concentrations related to the disposal phase are, as an example, indicated by US EPA [73], Chemtura & ICL-IP [103] and Covaci et al. [37].

The Oeko-Institute concluded that TBBPA can contribute to the formation of halogenated dibenzo-p-dioxins and furans generated during disposal processes but a quantification of the amounts and assessment of environmental significance of these products cannot be undertaken [45].

11.5.1.5 Conclusion and application of criterions according to Article 6(1)

For additional details and refinement see section 7.1.

Classification of waste relevance according to RoHS Article 6

The RoHS2 Directive defines a set of three criterions that determine the waste relevance of a substance [1]. The following subsection thus analyses, if these specifications apply to TBBPA.

Criterion a) is fulfilled if one of the following facts is true:

- There is evidence that the substance hinders recycling or recovery as it has adverse effects on recycling / recovery processes (examples are Pb in glass fractions, halogenated polymers in fractions to be used for energy recovery).

    - *TBBPA can contribute to the formation of halogenated dibenzo-p-dioxins and dibenzofurans but quantification of amounts is currently not possible… [5, 45]. Use as reactive flame retardant leads to formation of brominated polymers.*
    - *Only limited information has been available on environmental (e.g. energy use, toxicity, impact on waste stream), social (occupational health and consumer safety) and economic impacts emerging from a phase out and substitu tion of TBBPA. [45]*
    - *"This study (…) started out from the assumption that all existing waste-to-energy plants (WTE) suffer more or less corrosion. The corrosion of boiler parts as waterwalls and superheaters are due to a combination of relatively high chlorine levels, high temperatures in the flue gas, and resulting deposit formation on heat transfer surfaces. The corrosion mechanisms include deposit build up, evaporation of metalchlorides, and melting of salt deposits. Design and operation aspects play an important role. In practice, simple changes in heating values and impurity levels of waste can result in considerable variations in the potential for corrosion. Information about a possible additional corrosion effect of bromine (or fluorine) has in the past been lacking." [175]*
    - *"For many waste streams recycling routes may be blocked due to the presence of BFRs. For example, the use of recycled ABS (acrylonitrile-butadiene-styrene) as a blend with PC (polycarbonate) is not possible because the BFR causes the PC to depolymerise, resulting in poor quality of the recyclate." [95]*

- There is evidence that large proportions of the substance remain in the recycling loop and are not discharged during the treatment processes and collected for subsequent safe disposal. As a consequence the hazardous substance / substance group may be distributed across various types of recycled materials such as metals, plastics, glass or building material and finally in the environment.

    - *There is slight evidence according to the EU risk assessment [3, 34, 45]*

Criterion b) is fulfilled if one of the following facts is true:

- There is evidence that the substance was measured at significantly elevated levels in the environment (air, water, soil, biota) near WEEE treatment installations / locations

    - *There is evidence according to EU RAR (2008) (Ref. [5], p.45-46) but not clear whether the levels are significantly elevated.*
    - *According to Covaci et al. [50] air levels at recycling plants go up to 140 ng/m3 (shredder), while as an example a computer office only shows 0.035 ng/m3. Other values, e.g. for leachate or sediment are reported, but not necessarily related to WEEE treatment.*
    - *Hlouskova et al. [176] report elevated levels in river sediment downstream of a hazardous waste incinerator.*

- There is evidence that hazardous degradation/transformation products are formed during WEEE management (including thermal processes (combustion, milling), mechanical, chemical and biological processes (MBT, landfilling)

    - *See above (halogenated dibenzo-p-dioxins and dibenzofurans)*

- The substance is used as a nano-material in EEE and there are concerns about negative effects on human health or the environment

    - *No data found*

- The substance is comparably easily releasable due to following reasons
    - The substance is used in or as a liquid in EEE
    - The substance is used in powders

    - *During production yes, waste treatment no*
- The substance is highly volatile
    - *No (see Ref. [5] and section 0)*

Criterion c) if fulfilled if one of the following facts are true:

- Evidence exists that negative health impacts during WEEE management occur
    - *No, we could not find evidence of negative health impacts (RAR 2008)*
- The substance was found at significantly elevated levels in humans near WEEE treatment plants / locations
    - *Yes.*

    See e.g. Covaci et al. [37]: "Due to its limited presence in foodstuffs (as far as it has been investigated), direct exposure via inhalation might be considered the predominant route of human exposure [119]. In this respect, occupationally exposed workers are at higher risk than the general population. High concentrations of TBBPA in the air (30 ng/m^3) inside an electronics dismantling area of a dismantling facility were measured [119]. In a follow-up study of the people working in them same electronics recycling facility, Hagmar et al. [114] revealed the presence of TBBPA (range 1.1–4.0 ng/g lw) in the serum of the workers engaged in the recycling process, which indicates systemic uptake of this chemical.

    Jakobsson et al. [115] investigated TBBPA exposure in computer technicians. TBBPA could be found in 80% of the technicians, while the compound could not be measured in the serum of a control group comprising office clerks and hospital cleaners. The concentrations found in this study ranged between <0.55 and 1.84 ng/g lw, which are comparable to the concentrations reported by Hagmar et al. [114]. Thomsen et al. [116] analyzed serum from Norwegian individuals working at an electronics dismantling facility, in the production of printed circuit boards and as laboratory personnel, the latter being a control group. In that study, TBBPA levels were elevated significantly ($p < 0.05$) in the dismantlers (1.3 ng/g lw), while in both other groups the levels were lower (0.54 and 0.34 ng/g lw, respectively).

    Data on TBBPA in non-occupationally exposed individuals was published by Thomsen et al. [79], where time trends from 1977 to 1999were also investigated. TBBPA could not be found in the oldest serum pools (1977 and 1981), but was present in all other samples.

    Further, Thomsen et al. [79] also looked at age classes of the 1998- population. TBBPA levels tended to be the highest in the age group of 0–4 years. This was also the only age group where diMe-TBBPA was found, although at a level close to the LOQ. Further, no concentration vs. age relationship could be observed. Concentrations in that study ranged between 0.34–0.71 ng/g lw. After further method

    optimisation, the same samples were re-analyzed and Me-TBBPA was found in all samples [80].

    In Japan, TBBPA was analyzed in 24 blood samples from adult volunteers. TBBPA was detected in only 14 of these samples with a mean concentration of 1.35 ng/g lw [117].

    Recently, Johnson-Restrepo et al. [68] measured the concentrations of TBBPA in 20 adipose tissue samples from New York, USA. The overall mean concentration (mean±SD) of TBBPA was 0.048±0.102 ng/g lw, with a maximum concentration of 0.46 ng/g lw. TBBPA correlated well with concentrations of HBCDs, but not with those of PBDEs. Moreover, concentrations of TBBPA were 10- fold lower than HBCD concentrations and 3–4 orders of magnitude lower than PBDEs measured in the same samples.

Detection of TBBPA in humans can be hampered by the short biological half-life of the compound, which has been estimated to be 2 days [89,114]. This is not surprising since TBBPA is a phenol that can be rapidly conjugated and subsequently excreted [125].
Still, TBBPA may accumulate in humans, but a continuous exposure to this BFR is required to maintain a detectable level in the human subject."

Table 44: Determination of TBBPA waste relevance

Waste relevance, crit. a	Yes	🟥
Waste relevance, crit. a	Yes	🟥
Waste relevance, crit. a	Yes	🟥

Concluding, a waste relevance for TBBPA is determined as shown in Table 6 below.

Table 45: Waste relevance of TBBPA

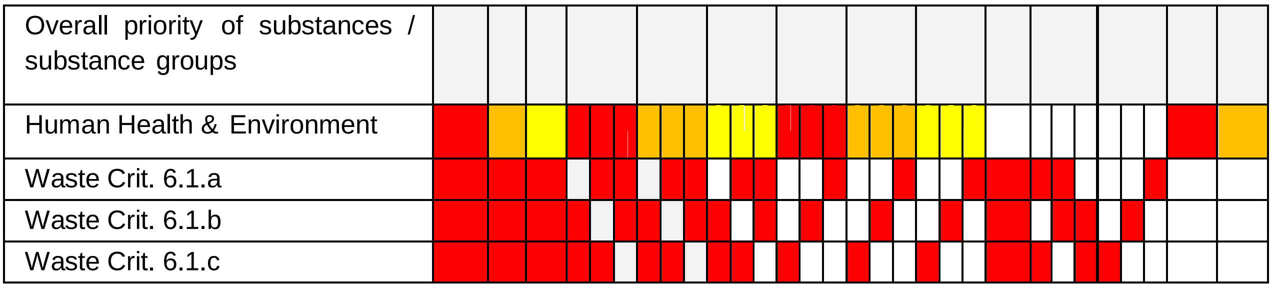
Waste Relevance
One of the criteria of Article 6 (1) a, b, c are fulfilled: YES
No Waste Relevance
None of the criteria of Article 6 (1) a, b, c is fulfilled: No

Priority class

Priority classes under RoHS are summarised in Table 46. TBBPA has been assigned to hazard group II concerning human health and environment. The three waste criteria are fulfilled, resulting in an overall priority class of II.

This result confirms the priority class already assigned by the Austrian Umweltbundesamt.[2]

Table 46: Priority class: Overview of possible combinations



Overall priority of substances / substance groups																														
Human Health & Environment	🟥	🟧	🟨	🟥	🟥	🟥	🟧	🟧	🟧	🟨	🟨	🟨	🟥	🟥	🟥	🟧	🟧	🟧	🟨	🟨	🟨	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟧
Waste Crit. 6.1.a	🟥	🟥	🟥	░	🟥	🟥	░	🟥	🟥	⬜	🟥	🟥	⬜	⬜	🟥	⬜	⬜	🟥	⬜	⬜	🟥	🟥	🟥	🟥	⬜	⬜	⬜	🟥	⬜	⬜
Waste Crit. 6.1.b	🟥	🟥	🟥	🟥	░	🟥	🟥	░	🟥	🟥	⬜	🟥	⬜	🟥	⬜	⬜	🟥	⬜	⬜	🟥	⬜	🟥	⬜	🟥	🟥	⬜	🟥	⬜	⬜	⬜
Waste Crit. 6.1.c	🟥	🟥	🟥	🟥	🟥	░	🟥	🟥	░	🟥	🟥	⬜	🟥	⬜	⬜	🟥	⬜	⬜	🟥	⬜	⬜	🟥	🟥	⬜	🟥	🟥	⬜	⬜	⬜	⬜

Other category II substances

Volumes

In this section a short comparison of tonnages of TBBPA and other flame retardants with priority class II will be done.

In general, the tonnage of relevance represents the amount of flame retardant in WEEE in the EU, which is not necessarily identical to the amount used in the EU, as articles or half-finished products may be imported into the EU from other countries (e.g. Asia). As an example, the EU risk assessment for TBBPA refers to assumptions concerning import of EEE and EEE parts to estimate the release from these articles.

Since the EU risk assessment, more detailed numbers about the annual amount of eee waste produced world-wide and in the EU have become available [42, 43] which are considered to be a more reliable option for an estimation of the volumes present in WEEE per year.

Using the reported ~40 million t/a WEEE world-wide and 9.1 million t/a WEEE in the EU, this results in ~23% of the global WEEE being produced in the EU.

The amount of chemicals present in this WEEE is now derived using the fraction of WEEE (23%) and the global tonnage of the corresponding substance used in EEE.[59]

TBBPA (tetrabromobisphenol A)

For details and refinements see section 2.2.

Gensch et al. (2014, [33]) indicate an overall usage of ~5850 t/a as a reactive flame retardant in the EU (based on tonnage information from 2008). However, as the amount present in EEE / WEEE in the EU also depends on importend parts and articles a higher tonnage of ~40000 t/a present in EEE in the EU is overall estimated (13800 t/a imported as substance, 6000 t/a as partly finished products assumed, 20200 t/a as finished products assumed).

This number is approximately consistent with the approach that has been used for the EU risk assessment [5], which uses ~120000 t/a global consumption (based on data from 2001), and 6500 t/a import of the substance, assumes 6000 t/a import in partly finished products and 27500 t/a import in finished products, which results in 40000 t/a TBBPA in EEE waste per year (see also Morose (2006, [36]), world-wide use of 119700 t/a in 2001).

According to the Austrian Umweltbundesamt (2008, [46]), 145000 t/a TBBPA are used world wide, while ~7000 t/a are used in the EU (data source not indicated).

The current use of TBBPA in the EU is at approximately 1000-2500 t/a according to Gensch et al. and the most recent VECAP report from 2013 [33, 47].

Updates on the global use of TBBPA published by EFRIP report volumes between 104000 t/a and 170000 t/a between 1995 and 2004, with **170000** t/a representing 2004.[35] However, only 139000 t/a of this are used in ABS or laminates as a flame retardant, while the remaining 30500 t/a are used for the production of derivatives and oligomers.[159]

Using **139000 t/a TBBPA** consumption world wide as flame retardant (worst case and most recent available volume) in EEE this leads to ~**32000** t/a TBBPA in WEEE in Europe. This tonnage will be used for the further risk assessment.

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[59] Assumption: The substances are evenly distributed within the WEEE.

DEP (Diethyl phthalate)

DEP is mainly used as plasticizer in tools, automotive parts, toothbrushes, food packaging, cosmetics and insecticide [33]. The assessment by Gensch et al. indicates that DEP is not used in EEE. However, the scope of RoHS 2 is wider compared to RoHS 1, therefore tools or toothbrushes fall under its scope and no definite conclusion on the use in EEE is possible.

Two entries for DEP are present in the ECHA database, indicating use as intermediate and one full registration for 1000-10000 t/a.

Annual global tonnages of DEP are around 22500 t/a [177], thereof 11800 t/a are produced in the US, 10000 t/a in the EU and 700 t/a in Japan (data from the 1990s). 4000 t/a of this are used in fragrances.

The US EPA reported ~23000 t/a production in 2004 in the US.[178]

This results in a maximum tonnage of **29700 t/a world-wide** potentially used in EEE and, together with 23% WEEE production in the EU to **~6831 t/a** DEP in WEEE in the EU.

Antimony trioxide

The ECHA database of registered substances indicates two entries for antimony trioxide with 100-1000 and > 10000 t/a volumes.[4]

The consumption of Antimony oxides as a flame retardant is ~25,000 t/a in western Europe, ~45000 t/a for Asia and ~30,000 t/a for the USA,[179] i.e. overall ~100,000 t/a (data from 2001).

Global production volumes are were **120000 t/a** according to the EU risk assessment report (data from 2005) [180], whereas ~24000-25000 t/a are used in the EU (EU15), including ~20200 t/a used as synergist for additive flame retardants in products which can be potentially part of EEE.

Assuming that the majority of the global production volume is used for EEE, this leads to **~27600 t/a** present in WEEE in the EU (23% of weee produced in EU, see above).

Medium chain chlorinated paraffins, C14-17

The current total production capacity of medium chain chlorinated paraffins is in the range of 45000-160000 t/year in Europe according to the corresponding EU risk assessment (data from 1990s) [181]. Approximately 79.4-83% of this are used as a flame retardant in PVC, 4.6-9.1% in lubricants, 4.1-5.4 % in paints/adhesives, 3.3-4.7 in rubber/ other polymers and the remaining amount for carbonless copy paper and leather fat liquor. Overall, this will result in a maximum of ~93% usage in EEE, if it is assumed that all PVC, adhesives and other polymers/ rubber are incorporated into EEE.

According to the Oeko-Institut [45] a main use relevant for EEE is in PVC for cable sheathings (probably ~17% of use in PVC production).

Global consumption is estimated to be **300000 t/a** (data from 1990s) according to Muir et al., [182]. The use patterns published in this document suggest a considerable amount of MCCPs being used in metalworking fluids (no exact differentiation possible, as use pattern adds up fire retardants and additive in lubricants), however, use as additive in PVC and rubber (e.g. cables, wallpapers, floor coverings, leisure and travel articles) is also possible [33].

Information given by Gensch et al. concerning application in EEE varies (~38 % t/a used in PVC cable formulations (Ineos Vinyl) vs. no use in EEE could be confirmed (Kemi)). However, as a conclusions it is assumed that ~15000 t/a MCCPs are used in EEE per year.

According to Gensch et al. [33] in 2006, approximately 64000 tonnes of MCCPs were sold in the EU 25. Around 50 % (34676 tonnes) of the total were applied in the manufacture of PVC; metal working / cutting applications accounted for 8,920 tonnes; rubber/polymers (other than PVC) accounted for 7,077 tonnes; and carbonless copy paper for 89 tonnes. This would result in a maximum of ~ 65.2% of MCCP potentially used in EEE (rubber, polymers, PVC).

Assuming that ~90% of the global tonnage is incorporated into EEE this leads to **~62100 t/a** medium chain chlorinated paraffins in WEEE produced in the EU (23% of WEEE produced in Europe, 300000 t/a MCCP world-wide).

Summary

A short comparison of global production volumes as well as estimated volumes contained in WEEE in the EU showed that of the four substances with priority class II two are quite similar (TBBPA and Antimony Trioxide). MCCP seems to show an annual tonnage which is approximately twice as high as the one of TBBPA and only DEP seems to show significantly lower tonnages.

Especially for MCCPs and DEP it is not completely sure to which extent the produced volumes are actually used in electronic equipment.

Furthermore, the use volumes found in literature are not referring to the same year for all substances and have been shown to fluctuate from year to year, thus, the comparison bears some uncertainty.

According to the Oeko-Institut MCCP, TBBPA and Antimony trioxide are all considered to be of "medium use volume".[183]

Overall a clear priorisation is difficult, although the currently available data suggest the highest tonnage in WEEE for MCCPs.

Available Substitutes

TBBPA (tetrabromobisphenol A)

For more details and refinements see section 8.1.

The flame retardant TBBPA is mainly used as a reactive flame retardant in epoxy resins which are used in printed circuit boards (PCBs, ~90% of use). The remaining 10% are used as additive flame retardant, mainly in ABS (Acrylonitrile butadiene styrene) which can be used for computer or TV housings.

Substitution of TBBPA as a flame retardant is usually done via organic phosphorus compounds. However, in ABS other brominated flame retardants in combination with antimony trioxide are also a possibility. In this case also a change in the polymer is necessary to more expensive and less flammable mixtures of ABS with polycarbonate or polyphenylenether [33, 46].

In printed circuit boards DOPO (9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide) can be used as a substitute. However, only about 6-7% of the FR-4 printed wiring boards currently on the market are partly based on this technology. [33]

Phosphorous resins can be used in combination with metal oxides such as Aluminium Tri-hydroxide (ATH) or Aluminium Oxide-hydroxide (AOH). These formulations have good thermal stability, but tend to lead to a variety of technical challenges, such as higher water uptake or increased brittleness, while with printed wiring boards, the interaction of metal hydroxides with can lead to the presence of water in the laminate during soldering operations, potentially increasing the assembly failure rate and affecting electrical properties. As a consequence, ATH is essentially used in intrinsically less-flammable flexible wiring boards for smaller devices like mobile phones or cameras. [39]

Replacement of the resins with less flammable polymers such as polyetherimid or polyethersulfon has also recently been evaluated [46].

Further alternatives for TBBPA in epoxy resins are discussed by Vik (zinc borate, [151]) and Mariappan and Wilkie (poly(m-phenylene methyl phosphonate) = (Phosphonic acid, P-methyl-, diphenyl ester, polymer with 1,3-benzenediol); 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide; red phosphorus, aluminium diethylphosphinate, [152]).

A detailed comparison and discussion of possible alternatives is also given by Morose [36], who describes amongst others alternative brominated compounds, red phosphorus and metal hydroxides.

Overall it can be summarised that substitutes for TBBPA are available. However, according to BSEF [184] the reliability of other flame retardants e.g. in printed circuit boards (PCBs) has not been proven to be comparable to TBBPA, yet. A shorter service life could be the consequence, which would in turn lead to a higher production of electronic waste. Higher costs are also to be expected as the production chaings would have to be adapted.

Partly, the available substitutes are also toxic for humans or the environment [36].

DEP (Diethyl phthalate)

As mentioned above, DEP is mainly used as plasticizer in tools, automotive parts, toothbrushes, food packaging, cosmetics and insecticide [33].

Some possible substitutes for phthalates in general are given by the Lowell Center for sustainable Production (2011) (e.g. Di-isononylcyclohexane-1,2-dicarboxylate), however, these do not necessarily use in EEE [185].

No further substitutes could be identified for DEP.

Antimony trioxide

As mentioned above Antimony trioxide is only used in combination with other flame retardants.

It effectively reduces the decomposition temperature of certain brominated flame

retardants, such as deca-PBDE, resulting in an observed synergism. Less thermally stable flame retardants (e.g. HBCD) are slightly more efficient in some applications and are therefore less dependant on the use of antimony oxide. In these cases more HBCD will be required than with the addition of antimony oxide to meet the required flame retardancy. [186]

Sometimes phosphorous compounds (TCP: Tricresyl phosphate), magnesium oxide, alumina trihydrate, molybdic oxide, zinc borate, or zinc oxide are used in combination or in place of antimony oxide. However, as mentioned above the substitution reduces the flame retardance normally rendered by antimony oxide. Testing of the amounts of the halogen and antimony oxide in each formulation is necessary to optimize the flame retardance and lower costs. Alumina trihydrate is not synergistic with halogenated flame retardants and it cannot be used in high temperature processes.[187]

Medium chain chlorinated paraffins, C14-17

An alternative for medium chain chlorinated paraffins can be, as an example, aluminium trioxide in combination with antimony trioxide in cable sheathing. For some uses also phosphates are suggested, however, these have poorer properties and thus, require higher quantities.

Other alternatives also have environmental properties of concern, e.g. trialkyl phosphate, which can be used in PVC. [188]

Summary

For all four substances substitutes seem to be available to a certain extent. However, they are usually not applicable for all products and uses identified for a certain substance. For diethyl phthalate the available information seems somewhat unclear.

Sometimes further research and experience seem to be advisable for most possible substitutes, before it can be decided how a replacement of a certain substance would affect the corresponding article and its lifetime.

Conclusion

For a final priorisation of substances the RoHS manual [1] suggests the comparison of substances with identical priority classes concerning volumes in EEE and availability of substitutes. Results of this evaluation are summarised in Table 47.

Table 47: Summary of volumes and availability of substitutes for substances with priority class II.

	MCCPs (medium chain chlorinated paraffins)	**TBBPA**	**Antimony Trioxide**	**DEP (diethyl phthalate)***
t/a world wide	300000	170000	120000	29700
t/a in EEE in EU	62100	32000	27600	6831
Substitutes available?	yes	yes	yes	unclear

** use in EEE not clear*

Results indicate that according to the available information, TBBPA is of medium priority when compared to the other substances with priority class II[2].

However, there are some uncertainties especially concerning the presence of some of the substances in EEE as assumptions are always needed to a certain extent for the derivation of tonnage values (e.g. use of global production volumes and EU fraction of waste vs. use of EU production volume and assumptions concerning import in articles). This also explains the different categorisation in Ref. [33] which assign MCCPs, Antimony trioxide, and TBBPA quite similar tonnages of 15000 t/a, 20000 t/a and 6000-22500 t/a use in EEE in the EU, leading to a similar priorisation (medium use volume).

