RISK ASSESSMENT
OF
2,2',6,6'-TETRABROMO-4,4'-ISOPROPYLIDENE DIPHENOL
(TETRABROMOBISPHENOL-A)

CAS Number: 79-94-7
EINECS Number: 201-236-9

Final Environmental Rar of February 2008

FINAL APPROVED VERSION

Foreword

This risk assessment of the priority substance covered by this Draft Risk Assessment Report is carried out in accordance with Council Regulation (EEC) 793/93[1] on the evaluation and control of the risks of "existing" substances. Regulation 793/93 provides a systematic framework for the evaluation of the risks to human health and the environment of these substances if they are produced or imported into the Community in volumes above 10 tonnes per year.

There are four overall stages in the Regulation for reducing the risks: data collection, priority setting, risk assessment and risk reduction. Data provided by Industry are used by Member States and the Commission services to determine the priority of the substances which need to be assessed. For each substance on a priority list, a Member State volunteers to act as "Rapporteur", undertaking the in-depth Risk Assessment and if necessary, recommending a strategy to limit the risks of exposure to the substance.

Tetrabromobisphenol-A was identified as a priority substance for Risk Assessment based on its high consumption, its perceived environmental persistence, bioaccumulation potential and toxicity, and its similarity (in terms of chemical structure or uses) to other priority substances such as bisphenol-A, polybrominated diphenyl ethers and hexabromocyclododecane that have undergone, or are currently undergoing, Risk Assessments. In addition tetrabromobisphenol-A is considered a priority substance by other international organisations such as OSPAR. Tetrabromobisphenol-A appeared on the 4th priority list published on 25th October 2000.

The methods for carrying out an in-depth Risk Assessment at Community level are laid down in Commission Regulation (EC) 1488/94[2] which is supported by a technical guidance document[3]. Normally, the "Rapporteur" and individual companies producing, importing and/or using the chemicals work closely together to develop a draft Risk Assessment Report, which is then presented to the Competent Group of Member State experts for endorsement. Observers from Industry, Consumer Organisations, Trade Unions, Environmental Organisations and certain International Organisations are also invited to attend the meetings. The Risk Assessment Report is then peer-reviewed by the Scientific Committee on Health and Environmental Risks (SCHER) which gives its opinion to the European Commission on the quality of the risk assessment.

This Draft Risk Assessment Report is currently under discussion in the Competent Group of Member State experts with the aim of reaching consensus. During the course of these discussions, the scientific interpretation of the underlying scientific information may change, more information may be included and even the conclusions reached in this draft may change. The Competent Group of Member State experts seek as wide a distribution of these drafts as possible, in order to assure as complete and accurate an information basis as possible. The information contained in this Draft Risk Assessment Report does not, therefore, necessarily provide a sufficient basis for decision making regarding the hazards, exposures or the risks associated with the priority substance under consideration herein.

[1] O.J. No L 084, 05/04/1993 p. 0001 - 0075
[2] O.J. No. L 161, 29/06/1994 p. 0003 – 0011
[3] Technical Guidance Document, Part I-V, ISBN 92-827-801[1234]

This Draft Risk Assessment Report is the responsibility of the Member State rapporteur. In order to avoid possible misinterpretations or misuse of the findings in this draft, anyone wishing to cite or quote this report is advised contact the Member State rapporteur beforehand.

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Date of last literature search: October 2006.

0 OVERALL RESULTS OF THE RISK ASSESSMENT

CAS Number: 79-94-7
EINECS Number: 287-477-0
IUPAC Name: 2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol

Overall results of the Risk Assessment

Environment

(x) i) There is a need for further information and/or testing.

It is possible that tetrabromobisphenol-A may be degraded to bisphenol-A in anaerobic freshwater and marine sediments. The potential risks to sediment have been assessed in the updated risk assessment of bisphenol-A, for both reactive and additive flame retardant uses (ECB, 2008). No risks are identified based on the PNECs derived in that report. However, further work is on-going at present within the UK that could affect the aquatic and hence the sediment PNEC. The conclusion should therefore be reconsidered once the bisphenol-A sediment PNEC is finally agreed (conclusion (i) on-hold). This conclusion applies to regional sources, and also for sites manufacturing and processing epoxy and polycarbonate resins, and sites carrying out conversion of ABS.

Another possible metabolite/degradation product – tetrabromobisphenol-