APPENDIX B: MONITORING DATA

HUMAN EXPOSURE

Table 48: Exposure data relevant for humans not related to WEEE treatment: TBBPA concentrations in house dust, human milk, blood, serum, examples

Reference	Cross reference	Location	Sampled medium	results	unit
House dust					
Abb et al., 2011 [189]		2 samples from USA, 24 from Germany	House dust	not detected - 470	ng/g
	Abdallah, M.A.-E., Harrad, S., Covaci, A., 2008. Hexabromocyclododecanes and tetrabromobisphenol-A in indoor air and dust in Birmingham, UK: implications for human exposure. Environ. Sci. Technol. 42, 6855–6861.	UK	House dust	average 87, median 62	ng/g
	Takigami, H., Suzuki, G., Hirai, Y., Sakai, S., 2009. Brominated flame retardants and other polyhalogenated compounds in indoor air and dust from two houses in Japan. Chemosphere 76, 270–277.	Japan	House dust	median 520 and 490	ng/g
	Harrad, S., Abdallah, M.A.E., Covaci, A., 2009. Causes of variability in concentrations and diastereomer patterns of hexabromocyclododecanes in indoor dust. Environ. Int. 35, 573–579.	UK (14 samples)	dust in car cabin	4.5 (median)	ng/g
		UK (14 samples)	dust in car trunk	< 0.2 (median)	ng/g
Geens et al., 2009 [190]		Belgium	Indoor dust	10 (median) 1-1480	ng/g
Fromme et al., 2014 [191]		Germany	Indoor dust	28 (median) 2.9-233	ng/g
	Ali N, Harrad S., Goosey E, Neels H, Covaci A, “Novel” brominated flame retardants in Belgian and UK indoor dust: implications for human exposure. Chemosphere 2011, 83, 1360-1365	Belgium	Indoor dust	78	ng/g
	Batterman SA, Chernyak S, Jia C, Godwin C, Charles C. Concentrations and emissions of polybrominated diphenyl ethers from US houses and garages., Environ Sci Technol 2009, 43, 2693-2700	USA	Indoor dust	57	ng/g
Covaci et al., 2009 [37]	H. Takigami, G. Suzuki, Y. Hirai, S. Sakai, Organohalogen Compd. 69 (2007) 2785.	Hokkaido, Japan	Domestic dust	490–520	ng/g
	D. Santillo, I. Labunska, H. Davidson, P. Johnston, M. Strutt, O. Knowles, Greenpeace Research Laboratories technical note 01/2003 (GRL-TN-01- 2003) 2003, http://www.greenpeace.to/publications/housedust uk	UK	Pooled domestic dust	190–340	ng/g

Reference	Cross reference	Location	Sampled medium	results	unit
	2003.pdf (accessed January 4th 2008).				
	P.E.G. Leonards, D. Santillo, K. Brigden, I. van der Veen, J. von Hesselingen, J. de Boer, P. Johnston, Proceedings of the Second International Workshop on Brominated Flame Retardants BFR 2001, Stockholm, Sweden, May 14–16, 2001, p. 299	EU offices	Office dust	5–47	ng/g
	S. Chernyak, S. Batterman, C. Godwin, C. Jia, S. Charles, Organohalogen Compd. 69 (2007) 994	Michigan, USA	Newly constructed building	0.4–2	ng/g
	C. Yu, B. Hu, J. Chromatogr. A 1160 (2007) 71.	China	Dust inside computers	0.0089–0.0396	ng/g
EU RAR [5]	Santillo D., Johnston P. and Brigden K. (2001). The presence of brominated flame retardants and organotin compounds in dusts collected from Parliament buildings from eight countries. Greenpeace Research Laboratories Technical Note 03/2001.	8 EU countries	dust from vacuum cleaners	5 (1 of 10 samples)	ng/g
Humans					
Antignac et al., 2008 [192]		France	human milk	not detected	
EU RAR [3]	various	France, Faroe Islands, Norway, Germany	human milk	0.18-11	ng/g fat
EFSA 2011 [52]	Shi et al., 2009, Dietary exposure assessment of chinese adults and nursing infants to tetrabromobisphenol A and hexabromocyclododecanes: occurence measurements in foods and human milk. Environmental science and Technology, 43, 4314	China	human milk	< LOD-5.1	ng/g fat
Abdallah and Harrad, 2011 [193]		UK, 34 samples	human milk	<0.04-0.65	ng/g fat
	Thomsen C, Leknes H, Lundanes E, Becher G. A new method for determination of halogenated flame retardants in human milk using solid-phase extraction. J Anal Toxicol 2002a;26:129–37.	Norway, 9 women (pooled samples)	human milk	0.067	ng/g fat
	Cariou R, Antignac JP, Zalko D, Berrebi A, Cravedi JP, Maume D, et al. Exposure assessment of French women and their newborns to tetrabromobisphenol-A: occurrence measurements in maternal adipose tissue, serum, breast milk and cord serum. Chemosphere 2008;73:1036–41.	France, 77 samples	human milk	0.477 (median) 0.06-37.34	ng/g fat
	Shi ZX,Wu YN, Li JG, Zhao YF, Feng JF. Dietary exposure assessment of Chinese adults and nursing infants to tetrabromobisphenol-A and hexabromocyclodo-	China, 24 pooled samples	human milk	0.933	ng/g fat

Reference	Cross reference	Location	Sampled medium	results	unit
	decanes: occurrence measurements in foods and human milk. Environ Sci Technol 2009;43:4314–9.				
	Thomsen C, Lundanes E, Becher G. Brominated flame retardants in archived serum samples from Norway: a study on temporal trends and the role of age. Environ Sci Technol 2002b;36:1414–8.	Norway, pooled samples from previous years	serum	0.44 (data from 1986) -0.65 (data from 1999); increasing levels over years	ng/g lw
	Nagayama J, Tsuji H, Takasuga T. Comparison between brominated flame retardants and dioxins or organochlorine compounds in blood levels of Japanese adults. Organohalogen Compd 2000;48:27–30.	Japan	serum	1.35 (average)	ng/g lw
Covaci et al., 2009 [37]	C. Thomsen, E. Lundanes, G. Becher, Environ. Sci. Technol. 36 (2002) 1414	Norway	General population Serum	0.34 (age > 60 years) – 0.71 (age 0-4 years)	ng/g lw
	K. Jakobsson, K. Thuresson, L. Rylander, A. Sjödin, L. Hagmar, Å. Bergman, Chemosphere 46 (2002) 709.	Sweden	Computer technicians Serum	0.55–1.84	ng/g lw
	C. Thomsen, E. Lundanes, G. Becher, J. Environ. Monit. 23 (2001) 366.	Norway	Circuit board producers Serum	<0.1–0.80 (mean 0.54)	ng/g lw
	C. Thomsen, E. Lundanes, G. Becher, J. Environ. Monit. 23 (2001) 366.	Norway	Laboratory personnel Serum	<0.1–0.52 (mean 0.34)	ng/g lw
	J. Nagayama, H. Tsuji, T. Takasuga, Organohalogen Compd. 48 (2000) 27.	Japan	General population Serum	1.35	ng/g lw
EU RAR [3]	various	Norway, Japan, France.	blood serum	not detected - 12	microg/kg lipid
				0.4	ng/kg plasma
				2-330	ng/kg whole blood
German Umweltbundesamt 2008 [46]	no cross reference given.		blood	< 0.1 – 10	µg / kg fat
Johnson-Restrepo et al., 2008 [194]		US (Florida)	tissues of humans (adipose tissue), N=20	0.0033-0.464 (0.048+/0.102 (average)	ng/g lw
Mäkinen et al. (2009) [195]		Sweden, circuit board factory	patch sample	<0.09	ng/cm^2
			hand-wash sample	<2	ng/hands
		Sweden, Furniture workshop	ng/cm^2	<0.09	ng/cm^2
			ng/hands	<2	ng/hands
EU RAR [3]	DeCarlo VJ (1979) Studies on brominated chemicals in the environment. Annals N.Y. Acad. Sci. 320, 678-681.	US, TBBPA manufacturing facility	Human hair	2	ng/g

Table 49: Monitoring of recycling plant employees.

Reference	Location	Sampled medium	results	unit	
L. Hagmar, A. Sjödin, P. Häglund, K. Thuresson, L. Rylander, Å. Bergman, Organohalogen Compd. 47 (2000) 198. [196]	Sweden	Electronics dismantling site employees; Serum	1.1–4.0	ng/g lw	no information about RMMs etc. Decreasing concentration over summer vacation observed.
C. Thomsen, E. Lundanes, G. Becher, J. Environ. Monit. 23 (2001) 366 [197]	Norway	Electronics dismantling site employees; Serum	0.64–1.8 (mean 1.3)	ng/g lw	work included manual dismantling of WEEE, e.g. TV sets, computers. Dust protection masks occasionally on a voluntary basis. Shredder located outdoors.

Table 50: TBBPA concentrations in indoor dust at recycling facilities

Reference	Cross reference	Location		results	unit	Comments / contextual information
Deng et al., 2014 [198]		China (dust in TV recycling facility)	at manual dismantling and sorting line	206-950	ng/g	dismantling includes removal of plastic casings, wires, printed circuit boards and CRTs. Circuit boards are then crushed and sorted (electrostatic separation). Shredding and separation of wires, panel-funnel separation of CRTs, then shredding of outer casings.
			circuit board recycling line	189-961	ng/g	
			Waste wire recycling dust	80.4	ng/g	
Morf et al. (2004) [111]		Switzerland	recycling site (mixed small WEEE, including TVs, PCs etc.)	653	mg/kg dust	concentrations in dust < 0.44% of the original concentration in shredded material
EU RAR (environment) [5]	Pettersson et al. (2001)	Sweden, electronics dismantling facility, removal area	sedimentary dust	31	mg/kg	
		Sweden, electronics dismantling facility, dismantling hall	sedimentary dust	4.1	mg/kg	

Table 51: Air concentrations and dermal exposure of TBBPA at recycling sites.

Reference	Cross reference	Location	sampling strategy	results	unit	Comments / contextual information
Rosenberg et al., 2011 [199]		Finland WEEE recycling site A	Thirty-four exposed workers were recruited from the four recycling sites. Eleven workers participated in both years. The workers were either sorters or dismantlers, or both, or process controllers. As the work processes were done in open factory sheds, it was not possible to distinguish separate areas for the different tasks. Air was monitored during one work shift. Measurements were started on the second day of the working week after a production stop during the weekend. Altogether 45 personal (breathing zone) air samples were collected. The sampling periods ranged from 191 to 408 min.	0.019-0.42	µg /m^3	"**Work processes at recycling sites:** Two commercial recycling sites **(A and B**) and the social enterprise site **(C)** carried out manual disassembly and sorting of WEEE and selective removal of hazardous and valuable components. The waste was mainly from small household appliances, IT, and consumer equipment and electrical tools and toys. Those sites also performed mechanical size reduction, for example, by separating television (TV) cathode ray tubes from the plastic covers and collecting the fractions and sending them on for further processing. **Commercial Site A** did additional crude crushing of TV set glass and plastic fractions. Commercial **Site B** carried out a supplementary separation of the tube, based on laser technique, removing the lead-containing back pane from the rest of the tube. This semiautomatic operation took place in fume cupboards. The glass fractions were then mechanically ground and sent for further processing. **Site B** also performed mechanical separation of metals based on their magnetic properties. **Site D** processed discarded batteries and dry accumulators which were recycled using an enclosed dry process for crushing and grinding the products. The recovered metal fractions were sent for further processing. The material volume handled was the same in both years within each site but differed among the four sites. **Measures to reduce exposures:** Measures to reduce exposures to FRs were suggested after the first year's survey. The recyclers were asked to improve the maintenance of the ventilation at the sites. Particular attention was to be paid to the air pressure ratio between the factory shed and the adjacent restrooms, lunchrooms, or offices. Sorting and dismantling areas should be equipped with local exhaust ventilation or if possible with fume cupboards. Furthermore, cleaning of working areas should be stepped up by vacuum cleaning or wet brushing of floors and other surfaces instead of dry brushing. The workers at **Sites A and B** used 3M 9322 Protective Respirators (Berkshire, UK) during particularly dusty operations. At **Site C,** none of the workers used respirators, whereas four of the six workers at **Site D** used Clean-air Basic 2000 respirators (dual flow with HEPA P3 filter and full face mask; Birmingham, UK). The importance of the adequate use, maintenance, and storage of personal protective equipment was emphasized. The measurements were, however, all collected outside the respirator and therefore, the airborne concentrations represent the highest possible inhalation exposure." "None of Recyclers A, C, and D were able to install local exhaust ventilation or fume cupboards in the dismantling lines. At Site A, a full-time cleaner was employed and a new floor covering was laid facilitating cleaning. At site D, four of
		Finland WEEE recycling site B		0.03-1.1	µg /m^3	
		Finland WEEE recycling site C		nd-0.11	µg /m^3	
		Finland WEEE recycling site D		nd-0.047	µg /m^3	

Reference	Cross reference	Location	sampling strategy	results	unit	Comments / contextual information
						the six workers used Clean-air Basic respirators. Filters were installed for the exhaust air and care was taken not to recirculate the air from the work premises. A new, less dust creating feeder line to the crushing and grinding machine for sorted batteries and accumulators was installed. Effectiveness of the remedial actions was evident at Sites A and D in the results of the follow-up study in 2009. The mean levels of FRs in personal samples were 10–68%of those in 2008 at Site A. At Site D, the corresponding figures were 14–79% with the exception of the concentrations for HBCD, HBBe, and PBB. The concentrations of these compounds were below the LOQ in 2009. At Sites B and C, the reductions in FR exposures were less consistent"
Å. Bergman et al., Organohalogen Compd. 43 (1999) 89. [200]		Sweden, Recycling plant	" sampling as described by Sjodin et al."	0.0081-0.0585	μg /m^3	BFRs were not detected in ambient outdoor air. No details concerning RMMS and workplaces
J. Tollbäck et al., Chromatogr. A 1104 (2006) 106. [201]		Sweden; Dismantling hall electronics recycling plant	AirCheck 2000 personal air sampling pumps	0.0138	μg /m^3	No further details, publication mainly related to sampling technique.
EU RAR [3]	Sjödin et al., Environ. Sci. Technol., 2001, 35 (3), pp 448–454	Sweden; In the dismantling hall, where the outer casings were removed, static air samples	static samples	0.007 to 0.061	μg/m^3	"In a Swedish study (Sjodin et al., 2001) air concentrations of a range of brominated flameretardants at a factory that recycled electronic equipment such as computers, printers and TV sets were investigated. In the dismantling hall, where the outer casings were removed, static samples for TBBPA ranged from 0.007 to 0.061 µg/m3 (30 samples). In the shredding hall, where the internal parts of the equipment were ground up, the samplers were placed on a clean shelf 1.8 metres above the floor and about 2 metres from the conveyor belt taking the plastics to the shredder. This was meant to approximate to the operator's breathing zone. Sampling was divided into a day when no brominated flame retardant (bfr) material was shredded and a day when only bfr material was used. When bfr material was absent, TBBPA air concentrations were measured at 0.034 and 0.041µg/m3 (duplicate samples). On the day that brominated flame retardant material was used, TBBPA air concentrations were found to be 0.13 and 0.15 µg/m3."
		Sweden, In the shredding hall	static samples	0.034 - 0.041	μg/m^3	
		Sweden, In the shredding hall,	static samples	0.13 and 0.15 (0.034-0.041 if plastic without BRFs was shredded)	μg/m^3	
EU RAR (environment) [5]	Pettersson et al. (2001)	Sweden, electronics dismantling facility, removal area	air samples	0.012	μg/m^3	no further details available
		Sweden, electronics dismantling facility, dismantling hall	air samples	0.037	μg/m^3	

Reference	Cross reference	Location	sampling strategy	results	unit	Comments / contextual information
EU RAR [3] describing a HSE survey from 2002		Printed circuit board shredding site 1 / shredding operator	personal sampgling (lapel 1) / air	1.1	µg/m^3 (8h)	“HSE visited two sites that carry out computer recycling during 2002 and sampled for TBBPA. Most sites in the UK (around thirty) only dismantle electronic equipment and the circuit board shredding is restricted to about five UK sites. Virtually all the shredded circuit boards are the FR4 type – where the TBBPA has been reacted into the polymer. At the first company, the main activity was precious metal refining. As part of this process, old printed circuit boards were shredded prior to burning, and this represents the highest potential for TBBPA exposure. Old boards were transported in large fabric bags. The bags were slit at the bottom and the boards were manually fed onto an inclined conveyor that carried them to the shredder. The boards fell into the shredder and passed through to another conveyor, which fed them to a receiving bag. The receiving bag was fitted with LEV. When full (450 kg), the bag is removed and replaced. Periodically, the conveyor belt reversed to feed samples of the shredded material into a sample bin that provided material for analysis of the precious metal content. A single operator worked the shredder but the task was rotated and the shredder only operated periodically. The operator wore safety boots, gloves, helmet, safety glasses, and for dusty tasks, such as tying up the top of the full receiving bag and emptying the sampling bin, man FFP2 respirator was provided. There was a wide variation between the parallel lapel badges on the single shredder operator who worked a nine-hour shift, but both measured levels were below 1 µg/m3. The static values were lower because during much of their 24-hour running period, there was no shredder activity. At the second company, waste computers, printers and monitors were dismantled. Printed circuit boards were shredded and exported for the recovery of precious metals. Dismantling and shredding were performed in the same building. Dismantling is a manual operation using hammers and screwdrivers providing little potential for TBBPA exposure. Circuit boards were manually loaded from a hopper onto a conveyor belt that led to a shredder. Boards fell into a shredder and the shredded material emerged onto a vibration plate that directed it into a collection container. A portion of this material was periodically separated into a sampling bin. Samples of this bin were weighed into crucibles and burnt in small furnaces preparatory to precious metal analysis. The collection container was a large cardboard box, and the shredded material was manually raked to pack it down. A receptor hood for LEV was positioned directly above the container but the design and positioning was poor. Dust also escaped above the shredder and dust was visible on the floor round the shredder. Cleaning is by dry brushing – allowing resuspension of this dust. The shredder operator worked a full eight-hour shift when necessary. Expo-
		Printed circuit board shredding site 1 / shredding operator	personal sampgling (lapel 2)/ air	0.13	µg/m^3 (8h)	
		Printed circuit board shredding site 1 / shredding operator	personal sampgling (lapel 1) / air	1	µg/m^3 (9h shift)	
		Printed circuit board shredding site 1 / shredding operator	personal sampgling (lapel 2)/ air	0.12	µg/m^3 (9h shift)	
		Printed circuit board shredding site 1 / Shredder	Static / air	0.019	µg/m^3 (9h shift)	
		Printed circuit board shredding site 1 / Background of shredder	Static / air	0.013	µg/m^3 (9h shift)	
		Printed circuit board shredding site 2: shredding	personal	20.8	µg/m^3 (8h)	
		Printed circuit board shredding site 2: dismantling	personal	0.97	µg/m^3 (8h)	
		Printed circuit board shredding site 2: small furnace (sampling)	personal	13.45	µg/m^3 (8h)	
		Printed circuit board shredding site 2: peripatetic	personal	0.16	µg/m^3 (8h)	
		Printed circuit board shredding site 2: shredding	personal	20.8	µg/m^3 (9h shift)	

Reference	Cross reference	Location	sampling strategy	results	unit	Comments / contextual information
		Printed circuit board shredding site 2: shredding	static	0.095	μg/m^3 (9h shift)	sure results are shown in Table 4.5. The personal sampling period extended for more than four hours and was representative of the shift (nine hours) as a whole. The relatively high personal samples from the shredder operator and furnace operator at this second site represented dustier processes and a dirtier floor than was the case at the first site.”
		Printed circuit board shredding site 2: dismantling	personal	0.97	μg/m^3 (9h shift)	
		Printed circuit board shredding site 2: dismantling	static	0.022	μg/m^3 (9h shift)	
		Printed circuit board shredding site 2: small furnace (sampling)	personal	13.45	μg/m^3 (9h shift)	
		Printed circuit board shredding site 2: peripatetic	personal	0.16	μg/m^3 (9h shift)	
Mäkinen et al., 2009 [195]		Sweden, Electronics dismantling facilities	personal (air)	2.9 and 3.8	μg /m^3	no details concerning contextual information
			stationary (air)	0.090 and 0.720	μg /m^3	
			patches on clothing (dermal, chest, arm, thigh)	2.0 and 6.7	ng/cm^2	

Table 52: TBBPA and other brominated flame retardants in equipment with potential contact to food. TBBPA concentrations in the last column have been estimated assuming that the whole bromine content has been caused by TBBPA. [129]

	Sample	Colour	Main polymer	Detected monomers (pyrolysis GC-MS)	Macromolecular contamination	Br content (mg kg^{-1})	Detected BFRs	TBBPA (mg/kg)
1	Egg cutter	Black	PP/PE	4-Ethenyl-cyclohexene; styrene; α-methylstyrene; benzoic acid	HIPS/PBT or PET	57	TBBPA, decaBDE	97
2	Electric frying pan	Black	PBT	1,4-Butadiene; 4-ethenyl-cyclohexene; styrene; α-methylstyrene	HIPS or ABS or SAN	5975	TBBPA, DBDPE	10168
3	Apple cutter	Black	ABS	Methylmethacrylate	PMMA	279	TBBPA, DBDPE, BTBPE	475
4	Screwable part (thermo-cup cover)	Black	PP/PE	Styrene; α-methylstyrene	PS/PBT or PET	66	TBBPA, decaBDE	112

	Sample	**Colour**	**Main polymer**	**Detected monomers (pyrolysis GC-MS)**	**Macromolecular contamination**	**Br content (mg kg^{-1})**	**Detected BFRs**	**TBBPA (mg/kg)**
5	Movable lid (thermo-cup cover)	Black	ABS	Methylmethacrylate; benzoic acid	PMMA/PBT or PET	504	TBBPA, decaBDE	858
6	Screwable part (thermo-cup cover)	Black	PP/PE	Benzoic acid; 4-ethenyl-cyclohexene styrene; α-methylstyrene	PBT or PET HIPS or ABS or SAN	n.d.	n.d.	0
7	Screwable closure	Black	PP/PE	Benzoic acid; 4-ethenyl-cyclohexene;	PBT or PET HIPS or	62	TBBPA, decaBDE	106
8	Screwable part (thermo-cup cover)	Black	PP/PE	Benzoic acid; styrene; α-methylstyrene	PBT or PET PS	n.d.	n.d.	0
9	Screwable part (thermo-cup cover)	Black	ABS	Methylmethacrylate	PMMA PC PP	1521	TBBPA, decaBDE, DBDPE	2588
10	Screwable closure (thermo-cup cover)	Black	PP/PE	Methylmethacrylate; styrene; α-methylstyrene	PMMA PS PBT or PET	n.d.	n.d.	0

ENVIRONMENTAL EXPOSURE AND BIOTA

Table 53: TBBPA concentrations in environmental compartments related to WEEE treatment.

Reference	Cross reference	Location	Sampled medium	results	unit
Biota					
Zeng et al., 2014 [202]		China (e-waste site)	serum of mud-carp	1.6 (average)	ng/g ww
			serum of northern snakehead	2.9 (average)	ng/g ww
He et al., 2010 [203]		China (e-waste region)	birds	28.2-173	ng / g lipid weight
			fish	1.14	ng / g lipid weight
			grain	3.618	ng/g dw
			plant leaf	8.917	ng/g dw
water					
He et al., 2010 [203]		China (e-waste region)	water	68	pg/l
Sediment					
Hlouskova et al., 2014 [176]		Czech Republic, site 1 downstream incinerator	sediment (river)	< loq	
		Czech Republic, site 2 downstream hazardous waste incinerator	sediment (river)	4.23	ng/g dw
		Czech Republic, site 3 downstream incinerator	sediment (river)	not reported	
Huang et al., 2014 [204]		China (typical e-waste regions, locations in 9 villages)	pond sediments	0.48-1.74	ng/g dw
EU RAR [5]	Peltola J. (2002). An environmental screening of four brominated flame retardants in Finland. To be published in Chemosphere	Finland	sediment from stormwater trench of metal dismantling plant	21	ng/g dw
	Fjeld E., Schlabach M., Berge J. A., Eggen T., Snilsberg P., Källberg G., Rognerud S., Enke E. K., Borgwn A. and Gundersen H. (2004). Screening of selected new organic contaminants – brominated flame retardants, chlorinated paraffins,	Norway	sediment / soil from landfill sites and industrial sites	0.06-6.2	ng/g dw

Reference	Cross reference	Location	Sampled medium	results	unit
	bisphenol-A and trichlosan. Norsk Institutt for vannfoskning, 25th February 2004.				
	SFT (2002). Kartlegging av bromerte flammehemmere og klorerte parifiner. Rapport 866/02. Norwegian Pollution Control Authority.	Norway (effluent from waste dumps)	sediments	1.92-44.4 (6 of 6 samples)	ng/g ww
	Suzuki S. and Hasegawa A. (2006). Determination of hexabromocyclododecane diastereoisomers and tetrabromobisphenol-A in water and sediment by liquid chromatography/mass spectrometry. Anal. Sci., 22, 469-474.	Japan (industrial waste landfill sites)	sediments from landfill sites	<0.2-1.6	ng/g dw
Soil					
Tang et al., 2014 [205]		China (industrialised region)	soil (waste dumping sites, industrial area, residential area, traffic area, vegetable soil, farmland soil)	<0.025-78.6 (median 9.17)	ng/g dw
			only waste dumping site	9.91-43.1 (median 22.8)	ng/g dw
He et al., 2010 [203]		China (e-waste region)	soil	295	ng/g dw
Covaci et al., 2009 [37]	C. Yu, B. Hu, J. Chromatogr. A 1160 (2007) 71.	China	Near garbage discharge site	1400–1800	ng/g dw
Huang et al., 2014 [204]		China (typical e-waste regions, locations in 9 villages)	former open burning sites	21.19-182.04	ng/g dw
			dismantling sites	8.71-34.1	ng/g dw
			wasteland	1.3-7.92	ng/g dw
			paddy fields	0.85-5.6	ng/g dw
			vegetable fields	0.66-5.92	ng/g dw
Incineration / recycling residues					
EBRC 2011 [103]	Borgnes, D. & Rikheim, B. (2004). Emission measurements during incineration of waste containing Bromine. Final report on behalf of the Nordisk Ministerråd, Statens Forurensningstilsyn, Norsk Renholdsverks-forening, Elektronikkretur AS, Hvitevareretur AS, Stena Miljø AS, RENAS AS.	Japan	Bottom ash from incinerator for plastic waste	0.02	mg/kg
		Japan	Fly ash from incinerator for plastic waste	0.0013	mg/kg
		Norway / Klemetsrud Plant	Flue gas from incinerator (total bfrs measured)	14-22	ng/m^3
		Norway / Energos Plant	Flue gas from incinerator (total bfrs measured)	<5	ng/m^3

Reference	Cross reference	Location	Sampled medium	results	unit
		Norway / Klemetsrud Plant	Scrubber Water (untreated)	0.01	mg/l
		Norway / Energos Plant	Scrubber Water (untreated)	0	ng/l
		Norway / Klemetsrud Plant	Bottom ash from incinerator for plastic waste	0.034-0.1	mg/kg
		Norway / Energos Plant	Bottom ash from incinerator for plastic waste	<0.016	mg/kg
		Norway / Klemetsrud Plant	Filter dust	0.04	mg/kg
		Norway / Energos Plant	Filter dust	0	mg/kg
		Japan; Air emission from incinerator for plastic	air	8	ng /m^3
Hall and Williams, 2006 [206]			Pyrolysis residue / oil from pyrolysis of printed circuit boards	0 (mobile phones) 0.0013 (TV) 0.0006 (computers)	%
EU RAR [5]	Peltola J. (2002). An environmental screening of four brominated flame retardants in Finland. To be published in Chemosphere	Finland	bottom ash from municipal incinerators	< 0.0002	mg/kg
	Sakai S., Takahashi S., Osada M., Miyazaki T. (2006). Dioxin-related compounds, brominated flame retardants and heavy metals in automobile shredder residue (ASR) and their behavior in high-temperature melting process. Abstract from “DIOXIN, 2006”, Oslo, August 21-24, 2006.	Japan	automobile shredder residues	15	mg/kg

Table 54: TBBPA concentrations in environmental compartments not necessarily related to WEEE treatment. Examples.

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
STP sludge					
German Umweltbundesamt 2008 [46]	No cross references given		Sewage sludge	< 0,1 – 192	µg / kg dw
Mascolo et al., 2010 [207]		7 municipal STPs in Apulia, Italy	digested-dewatered and secondary excess sludge	<0.01 – 0.54 (DWS)	µg/kgdw
				<0.01 – 0.5 (SES)	
Hwang et al., 2012 [208]		Korea (N=7)	sludge of industrial stps	4.01-144	µg/kgdw
		Korea (N=4)	sludge of municipal stps	67.1-618	µg/kgdw
Gorga et al., 2013 [209]		Spain (17 wwtps)	sludge	ng-472	µg/kgdw
Law et al., 2006 [210]		Sweden (50 stps)	sludge	4-180 (mean 40)	µg/kgdw
Kuch et al., 2001 [211]		Germany	sludge	<0.2-34.45	µg/kgdw
Covaci et al., 2009 [37]	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	The Netherlands	Sewage sludge (influent)	<6.9	µg/kgdw
		The Netherlands	Sewage sludge (effluent)	42	µg/kgdw
		The Netherlands	Sewage sludge	79	µg/kgdw
		UK	Sewage sludge (influent)	7.5	µg/kgdw
		UK	Sewage sludge (effluent)	<3.9	µg/kgdw
		UK	Sewage sludge	57	µg/kgdw
		Cork, Ireland	Treated sludge	192	µg/kgdw
	K. Öberg, K. Warman, T. Oberg, Chemosphere 48 (2002) 805.	Sweden	Sewage sludge	<0.3–220	µg/kgdw
	C. de Wit, K. Nylund, U. Eriksson, A. Kierkegaard, L. Asplund, Organohalogen Compd. 69 (2007) 2686.	Sweden	Sewage sludge	32	µg/kgdw
	R.C. Brandli, T. Kupper, T.D. Bucheli, M. Zennegg, S. Huber, D. Ortelli, J. Muller, C. Schaffner, S. Iozza, P. Schmid, U. Berger, P. Edder, M. Oehme, F.X. Stadelman, J. Tarradellas, J. Environ. Monit. 9 (2007) 465.	Switzerland	Compost and digestate	510	µg/kgdw
	S. Chu, G.D. Haffner, R.J. Letcher, J. Chromatogr. A 1097 (2005) 25.	Ontario, Canada	Sewage sludge from wastewater treatment and pollution control plant	2.1–28.3	µg/kgdw
	J. Voordeckers, D. Fennell, K. Jones, M. Haggblom, Environ. Sci. Technol. 36 (2002) 696.	Montreal, Canada	Sewage sludge from wastewater	300	µg/kgdw

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
	H.B. Lee, T.E. Peart, Water Qual. Res. J. Canada 37 (2002) 681.	Canada	Sewage sludge from sewage treatment plants	<1–46.2	µg/kgdw
	H.B. Lee, T.E. Peart, Water Qual. Res. J. Canada 37 (2002) 681.	Southern Ontario, Canada	Sewage sludge	14.3–43.8	µg/kgdw
EU RAR [5]	Peltola J. (2002). An environmental screening of four brominated flame retardants in Finland. To be published in Chemosphere	Finland	Sewage sludge	< 0.2	µg/kgdw
	Öberg K., Warman K. and Öberg T. (2002). Distribution and levels of brominated flame retardants in sewage sludge. Chemosphere, 48, 805-809.	Sweden	Sewage sludge	< 0.3-220 (median 2) (1999-2000)	µg/kgww
	Metzger J. W. and Kuch B. (2003). Organic flame retardants in wastewater treatment plants. Chimia, 37, 24-26	Germany	Sewage sludge	0.6-62 (mean 16)	µg/kgdw
	de Boer J., Allchin C., Zegers B., Boon J. P., Brandsma S. H., Morris S., Kruijt A. W., van der Veen I., van Hesselingen J. M. and Haftka J. J. H. (2002). HBCD and TBBPA in sewage R402_0802_env 291 June 2007 sludge, sediments and biota, including interlaboratory study. RIVO Report No. C033/02. September 2002.	NL	Sewage sludge	2.1-600 (8 of 8 samples) (mean 79)	µg/kgdw
	Lee H-B. and Peart T. E. (2002). Organic contaminants in Canadian municipal sewage sludge. Part 1. Toxic or endocrine-disrupting phenolic compounds. Water Qual. Res. J. Canada, 37, 681-696.	Canada	Sewage sludge (raw and digested)	2.9-46.2 (median 12.4) (34 of 35 samples)	µg/kgdw
	Quade S. C., Alaee M., Marvin C., Hale R., Solomon K. R., Bunce N. J., and Fisk A. T. (2003). Determination of tetrabromobisphenol A in Detroit river sediment and sewage sludge. Dioxin 2003, Organohalogen Compounds, 62, 327-330.	Great Lakes area	Sewage sludge	14.3-43.8	µg/kgdw
	Saint-Louis R. and Pelletier E. (2004). LC-ESI-MS-MS Method for the analysis of tetrabromobisphenol A in sediment and sewage sludge. Analyst, 129, 724-730.	Canada	Sewage sludge	330 and 310	µg/kgdw
	Chu S., Haffner G. D. and Letcher R. J. (2005). Simultaneous determination of tetrabromobisphenol A, tetrachlorobisphenol A, bisphenol A and other halogenated analogues in sediment and sludge by high performance liquid chromatography-electrospray tandem mass spectrometry. J. Chromatogr. A, 1097, 25-32.	Canada	sewage sludge	2.09-28.3	µg/kgdw
Sediment					
German Umweltbundesamt	no cross reference given	freshwater	Sediment	< 0.1 – 270	µg / kg dw

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
2008 [46]					
Qu et al., 2013 [71]		China (Bohei Sea), near BFR manufacturing plant	sediment	<0.03-132	µg / kg
Vorkamp and Riget, 2014 [68]	De Wit, C., Herzke, D., Vorkamp, K., 2010. Brominated flame retardants in the Arctic – trends and new candidates. Sci. Total Environ. 408, 2885–2918., Frederiksen, M., Vorkamp, K., Bossi, R., Rigét, F., Dam, M., Svensmark, B., 2007. Method development for simultaneous analysis of HBCD, TBBPA in marine biota from Greenland and the F aroe Islands. Int. J. Environ. Anal. Chem. 87 (15), 1095– 1109., Bakke, T., Boitsov, S., Brevik, E.M., Gabrielsen, G.W., Green, N., Helgason, L.B., Klungsøyr, J., Leknes, H., Miljeteig, C., Måge, A., Rolfsnes, B.E., Savonova, T., Schlabach, M., Skaage, B.B., Valdersnes, S., 2008. Mapping selected organic contaminants in the Barents Sea 2007. SPFO-report 1021/2008, TA-2400/2008.	Arctic	marine sediments and a variety of biota samples	below detection limit	
de Wit et al., 2006 [212]	Fjeld, E., Schlabach, M., Berge, J.A., Eggen, T., Snilsberg, P., Ka¨llberg, G., Rognerud, S., Enge, E.K., Borgen, A., Gundersen, H., 2004. Kartlegging av utvalgte nye organiske miljøgifter –bromerte flammehemmere, klorerte parafiner, bisfenol A og trichlosan. Norsk institutt fo¨ r vannforskning (NIVA), Rapport 4809-2004, Oslo, Norway (in Norwegian). Available from: <http://www.nilu.no/index.cfm?ac=publications &folder_id=4309&publication_id=5203&view=rep>.	Norway	marine sediment	1.24	µg/kg dw
He et al., 2013 [213]		China (industrialised region)	sediments (N=42)	15.2 (n.d.-82.3)	µg/kg dw
			sediment cores 1 (N=19)	91.6 (7.9-450)	µg/kg dw
			sediment cores 2 (N=19)	2.9 (0.2-14)	µg/kg dw
Hlouskova et al., 2013 [214]		Czech republic (31 samples at different locations)	sediment	3.18-17.7 (median 4.23, mean 6.91)	µg/kg dw
Feng et al., 2012 [215]		China	sediment (Pearl river delta)	0.06–304	µg/kg dw
Zhang et al., 2009 [216]		China (heavily industrialised region)	15 surface sediments, 2 sediment cores (river)	3.8-230	µg/kg dw
Kuch et al., 2001 [211]		Germany	river sediments	0.17-1.83 (8 of 19 samples)	µg/kg dw
Covaci et al., 2009 [37]	I. Watanabe, T. Kashimoto, R. Tatsukawa, Bull. Environ. Contam. Toxicol 31 (1983) 48.	Neya River, Japan	Sediment	20	µg/kg dw

Reference	Cross reference	Location	Sampled medium	results	unit
	U. Sellström, B. Jansson, Chemosphere 31 (1995) 3085.	Sweden	Sediment downstream plastic factory	270	µg/kg dw
		Sweden	Sediment upstream plastic factory	34	µg/kg
	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	River Skerne, UK	Sediment close to BFR manufacturing site	9800	µg/kg dw
		River Tees, UK	Sediment	25	µg/kg dw
		Scheldt basin	Sediment	0.1–67	µg/kg dw
		Western Scheldt	Sediment	0.1–3.2	µg/kg dw
		Dutch rivers	Sediment	0.1–6.9	µg/kg dw
		UK rivers	Sediment	2–5	µg/kg dw
	S.C. Quade, M. Alaee, C. Marvin, R. Hale, K.R. Solomon, N.J. Bunce, A.T. Fisk, Organohalogen Compd. 62 (2003) 327.	Detroit River	Sediment	0.6–1.84	µg/kg dw
	M. Schlabach, E. Fjeld, H. Gundersen, E. Mariussen, G. Kjellberg, E. Breivik, Organohalogen Compd. 66 (2004) 3730.	Lakes Mjøsa, Losna Norway	Sediment	0.04–0.13	µg/kg dw
	S. Suzuki, A. Hasegawa, Anal. Sci. 22 (2006) 469.	Asia	Sediments	<0.2–1.6	µg/kg
EU RAR [5]	Kemmlein S. (2000). Polybromierte Flammschutzmittel: Entwicklung eines Analyseverfahrens und Untersuchung und Bewertung der Belastungssituation ausgewählter Umweltkompartimente. Fachberiech 06. Vorgelegt von Diplom-Chemikerin, Berlin.	Germany, Berlin area	Sediments from lakes and marine environment	n.-18.68	µg/kg dw
	Sellström U. and Jansson B. (1995). Analysis of tetrabromobisphenol A in a product and environmental samples. Chemosphere, 31, 3085-3092	Sweden (near plastics factory)	river sediments	34 upstream 270 downstream	µg/kg dw
	Heemken O. P., Kuballa J. and Stachel B. (2001). Flame retardants in sediments of the River Elbe. A first review and assessment. Poster presentation at Second International Workshop on Brominated Flame Retardants, May 14-16, Stockholm University, Sweden.	Germany (Elbe)	river sediments	0.5-4.6 (mean 2.5) (7 of 20 samples)	µg/kg dw
	Verslycke T. A., Vethaak A. D., Arijs K. and Janssen C. R. (2005). Flame retardants, surfactants and organotins in sediment and mysid shrimp of the Scheldt estuary (the Netherlands). Environ. Pollut., 136, 19-31.	Scheldt estuary	sediments	< 0.1	µg/kg dw
	CEFAS (2002). Sampling for priority chemicals in the environment. CEFAS Contract Report C1337 for Department of Environment, Food and Rural Affairs (DEFRA).	UK, near industrial areas	sediments	2.3 (1 of 50 samples)	µg/kg ww
	Peltola J. (2002). An environmental screening of four	Finland, Finnish gulf	sediments	< 0.2	µg/kg dw

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
	brominated flame retardants in Finland. To be published in Chemosphere				
		Finland, Helsinki (urban creek)	sediments	0.4	µg/kg dw
	Sternbeck J., Brorström-Lundén E., Remberger M., Kaj L., Palm A., Junedahl E. and Cato I. (2003). WFD Priority substances in sediments from Stockholm and the Svealand coastal region. IVL Report B1538, September 2003. Swedish Environmental Research Institute	Sweden	sediment (14 of 34 sites)	< 5	µg/kg dw
	Fjeld E., Schlabach M., Berge J. A., Eggen T., Snilsberg P., Källberg G., Rognerud S., Enke E. K., Borgwn A. and Gundersen H. (2004). Screening of selected new organic contaminants – brominated flame retardants, chlorinated paraffins, bisphenol-A and trichlosan. Norsk Institutt for vannfoskning, 25th February 2004.	Norway	sediment (Lakes)	0.04-0.13	µg/kg dw
			sediments (Drammens river)	0.2-10	µg/kg dw
			Drammensfjort	0.3-39	µg/kg dw
			marine sediments	0.01-2.4	µg/kg dw
	Chu S., Haffner G. D. and Letcher R. J. (2005). Simultaneous determination of tetrabromobisphenol A, tetrachlorobisphenol A, bisphenol A and other halogenated analogues in sediment and sludge by high performance liquid chromatography-electrospray tandem mass spectrometry. J. Chromatogr. A, 1097, 25-32.	Lake Erie	lake sediments	0.51 (detected in 3 of 46 samples, quantified in 1)	µg/kg dw
	Watanabe I., Kashimoto T. and Tatsukawa R. (1983a). Identification of the flame retardant tetrabromobisphenol-A in the river sediment and the mussel collected in Osaka. Bull. Environ. Contam. Toxicol., 31, 48-52.	japan (Osaka)	river sediments	20	µg/kg dw
	Watanabe I. and Tatsukawa R. (1989). Anthropogenic brominated aromatics in the Japanese environment. Proceedings of the Workshop on Brominated Aromatic Flame Retardants. Skokloster, Sweden, 24-26 October 1989. Swedish National Chemicals Inspectorate, pp63-71.	Japan (Osaka)	sediments (1981-1983)	0.5-140 (14 of 19 samples)	µg/kg dw
		Japan	sediments (1987)	20-150 (14 of 66 samples)	µg/kg dw
	Environment Agency Japan (1996). Chemicals in the Environment. Report on Environmental Survey and Wildlife Monitoring of Chemicals in F.Y. 1994. Environmental Health and Safety Division, Environment Agency Japan,	Japan	sediments (1977)	not detected (varying detection limits)	

Reference	Cross reference	Location	Sampled medium	results	unit
	May 1996				
			sediments (1988)	2-108 (20 of 130 samples)	µg/kg dw
	Ohta S., Nakao T., Nishimura H., Okumura T., Aozasa O. and Miyata H. (2002). Contamination levels of PBDEs, TBBPA, PCDDs/DFs, PBDDs/DFs and PXDDs/DFs in the environment of Japan. Organohalogen Compounds, 57, 57-60.	Japan (Osaka Bay)	sediments	0.68-12 (6 of 6 samples)	µg/kg dw
	Ohta S., Okumura T., Nishimura H., Nakao T., Aozasa O. and Miyata H. (2004b). Characterization of Japanese pollution by PBDEs, TBBPA, PCDDs/DFs, PBDDs/DFs and PXDD/DFs observed in the long-term stock-fishes and sediments. Abstract from “Third International Workshop on Brominated Flame Retardants, BFR2004”, University of Toronto, Canada, June 6-9, 2004.	Japan (Setouchi Sea)	sediments	0.08-5	µg/kg dw
	DeCarlo V. J. (1979). Studies on brominated chemicals in the environment. Annals N.Y. Acad. Sci., 320, 678-681.	US (Arkansas) near TBBPA manufacturing facilities	sediments	not given	µg/kg dw
	Zweidinger R. A., Cooper S. D. and Pellizzari E. D. (1979). Identification and quantification of brominated fire retardants. Measurements of Organic Pollutants in Water and Waste Water, ASTM STP 686. American Society for Testing and Materials, pp234-250.	US near brominated chemicals manufacturing sites	sediments (1977)	300-330000 (site A) nd-30 (site B)	µg/kg dw
	Quade S. C., Alaee M., Marvin C., Hale R., Solomon K. R., Bunce N. J., and Fisk A. T. (2003). Determination of tetrabromobisphenol A in Detroit river sediment and sewage sludge. Dioxin 2003, Organohalogen Compounds, 62, 327-330.	Canada (Detroit river and Trenton Canal)	sediments (2000)	0.6-1.84	µg/kg dw
	SFT (2002). Kartlegging av bromerte flammehemmere og klorerte parifiner. Rapport 866/02. Norwegian Pollution Control Authority.	Norway (effluent from waste dumps)	sediments	1.92-44.4 (6 of 6 samples)	µg/kg ww
	Suzuki S. and Hasegawa A. (2006). Determination of hexabromocyclododecane diastereoisomers and tetrabromobisphenol-A in water and sediment by liquid chromatography/mass spectrometry. Anal. Sci., 22, 469-474	Japan (industrial waste landfill sites)	sediments from landfill sites	<0.2-1.6 (2004)	µg/kg dw
		Japan	marine sediments	5.5	µg/kg dw
air					
Vorkamp and Riget, 2014 [68]	Xie, Z.Y., Ebinghaus, R., Lohman, R., Heemken, O., Caba, A., Püttmann, W., 2007a. Trace determination of the flame retardant tetrabromobisphenol A in the atmosphere by gas chromatography–mass spectrometry. Anal.	Arctic	air	detected	

Reference	Cross reference	Location	Sampled medium	results	unit
	Chim. Acta 584, 333–342.				
Covaci et al., 2009 [37]	Å. Bergman, M. Athanasiadou, E. Klasson Wehler, A. Sjödin, Organohalogen Compd. 43 (1999) 89.	Sweden	Computer office	0.035	ng/m^3
	Å. Bergman, M. Athanasiadou, E. Klasson Wehler, A. Sjödin, Organohalogen Compd. 43 (1999) 89.	Sweden	Outdoor air	<LOD	ng/m^3
	A. Sjödin, H. Carlsson, K. Thuresson, S. Sjolin, A. Bergman, C. Ostman, Environ. Sci. Technol. 35 (2001) 448.	Sweden	Computer office	0.036	ng/m^3
	A. Sjödin, H. Carlsson, K. Thuresson, S. Sjolin, A. Bergman, C. Ostman, Environ. Sci. Technol. 35 (2001) 448.	Sweden	Teaching hall	0.093	ng/m^3
	A. Sjödin, H. Carlsson, K. Thuresson, S. Sjolin, A. Bergman, C. Ostman, Environ. Sci. Technol. 35 (2001) 448.	Sweden	Computer repair facility	0.035	ng/m^3
	A. Sjödin, H. Carlsson, K. Thuresson, S. Sjolin, A. Bergman, C. Ostman, Environ. Sci. Technol. 35 (2001) 448.	Sweden	Outdour air	<LOD	ng/m^3
	K. Inoue, S. Yoshida, S. Nakayama, R. Ito, N. Okanouchi, H. Nakazawa, Arch. Environ. Contam. Toxicol. 51 (2006) 503.	Japan	Indoor air microenvironments	0.200	ng/m^3
	H. Takigami, G. Suzuki, Y. Hirai, S. Sakai, Organohalogen Compd. 69 (2007) 2785.	Japan	Outdoor air	0.0071–0.0095	ng/m^3
	H. Takigami, G. Suzuki, Y. Hirai, S. Sakai, Organohalogen Compd. 69 (2007) 2785.	Japan	Indoor air house	0.009–0.016	ng/m^3
	Z. Xie, R. Ebinghaus, R. Lohmann, O. Heemken, A. Cabaa, W. Puttmann, Anal. Chim. Acta 584 (2007) 333.	Northern Germany	Outdoor air rural site	<0.00004–0.00085	ng/m^3
		Wadden Sea	Outdoor air	0.00031–0.00069	ng/m^3
		Northeast Atlantic	Outdoor air	<0.00004–0.00017	ng/m^3
	M. Alaee, D. Muir, C. Cannon, P. Helm, T. Harner, T. Bidleman, Contam. Assess. 1 Rep. 2 (2003) 116.	Arctic, Russia	Outdoor air	0.070	ng/m^3
Mäkinen et al. (2009) [195]		Sweden, circuit board factory	personal air sample	<10	ng/m^3
			stationary air sample	<3	ng/m^3
		Sweden, Furniture workshop	personal air sample	<10	ng/m^3
			stationary air sample	<6	ng/m^3
		Sweden, Computer classroom	stationary air sample	< 6	ng/m^3

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
		Sweden, Offices at circuit board factory, furniture workshop, dismantling facility and social premises at sites	stationary air sample	< 6	ng/m^3
EU RAR [5]	Zweidinger R. A., Cooper S. D., Erickson M. D., Michael L. C. and Pellizzari E. D. (1977). Sampling and analysis for semivolatile brominated organics in ambient air. Monitoring Toxic Substances. ACS Symposium Series No. 94, pp217-231.Zweidinger R. A., Cooper S. D. and Pellizzari E. D. (1979). Identification and quantification of brominated fire retardants. Measurements of Organic Pollutants in Water and Waste Water, ASTM STP 686. American Society for Testing and Materials, pp234-250	US	particulates in outdoor air at organobromine chemical production facilities	< 10-28 and < 10-1800	ng/m^3
	DeCarlo V. J. (1979). Studies on brominated chemicals in the environment. Annals N.Y. Acad. Sci., 320, 678-681.	US, Arkansas	air particulates	detected (no value given)	
	Sjödin A., Carlsson H., Thuresson K., Sjölin S., Bergman Å. and Östman C. (2001). Flame retardants in indoor air at an electronics recycling plant and at other work environments. Environ. Sci. Technol., 35, 448-454	Sweden	air at circuit board factory	0.11-0.37	ng/m^3
			air at offices with computers	0.01-0.070	ng/m^3
			air at computer repair facility	0.031-0.038	ng/m^3
	Kemmlein S. (2000). Polybromierte Flammschutzmittel: Entwicklung eines Analyseverfahrens und Untersuchung und Bewertung der Belastungssituation ausgewählter Umweltkompartimente. Fachberiech 06. Vorgelegt von Diplom-Chemikerin, Berlin.	Germany	air in offices with computers	0.029 and 0.008	ng/m^3
	Inoue K., Yoshida S., Kawaguchi M., Ito R., Nakayama S. and Nakazawa H. (2003). Tetrabromobisphenol A and phenolic xeno-estrogen levels in indoor air. Dioxin 2003, Organohalogen Compounds, 61, 171-174	Japan	houses	0.1-1.1	ng/m^3
	de Wit (2000). Brominated flame retardants. Swedish Environmental Protection Agency Report 5065. de Wit C. A. and Muir D. C. G. (2004). Levels and trends of brominated flame retardants in the Arctic. Abstract from “Third International Workshop	Russian Arctic	air filter sample	0.070	ng/m3

Reference	Cross reference	Location	Sampled medium	results	unit
	on Brominated Flame Retardants, BFR2004", University of Toronto, Canada, June 6-9, 2004.				
Soil					
EU RAR [5]	Ronen Z. and Abeliovich A. (2000). Anaerobic-aerobic process for microbial degradation of tetrabromobisphenol A. Appl. Environ. Microbiol., 66, 2372-2377.	Israel (contaminated site) (1999)	soil	450000	ng/g
	DeCarlo V. J. (1979). Studies on brominated chemicals in the environment. Annals N.Y. Acad. Sci., 320, 678-681.	US (near tbbpa manufacturing sites) Arkansas	soil	no value given but detected	ng/g dw
	Jin J., Peng H., Wang Y., Yang R. and Cui J. (2006). An enhanced LC/MS/MS method for the determination of tetrabromobisphenol-A (TBBPA) in soil using the Quattro premier mass spectrometer. Abstract from "DIOXIN, 2006", Oslo, August 21-24, 2006.	China (outside TBBPA production plant)	soil	0.12	ng/g ww
	Brändli R. C., Bucheli T. D., Kupper T., Zennegg M., Berger U., Edder P., Oehme M., Müller J., Schaffner C., Furrer R., Schmid P., Huber S., Ortelli D., Iozza S., Stadelmann F. X. and Tarradellas J. (2006). Organic pollutants in source-separated compost. Abstract from "DIOXIN, 2006", Oslo, August 21-24, 2006	Switzerland	compost derived from kitchen and green waste	0.1-2.3 (median 0.51)	ng/g dw
Zhu et al., 2014 [217]		China (BFR manufacturing region)	agricultural soil	672 (mean)	ng/g
German Umweltbundesamt 2008 [46]	no cross reference given.		soil	< 0.1	ng/g dw
Covaci et al., 2009 [37]	H. Peng, J. Jin, Y. Wang, W.Z. Liu, R.M. Yang, Chin. J. Anal. Chem. 35 (2007) 549.	China	Soil	25.2 ± 2.7	ng/g
water					
Labadie et al., 2010 [218]		France	water (river near Paris)	< 0.035-0.068	ng/l
German Umweltbundesamt 2008 [46]	no cross reference given.		surface water (freshwater)	< 1 – 20	ng/l
Kuch et al., 2001 [211]		Germany	STP effluents	0.62 - 25, mostly below 10 (also TBBPA-Me and TBBPA-M2 were measured)	ng/l
			receiving waters	0.81-20.4 (detected in 4 of 15 samples)	ng/l

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
Covaci et al., 2009 [37]	S. Suzuki, A. Hasegawa, Anal. Sci. 22 (2006) 469.	Japan	Before treatment plant	130	ng/l
	S. Suzuki, A. Hasegawa, Anal. Sci. 22 (2006) 469.	Japan	After treatment plant	7	ng/l
	M. Osako, Y.J. Kim, S.I. Sakai, Chemosphere 57 (2004) 1571.			<LOD −11	ng/l
Potvin et al., 2012 [219]		Canada	influent and effluent of STP, City of Guelph, Ontario	influent 13, 25, 29	ng/l
				effluent < 0.1, 2.2, < 0.1	
He et al., 2013 [213]		China (industrialised region)	water dissolved (N=5)	1.750 (1.110-2.830)	ng/l
			water particulate (N=5)	1.3 (n.d.-1.6)	ng/g dw
EU RAR [5]	Peltola J. (2002). An environmental screening of four brominated flame retardants in Finland. To be published in Chemosphere	Finland	creek water	< 200	ng/l
	de Boer J., Allchin C., Zegers B., Boon J. P., Brandsma S. H., Morris S., Kruijt A. W., van der Veen I., van Hesselingen J. M. and Haftka J. J. H. (2002). HBCD and TBBPA in sewage R402_0802_env 291 June 2007 sludge, sediments and biota, including interlaboratory study. RIVO Report No. C033/02. September 2002	NL	particulate phase STPs , influent	not found	
			particulate phase STPs , effluent	3.1-63 (mean 42)	microg/kg dw
		UK	influent of STPs (dissolved)	detected in 4 of 5 influent samples; 2.6-85.2	ng/l
			influent of STPs (particulate)	detected in 1 of 5 samples; 21.7	microg/kg dw
			effluent of STPs	not detected	
	Kuch B., Körner W. and Hagenmaier H. (2001). Monitoring von bromierten Flammschutzmitteln in Fliessgewässern, Abwässern und Klärschlämmen in Baden-Würtemberg. Abschlissbericht des BWPlus-Forschungsvorhabens BWBO 99-11.	Germany	influent of STPs (dissolved)	0.86-17.4 (5 of 5 samples)	ng/l
			influent of STPs (particulate)	not detected	
	Watanabe I. and Tatsukawa R. (1989). Anthropogenic brominated aromatics in the Japanese environment. Proceedings of the Workshop on Brominated Aromatic Flame Retardants. Skokloster, Sweden, 24-26 October 1989. Swedish National Chemicals Inspectorate, pp63-	Japan (industrialised and not-industrialised areas)	river, lake and marine surface waters	50 (1 of 75 samples)	ng/l

Reference	Cross reference	Location	Sampled medium	results	unit
	71.				
	Environment Agency Japan (1996). Chemicals in the Environment. Report on Environmental Survey and Wildlife Monitoring of Chemicals in F.Y. 1994. Environmental Health and Safety Division, Environment Agency Japan, May 1996.	Japan	surface waters (15 samples 1977, 150 samples in 1988)	< (20-40) (1977) <40 (1988)	ng/l
	Peters R. J. B. (2003). Hazardous Chemicals in Precipitation. TNO-Report R 2003/198, Netherlands Organisation for Applied Scientific Research	NL, Germany, Belgium	deposition in open sample collectors	maximum 2.6 , mean 1.1, median 0.9 (detected in 16% of samples)	ng/l
	Duyzer J. H. and Vonk A. W. (2002). Atmosferische depositie van pesticiden, PAK en PCB's in Nederland. TNO Report R2002/606, October 2002 (as reported in Peters, 2003).	NL	precipitation samples	detected in 50% of samples, max 4.1	ng/l
	Almqvist H. and Hanæus J. (2006). Organic hazardous substances in graywater from Swedish households. J. Environ. Eng., 132, 901-908.	Sweden	Graywater (household wastewater without input from toilets)	< 5	ng/l
Biota[60]					
Various					
Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment, Volume 25, Issue 7, July 2008, Pages 895-903 . Determination of brominated flame retardants in food by LC-MS/MS: Diastereoisomer-specific hexabromocyclododecane and tetrabromobisphenol A , Driffield, M., Harmer, N.a, Bradley, E., Fernandes, A.R., Rose, M., Mortimer, D.B, Dicks, P. (information from abstract)		Scotland	shell fish and oysters	below level of detection (0.05)	µg / kg

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[60] Various further values not listed here are given in the EU risk assessment for the environment, Table 3.49

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
International Journal of Environmental Analytical Chemistry. Volume 87, Issue 15, 2007. Method development for simultaneous analysis of HBCD, TBBPA, and dimethyl-TBBPA in marine biota from Greenland and the Faroe Islands. Method development for simultaneous analysis of HBCD, TBBPA, and dimethyl-TBBPA in marine biota from Greenland and the Faroe Islands. Marie Frederiksen, Katrin Vorkamp, Rossana Bossi, Frank Rigét, Maria Dam & Bo Svensmark pages 1095-1109 (information from abstract)		Greenland/Faroe islands	egg, liver, adipose tissue of marine biota	below level of detection	
Vorkamp and Riget, 2014 [68]	Evenset, A., Leknes, H., Christensen, G.N., Warner, N., Remberger, M., Gabrielsen, G.W., 2009. Screening of new contaminants in samples from the Norwegian Arctic. Akvaplan-niva report 4351-1. Schlabach, M., Remberger, M., Brorström-Lunden, E., Herzke, D., 2011. Brominated Flame Retardants (BFR) in the Nordic environment. TemaNord 2011, 528.	Arctic	wet weight biota	<0.03-<3.3	ng/g ww
		Svalbard, Faroe Islands and Iceland	fish, bird eggs and mussels	below detection limit	
de Wit et al., 2006 [212]	Schlabach, M., Mariussen, E., Borgen, A., Dye, C., Enge, E.-K., Steinnes, E., Green, N., Mohn, H., 2002. Kartlegging av bromerte flammehemmere og klorerte parafiner. Norsk institutt fo¨ r luftforskning (NILU), Kjeller, Norway, Rapport 62/2002, p. 71 (in Norwegian). Available from: http://www.nilu.no/index.cfm?ac=publications&folder_id=4309&publication_id=3221&view= rep>.	Norway	vegetation, moss	0.019-0.14	ng/g ww
EFSA, 2011 [52]	various	NL, Be, Greenland, No, UK, Scotland, China	fish + crustacea	< 0.005-245	ng/g fat
Invertebrates					
Covaci et al., 2009 [37]	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	North Sea	Common whelk (Whole)	5.0–96	ng/g lw
		Scheldt estuary	Sea star (Whole)	<1–2	ng/g lw
		Tees estuary	Sea star (Whole)	205	ng/g lw

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
		North Sea	Hermit crab (Whole)	<1–35	ng/g lw
	T.A. Verslycke, A.D. Vethaak, K. Arijs, C.R. Janssen, Environ. Pollut. 136 (2005) 19.	Scheldt estuary	Mysid (Whole)	0.8–0.9	ng/g lw
Umweltbundesamt 2008 [46]		estuary, UK	sea star,	4,5	µg / kg ww
		north sea	hermit crab,	< 1 - 35	µg / kg fat
Fish					
Umweltbundesamt 2008 [46]	No cross references given.	Germany, Berlin	freshwater eel	0.045 – 0.10	µg / kg ww
		Mjøsa lake, Norway	fish	0.01 – 0.18	µg / kgww
		Norway	Codfish, liver	0.35 – 1.73	µg / kg ww
		north sea	white fish, filet	97 -245	µg / kg fat
		UK	common porpoise, blubber	12936	µg / kg ww
de Wit et al., 2006 [212]	Fjeld, E., Schlabach, M., Berge, J.A., Eggen, T., Snilsberg, P., Ka¨llberg, G., Rognerud, S., Enge, E.K., Borgen, A., Gundersen, H., 2004. Kartlegging av utvalgte nye organiske miljøgifter -bromerte flammehemmere, klorerte parafiner, bisfenol A og trichlosan. Norsk institutt fo¨ r vannforskning (NIVA), Rapport 4809-2004, Oslo, Norway (in Norwegian). Available from: <http://www.nilu.no/index.cfm?ac=publications &folder_id=4309&publication_id=5203&view=rep>.	Norway and Lofoten	cod liver	0.5-2.5	ng/g lw
Johnson-Restrepo et al., 2008 [194]		US (Florida)	tissues of bull sharks (muscle)	0.035–35.6	ng/g lw
			tissues of atlantic sharpnosesharks (muscle)	0.495–1.43	ng/g lw
Mchugh et al., 2010 [220]		Ireland	european eel (Anguilla anguilla), muscle	not above limit of detection	
	Santillo, D., Johnston, P., Labunska, I., Brigden, K., 2005. Widespread Presence of Brominated Flame Retardants and PCBs in Eels (Anguilla anguilla) from Rivers and Lakes in 10 European Countries. Greenpeace Research Laboratories Technical Note 12:56.			not above limit of detection	
	Food Standards Agency 2006. Brominated Chemicals in Farmed and Wild Fish and Shellfish and Fish Oil Dietary Supplements. <http://www.food.gov.uk>.		fishery products	not above limit of detection	

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
He et al., 2013 [213]	Harrad, S., Abdallah, M.A., Rose, N.L., Turner, S.D., Davidson, T.A., 2009. Current-use brominated flame retardants in water, sediment, and fish from English lakes. Environmental Science & Technology 43, 9077e9083.	UK	fish samples	< 2	ng/g
		China (industrialised region)	mud carp (N=9)	35.2 (6.5-66)	ng/g lw
		China (industrialised region)	nile tilapia (N=15)	18.1 (nd-51)	ng/g lw
		China (industrialised region)	plecostomus (N=10)	21.2 (nd-53.4)	ng/g lw
Hlouskova et al., 2013 [214]		Czech republic (48 samples)	fish samples	0.14-4.43	µg/kg ww
Webster et al., 2009 [221]		Scotland	deep water fish (marine)	below level of detection	
Covaci et al., 2009 [37]	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	North Sea	Whiting Muscle	<97 to 245 (mean 136)	ng/g lw
		North Sea	Cod Liver	<0.3–1.8	ng/g lw
		Atlantic	Hake Liver	<0.2	ng/g lw
		Scheldt estuary	Eel Muscle	<0.1–13 (mean 1.6)	ng/g lw
		Dutch rivers	Eel Muscle	<0.1–1.3 (mean 0.3)	ng/g lw
		Scheldt basin	Yellow eel Muscle	<0.1–2.1	ng/g lw
		Dutch rivers	Yellow eel Muscle	<0.1–1.0	ng/g lw
	M. Schlabach, E. Fjeld, H. Gundersen, E. Mariussen, G. Kjellberg, E. Breivik, Organohalogen Compd. 66 (2004) 3730.	Norway	Perch, pike, smelt, vendace, trout Muscle	1.0–13.7	ng/g lw
	E. Fjeld, M. Schlabach, J.A. Berge, T. Eggen, P. Snilsberg, G. Källberg, S. Rognerud, E.K. Enge, A. Borgen, H. Gundersen, Kartlegging av utvalgte nye organiske miljøgifter-bromerte flammehemmere, klorerte parafiner, bisfenol A og trichlosan. Norsk institutt för vannforskning (NIVA), Rapport 4809- 2004, Oslo, Norway (in Norwegian), 2004 (available from http://www.nilu.no).	Norway	Atlantic cod Muscle	0.5 and 2.5	ng/g lw
Birds					
German Umweltbundesamt	no cross reference given	UK	cormorant, liver	0.07-10.9	µg / kgww

Reference	**Cross reference**	**Location**	**Sampled medium**	**results**	**unit**
2008 [46]		Norway	birds of prey, eggs,	< 0.004 – 0.013	µg / kg ww
Eulaers et al., 2014 [222]		Belgium	barn owl tissues (muscle, liver, adipose and preen gland) and feathers	0.4-6.06	ng/g dw feathers
		France	barn owl tissues (muscle, liver, adipose and preen gland) and feathers	0.36-7.07	ng/g dw feathers
von der Trenck et al., 2007 [223]		23 eggs (pelegrine) from Baden-Würthemberg, Germany	Pelegrine eggs	0.004	µg/g lw
Vorkamp and Riget, 2014 [68]	Vorkamp, K., Thomsen, M., Falk, K., Leslie, H., Møller, S., Sørensen, P.B., 2005. Temporal development of brominated flame retardants in peregrine falcon (Falco peregrinus) eggs from South Greenland (1986–2003). Environ. Sci. Technol. 39, 8199–8206.	Greenland	eggs of pelegrines	TBBPA undetectable, but dimethyl TBBPA detected in 88% of samples, 380 (<0.1–940 (diMe-TBBPA))	ng/g lw
Covaci et al., 2009 [37]	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	Western Scheldt	Common tern Egg	<2.9	ng/g lw
	D. Herzke, U. Berger, R. Kallenborn, T. Nygard, W. Vetter, Chemosphere 61 (2005) 441.	Norway	Peregrine falcon, White-tailed sea eagle, Osprey, Golden eagle, Egg	<0.003–0.013	ng/g lw
	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	Wales and England	Cormorant Liver	2.5–14	ng/g lw
Marine mammals					
Johnson-Restrepo et al., 2008 [194]		US (Florida)	tissues of dolphins (blubber)	1.2-83	ng/g lw
Covaci et al., 2009 [37]	S. Morris, C.R. Allchin, B.N. Zegers, J.J.H. Haftka, J.P. Boon, C. Belpaire, P.E.G. Leonards, S.P.J. van Leeuwen, J. de Boer, Environ. Sci. Technol. 38 (2004) 5497.	Wadden Sea	Harbour seal Blubber	<14	ng/g lw
		North Sea	Harbour porpoise Blubber	<11	ng/g lw
		North Sea	Harbour porpoise Blubber	0.1–418	ng/g lw
		Tyne/Tees	Harbour porpoise Blubber	0.31	ng/g lw
	R.J. Law, P. Bersuder, C. Allchin, J. Barry, Environ. Sci. Technol. 40 (2006) 2177.	UK	Harbour porpoise Blubber	6–35	ng/g lw

APPENDIX C: ENVIRONMENTAL EXPOSURE MODELLING – EUSES EXPORT FILES

KOC = 147360 L/KG

STUDY		
STUDY IDENTIFICATION		
Study name		S
Study description		D
Author		D
Institute		D
Address		D
Zip code		D
City		D
Country		D
Telephone		D
Telefax		D
Email		D
Calculations checksum	ED3500F2	S

DEFAULTS

DEFAULT IDENTIFICATION

General name	Standard Euses 2.1		D
Description	According to TGDs		D

CHARACTERISTICS OF COMPARTMENTS

GENERAL

Density of solid phase	2.5	[kg.l-1]	D
Density of water phase	1	[kg.l-1]	D
Density of air phase	1.3E-03	[kg.l-1]	D
Environmental temperature	12	[oC]	D
Standard temperature for Vp and Sol	25	[oC]	D
Temperature correction method	Temperature correction for local distribution		D
Constant of Junge equation	0.01	[Pa.m]	D
Surface area of aerosol particles	0.01	[m2.m-3]	D
Gas constant (8.314)	8.314	[Pa.m3.mol-1.K-1]	D

SUSPENDED MATTER

Volume fraction solids in suspended matter	0.1	[m3.m-3]	D
Volume fraction water in suspended matter	0.9	[m3.m-3]	D
Weight fraction of organic carbon in suspended matter	0.1	[kg.kg-1]	D
Bulk density of suspended matter	1.15E+03	[kgwwt.m-3]	O
Conversion factor wet-dry suspened matter	4.6	[kgwwt.kgdwt-1]	O

SEDIMENT

Volume fraction solids in sediment	0.2	[m3.m-3]	D
Volume fraction water in sediment	0.8	[m3.m-3]	D
Weight fraction of organic carbon in sediment	0.05	[kg.kg-1]	D

SOIL

Volume fraction solids in soil	0.6	[m3.m-3]	D
Volume fraction water in soil	0.2	[m3.m-3]	D
Volume fraction air in soil	0.2	[m3.m-3]	D
Weight fraction of organic carbon in soil	0.02	[kg.kg-1]	D
Weight fraction of organic matter in soil	0.034	[kg.kg-1]	O
Bulk density of soil	1.7E+03	[kgwwt.m-3]	O
Conversion factor wet-dry soil	1.13	[kgwwt.kgdwt-1]	O

STP SLUDGE

Fraction of organic carbon in raw sewage sludge	0.3	[kg.kg-1]	D
Fraction of organic carbon in settled sewage sludge	0.3	[kg.kg-1]	D
Fraction of organic carbon in activated sewage sludge	0.37	[kg.kg-1]	D
Fraction of organic carbon in effluent sewage sludge	0.37	[kg.kg-1]	D

DEGRADATION AND TRANSFORMATION RATES

Rate constant for abiotic degradation in STP	0	[d-1]	D
Rate constant for abiotic degradation in bulk sediment	0	[d-1] (12[oC])	D
Rate constant for anaerobic biodegradation in sediment	0	[d-1] (12[oC])	D
Fraction of sediment compartment that is aerated	0.1	[m3.m-3]	D
Concentration of OH-radicals in atmosphere	5E+05	[molec.cm-3]	D
Rate constant for abiotic degradation in bulk soil	0	[d-1] (12[oC])	D

RELEASE ESTIMATION

Fraction of EU production volume for region	10	[%]	S
Fraction of EU tonnage for region (private use)	10	[%]	D
Fraction connected to sewer systems	80	[%]	D

SEWAGE TREATMENT

GENERAL

Number of inhabitants feeding one STP	1E+04	[eq]	D
Sewage flow	200	[l.eq-1.d-1]	D
Effluent discharge rate of local STP	2E+06	[l.d-1]	O
Temperature correction for STP degradation	No		D
Temperature of air above aeration tank	15	[oC]	D
Temperature of water in aeration tank	15	[oC]	D
Height of air column above STP	10	[m]	D
Number of inhabitants of region	2E+07	[eq]	D
Number of inhabitants of continental system	3.5E+08	[eq]	O
Windspeed in the system	3	[m.s-1]	D

RAW SEWAGE

Mass of O2 binding material per person per day	54	[g.eq-1.d-1]	D
Dry weight solids produced per person per day	0.09	[kg.eq-1.d-1]	D
Density solids in raw sewage	1.5	[kg.l-1]	D
Fraction of organic carbon in raw sewage sludge	0.3	[kg.kg-1]	D

PRIMARY SETTLER

Depth of primary settler	4	[m]	D
Hydraulic retention time of primary settler	2	[hr]	D
Density suspended and settled solids in primary settler	1.5	[kg.l-1]	D
Fraction of organic carbon in settled sewage sludge	0.3	[kg.kg-1]	D

ACTIVATED SLUDGE TANK

Depth of aeration tank	3	[m]	D
Density solids of activated sludge	1.3	[kg.l-1]	D
Concentration solids of activated sludge	4	[kg.m-3]	D
Steady state O2 concentration in activated sludge	2E-03	[kg.m-3]	D
Mode of aeration	Surface		D
Aeration rate of bubble aeration	1.31E-05	[m3.s-1.eq-1]	D
Fraction of organic carbon in activated sewage sludge	0.37	[kg.kg-1]	D
Sludge loading rate	0.15	[kg.kg-1.d-1]	D
Hydraulic retention time in aerator (9-box STP)	6.9	[hr]	O
Hydraulic retention time in aerator (6-box STP)	10.8	[hr]	O
Sludge retention time of aeration tank	9.2	[d]	O

SOLIDS-LIQUIDS SEPARATOR

Depth of solids-liquid separator	3	[m]	D
Density suspended and settled solids in solids-liquid separator	1.3	[kg.l-1]	D
Concentration solids in effluent	30	[mg.l-1]	D
Hydraulic retention time of solids-liquid separator	6	[hr]	D
Fraction of organic carbon in effluent sewage sludge	0.37	[kg.kg-1]	D

LOCAL DISTRIBUTION

AIR AND SURFACE WATER

Concentration in air at source strength 1 [kg.d-1]	2.78E-04	[mg.m-3]	D
Standard deposition flux of aerosol-bound compounds	0.01	[mg.m-2.d-1]	D
Standard deposition flux of gaseous compounds	4E-04	[mg.m-2.d-1]	O
Suspended solids concentration in STP effluent water	15	[mg.l-1]	D
Dilution factor (rivers)	10	[-]	D
Flow rate of the river	1.8E+04	[m3.d-1]	D
Calculate dilution from river flow rate	No		D
Dilution factor (coastal areas)	100	[-]	D

SOIL

Mixing depth of grassland soil	0.1	[m]	D
Dry sludge application rate on agricultural soil	5E+03	[kg.ha-1.yr-1]	D
Dry sludge application rate on grassland	1000	[kg.ha-1.yr-1]	D
Averaging time soil (for terrestrial ecosystem)	30	[d]	D
Averaging time agricultural soil	180	[d]	D
Averaging time grassland	180	[d]	D
PMTC, air side of air-soil interface	1.05E-03	[m.s-1]	O
Soil-air PMTC (air-soil interface)	5.56E-06	[m.s-1]	D
Soil-water film PMTC (air-soil interface)	5.56E-10	[m.s-1]	D
Mixing depth agricultural soil	0.2	[m]	D
Fraction of rain water infiltrating soil	0.25	[-]	D
Average annual precipitation	700	[mm.yr-1]	D

REGIONAL AND CONTINENTAL DISTRIBUTION

CONFIGURATION

Fraction of direct regional emissions to seawater	1	[%]	D
Fraction of direct continental emissions to seawater	0	[%]	D
Fraction of regional STP effluent to seawater	0	[%]	D
Fraction of continental STP effluent to seawater	0	[%]	D
Fraction of flow from continental rivers to regional rivers	0.034	[-]	D
Fraction of flow from continental rivers to regional sea	0	[-]	D
Fraction of flow from continental rivers to continental sea	0.966	[-]	O
Number of inhabitants of region	2E+07	[eq]	D
Number of inhabitants in the EU	3.7E+08	[eq]	D
Number of inhabitants of continental system	3.5E+08	[eq]	O

AREAS

REGIONAL

Area (land+rivers) of regional system	4E+04	[km2]	D
Area fraction of freshwater, region (excl. sea)	0.03	[-]	D
Area fraction of natural soil, region (excl. sea)	0.27	[-]	D
Area fraction of agricultural soil, region (excl. sea)	0.6	[-]	D
Area fraction of industrial/urban soil, region (excl. sea)	0.1	[-]	D
Length of regional seawater	40	[km]	D
Width of regional seawater	10	[km]	D
Area of regional seawater	400	[km2]	O
Area (land+rivers+sea) of regional system	4.04E+04	[km2]	O
Area fraction of freshwater, region (total)	0.0297	[-]	O
Area fraction of seawater, region (total)	9.9E-03	[-]	O
Area fraction of natural soil, region (total)	0.267	[-]	O
Area fraction of agricultural soil, region (total)	0.594	[-]	O
Area fraction of industrial/urban soil, region (total)	0.099	[-]	O

CONTINENTAL

Total area of EU (continent+region, incl. sea)	7.04E+06	[km2]	D
Area (land+rivers+sea) of continental system	7E+06	[km2]	O
Area (land+rivers) of continental system	3.5E+06	[km2]	O
Area fraction of freshwater, continent (excl. sea)	0.03	[-]	D
Area fraction of natural soil, continent (excl. sea)	0.27	[-]	D
Area fraction of agricultural soil, continent (excl. sea)	0.6	[-]	D
Area fraction of industrial/urban soil, continent (excl. sea)	0.1	[-]	D
Area fraction of freshwater, continent (total)	0.015	[-]	O
Area fraction of seawater, continent (total)	0.5	[-]	D
Area fraction of natural soil, continent (total)	0.135	[-]	O
Area fraction of agricultural soil, continent (total)	0.3	[-]	O
Area fraction of industrial/urban soil, continent (total)	0.05	[-]	O

MODERATE

Area of moderate system (incl.continent,region)	8.5E+07	[km2]	D
Area of moderate system (excl.continent, region)	7.8E+07	[km2]	O
Area fraction of water, moderate system	0.5	[-]	D

ARCTIC

Area of arctic system	4.25E+07	[km2]	D
Area fraction of water, arctic system	0.6	[-]	D

TROPIC

Area of tropic system	1.275E+08	[km2]	D
Area fraction of water, tropic system	0.7	[-]	D

TEMPERATURE

Environmental temperature, regional scale	12	[oC]	D
Environmental temperature, continental scale	12	[oC]	D
Environmental temperature, moderate scale	12	[oC]	D
Environmental temperature, arctic scale	-10	[oC]	D
Environmental temperature, tropic scale	25	[oC]	D
Enthalpy of vaporisation	50	[kJ.mol-1]	D
Enthalpy of solution	10	[kJ.mol-1]	D

MASS TRANSFER

Air-film PMTC (air-water interface)	2.87E-03	[m.s-1]	O
Water-film PMTC (air-water interface)	3.74E-06	[m.s-1]	O
PMTC, air side of air-soil interface	1.05E-03	[m.s-1]	O
PMTC, soil side of air-soil interface	5.95E-11	[m.s-1]	O
Soil-air PMTC (air-soil interface)	5.56E-06	[m.s-1]	D
Soil-water film PMTC (air-soil interface)	5.56E-10	[m.s-1]	D
Water-film PMTC (sediment-water interface)	2.78E-06	[m.s-1]	D
Pore water PMTC (sediment-water interface)	2.78E-08	[m.s-1]	D

AIR

GENERAL

Atmospheric mixing height	1000	[m]	D
Windspeed in the system	3	[m.s-1]	D
Aerosol deposition velocity	1E-03	[m.s-1]	D
Aerosol collection efficiency	2E+05	[-]	D

RAIN

Average precipitation, regional system	700	[mm.yr-1]	D
Average precipitation, continental system	700	[mm.yr-1]	D
Average precipitation, moderate system	700	[mm.yr-1]	D
Average precipitation, arctic system	250	[mm.yr-1]	D
Average precipitation, tropic system	1.3E+03	[mm.yr-1]	D

RESIDENCE TIMES

Residence time of air, regional	0.687	[d]	O
Residence time of air, continental	9.05	[d]	O
Residence time of air, moderate	30.2	[d]	O
Residence time of air, arctic	22.3	[d]	O
Residence time of air, tropic	38.6	[d]	O

WATER

DEPTH

Water depth of freshwater, regional system	3	[m]	D
Water depth of seawater, regional system	10	[m]	D
Water depth of freshwater, continental system	3	[m]	D
Water depth of seawater, continental system	200	[m]	D
Water depth, moderate system	1000	[m]	D
Water depth, arctic system	1000	[m]	D
Water depth, tropic system	1000	[m]	D

SUSPENDED SOLIDS

Suspended solids conc. freshwater, regional	15	[mg.l-1]	D
Suspended solids conc. seawater, regional	5	[mg.l-1]	D
Suspended solids conc. freshwater, continental	15	[mg.l-1]	D
Suspended solids conc. seawater, continental	5	[mg.l-1]	D
Suspended solids conc. seawater, moderate	5	[mg.l-1]	D
Suspended solids conc. seawater, arctic	5	[mg.l-1]	D
Suspended solids conc. seawater, tropic	5	[mg.l-1]	D
Concentration solids in effluent, regional	30	[mg.l-1]	D
Concentration solids in effluent, continental	30	[mg.l-1]	D
Concentration biota	1	[mgwwt.l-1]	D

RESIDENCE TIMES

Residence time of freshwater, regional	43.3	[d]	O
Residence time of seawater, regional	4.64	[d]	O
Residence time of freshwater, continental	172	[d]	O
Residence time of seawater, continental	365	[d]	O
Residence time of water, moderate	2.69E+03	[d]	O
Residence time of water, arctic	5.84E+03	[d]	O
Residence time of water, tropic	1.09E+04	[d]	O

SEDIMENT

DEPTH

Sediment mixing depth	0.03	[m]	D

SUSPENDED SOLIDS

(Biogenic) prod. susp. solids in freshwater, reg	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in seawater, reg	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in freshwater, cont	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in seawater, cont	5	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, moderate	1	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, arctic	1	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, tropic	1	[g.m-2.yr-1]	D

SEDIMENTATION RATES

Settling velocity of suspended solids	2.5	[m.d-1]	D
Net sedimentation rate, freshwater, regional	2.8	[mm.yr-1]	O
Net sedimentation rate, seawater, regional	1.53	[mm.yr-1]	O
Net sedimentation rate, freshwater, continental	2.75	[mm.yr-1]	O
Net sedimentation rate, seawater, continental	6.69E-03	[mm.yr-1]	O
Net sedimentation rate, moderate	2.8E-03	[mm.yr-1]	O
Net sedimentation rate, arctic	2E-03	[mm.yr-1]	O
Net sedimentation rate, tropic	2E-03	[mm.yr-1]	O

SOIL

GENERAL

Fraction of rain water infiltrating soil	0.25	[-]	D
Fraction of rain water running off soil	0.25	[-]	D

DEPTH

Chemical-dependent soil depth	No		D
Mixing depth natural soil	0.05	[m]	D
Mixing depth agricultural soil	0.2	[m]	D
Mixing depth industrial/urban soil	0.05	[m]	D
Mixing depth of soil, moderate system	0.05	[m]	D
Mixing depth of soil, arctic system	0.05	[m]	D
Mixing depth of soil, tropic system	0.05	[m]	D

EROSION

Soil erosion rate, regional system	0.03	[mm.yr-1]	D
Soil erosion rate, continental system	0.03	[mm.yr-1]	D
Soil erosion rate, moderate system	0.03	[mm.yr-1]	D
Soil erosion rate, arctic system	0.03	[mm.yr-1]	D
Soil erosion rate, tropic system	0.03	[mm.yr-1]	D

CHARACTERISTICS OF PLANTS, WORMS AND CATTLE

PLANTS

Volume fraction of water in plant tissue	0.65	[m3.m-3]	D
Volume fraction of lipids in plant tissue	0.01	[m3.m-3]	D
Volume fraction of air in plant tissue	0.3	[m3.m-3]	D
Correction for differences between plant lipids and octanol	0.95	[-]	D
Bulk density of plant tissue (wet weight)	0.7	[kg.l-1]	D
Rate constant for metabolism in plants	0	[d-1]	D
Rate constant for photolysis in plants	0	[d-1]	D
Leaf surface area	5	[m2]	D
Conductance	1E-03	[m.s-1]	D
Shoot volume	2	[l]	D
Rate constant for dilution by growth	0.035	[d-1]	D
Transpiration stream	1	[l.d-1]	D

WORMS

Volume fraction of water inside a worm	0.84	[m3.m-3]	D
Volume fraction of lipids inside a worm	0.012	[m3.m-3]	D
Density of earthworms	1	[kgwwt.l-1]	D
Fraction of gut loading in worm	0.1	[kg.kg-1]	D

CATTLE

Daily intake for cattle of grass (dryweight)	16.9	[kg.d-1]	D
Conversion factor grass from dryweight to wetweight	4	[kg.kg-1]	D
Daily intake of soil (dryweight)	0.41	[kg.d-1]	D
Daily inhalation rate for cattle	122	[m3.d-1]	D
Daily intake of drinking water for cattle	55	[l.d-1]	D

SUBSTANCE

SUBSTANCE IDENTIFICATION

General name	TBBPA		S
Description			D
CAS-No			D
EC-notification no.			D
EINECS no.			D

PHYSICO-CHEMICAL PROPERTIES

Molecular weight	543.88	[g.mol-1]	S
Melting point	180	[oC]	S
Boiling point	316	[oC]	S
Vapour pressure at test temperature	1.19E-05	[Pa]	S
Temperature at which vapour pressure was measured	20	[oC]	S
Vapour pressure at 25 [oC]	1.68E-05	[Pa]	O
Octanol-water partition coefficient	5.9	[log10]	S
Water solubility at test temperature	0.24	[mg.l-1]	S
Temperature at which solubility was measured	25	[oC]	D
Water solubility at 25 [oC]	0.24	[mg.l-1]	O

PARTITION COEFFICIENTS AND BIOCONCENTRATION FACTORS

SOLIDS-WATER

Chemical class for Koc-QSAR	Phenols, benzonitriles		S
Organic carbon-water partition coefficient	1.4736E+05	[l.kg-1]	S
Solids-water partition coefficient in soil	2.947E+03	[l.kg-1]	S
Solids-water partition coefficient in sediment	7.368E+03	[l.kg-1]	S
Solids-water partition coefficient suspended matter	1.4736E+04	[l.kg-1]	S
Solids-water partition coefficient in raw sewage sludge	4.42E+04	[l.kg-1]	S
Solids-water partition coefficient in settled sewage sludge	4.42E+04	[l.kg-1]	S
Solids-water partition coefficient in activated sewage sludge	5.45E+04	[l.kg-1]	S
Solids-water partition coefficient in effluent sewage sludge	5.45E+04	[l.kg-1]	S
Soil-water partition coefficient	4.42E+03	[m3.m-3]	O
Suspended matter-water partition coefficient	3.68E+03	[m3.m-3]	O
Sediment-water partition coefficient	3.68E+03	[m3.m-3]	O

AIR-WATER

Environmental temperature	12	[oC]	D
Water solubility at environmental temperature	0.2	[mg.l-1]	O
Vapour pressure at environmental temperature	6.69E-06	[Pa]	O
Sub-cooled liquid vapour pressure	3.66E-04	[Pa]	O
Fraction of chemical associated with aerosol particles	0.215	[-]	O
Henry's law constant at test temparature	??	[Pa.m3.mol-1]	D
Temperature at which Henry's law constant was measured	25	[oC]	D
Henry's law constant at 25 [oC]	0.0141	[Pa.m3.mol-1]	S
Henry's law constant at enviromental temparature	6.75E-03	[Pa.m3.mol-1]	O
Air-water partitioning coefficient	2.85E-06	[m3.m-3]	O

BIOCONCENTRATION FACTORS

PREDATOR EXPOSURE

Bioconcentration factor for earthworms	9.533E+03	[l.kgwwt-1]	S

HUMAN AND PREDATOR EXPOSURE

Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S
QSAR valid for calculation of BCF-Fish	Yes		O
Biomagnification factor in fish	1	[-]	O
Biomagnification factor in predator	1	[-]	O

HUMAN EXPOSURE

Partition coefficient between leaves and air	1.41E+09	[m3.m-3]	O
Partition coefficient between plant tissue and water	4.03E+03	[m3.m-3]	O
Transpiration-stream concentration factor	0.0378	[-]	O
Bioaccumulation factor for meat	0.02	[d.kg-1]	O
Bioaccumulation factor for milk	6.31E-03	[d.kg-1]	O
Purification factor for surface water	0.25	[-]	O

BIOTA-WATER
FOR REGIONAL/CONTINENTAL DISTRIBUTION

Bioconcentration factor for aquatic biota	1.23E+03	[l.kgwwt-1]	O

DEGRADATION AND TRANSFORMATION RATES
CHARACTARIZATION

Characterization of biodegradability	Not biodegradable		S

STP

Degradation calculation method in STP	First order, standard OECD/EU tests		D
Rate constant for biodegradation in STP	0	[d-1]	O
Total rate constant for degradation in STP	0	[d-1]	O
Maximum growth rate of specific microorganisms	2	[d-1]	D
Half saturation concentration	0.5	[g.m-3]	D

WATER/SEDIMENT
WATER

Rate constant for hydrolysis in surface water	1E+06	[d] (DT50,12[oC])	O
Rate constant for photolysis in surface water	6.93E-07	[d-1]	O
Rate constant for biodegradation in surface water	147.478	[d] (DT50,12[oC])	S
Total rate constant for degradation in bulk surface water	4.7E-03	[d-1] (12[oC])	O
Rate constant for biodegradation in saltwater	0	[d-1] (12[oC])	O
Total rate constant for degradation in bulk saltwater	1.39E-06	[d-1] (12[oC])	O

SEDIMENT

Rate constant for biodegradation in aerated sediment	2.31E-05	[d-1] (12[oC])	S
Total rate constant for degradation in bulk sediment	2.31E-06	[d-1] (12[oC])	O

AIR

Specific degradation rate constant with OH-radicals	2.96E-12	[cm3.molec-1.s-1]	S
Rate constant for degradation in air	0.128	[d-1]	O

SOIL

Rate constant for biodegradation in bulk soil	2.31E-05	[d-1] (12[oC])	S
Total rate constant for degradation in bulk soil	2.31E-05	[d-1] (12[oC])	O

REMOVAL RATE CONSTANTS SOIL

Total rate constant for degradation in bulk soil	2.31E-05	[d-1] (12[oC])	O
Rate constant for volatilisation from agricultural soil	2.88E-07	[d-1]	O
Rate constant for leaching from agricultural soil	5.42E-07	[d-1]	O
Total rate constant for removal from agricultural top soil	2.39E-05	[d-1]	O
Rate constant for volatilisation from grassland soil	5.77E-07	[d-1]	O
Rate constant for leaching from grassland soil	1.08E-06	[d-1]	O
Total rate constant for removal from grassland top soil	2.48E-05	[d-1]	O
Rate constant for volatilisation from industrial soil	1.15E-06	[d-1]	O
Rate constant for leaching from industrial soil	2.17E-06	[d-1]	O
Total rate constant for removal from industrial soil	2.64E-05	[d-1]	O

RELEASE ESTIMATION

CHARACTERIZATION AND TONNAGE

High Production Volume Chemical	No		D
Production volume of chemical in EU	0	[tonnes.yr-1]	D
Fraction of EU production volume for region	10	[%]	S
Regional production volume of substance	0	[tonnes.yr-1]	O
Continental production volume of substance	0	[tonnes.yr-1]	O
Volume of chemical imported to EU	0	[tonnes.yr-1]	D
Volume of chemical exported from EU	0	[tonnes.yr-1]	D
Tonnage of substance in Europe	2.939E+03	[tonnes.yr-1]	S

USE PATTERNS

PRODUCTION STEPS

OTHER LIFE CYCLE STEPS

EMISSION INPUT DATA

Usage/production title	average shredding		S

USE PATTERN

Industry category	4 Electrical/electronic engineering industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	No extra details necessary		S
Extra details on use category	No extra details necessary		S

WASTE TREATMENT

Use specific emission scenario	No		D
Emission scenario	no special scenario selected/available		S

TONNAGE

Fraction of tonnage for application	1	[-]	S
Fraction of chemical in formulation	1	[-]	D
Tonnage of formulated product	294	[tonnes.yr-1]	O
Relevant tonnage for application	2.94E+03	[tonnes.yr-1]	O
Regional tonnage of substance	294	[tonnes.yr-1]	O
Tonnage of formulated product	294	[tonnes.yr-1]	O
Regional tonnage of substance (private use step)	294	[tonnes.yr-1]	O
Continental tonnage of substance (private use step)	2.65E+03	[tonnes.yr-1]	O
Total of fractions for all applications	1	[-]	O

INTERMEDIATE RESULTS

INTERMEDIATE

RELEASE FRACTIONS AND EMISSION DAYS

WASTE TREATMENT

Emission tables	No applicable emission tables	S	

RELEASE FRACTIONS

Fraction of tonnage released to air	1E-03	[-]	S
Fraction of tonnage released to wastewater	0	[-]	O
Fraction of tonnage released to surface water	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Emission fractions determined by special scenario	No		O

EMISSION DAYS

Fraction of the main local source	0.02	[-]	S
Number of emission days per year	220	[-]	S
Release to wastewater only	No		O
Emission days determined by special scenario	No		O

REGIONAL AND CONTINENTAL RELEASES

WASTE TREATMENT

REGIONAL

Regional release to air	0.805	[kg.d-1]	O
Regional release to wastewater	0	[kg.d-1]	O
Regional release to surface water	0	[kg.d-1]	O
Regional release to industrial soil	0	[kg.d-1]	O
Regional release to agricultural soil	0	[kg.d-1]	O

CONTINENTAL

Continental release to air	7.25	[kg.d-1]	O
Continental release to wastewater	0	[kg.d-1]	O
Continental release to surface water	0	[kg.d-1]	O
Continental release to industrial soil	0	[kg.d-1]	O
Continental release to agricultural soil	0	[kg.d-1]	O

REGIONAL AND CONTINENTAL TOTAL EMISSIONS

Total regional emission to air	0.805	[kg.d-1]	O
Total regional emission to wastewater	0	[kg.d-1]	O
Total regional emission to surface water	0	[kg.d-1]	O
Total regional emission to industrial soil	0	[kg.d-1]	O
Total regional emission to agricultural soil	0	[kg.d-1]	O
Total continental emission to air	7.25	[kg.d-1]	O
Total continental emission to wastewater	0	[kg.d-1]	O
Total continental emission to surface water	0	[kg.d-1]	O
Total continental emission to industrial soil	0	[kg.d-1]	O
Total continental emission to agricultural soil	0	[kg.d-1]	O

LOCAL

[WASTE TREATMENT]

Local emission to air during episode	0.13	[kg.d-1]	S
Emission to air calculated by special scenario	No		O
Local emission to wastewater during episode	0	[kg.d-1]	O
Emission to water calculated by special scenario	No		O
Show this step in further calculations	Yes		O
Intermittent release	No		D

DISTRIBUTION

SEWAGE TREATMENT

CONTINENTAL

Fraction of emission directed to air	0	[%]	O
Fraction of emission directed to water	0	[%]	O
Fraction of emission directed to sludge	0	[%]	O
Fraction of the emission degraded	0	[%]	O
Total of fractions	0	[%]	O
Indirect emission to air	0	[kg.d-1]	O
Indirect emission to surface water	0	[kg.d-1]	O
Indirect emission to agricultural soil	0	[kg.d-1]	O

REGIONAL

Fraction of emission directed to air	0	[%]	O
Fraction of emission directed to water	0	[%]	O
Fraction of emission directed to sludge	0	[%]	O
Fraction of the emission degraded	0	[%]	O
Total of fractions	0	[%]	O
Indirect emission to air	0	[kg.d-1]	O
Indirect emission to surface water	0	[kg.d-1]	O
Indirect emission to agricultural soil	0	[kg.d-1]	O

LOCAL

[WASTE TREATMENT]

INPUT AND CONFIGURATION [WASTE TREATMENT]

INPUT

Use or bypass STP (local freshwater assessment)	Bypass STP		S
Use or bypass STP (local marine assessment)	Bypass STP		D
Local emission to wastewater during episode	0	[kg.d-1]	O
Concentration in untreated wastewater	0	[mg.l-1]	O
Local emission entering the STP	0	[kg.d-1]	O

CONFIGURATION

Type of local STP	With primary settler (9-box)		D
Number of inhabitants feeding this STP	1E+04	[eq]	O
Effluent discharge rate of this STP	2E+06	[l.d-1]	O
Calculate dilution from river flow rate	No		O
Flow rate of the river	1.8E+04	[m3.d-1]	O
Dilution factor (rivers)	10	[-]	O
Dilution factor (coastal areas)	100	[-]	O

OUTPUT [WASTE TREATMENT]

Fraction of emission directed to air by STP	0	[%]	O
Fraction of emission directed to water by STP	100	[%]	O
Fraction of emission directed to sludge by STP	0	[%]	O
Fraction of the emission degraded in STP	0	[%]	O
Total of fractions	100	[%]	O
Local indirect emission to air from STP during episode	0	[kg.d-1]	O
Concentration in untreated wastewater	0	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0	[mg.kg-1]	O
PEC for micro-organisms in the STP	0	[mg.l-1]	O

REGIONAL, CONTINENTAL AND GLOBAL DISTRIBUTION

PECS

REGIONAL

Regional PEC in surface water (total)	1.26E-07	[mg.l-1]	O
Regional PEC in seawater (total)	2.07E-08	[mg.l-1]	O
Regional PEC in surface water (dissolved)	1.03E-07	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Regional PEC in seawater (dissolved)	1.93E-08	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Regional PEC in air (total)	1.16E-08	[mg.m-3]	O
Regional PEC in agricultural soil (total)	4.92E-04	[mg.kgwwt-1]	O
Regional PEC in pore water of agricultural soils	1.89E-07	[mg.l-1]	O
Regional PEC in natural soil (total)	1.55E-03	[mg.kgwwt-1]	O
Regional PEC in industrial soil (total)	1.55E-03	[mg.kgwwt-1]	O
Regional PEC in sediment (total)	6.57E-04	[mg.kgwwt-1]	O
Regional PEC in seawater sediment (total)	1.21E-04	[mg.kgwwt-1]	O

CONTINENTAL

Continental PEC in surface water (total)	2.83E-08	[mg.l-1]	O
Continental PEC in seawater (total)	6.85E-09	[mg.l-1]	O
Continental PEC in surface water (dissolved)	2.32E-08	[mg.l-1]	O
Continental PEC in seawater (dissolved)	6.38E-09	[mg.l-1]	O
Continental PEC in air (total)	1.71E-09	[mg.m-3]	O
Continental PEC in agricultural soil (total)	7.27E-05	[mg.kgwwt-1]	O
Continental PEC in pore water of agricultural soils	2.8E-08	[mg.l-1]	O
Continental PEC in natural soil (total)	2.29E-04	[mg.kgwwt-1]	O
Continental PEC in industrial soil (total)	2.29E-04	[mg.kgwwt-1]	O
Continental PEC in sediment (total)	1.48E-04	[mg.kgwwt-1]	O
Continental PEC in seawater sediment (total)	4.02E-05	[mg.kgwwt-1]	O

GLOBAL: MODERATE

Moderate PEC in water (total)	5.35E-09	[mg.l-1]	O
Moderate PEC in water (dissolved)	4.98E-09	[mg.l-1]	O
Moderate PEC in air (total)	3.7E-11	[mg.m-3]	O
Moderate PEC in soil (total)	4.95E-06	[mg.kgwwt-1]	O
Moderate PEC in sediment (total)	3.14E-05	[mg.kgwwt-1]	O

GLOBAL: ARCTIC

Arctic PEC in water (total)	5.34E-09	[mg.l-1]	O
Arctic PEC in water (dissolved)	4.97E-09	[mg.l-1]	O
Arctic PEC in air (total)	5.61E-12	[mg.m-3]	O
Arctic PEC in soil (total)	2.87E-06	[mg.kgwwt-1]	O
Arctic PEC in sediment (total)	3.14E-05	[mg.kgwwt-1]	O

GLOBAL: TROPIC

Tropic PEC in water (total)	4.99E-09	[mg.l-1]	O
Tropic PEC in water (dissolved)	4.64E-09	[mg.l-1]	O
Tropic PEC in air (total)	2.1E-11	[mg.m-3]	O
Tropic PEC in soil (total)	1.19E-06	[mg.kgwwt-1]	O
Tropic PEC in sediment (total)	2.92E-05	[mg.kgwwt-1]	O

STEADY-STATE FRACTIONS

REGIONAL

Steady-state mass fraction in regional freshwater	4.25E-05	[%]	O
Steady-state mass fraction in regional seawater	7.75E-06	[%]	O
Steady-state mass fraction in regional air	4.39E-05	[%]	O
Steady-state mass fraction in regional agricultural soil	0.376	[%]	O
Steady-state mass fraction in regional natural soil	0.133	[%]	O
Steady-state mass fraction in regional industrial soil	0.0494	[%]	O
Steady-state mass fraction in regional freshwater sediment	2.55E-03	[%]	O
Steady-state mass fraction in regional seawater sediment	1.57E-04	[%]	O

CONTINENTAL

Steady-state mass fraction in continental freshwater	8.36E-04	[%]	O
Steady-state mass fraction in continental seawater	0.449	[%]	O
Steady-state mass fraction in continental air	1.12E-03	[%]	O
Steady-state mass fraction in continental agricultural soil	4.86	[%]	O
Steady-state mass fraction in continental natural soil	1.73	[%]	O
Steady-state mass fraction in continental industrial soil	0.639	[%]	O
Steady-state mass fraction in continental freshwater sediment	0.0501	[%]	O
Steady-state mass fraction in continental seawater sediment	0.455	[%]	O

GLOBAL: MODERATE

Steady-state mass fraction in moderate water	19.5	[%]	O
Steady-state mass fraction in moderate air	2.7E-04	[%]	O
Steady-state mass fraction in moderate soil	1.54	[%]	O
Steady-state mass fraction in moderate sediment	3.95	[%]	O

GLOBAL: ARCTIC

Steady-state mass fraction in arctic water	12.8	[%]	O
Steady-state mass fraction in arctic air	2.23E-05	[%]	O
Steady-state mass fraction in arctic soil	0.388	[%]	O
Steady-state mass fraction in arctic sediment	2.59	[%]	O

GLOBAL: TROPIC

Steady-state mass fraction in tropic water	41.7	[%]	O
Steady-state mass fraction in tropic air	2.51E-04	[%]	O
Steady-state mass fraction in tropic soil	0.362	[%]	O
Steady-state mass fraction in tropic sediment	8.41	[%]	O

STEADY-STATE MASSES

REGIONAL

Steady-state mass in regional freshwater	0.454	[kg]	O
Steady-state mass in regional seawater	0.0828	[kg]	O
Steady-state mass in regional air	0.468	[kg]	O
Steady-state mass in regional agricultural soil	4.01E+03	[kg]	O
Steady-state mass in regional natural soil	1.43E+03	[kg]	O
Steady-state mass in regional industrial soil	528	[kg]	O
Steady-state mass in regional freshwater sediment	27.2	[kg]	O
Steady-state mass in regional seawater sediment	1.68	[kg]	O

CONTINENTAL			
Steady-state mass in continental freshwater	8.92	[kg]	O
Steady-state mass in continental seawater	4.8E+03	[kg]	O
Steady-state mass in continental air	12	[kg]	O
Steady-state mass in continental agricultural soil	5.19E+04	[kg]	O
Steady-state mass in continental natural soil	1.84E+04	[kg]	O
Steady-state mass in continental industrial soil	6.83E+03	[kg]	O
Steady-state mass in continental freshwater sediment	535	[kg]	O
Steady-state mass in continental seawater sediment	4.86E+03	[kg]	O
GLOBAL: MODERATE			
Steady-state mass in moderate water	2.08E+05	[kg]	O
Steady-state mass in moderate air	2.88	[kg]	O
Steady-state mass in moderate soil	1.64E+04	[kg]	O
Steady-state mass in moderate sediment	4.22E+04	[kg]	O
GLOBAL: ARCTIC			
Steady-state mass in arctic water	1.36E+05	[kg]	O
Steady-state mass in arctic air	0.238	[kg]	O
Steady-state mass in arctic soil	4.14E+03	[kg]	O
Steady-state mass in arctic sediment	2.76E+04	[kg]	O
GLOBAL: TROPIC			
Steady-state mass in tropic water	4.46E+05	[kg]	O
Steady-state mass in tropic air	2.68	[kg]	O
Steady-state mass in tropic soil	3.86E+03	[kg]	O
Steady-state mass in tropic sediment	8.98E+04	[kg]	O
LOCAL			
[WASTE TREATMENT]			
LOCAL CONCENTRATIONS AND DEPOSITIONS [WASTE TREATMENT]			
AIR			
Concentration in air during emission episode	3.61E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	2.18E-05	[mg.m-3]	O
Total deposition flux during emission episode	3.2E-04	[mg.m-2.d-1]	O
Annual average total deposition flux	1.93E-04	[mg.m-2.d-1]	O
WATER, SEDIMENT			
Concentration in surface water during emission episode (dissolved)	0	[mg.l-1]	O
Concentration in surface water exceeds solubility	No		O
Annual average concentration in surface water (dissolved)	0	[mg.l-1]	O
Concentration in seawater during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in seawater (dissolved)	0	[mg.l-1]	O
SOIL, GROUNDWATER			
Concentration in agric. soil averaged over 30 days	1.99E-03	[mg.kgwwt-1]	O
Concentration in agric. soil averaged over 180 days	2.03E-03	[mg.kgwwt-1]	O
Concentration in grassland averaged over 180 days	4.05E-03	[mg.kgwwt-1]	O
Fraction of steady-state (agricultural soil)	0.0836	[-]	O
Fraction of steady-state (grassland soil)	0.0864	[-]	O

LOCAL PECS [WASTE TREATMENT]

AIR

Annual average local PEC in air (total)	2.18E-05	[mg.m-3]	O

WATER, SEDIMENT

Local PEC in surface water during emission episode (dissolved)	1.03E-07	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Annual average local PEC in surface water (dissolved)	1.03E-07	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	3.31E-04	[mg.kgwwt-1]	O
Local PEC in seawater during emission episode (dissolved)	1.93E-08	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Annual average local PEC in seawater (dissolved)	1.93E-08	[mg.l-1]	O
Local PEC in marine sediment during emission episode	6.17E-05	[mg.kgwwt-1]	O

SOIL, GROUNDWATER

Local PEC in agric. soil (total) averaged over 30 days	3.54E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	3.58E-03	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	5.6E-03	[mg.kgwwt-1]	O
Local PEC in pore water of agricultural soil	1.38E-06	[mg.l-1]	O
Local PEC in pore water of grassland	2.15E-06	[mg.l-1]	O
Local PEC in groundwater under agricultural soil	1.38E-06	[mg.l-1]	O

EXPOSURE

SECONDARY POISONING

SECONDARY POISONING [WASTE TREATMENT]

Concentration in fish for secondary poisoning (freshwater)	1.27E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	6.91E-03	[mg.kg-1]	O
Concentration in fish for secondary poisoning (marine)	2.38E-05	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	2.38E-05	[mg.kgwwt-1]	O

EFFECTS

INPUT OF EFFECTS DATA

MICRO-ORGANISMS

Test system	Respiration inhibition, EU Annex V C.11, OECD 209		D
EC50 for micro-organisms in a STP	??	[mg.l-1]	D
EC10 for micro-organisms in a STP	??	[mg.l-1]	D
NOEC for micro-organisms in a STP	>15	[mg.l-1]	S

AQUATIC ORGANISMS

FRESH WATER

L(E)C50 SHORT-TERM TESTS

LC50 for fish	0.54	[mg.l-1]	S
L(E)C50 for Daphnia	0.96	[mg.l-1]	S
EC50 for algae	0.09	[mg.l-1]	S
LC50 for additional taxonomic group	??	[mg.l-1]	D
Aquatic species	other		D

NOEC LONG-TERM TESTS

NOEC for fish	0.16	[mg.l-1]	S
NOEC for Daphnia	0.3	[mg.l-1]	S
NOEC for algae	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D

MARINE

L(E)C50 SHORT-TERM TESTS

LC50 for fish (marine)	??	[mg.l-1]	D
L(E)C50 for crustaceans (marine)	??	[mg.l-1]	D
EC50 for algae (marine)	??	[mg.l-1]	D
LC50 for additional taxonomic group (marine)	??	[mg.l-1]	D
Marine species	other		D
LC50 for additional taxonomic group (marine)	??	[mg.l-1]	D
Marine species	other		D

NOEC LONG-TERM TESTS

NOEC for fish (marine)	??	[mg.l-1]	D
NOEC for crustaceans (marine)	0.0127	[mg.l-1]	S
NOEC for algae (marine)	??	[mg.l-1]	D
NOEC for additional taxonomic group (marine)	0.017	[mg.l-1]	S
NOEC for additional taxonomic group (marine)	??	[mg.l-1]	D

FRESH WATER SEDIMENT

L(E)C50 SHORT-TERM TESTS

LC50 for fresh-water sediment organism	254	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested sediment	0.059	[kg.kg-1]	S

EC10/NOEC LONG-TERM TESTS

EC10 for fresh-water sediment organism	414	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested sediment	0.025	[kg.kg-1]	S
EC10 for fresh-water sediment organism	125	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

MARINE SEDIMENT

L(E)C50 SHORT-TERM TESTS

LC50 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

EC10/NOEC LONG-TERM TESTS

EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

TERRESTRIAL ORGANISMS

L(E)C50 SHORT-TERM TESTS

LC50 for plants	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
LC50 for earthworms	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
EC50 for microorganisms	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
LC50 for other terrestrial species	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D

NOEC LONG-TERM TESTS

NOEC for plants	25.9	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for earthworms	0.29	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested soil	0.044	[kg.kg-1]	S
NOEC for microorganisms	1E+03	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
Terrestrial species	other		D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
Terrestrial species	other		D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D

BIRDS

LC50 in avian dietary study (5 days)	??	[mg.kg-1]	D
NOEC via food (birds)	??	[mg.kg-1]	D
NOAEL (birds)	??	[mg.kg-1.d-1]	D
Conversion factor NOAEL to NOEC (birds)	8	[kg.d.kg-1]	D

MAMMALS

REPEATED DOSE

ORAL

Oral NOAEL (repdose)	??	[mg.kg-1.d-1]	D
Oral LOAEL (repdose)	??	[mg.kg-1.d-1]	D
Oral CED (repdose)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (repdose)	??	[mg.kg-1]	D
LOEC via food (repdose)	??	[mg.kg-1]	D
CED via food (repdose)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (repdose)	??	[mg.m-3]	D
Inhalatory LOAEL (repdose)	??	[mg.m-3]	D
Inhalatory CED (repdose)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (repdose)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (repdose)	??	[mg.kg-1.d-1]	D
Dermal CED (repdose)	??	[mg.kg-1.d-1]	D

FERTILITY

ORAL

Oral NOAEL (fert)	??	[mg.kg-1.d-1]	D
Oral LOAEL (fert)	??	[mg.kg-1.d-1]	D
Oral CED (fert)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (fert)	??	[mg.kg-1]	D
LOEC via food (fert)	??	[mg.kg-1]	D
CED via food (fert)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (fert)	??	[mg.m-3]	D
Inhalatory LOAEL (fert)	??	[mg.m-3]	D
Inhalatory CED (fert)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (fert)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (fert)	??	[mg.kg-1.d-1]	D
Dermal CED (fert)	??	[mg.kg-1.d-1]	D

MATERNAL-TOX

ORAL

Oral NOAEL (mattox)	??	[mg.kg-1.d-1]	D
Oral LOAEL (mattox)	??	[mg.kg-1.d-1]	D
Oral CED (mattox)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (mattox)	??	[mg.kg-1]	D
LOEC via food (mattox)	??	[mg.kg-1]	D
CED via food (mattox)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (mattox)	??	[mg.m-3]	D
Inhalatory LOAEL (mattox)	??	[mg.m-3]	D
Inhalatory CED (mattox)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (mattox)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (mattox)	??	[mg.kg-1.d-1]	D
Dermal CED (mattox)	??	[mg.kg-1.d-1]	D

DEVELOPMENT-TOX

ORAL

Oral NOAEL (devtox)	??	[mg.kg-1.d-1]	D
Oral LOAEL (devtox)	??	[mg.kg-1.d-1]	D
Oral CED (devtox)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (devtox)	??	[mg.kg-1]	D
LOEC via food (devtox)	??	[mg.kg-1]	D
CED via food (devtox)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (devtox)	??	[mg.m-3]	D
Inhalatory LOAEL (devtox)	??	[mg.m-3]	D
Inhalatory CED (devtox)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (devtox)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (devtox)	??	[mg.kg-1.d-1]	D
Dermal CED (devtox)	??	[mg.kg-1.d-1]	D

CARC (THRESHOLD)

ORAL

Oral NOAEL (carc)	??	[mg.kg-1.d-1]	D
Oral LOAEL (carc)	??	[mg.kg-1.d-1]	D
Oral CED (carc)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (carc)	??	[mg.kg-1]	D
LOEC via food (carc)	??	[mg.kg-1]	D
CED via food (carc)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (carc)	??	[mg.m-3]	D
Inhalatory LOAEL (carc)	??	[mg.m-3]	D
Inhalatory CED (carc)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (carc)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (carc)	??	[mg.kg-1.d-1]	D
Dermal CED (carc)	??	[mg.kg-1.d-1]	D

CARC (NON-THRESHOLD)

ORAL

Oral T25 for non-threshold effects	??	[mg.kg-1.d-1]	D
Oral CED for non-threshold effects	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
T25 via food for non-threshold effects	??	[mg.kgfood-1]	D
CED via food for non-threshold effects	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory T25 for non-threshold effects	??	[mg.m-3]	D
Inhalatory CED for non-threshold effects	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal T25 for non-threshold effects	??	[mg.kg-1.d-1]	D
Dermal CED for non-threshold effects	??	[mg.kg-1.d-1]	D

ACUTE

Oral LD50	??	[mg.kg-1]	D
Oral Discriminatory Dose	??	[mg.kg-1]	D
Inhalatory LC50	??	[mg.m-3]	D
Dermal LD50	??	[mg.kg-1]	D

PREDATOR

Duration of (sub-)chronic oral test	28 days		D
NOEC via food for secondary poisoning	??	[mg.kg-1]	O
Source for NOEC-via-food data	No data available, enter manually		S

BIO-AVAILIBILITY

Bioavailability for oral uptake (oral to inhalation)	0.5	[-]	D
Bioavailability for oral uptake (oral to dermal)	1	[-]	D
Bioavailability for oral uptake (route to oral)	1	[-]	D
Bioavailability for inhalation (route from inhalation)	1	[-]	D
Bioavailability for inhalation (route to inhalation)	1	[-]	D
Bioavailability for dermal uptake (route from dermal)	0.1	[-]	O
Bioavailability for dermal uptake (route to dermal)	0.1	[-]	O

ENVIRONMENTAL EFFECTS ASSESSMENT

ENVIRONMENTAL PNECS

FRESH WATER

Same taxonomic group for LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Aqua	1.3E-03	[mg.l-1]	S
Assessment factor applied in extrapolation to PNEC Aqua	1	[-]	S
PNEC for aquatic organisms	1.3E-03	[mg.l-1]	O

INTERMITTENT RELEASES

Toxicological data used for extrapolation to PNEC Aqua	0.09	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC Aqua	100	[-]	O
PNEC for aquatic organisms, intermittent releases	9E-04	[mg.l-1]	O

STATISTICAL

PNEC for aquatic organisms with statistical method	??	[mg.l-1]	D

MARINE

Same taxonomic group for marine LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Marine	0.25	[ug.l-1]	S
Assessment factor applied in extrapolation to PNEC Marine	1	[-]	S
PNEC for marine organisms	2.5E-04	[mg.l-1]	O

STATISTICAL

PNEC for marine organisms with statistical method	??	[mg.l-1]	D

FRESH WATER SEDIMENT

Toxicological data used for extrapolation to PNEC sediment (fresh)	2.7	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC sediment (fresh)	1	[-]	S
PNEC for fresh-water sediment organisms (from toxicological data)	2.7	[mg.kgwwt-1]	O
PNEC for fresh-water sediment organisms (equilibrium partitioning)	4.17	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in fresh-water sediment?	No		O
PNEC for fresh-water sediment, normalised to 10% o.c. (local)	2.7	[mg.kgwwt-1]	S
PNEC for fresh-water sediment, normalised to 5% o.c. (regional)	2.7	[mg.kgwwt-1]	O

MARINE SEDIMENT

Toxicological data used for extrapolation to PNEC sediment (marine)	0.54	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC sediment (marine)	1	[-]	S
PNEC for marine sediment organisms (from toxicological data)	0.54	[mg.kgwwt-1]	O
PNEC for marine sediment organisms (equilibrium partitioning)	0.801	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in marine sediment?	No		O
PNEC for marine sediment, normalised to 10% o.c. (local)	1.08	[mg.kgwwt-1]	O
PNEC for marine sediment, normalised to 5% o.c. (regional)	0.54	[mg.kgwwt-1]	O

TERRESTRIAL

Same taxonomic group for LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Terr	0.012	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC Terr	1	[-]	S
PNEC for terrestrial organisms (from toxicological data)	0.012	[mg.kgwwt-1]	O
PNEC for terrestrial organisms (equilibrium partitioning)	3.38	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in soil?	No		O
PNEC for terrestrial organisms	0.012	[mg.kgwwt-1]	O

STATISTICAL

PNEC for terrestrial organisms with statistical method	??	[mg.kgwwt-1]	D

SECONDARY POISONING

Toxicological data used for extrapolation to PNEC oral	667	[mg.kg-1]	S
Assessment factor applied in extrapolation to PNEC oral	1	[-]	S
PNEC for secondary poisoning of birds and mammals	667	[mg.kg-1]	O

STP

Toxicological data used for extrapolation to PNEC micro	1.5	[mg.l-1]	S
Assessment factor applied in extrapolation to PNEC micro	1	[-]	S
PNEC for micro-organisms in a STP	1.5	[mg.l-1]	O

RISK CHARACTERIZATION

ENVIRONMENTAL EXPOSURE

LOCAL

RISK CHARACTERIZATION OF [WASTE TREATMENT]

WATER

RCR for the local fresh-water compartment	7.93E-05	[-]	O
Intermittent release	No		D
RCR for the local marine compartment	7.7E-05	[-]	O
RCR for the local fresh-water compartment, statistical method	??	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O

SEDIMENT

RCR for the local fresh-water sediment compartment	1.22E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the local marine sediment compartment	5.71E-05	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O

SOIL

RCR for the local soil compartment	0.295	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the local soil compartment, statistical method	??	[-]	O

PREDATORS

RCR for fish-eating birds and mammals (fresh-water)	1.91E-07	[-]	O
RCR for fish-eating birds and mammals (marine)	3.56E-08	[-]	O
RCR for top predators (marine)	3.56E-08	[-]	O
RCR for worm-eating birds and mammals	1.04E-05	[-]	O

REGIONAL

WATER

RCR for the regional fresh-water compartment	7.93E-05	[-]	O
RCR for the regional marine compartment	7.7E-05	[-]	O
RCR for the regional fresh-water compartment, statistical method	??	[-]	O
RCR for the regional marine compartment, statistical method	??	[-]	O

SEDIMENT

RCR for the regional fresh-water sediment compartment	2.43E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the regional marine sediment compartment	2.25E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O

SOIL

RCR for the regional soil compartment	0.041	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the regional soil compartment, statistical method	??	[-]	O

KOC = 49726 L/KG

STUDY

STUDY IDENTIFICATION

Study name	KoC 49726 06022015		S
Study description		D	
Author		D	
Institute		D	
Address		D	
Zip code		D	
City		D	
Country		D	
Telephone		D	
Telefax		D	
Email		D	
Calculations checksum	374BA027	S	

DEFAULTS

DEFAULT IDENTIFICATION

General name	Standard Euses 2.1	D
Description	According to TGDs	D

CHARACTERISTICS OF COMPARTMENTS

GENERAL

Density of solid phase	2.5	[kg.l-1]	D
Density of water phase	1	[kg.l-1]	D
Density of air phase	1.3E-03	[kg.l-1]	D
Environmental temperature	12	[oC]	D
Standard temperature for Vp and Sol	25	[oC]	D
Temperature correction method	Temperature correction for local distribution		D
Constant of Junge equation	0.01	[Pa.m]	D
Surface area of aerosol particles	0.01	[m2.m-3]	D
Gas constant (8.314)	8.314	[Pa.m3.mol-1.K-1]	D

SUSPENDED MATTER

Volume fraction solids in suspended matter	0.1	[m3.m-3]	D
Volume fraction water in suspended matter	0.9	[m3.m-3]	D
Weight fraction of organic carbon in suspended matter	0.1	[kg.kg-1]	D
Bulk density of suspended matter	1.15E+03	[kgwwt.m-3]	O
Conversion factor wet-dry suspened matter	4.6	[kgwwt.kgdwt-1]	O

SEDIMENT

Volume fraction solids in sediment	0.2	[m3.m-3]	D
Volume fraction water in sediment	0.8	[m3.m-3]	D
Weight fraction of organic carbon in sediment	0.05	[kg.kg-1]	D

SOIL

Volume fraction solids in soil	0.6	[m3.m-3]	D
Volume fraction water in soil	0.2	[m3.m-3]	D
Volume fraction air in soil	0.2	[m3.m-3]	D
Weight fraction of organic carbon in soil	0.02	[kg.kg-1]	D
Weight fraction of organic matter in soil	0.034	[kg.kg-1]	O
Bulk density of soil	1.7E+03	[kgwwt.m-3]	O
Conversion factor wet-dry soil	1.13	[kgwwt.kgdwt-1]	O

STP SLUDGE

Fraction of organic carbon in raw sewage sludge	0.3	[kg.kg-1]	D
Fraction of organic carbon in settled sewage sludge	0.3	[kg.kg-1]	D
Fraction of organic carbon in activated sewage sludge	0.37	[kg.kg-1]	D
Fraction of organic carbon in effluent sewage sludge	0.37	[kg.kg-1]	D

DEGRADATION AND TRANSFORMATION RATES

Rate constant for abiotic degradation in STP	0	[d-1]	D
Rate constant for abiotic degradation in bulk sediment	0	[d-1] (12[oC])	D
Rate constant for anaerobic biodegradation in sediment	0	[d-1] (12[oC])	D
Fraction of sediment compartment that is aerated	0.1	[m3.m-3]	D
Concentration of OH-radicals in atmosphere	5E+05	[molec.cm-3]	D
Rate constant for abiotic degradation in bulk soil	0	[d-1] (12[oC])	D

RELEASE ESTIMATION

Fraction of EU production volume for region	10	[%]	S
Fraction of EU tonnage for region (private use)	10	[%]	D
Fraction connected to sewer systems	80	[%]	D

SEWAGE TREATMENT

GENERAL

Number of inhabitants feeding one STP	1E+04	[eq]	D
Sewage flow	200	[l.eq-1.d-1]	D
Effluent discharge rate of local STP	2E+06	[l.d-1]	O
Temperature correction for STP degradation	No		D
Temperature of air above aeration tank	15	[oC]	D
Temperature of water in aeration tank	15	[oC]	D
Height of air column above STP	10	[m]	D
Number of inhabitants of region	2E+07	[eq]	D
Number of inhabitants of continental system	3.5E+08	[eq]	O
Windspeed in the system	3	[m.s-1]	D

RAW SEWAGE

Mass of O2 binding material per person per day	54	[g.eq-1.d-1]	D
Dry weight solids produced per person per day	0.09	[kg.eq-1.d-1]	D
Density solids in raw sewage	1.5	[kg.l-1]	D
Fraction of organic carbon in raw sewage sludge	0.3	[kg.kg-1]	D

PRIMARY SETTLER

Depth of primary settler	4	[m]	D
Hydraulic retention time of primary settler	2	[hr]	D
Density suspended and settled solids in primary settler	1.5	[kg.l-1]	D
Fraction of organic carbon in settled sewage sludge	0.3	[kg.kg-1]	D

ACTIVATED SLUDGE TANK

Depth of aeration tank	3	[m]	D
Density solids of activated sludge	1.3	[kg.l-1]	D
Concentration solids of activated sludge	4	[kg.m-3]	D
Steady state O2 concentration in activated sludge	2E-03	[kg.m-3]	D
Mode of aeration	Surface		D
Aeration rate of bubble aeration	1.31E-05	[m3.s-1.eq-1]	D
Fraction of organic carbon in activated sewage sludge	0.37	[kg.kg-1]	D
Sludge loading rate	0.15	[kg.kg-1.d-1]	D
Hydraulic retention time in aerator (9-box STP)	6.9	[hr]	O
Hydraulic retention time in aerator (6-box STP)	10.8	[hr]	O
Sludge retention time of aeration tank	9.2	[d]	O

SOLIDS-LIQUIDS SEPARATOR

Depth of solids-liquid separator	3	[m]	D
Density suspended and settled solids in solids-liquid separator	1.3	[kg.l-1]	D
Concentration solids in effluent	30	[mg.l-1]	D
Hydraulic retention time of solids-liquid separator	6	[hr]	D
Fraction of organic carbon in effluent sewage sludge	0.37	[kg.kg-1]	D

LOCAL DISTRIBUTION

AIR AND SURFACE WATER

Concentration in air at source strength 1 [kg.d-1]	2.78E-04	[mg.m-3]	D
Standard deposition flux of aerosol-bound compounds	0.01	[mg.m-2.d-1]	D
Standard deposition flux of gaseous compounds	4E-04	[mg.m-2.d-1]	O
Suspended solids concentration in STP effluent water	15	[mg.l-1]	D
Dilution factor (rivers)	10	[-]	D
Flow rate of the river	1.8E+04	[m3.d-1]	D
Calculate dilution from river flow rate	No		D
Dilution factor (coastal areas)	100	[-]	D

SOIL

Mixing depth of grassland soil	0.1	[m]	D
Dry sludge application rate on agricultural soil	5E+03	[kg.ha-1.yr-1]	D
Dry sludge application rate on grassland	1000	[kg.ha-1.yr-1]	D
Averaging time soil (for terrestrial ecosystem)	30	[d]	D
Averaging time agricultural soil	180	[d]	D
Averaging time grassland	180	[d]	D
PMTC, air side of air-soil interface	1.05E-03	[m.s-1]	O
Soil-air PMTC (air-soil interface)	5.56E-06	[m.s-1]	D
Soil-water film PMTC (air-soil interface)	5.56E-10	[m.s-1]	D
Mixing depth agricultural soil	0.2	[m]	D
Fraction of rain water infiltrating soil	0.25	[-]	D
Average annual precipitation	700	[mm.yr-1]	D

REGIONAL AND CONTINENTAL DISTRIBUTION

CONFIGURATION

Fraction of direct regional emissions to seawater	1	[%]	D
Fraction of direct continental emissions to seawater	0	[%]	D
Fraction of regional STP effluent to seawater	0	[%]	D
Fraction of continental STP effluent to seawater	0	[%]	D
Fraction of flow from continental rivers to regional rivers	0.034	[-]	D
Fraction of flow from continental rivers to regional sea	0	[-]	D
Fraction of flow from continental rivers to continental sea	0.966	[-]	O
Number of inhabitants of region	2E+07	[eq]	D
Number of inhabitants in the EU	3.7E+08	[eq]	D
Number of inhabitants of continental system	3.5E+08	[eq]	O

AREAS

REGIONAL

Area (land+rivers) of regional system	4E+04	[km2]	D
Area fraction of freshwater, region (excl. sea)	0.03	[-]	D
Area fraction of natural soil, region (excl. sea)	0.27	[-]	D
Area fraction of agricultural soil, region (excl. sea)	0.6	[-]	D
Area fraction of industrial/urban soil, region (excl. sea)	0.1	[-]	D
Length of regional seawater	40	[km]	D
Width of regional seawater	10	[km]	D
Area of regional seawater	400	[km2]	O
Area (land+rivers+sea) of regional system	4.04E+04	[km2]	O
Area fraction of freshwater, region (total)	0.0297	[-]	O
Area fraction of seawater, region (total)	9.9E-03	[-]	O
Area fraction of natural soil, region (total)	0.267	[-]	O
Area fraction of agricultural soil, region (total)	0.594	[-]	O
Area fraction of industrial/urban soil, region (total)	0.099	[-]	O

CONTINENTAL

Total area of EU (continent+region, incl. sea)	7.04E+06	[km2]	D
Area (land+rivers+sea) of continental system	7E+06	[km2]	O
Area (land+rivers) of continental system	3.5E+06	[km2]	O
Area fraction of freshwater, continent (excl. sea)	0.03	[-]	D
Area fraction of natural soil, continent (excl. sea)	0.27	[-]	D
Area fraction of agricultural soil, continent (excl. sea)	0.6	[-]	D
Area fraction of industrial/urban soil, continent (excl. sea)	0.1	[-]	D
Area fraction of freshwater, continent (total)	0.015	[-]	O
Area fraction of seawater, continent (total)	0.5	[-]	D
Area fraction of natural soil, continent (total)	0.135	[-]	O
Area fraction of agricultural soil, continent (total)	0.3	[-]	O
Area fraction of industrial/urban soil, continent (total)	0.05	[-]	O

MODERATE

Area of moderate system (incl.continent,region)	8.5E+07	[km2]	D
Area of moderate system (excl.continent, region)	7.8E+07	[km2]	O
Area fraction of water, moderate system	0.5	[-]	D

ARCTIC

Area of arctic system	4.25E+07	[km2]	D
Area fraction of water, arctic system	0.6	[-]	D

TROPIC

Area of tropic system	1.275E+08	[km2]	D
Area fraction of water, tropic system	0.7	[-]	D

TEMPERATURE

Environmental temperature, regional scale	12	[oC]	D
Environmental temperature, continental scale	12	[oC]	D
Environmental temperature, moderate scale	12	[oC]	D
Environmental temperature, arctic scale	-10	[oC]	D
Environmental temperature, tropic scale	25	[oC]	D
Enthalpy of vaporisation	50	[kJ.mol-1]	D
Enthalpy of solution	10	[kJ.mol-1]	D

MASS TRANSFER

Air-film PMTC (air-water interface)	2.87E-03	[m.s-1]	O
Water-film PMTC (air-water interface)	3.74E-06	[m.s-1]	O
PMTC, air side of air-soil interface	1.05E-03	[m.s-1]	O
PMTC, soil side of air-soil interface	2.37E-11	[m.s-1]	O
Soil-air PMTC (air-soil interface)	5.56E-06	[m.s-1]	D
Soil-water film PMTC (air-soil interface)	5.56E-10	[m.s-1]	D
Water-film PMTC (sediment-water interface)	2.78E-06	[m.s-1]	D
Pore water PMTC (sediment-water interface)	2.78E-08	[m.s-1]	D

AIR

GENERAL

Atmospheric mixing height	1000	[m]	D
Windspeed in the system	3	[m.s-1]	D
Aerosol deposition velocity	1E-03	[m.s-1]	D
Aerosol collection efficiency	2E+05	[-]	D

RAIN

Average precipitation, regional system	700	[mm.yr-1]	D
Average precipitation, continental system	700	[mm.yr-1]	D
Average precipitation, moderate system	700	[mm.yr-1]	D
Average precipitation, arctic system	250	[mm.yr-1]	D
Average precipitation, tropic system	1.3E+03	[mm.yr-1]	D

RESIDENCE TIMES

Residence time of air, regional	0.687	[d]	O
Residence time of air, continental	9.05	[d]	O
Residence time of air, moderate	30.2	[d]	O
Residence time of air, arctic	22.3	[d]	O
Residence time of air, tropic	38.6	[d]	O

WATER

DEPTH

Water depth of freshwater, regional system	3	[m]	D
Water depth of seawater, regional system	10	[m]	D
Water depth of freshwater, continental system	3	[m]	D
Water depth of seawater, continental system	200	[m]	D
Water depth, moderate system	1000	[m]	D
Water depth, arctic system	1000	[m]	D
Water depth, tropic system	1000	[m]	D

SUSPENDED SOLIDS

Suspended solids conc. freshwater, regional	15	[mg.l-1]	D
Suspended solids conc. seawater, regional	5	[mg.l-1]	D
Suspended solids conc. freshwater, continental	15	[mg.l-1]	D
Suspended solids conc. seawater, continental	5	[mg.l-1]	D
Suspended solids conc. seawater, moderate	5	[mg.l-1]	D
Suspended solids conc. seawater, arctic	5	[mg.l-1]	D
Suspended solids conc. seawater, tropic	5	[mg.l-1]	D
Concentration solids in effluent, regional	30	[mg.l-1]	D
Concentration solids in effluent, continental	30	[mg.l-1]	D
Concentration biota	1	[mgwwt.l-1]	D

RESIDENCE TIMES

Residence time of freshwater, regional	43.3	[d]	O
Residence time of seawater, regional	4.64	[d]	O
Residence time of freshwater, continental	172	[d]	O
Residence time of seawater, continental	365	[d]	O
Residence time of water, moderate	2.69E+03	[d]	O
Residence time of water, arctic	5.84E+03	[d]	O
Residence time of water, tropic	1.09E+04	[d]	O

SEDIMENT

DEPTH

Sediment mixing depth	0.03	[m]	D

SUSPENDED SOLIDS

(Biogenic) prod. susp. solids in freshwater, reg	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in seawater, reg	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in freshwater, cont	10	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in seawater, cont	5	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, moderate	1	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, arctic	1	[g.m-2.yr-1]	D
(Biogenic) prod. susp. solids in water, tropic	1	[g.m-2.yr-1]	D

SEDIMENTATION RATES

Settling velocity of suspended solids	2.5	[m.d-1]	D
Net sedimentation rate, freshwater, regional	2.8	[mm.yr-1]	O
Net sedimentation rate, seawater, regional	1.53	[mm.yr-1]	O
Net sedimentation rate, freshwater, continental	2.75	[mm.yr-1]	O
Net sedimentation rate, seawater, continental	6.69E-03	[mm.yr-1]	O
Net sedimentation rate, moderate	2.8E-03	[mm.yr-1]	O
Net sedimentation rate, arctic	2E-03	[mm.yr-1]	O
Net sedimentation rate, tropic	2E-03	[mm.yr-1]	O

SOIL

GENERAL

Fraction of rain water infiltrating soil	0.25	[-]	D
Fraction of rain water running off soil	0.25	[-]	D

DEPTH

Chemical-dependent soil depth	No		D
Mixing depth natural soil	0.05	[m]	D
Mixing depth agricultural soil	0.2	[m]	D
Mixing depth industrial/urban soil	0.05	[m]	D
Mixing depth of soil, moderate system	0.05	[m]	D
Mixing depth of soil, arctic system	0.05	[m]	D
Mixing depth of soil, tropic system	0.05	[m]	D

EROSION

Soil erosion rate, regional system	0.03	[mm.yr-1]	D
Soil erosion rate, continental system	0.03	[mm.yr-1]	D
Soil erosion rate, moderate system	0.03	[mm.yr-1]	D
Soil erosion rate, arctic system	0.03	[mm.yr-1]	D
Soil erosion rate, tropic system	0.03	[mm.yr-1]	D

CHARACTERISTICS OF PLANTS, WORMS AND CATTLE

PLANTS

Volume fraction of water in plant tissue	0.65	[m3.m-3]	D
Volume fraction of lipids in plant tissue	0.01	[m3.m-3]	D
Volume fraction of air in plant tissue	0.3	[m3.m-3]	D
Correction for differences between plant lipids and octanol	0.95	[-]	D
Bulk density of plant tissue (wet weight)	0.7	[kg.l-1]	D
Rate constant for metabolism in plants	0	[d-1]	D
Rate constant for photolysis in plants	0	[d-1]	D
Leaf surface area	5	[m2]	D
Conductance	1E-03	[m.s-1]	D
Shoot volume	2	[l]	D
Rate constant for dilution by growth	0.035	[d-1]	D
Transpiration stream	1	[l.d-1]	D

WORMS

Volume fraction of water inside a worm	0.84	[m3.m-3]	D
Volume fraction of lipids inside a worm	0.012	[m3.m-3]	D
Density of earthworms	1	[kgwwt.l-1]	D
Fraction of gut loading in worm	0.1	[kg.kg-1]	D

CATTLE

Daily intake for cattle of grass (dryweight)	16.9	[kg.d-1]	D
Conversion factor grass from dryweight to wetweight	4	[kg.kg-1]	D
Daily intake of soil (dryweight)	0.41	[kg.d-1]	D
Daily inhalation rate for cattle	122	[m3.d-1]	D
Daily intake of drinking water for cattle	55	[l.d-1]	D

SUBSTANCE

SUBSTANCE IDENTIFICATION

General name	TBBPA		S
Description			D
CAS-No			D
EC-notification no.			D
EINECS no.			D

PHYSICO-CHEMICAL PROPERTIES

Molecular weight	543.88	[g.mol-1]	S
Melting point	180	[oC]	S
Boiling point	316	[oC]	S
Vapour pressure at test temperature	1.19E-05	[Pa]	S
Temperature at which vapour pressure was measured	20	[oC]	S
Vapour pressure at 25 [oC]	1.68E-05	[Pa]	O
Octanol-water partition coefficient	5.9	[log10]	S
Water solubility at test temperature	0.24	[mg.l-1]	S
Temperature at which solubility was measured	25	[oC]	D
Water solubility at 25 [oC]	0.24	[mg.l-1]	O

PARTITION COEFFICIENTS AND BIOCONCENTRATION FACTORS

SOLIDS-WATER

Chemical class for Koc-QSAR	Phenols, benzonitriles		S
Organic carbon-water partition coefficient	4.9726E+04	[l.kg-1]	S
Solids-water partition coefficient in soil	3.321E+03	[l.kg-1]	S
Solids-water partition coefficient in sediment	4.813E+03	[l.kg-1]	S
Solids-water partition coefficient suspended matter	7.299E+03	[l.kg-1]	S
Solids-water partition coefficient in raw sewage sludge	1.7245E+04	[l.kg-1]	S
Solids-water partition coefficient in settled sewage sludge	1.7245E+04	[l.kg-1]	S
Solids-water partition coefficient in activated sewage sludge	2.0725E+04	[l.kg-1]	S
Solids-water partition coefficient in effluent sewage sludge	2.0725E+04	[l.kg-1]	S
Soil-water partition coefficient	4.98E+03	[m3.m-3]	O
Suspended matter-water partition coefficient	1.83E+03	[m3.m-3]	O
Sediment-water partition coefficient	2.41E+03	[m3.m-3]	O

AIR-WATER

Environmental temperature	12	[oC]	D
Water solubility at environmental temperature	0.2	[mg.l-1]	O
Vapour pressure at environmental temperature	6.69E-06	[Pa]	O
Sub-cooled liquid vapour pressure	3.66E-04	[Pa]	O
Fraction of chemical associated with aerosol particles	0.215	[-]	O
Henry's law constant at test temparature	??	[Pa.m3.mol-1]	D
Temperature at which Henry's law constant was measured	25	[oC]	D
Henry's law constant at 25 [oC]	0.0141	[Pa.m3.mol-1]	S
Henry's law constant at enviromental temparature	6.75E-03	[Pa.m3.mol-1]	O
Air-water partitioning coefficient	2.85E-06	[m3.m-3]	O

BIOCONCENTRATION FACTORS

PREDATOR EXPOSURE

Bioconcentration factor for earthworms	9.533E+03	[l.kgwwt-1]	S

HUMAN AND PREDATOR EXPOSURE

Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S
QSAR valid for calculation of BCF-Fish	Yes		O
Biomagnification factor in fish	1	[-]	O
Biomagnification factor in predator	1	[-]	O

HUMAN EXPOSURE

Partition coefficient between leaves and air	1.41E+09	[m3.m-3]	O
Partition coefficient between plant tissue and water	4.03E+03	[m3.m-3]	O
Transpiration-stream concentration factor	0.0378	[-]	O
Bioaccumulation factor for meat	0.02	[d.kg-1]	O
Bioaccumulation factor for milk	6.31E-03	[d.kg-1]	O
Purification factor for surface water	0.25	[-]	O

BIOTA-WATER

FOR REGIONAL/CONTINENTAL DISTRIBUTION

Bioconcentration factor for aquatic biota	1.23E+03	[l.kgwwt-1]	O

DEGRADATION AND TRANSFORMATION RATES

CHARACTARIZATION

Characterization of biodegradability	Not biodegradable	S

STP

Degradation calculation method in STP	First order, standard OECD/EU tests		D
Rate constant for biodegradation in STP	0	[d-1]	O
Total rate constant for degradation in STP	0	[d-1]	O
Maximum growth rate of specific microorganisms	2	[d-1]	D
Half saturation concentration	0.5	[g.m-3]	D

WATER/SEDIMENT

WATER

Rate constant for hydrolysis in surface water	6.93E-07	[d-1] (12[oC])	O
Rate constant for photolysis in surface water	2.89E-08	[hr-1]	O
Rate constant for biodegradation in surface water	4.7E-03	[d-1] (12[oC])	S
Total rate constant for degradation in bulk surface water	4.7E-03	[d-1] (12[oC])	O
Rate constant for biodegradation in saltwater	0	[d-1] (12[oC])	O
Total rate constant for degradation in bulk saltwater	1.39E-06	[d-1] (12[oC])	O

SEDIMENT

Rate constant for biodegradation in aerated sediment	2.31E-06	[d-1] (12[oC])	S
Total rate constant for degradation in bulk sediment	2.31E-07	[d-1] (12[oC])	O

AIR

Specific degradation rate constant with OH-radicals	2.96E-12	[cm3.molec-1.s-1]	S
Rate constant for degradation in air	0.128	[d-1]	O

SOIL

Rate constant for biodegradation in bulk soil	2.31E-06	[d-1] (12[oC])	S
Total rate constant for degradation in bulk soil	2.31E-06	[d-1] (12[oC])	O

REMOVAL RATE CONSTANTS SOIL

Total rate constant for degradation in bulk soil	2.31E-06	[d-1] (12[oC])	O
Rate constant for volatilisation from agricultural soil	2.52E-07	[d-1]	O
Rate constant for leaching from agricultural soil	4.81E-07	[d-1]	O
Total rate constant for removal from agricultural top soil	3.04E-06	[d-1]	O
Rate constant for volatilisation from grassland soil	5.05E-07	[d-1]	O
Rate constant for leaching from grassland soil	9.62E-07	[d-1]	O
Total rate constant for removal from grassland top soil	3.78E-06	[d-1]	O
Rate constant for volatilisation from industrial soil	1.01E-06	[d-1]	O
Rate constant for leaching from industrial soil	1.92E-06	[d-1]	O
Total rate constant for removal from industrial soil	5.24E-06	[d-1]	O

RELEASE ESTIMATION

CHARACTERIZATION AND TONNAGE

High Production Volume Chemical	No		D
Production volume of chemical in EU	0	[tonnes.yr-1]	D
Fraction of EU production volume for region	10	[%]	S
Regional production volume of substance	0	[tonnes.yr-1]	O
Continental production volume of substance	0	[tonnes.yr-1]	O
Volume of chemical imported to EU	0	[tonnes.yr-1]	D
Volume of chemical exported from EU	0	[tonnes.yr-1]	D
Tonnage of substance in Europe	2.939E+03	[tonnes.yr-1]	S

USE PATTERNS

PRODUCTION STEPS

OTHER LIFE CYCLE STEPS

EMISSION INPUT DATA

Usage/production title	ABS shredding		S

USE PATTERN

Industry category	4 Electrical/electronic engineering industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	No extra details necessary		S
Extra details on use category	No extra details necessary		S

WASTE TREATMENT

Use specific emission scenario	No		D
Emission scenario	no special scenario selected/available		S

TONNAGE

Fraction of tonnage for application	1	[-]	S
Fraction of chemical in formulation	1	[-]	D
Tonnage of formulated product	294	[tonnes.yr-1]	O
Relevant tonnage for application	2.94E+03	[tonnes.yr-1]	O
Regional tonnage of substance	294	[tonnes.yr-1]	O
Tonnage of formulated product	294	[tonnes.yr-1]	O
Regional tonnage of substance (private use step)	294	[tonnes.yr-1]	O
Continental tonnage of substance (private use step)	2.65E+03	[tonnes.yr-1]	O
Total of fractions for all applications	1	[-]	O

INTERMEDIATE RESULTS

INTERMEDIATE

RELEASE FRACTIONS AND EMISSION DAYS

WASTE TREATMENT

Emission tables	No applicable emission tables		S

RELEASE FRACTIONS

Fraction of tonnage released to air	1E-03	[-]	S
Fraction of tonnage released to wastewater	0	[-]	O
Fraction of tonnage released to surface water	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Emission fractions determined by special scenario	No		O

EMISSION DAYS			
Fraction of the main local source	0.02	[-]	S
Number of emission days per year	220	[-]	S
Release to wastewater only	No		O
Emission days determined by special scenario	No		O
REGIONAL AND CONTINENTAL RELEASES			
WASTE TREATMENT			
REGIONAL			
Regional release to air	0.805	[kg.d-1]	O
Regional release to wastewater	0	[kg.d-1]	O
Regional release to surface water	0	[kg.d-1]	O
Regional release to industrial soil	0	[kg.d-1]	O
Regional release to agricultural soil	0	[kg.d-1]	O
CONTINENTAL			
Continental release to air	7.25	[kg.d-1]	O
Continental release to wastewater	0	[kg.d-1]	O
Continental release to surface water	0	[kg.d-1]	O
Continental release to industrial soil	0	[kg.d-1]	O
Continental release to agricultural soil	0	[kg.d-1]	O
REGIONAL AND CONTINENTAL TOTAL EMISSIONS			
Total regional emission to air	0.805	[kg.d-1]	O
Total regional emission to wastewater	0	[kg.d-1]	O
Total regional emission to surface water	0	[kg.d-1]	O
Total regional emission to industrial soil	0	[kg.d-1]	O
Total regional emission to agricultural soil	0	[kg.d-1]	O
Total continental emission to air	7.25	[kg.d-1]	O
Total continental emission to wastewater	0	[kg.d-1]	O
Total continental emission to surface water	0	[kg.d-1]	O
Total continental emission to industrial soil	0	[kg.d-1]	O
Total continental emission to agricultural soil	0	[kg.d-1]	O
LOCAL			
[WASTE TREATMENT]			
Local emission to air during episode	0.13	[kg.d-1]	S
Emission to air calculated by special scenario	No		O
Local emission to wastewater during episode	0	[kg.d-1]	O
Emission to water calculated by special scenario	No		O
Show this step in further calculations	Yes		O
Intermittent release	No		D

DISTRIBUTION

SEWAGE TREATMENT

CONTINENTAL

Fraction of emission directed to air	0	[%]	O
Fraction of emission directed to water	0	[%]	O
Fraction of emission directed to sludge	0	[%]	O
Fraction of the emission degraded	0	[%]	O
Total of fractions	0	[%]	O
Indirect emission to air	0	[kg.d-1]	O
Indirect emission to surface water	0	[kg.d-1]	O
Indirect emission to agricultural soil	0	[kg.d-1]	O

REGIONAL

Fraction of emission directed to air	0	[%]	O
Fraction of emission directed to water	0	[%]	O
Fraction of emission directed to sludge	0	[%]	O
Fraction of the emission degraded	0	[%]	O
Total of fractions	0	[%]	O
Indirect emission to air	0	[kg.d-1]	O
Indirect emission to surface water	0	[kg.d-1]	O
Indirect emission to agricultural soil	0	[kg.d-1]	O

LOCAL

[WASTE TREATMENT]

INPUT AND CONFIGURATION [WASTE TREATMENT]

INPUT

Use or bypass STP (local freshwater assessment)	Bypass STP		S
Use or bypass STP (local marine assessment)	Bypass STP		D
Local emission to wastewater during episode	0	[kg.d-1]	O
Concentration in untreated wastewater	0	[mg.l-1]	O
Local emission entering the STP	0	[kg.d-1]	O

CONFIGURATION

Type of local STP	With primary settler (9-box)		D
Number of inhabitants feeding this STP	1E+04	[eq]	O
Effluent discharge rate of this STP	2E+06	[l.d-1]	O
Calculate dilution from river flow rate	No		O
Flow rate of the river	1.8E+04	[m3.d-1]	O
Dilution factor (rivers)	10	[-]	O
Dilution factor (coastal areas)	100	[-]	O

OUTPUT [WASTE TREATMENT]

Fraction of emission directed to air by STP	0	[%]	O
Fraction of emission directed to water by STP	100	[%]	O
Fraction of emission directed to sludge by STP	0	[%]	O
Fraction of the emission degraded in STP	0	[%]	O
Total of fractions	100	[%]	O
Local indirect emission to air from STP during episode	0	[kg.d-1]	O
Concentration in untreated wastewater	0	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0	[mg.kg-1]	O
PEC for micro-organisms in the STP	0	[mg.l-1]	O

REGIONAL, CONTINENTAL AND GLOBAL DISTRIBUTION

PECS

REGIONAL

Regional PEC in surface water (total)	4.34E-07	[mg.l-1]	O
Regional PEC in seawater (total)	5.25E-08	[mg.l-1]	O
Regional PEC in surface water (dissolved)	3.9E-07	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Regional PEC in seawater (dissolved)	5.06E-08	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Regional PEC in air (total)	1.2E-08	[mg.m-3]	O
Regional PEC in agricultural soil (total)	2.95E-03	[mg.kgwwt-1]	O
Regional PEC in pore water of agricultural soils	1.01E-06	[mg.l-1]	O
Regional PEC in natural soil (total)	4.91E-03	[mg.kgwwt-1]	O
Regional PEC in industrial soil (total)	4.91E-03	[mg.kgwwt-1]	O
Regional PEC in sediment (total)	1.23E-03	[mg.kgwwt-1]	O
Regional PEC in seawater sediment (total)	1.59E-04	[mg.kgwwt-1]	O

CONTINENTAL

Continental PEC in surface water (total)	1.09E-07	[mg.l-1]	O
Continental PEC in seawater (total)	9.3E-09	[mg.l-1]	O
Continental PEC in surface water (dissolved)	9.81E-08	[mg.l-1]	O
Continental PEC in seawater (dissolved)	8.96E-09	[mg.l-1]	O
Continental PEC in air (total)	1.79E-09	[mg.m-3]	O
Continental PEC in agricultural soil (total)	4.42E-04	[mg.kgwwt-1]	O
Continental PEC in pore water of agricultural soils	1.51E-07	[mg.l-1]	O
Continental PEC in natural soil (total)	7.36E-04	[mg.kgwwt-1]	O
Continental PEC in industrial soil (total)	7.36E-04	[mg.kgwwt-1]	O
Continental PEC in sediment (total)	3.1E-04	[mg.kgwwt-1]	O
Continental PEC in seawater sediment (total)	2.81E-05	[mg.kgwwt-1]	O

GLOBAL: MODERATE

Moderate PEC in water (total)	7.65E-09	[mg.l-1]	O
Moderate PEC in water (dissolved)	7.37E-09	[mg.l-1]	O
Moderate PEC in air (total)	4.5E-11	[mg.m-3]	O
Moderate PEC in soil (total)	1.84E-05	[mg.kgwwt-1]	O
Moderate PEC in sediment (total)	2.31E-05	[mg.kgwwt-1]	O

GLOBAL: ARCTIC

Arctic PEC in water (total)	7.64E-09	[mg.l-1]	O
Arctic PEC in water (dissolved)	7.36E-09	[mg.l-1]	O
Arctic PEC in air (total)	7.67E-12	[mg.m-3]	O
Arctic PEC in soil (total)	7.55E-06	[mg.kgwwt-1]	O
Arctic PEC in sediment (total)	2.31E-05	[mg.kgwwt-1]	O

GLOBAL: TROPIC

Tropic PEC in water (total)	7.24E-09	[mg.l-1]	O
Tropic PEC in water (dissolved)	6.98E-09	[mg.l-1]	O
Tropic PEC in air (total)	3.22E-11	[mg.m-3]	O
Tropic PEC in soil (total)	7.16E-06	[mg.kgwwt-1]	O
Tropic PEC in sediment (total)	2.18E-05	[mg.kgwwt-1]	O

STEADY-STATE FRACTIONS

REGIONAL

Steady-state mass fraction in regional freshwater	8.72E-05	[%]	O
Steady-state mass fraction in regional seawater	1.17E-05	[%]	O
Steady-state mass fraction in regional air	2.7E-05	[%]	O
Steady-state mass fraction in regional agricultural soil	1.34	[%]	O
Steady-state mass fraction in regional natural soil	0.252	[%]	O
Steady-state mass fraction in regional industrial soil	0.0932	[%]	O
Steady-state mass fraction in regional freshwater sediment	2.85E-03	[%]	O
Steady-state mass fraction in regional seawater sediment	1.22E-04	[%]	O

CONTINENTAL

Steady-state mass fraction in continental freshwater	1.92E-03	[%]	O
Steady-state mass fraction in continental seawater	0.363	[%]	O
Steady-state mass fraction in continental air	7.01E-04	[%]	O
Steady-state mass fraction in continental agricultural soil	17.6	[%]	O
Steady-state mass fraction in continental natural soil	3.3	[%]	O
Steady-state mass fraction in continental industrial soil	1.22	[%]	O
Steady-state mass fraction in continental freshwater sediment	0.0627	[%]	O
Steady-state mass fraction in continental seawater sediment	0.189	[%]	O

GLOBAL: MODERATE

Steady-state mass fraction in moderate water	16.6	[%]	O
Steady-state mass fraction in moderate air	1.96E-04	[%]	O
Steady-state mass fraction in moderate soil	3.41	[%]	O
Steady-state mass fraction in moderate sediment	1.73	[%]	O

GLOBAL: ARCTIC

Steady-state mass fraction in arctic water	10.9	[%]	O
Steady-state mass fraction in arctic air	1.82E-05	[%]	O
Steady-state mass fraction in arctic soil	0.609	[%]	O
Steady-state mass fraction in arctic sediment	1.13	[%]	O

GLOBAL: TROPIC

Steady-state mass fraction in tropic water	36.1	[%]	O
Steady-state mass fraction in tropic air	2.29E-04	[%]	O
Steady-state mass fraction in tropic soil	1.3	[%]	O
Steady-state mass fraction in tropic sediment	3.76	[%]	O

STEADY-STATE MASSES

REGIONAL

Steady-state mass in regional freshwater	1.56	[kg]	O
Steady-state mass in regional seawater	0.21	[kg]	O
Steady-state mass in regional air	0.484	[kg]	O
Steady-state mass in regional agricultural soil	2.41E+04	[kg]	O
Steady-state mass in regional natural soil	4.51E+03	[kg]	O
Steady-state mass in regional industrial soil	1.67E+03	[kg]	O
Steady-state mass in regional freshwater sediment	51.1	[kg]	O
Steady-state mass in regional seawater sediment	2.19	[kg]	O

CONTINENTAL

Steady-state mass in continental freshwater	34.3	[kg]	O
Steady-state mass in continental seawater	6.51E+03	[kg]	O
Steady-state mass in continental air	12.6	[kg]	O
Steady-state mass in continental agricultural soil	3.15E+05	[kg]	O
Steady-state mass in continental natural soil	5.91E+04	[kg]	O
Steady-state mass in continental industrial soil	2.19E+04	[kg]	O
Steady-state mass in continental freshwater sediment	1.12E+03	[kg]	O
Steady-state mass in continental seawater sediment	3.39E+03	[kg]	O

GLOBAL: MODERATE

Steady-state mass in moderate water	2.98E+05	[kg]	O
Steady-state mass in moderate air	3.51	[kg]	O
Steady-state mass in moderate soil	6.11E+04	[kg]	O
Steady-state mass in moderate sediment	3.1E+04	[kg]	O

GLOBAL: ARCTIC

Steady-state mass in arctic water	1.95E+05	[kg]	O
Steady-state mass in arctic air	0.326	[kg]	O
Steady-state mass in arctic soil	1.09E+04	[kg]	O
Steady-state mass in arctic sediment	2.03E+04	[kg]	O

GLOBAL: TROPIC

Steady-state mass in tropic water	6.46E+05	[kg]	O
Steady-state mass in tropic air	4.1	[kg]	O
Steady-state mass in tropic soil	2.33E+04	[kg]	O
Steady-state mass in tropic sediment	6.73E+04	[kg]	O

LOCAL

[WASTE TREATMENT]

LOCAL CONCENTRATIONS AND DEPOSITIONS [WASTE TREATMENT]

AIR

Concentration in air during emission episode	3.61E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	2.18E-05	[mg.m-3]	O
Total deposition flux during emission episode	3.2E-04	[mg.m-2.d-1]	O
Annual average total deposition flux	1.93E-04	[mg.m-2.d-1]	O

WATER, SEDIMENT

Concentration in surface water during emission episode (dissolved)	0	[mg.l-1]	O
Concentration in surface water exceeds solubility	No		O
Annual average concentration in surface water (dissolved)	0	[mg.l-1]	O
Concentration in seawater during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in seawater (dissolved)	0	[mg.l-1]	O

SOIL, GROUNDWATER

Concentration in agric. soil averaged over 30 days	2.07E-03	[mg.kgwwt-1]	O
Concentration in agric. soil averaged over 180 days	2.11E-03	[mg.kgwwt-1]	O
Concentration in grassland averaged over 180 days	4.21E-03	[mg.kgwwt-1]	O
Fraction of steady-state (agricultural soil)	0.011	[-]	O
Fraction of steady-state (grassland soil)	0.0137	[-]	O

LOCAL PECS [WASTE TREATMENT]

AIR

Annual average local PEC in air (total)	2.18E-05	[mg.m-3]	O

WATER, SEDIMENT

Local PEC in surface water during emission episode (dissolved)	3.9E-07	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Annual average local PEC in surface water (dissolved)	3.9E-07	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	6.2E-04	[mg.kgwwt-1]	O
Local PEC in seawater during emission episode (dissolved)	5.06E-08	[mg.l-1]	O
Qualitative assessment might be needed (TGD Part II, 5.6)	No		O
Annual average local PEC in seawater (dissolved)	5.06E-08	[mg.l-1]	O
Local PEC in marine sediment during emission episode	8.04E-05	[mg.kgwwt-1]	O

SOIL, GROUNDWATER

Local PEC in agric. soil (total) averaged over 30 days	6.97E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	7.02E-03	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	9.12E-03	[mg.kgwwt-1]	O
Local PEC in pore water of agricultural soil	2.39E-06	[mg.l-1]	O
Local PEC in pore water of grassland	3.11E-06	[mg.l-1]	O
Local PEC in groundwater under agricultural soil	2.39E-06	[mg.l-1]	O

EXPOSURE

SECONDARY POISONING

SECONDARY POISONING [WASTE TREATMENT]

Concentration in fish for secondary poisoning (freshwater)	4.82E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.0151	[mg.kg-1]	O
Concentration in fish for secondary poisoning (marine)	6.25E-05	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	6.25E-05	[mg.kgwwt-1]	O

EFFECTS

INPUT OF EFFECTS DATA

MICRO-ORGANISMS

Test system	Respiration inhibition, EU Annex V C.11, OECD 209		D
EC50 for micro-organisms in a STP	??	[mg.l-1]	D
EC10 for micro-organisms in a STP	??	[mg.l-1]	D
NOEC for micro-organisms in a STP	>15	[mg.l-1]	S

AQUATIC ORGANISMS

FRESH WATER

L(E)C50 SHORT-TERM TESTS

LC50 for fish	0.54	[mg.l-1]	S
L(E)C50 for Daphnia	0.96	[mg.l-1]	S
EC50 for algae	0.09	[mg.l-1]	S
LC50 for additional taxonomic group	??	[mg.l-1]	D
Aquatic species	other		D

NOEC LONG-TERM TESTS

NOEC for fish	0.16	[mg.l-1]	S
NOEC for Daphnia	0.3	[mg.l-1]	S
NOEC for algae	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D
NOEC for additional taxonomic group	??	[mg.l-1]	D

MARINE

L(E)C50 SHORT-TERM TESTS

LC50 for fish (marine)	??	[mg.l-1]	D
L(E)C50 for crustaceans (marine)	??	[mg.l-1]	D
EC50 for algae (marine)	??	[mg.l-1]	D
LC50 for additional taxonomic group (marine)	??	[mg.l-1]	D
Marine species	other		D
LC50 for additional taxonomic group (marine)	??	[mg.l-1]	D
Marine species	other		D

NOEC LONG-TERM TESTS

NOEC for fish (marine)	??	[mg.l-1]	D
NOEC for crustaceans (marine)	0.0127	[mg.l-1]	S
NOEC for algae (marine)	??	[mg.l-1]	D
NOEC for additional taxonomic group (marine)	0.017	[mg.l-1]	S
NOEC for additional taxonomic group (marine)	??	[mg.l-1]	D

FRESH WATER SEDIMENT

L(E)C50 SHORT-TERM TESTS

LC50 for fresh-water sediment organism	254	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested sediment	0.059	[kg.kg-1]	S

EC10/NOEC LONG-TERM TESTS

EC10 for fresh-water sediment organism	414	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested sediment	0.025	[kg.kg-1]	S
EC10 for fresh-water sediment organism	125	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

MARINE SEDIMENT

L(E)C50 SHORT-TERM TESTS

LC50 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

EC10/NOEC LONG-TERM TESTS

EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested sediment	0.05	[kg.kg-1]	D

TERRESTRIAL ORGANISMS

L(E)C50 SHORT-TERM TESTS

LC50 for plants	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
LC50 for earthworms	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
EC50 for microorganisms	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
LC50 for other terrestrial species	??	[mg.kgwwt-1]	D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D

NOEC LONG-TERM TESTS

NOEC for plants	25.9	[mg.kgdwt-1]	S
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for earthworms	0.29	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested soil	0.044	[kg.kg-1]	S
NOEC for microorganisms	1E+03	[mg.kgwwt-1]	S
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
Terrestrial species	other		D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
Terrestrial species	other		D
Weight fraction of organic carbon in tested soil	0.02	[kg.kg-1]	D

BIRDS

LC50 in avian dietary study (5 days)	??	[mg.kg-1]	D
NOEC via food (birds)	??	[mg.kg-1]	D
NOAEL (birds)	??	[mg.kg-1.d-1]	D
Conversion factor NOAEL to NOEC (birds)	8	[kg.d.kg-1]	D

MAMMALS

REPEATED DOSE

ORAL

Oral NOAEL (repdose)	??	[mg.kg-1.d-1]	D
Oral LOAEL (repdose)	??	[mg.kg-1.d-1]	D
Oral CED (repdose)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (repdose)	??	[mg.kg-1]	D
LOEC via food (repdose)	??	[mg.kg-1]	D
CED via food (repdose)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (repdose)	??	[mg.m-3]	D
Inhalatory LOAEL (repdose)	??	[mg.m-3]	D
Inhalatory CED (repdose)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (repdose)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (repdose)	??	[mg.kg-1.d-1]	D
Dermal CED (repdose)	??	[mg.kg-1.d-1]	D

FERTILITY

ORAL

Oral NOAEL (fert)	??	[mg.kg-1.d-1]	D
Oral LOAEL (fert)	??	[mg.kg-1.d-1]	D
Oral CED (fert)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (fert)	??	[mg.kg-1]	D
LOEC via food (fert)	??	[mg.kg-1]	D
CED via food (fert)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (fert)	??	[mg.m-3]	D
Inhalatory LOAEL (fert)	??	[mg.m-3]	D
Inhalatory CED (fert)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (fert)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (fert)	??	[mg.kg-1.d-1]	D
Dermal CED (fert)	??	[mg.kg-1.d-1]	D

MATERNAL-TOX

ORAL

Oral NOAEL (mattox)	??	[mg.kg-1.d-1]	D
Oral LOAEL (mattox)	??	[mg.kg-1.d-1]	D
Oral CED (mattox)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (mattox)	??	[mg.kg-1]	D
LOEC via food (mattox)	??	[mg.kg-1]	D
CED via food (mattox)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (mattox)	??	[mg.m-3]	D
Inhalatory LOAEL (mattox)	??	[mg.m-3]	D
Inhalatory CED (mattox)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (mattox)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (mattox)	??	[mg.kg-1.d-1]	D
Dermal CED (mattox)	??	[mg.kg-1.d-1]	D

DEVELOPMENT-TOX

ORAL

Oral NOAEL (devtox)	??	[mg.kg-1.d-1]	D
Oral LOAEL (devtox)	??	[mg.kg-1.d-1]	D
Oral CED (devtox)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (devtox)	??	[mg.kg-1]	D
LOEC via food (devtox)	??	[mg.kg-1]	D
CED via food (devtox)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (devtox)	??	[mg.m-3]	D
Inhalatory LOAEL (devtox)	??	[mg.m-3]	D
Inhalatory CED (devtox)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (devtox)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (devtox)	??	[mg.kg-1.d-1]	D
Dermal CED (devtox)	??	[mg.kg-1.d-1]	D

CARC (THRESHOLD)

ORAL

Oral NOAEL (carc)	??	[mg.kg-1.d-1]	D
Oral LOAEL (carc)	??	[mg.kg-1.d-1]	D
Oral CED (carc)	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
NOEC via food (carc)	??	[mg.kg-1]	D
LOEC via food (carc)	??	[mg.kg-1]	D
CED via food (carc)	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory NOAEL (carc)	??	[mg.m-3]	D
Inhalatory LOAEL (carc)	??	[mg.m-3]	D
Inhalatory CED (carc)	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal NOAEL (carc)	??	[mg.kg-1.d-1]	D
Dermal LOAEL (carc)	??	[mg.kg-1.d-1]	D
Dermal CED (carc)	??	[mg.kg-1.d-1]	D

CARC (NON-THRESHOLD)

ORAL

Oral T25 for non-threshold effects	??	[mg.kg-1.d-1]	D
Oral CED for non-threshold effects	??	[mg.kg-1.d-1]	D
Species for conversion of NOAEL to NOEC	Rattus norvegicus (<=6 weeks)		D
Conversion factor NOAEL to NOEC	10	[kg.d.kg-1]	O
T25 via food for non-threshold effects	??	[mg.kgfood-1]	D
CED via food for non-threshold effects	??	[mg.kgfood-1]	D

INHALATORY

Inhalatory T25 for non-threshold effects	??	[mg.m-3]	D
Inhalatory CED for non-threshold effects	??	[mg.m-3]	D
Correction factor for allometric scaling	1	[-]	D

DERMAL

Dermal T25 for non-threshold effects	??	[mg.kg-1.d-1]	D
Dermal CED for non-threshold effects	??	[mg.kg-1.d-1]	D

ACUTE

Oral LD50	??	[mg.kg-1]	D
Oral Discriminatory Dose	??	[mg.kg-1]	D
Inhalatory LC50	??	[mg.m-3]	D
Dermal LD50	??	[mg.kg-1]	D

PREDATOR

Duration of (sub-)chronic oral test	28 days		D
NOEC via food for secondary poisoning	??	[mg.kg-1]	O
Source for NOEC-via-food data	No data available, enter manually		S

BIO-AVAILIBILITY

Bioavailability for oral uptake (oral to inhalation)	0.5	[-]	D
Bioavailability for oral uptake (oral to dermal)	1	[-]	D
Bioavailability for oral uptake (route to oral)	1	[-]	D
Bioavailability for inhalation (route from inhalation)	1	[-]	D
Bioavailability for inhalation (route to inhalation)	1	[-]	D
Bioavailability for dermal uptake (route from dermal)	0.1	[-]	O
Bioavailability for dermal uptake (route to dermal)	0.1	[-]	O

ENVIRONMENTAL EFFECTS ASSESSMENT

ENVIRONMENTAL PNECS

FRESH WATER

Same taxonomic group for LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Aqua	1.3E-03	[mg.l-1]	S
Assessment factor applied in extrapolation to PNEC Aqua	1	[-]	S
PNEC for aquatic organisms	1.3E-03	[mg.l-1]	O

INTERMITTENT RELEASES

Toxicological data used for extrapolation to PNEC Aqua	0.09	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC Aqua	100	[-]	O
PNEC for aquatic organisms, intermittent releases	9E-04	[mg.l-1]	O

STATISTICAL

PNEC for aquatic organisms with statistical method	??	[mg.l-1]	D

MARINE

Same taxonomic group for marine LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Marine	0.25	[ug.l-1]	S
Assessment factor applied in extrapolation to PNEC Marine	1	[-]	S
PNEC for marine organisms	2.5E-04	[mg.l-1]	O

STATISTICAL

PNEC for marine organisms with statistical method	??	[mg.l-1]	D

FRESH WATER SEDIMENT

Toxicological data used for extrapolation to PNEC sediment (fresh)	2.7	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC sediment (fresh)	1	[-]	S
PNEC for fresh-water sediment organisms (from toxicological data)	2.7	[mg.kgwwt-1]	O
PNEC for fresh-water sediment organisms (equilibrium partitioning)	2.06	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in fresh-water sediment?	No		O
PNEC for fresh-water sediment, normalised to 10% o.c. (local)	2.7	[mg.kgwwt-1]	S
PNEC for fresh-water sediment, normalised to 5% o.c. (regional)	2.7	[mg.kgwwt-1]	O

MARINE SEDIMENT

Toxicological data used for extrapolation to PNEC sediment (marine)	0.54	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC sediment (marine)	1	[-]	S
PNEC for marine sediment organisms (from toxicological data)	0.54	[mg.kgwwt-1]	O
PNEC for marine sediment organisms (equilibrium partitioning)	0.397	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in marine sediment?	No		O
PNEC for marine sediment, normalised to 10% o.c. (local)	1.08	[mg.kgwwt-1]	O
PNEC for marine sediment, normalised to 5% o.c. (regional)	0.54	[mg.kgwwt-1]	O

TERRESTRIAL

Same taxonomic group for LC50 and NOEC	No		O
Toxicological data used for extrapolation to PNEC Terr	0.012	[mg.kgwwt-1]	S
Assessment factor applied in extrapolation to PNEC Terr	1	[-]	S
PNEC for terrestrial organisms (from toxicological data)	0.012	[mg.kgwwt-1]	O
PNEC for terrestrial organisms (equilibrium partitioning)	3.81	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in soil?	No		O
PNEC for terrestrial organisms	0.012	[mg.kgwwt-1]	O

STATISTICAL

PNEC for terrestrial organisms with statistical method	??	[mg.kgwwt-1]	D

SECONDARY POISONING

Toxicological data used for extrapolation to PNEC oral	667	[mg.kg-1]	S
Assessment factor applied in extrapolation to PNEC oral	1	[-]	S
PNEC for secondary poisoning of birds and mammals	667	[mg.kg-1]	O

STP

Toxicological data used for extrapolation to PNEC micro	1.5	[mg.l-1]	S
Assessment factor applied in extrapolation to PNEC micro	1	[-]	S
PNEC for micro-organisms in a STP	1.5	[mg.l-1]	O

RISK CHARACTERIZATION

ENVIRONMENTAL EXPOSURE

LOCAL

RISK CHARACTERIZATION OF [WASTE TREATMENT]

WATER

RCR for the local fresh-water compartment	3E-04	[-]	O
Intermittent release	No		D
RCR for the local marine compartment	2.03E-04	[-]	O
RCR for the local fresh-water compartment, statistical method	??	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O

SEDIMENT

RCR for the local fresh-water sediment compartment	2.3E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the local marine sediment compartment	7.44E-05	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O

SOIL

RCR for the local soil compartment	0.581	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the local soil compartment, statistical method	??	[-]	O

PREDATORS

RCR for fish-eating birds and mammals (fresh-water)	7.22E-07	[-]	O
RCR for fish-eating birds and mammals (marine)	9.37E-08	[-]	O
RCR for top predators (marine)	9.37E-08	[-]	O
RCR for worm-eating birds and mammals	2.26E-05	[-]	O

REGIONAL

WATER

RCR for the regional fresh-water compartment	3E-04	[-]	O
RCR for the regional marine compartment	2.03E-04	[-]	O
RCR for the regional fresh-water compartment, statistical method	??	[-]	O
RCR for the regional marine compartment, statistical method	??	[-]	O

SEDIMENT

RCR for the regional fresh-water sediment compartment	4.57E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the regional marine sediment compartment	2.94E-04	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O

SOIL

RCR for the regional soil compartment	0.246	[-]	O
Extra factor 10 applied to PEC/PNEC	No		O
RCR for the regional soil compartment, statistical method	??	[-]	O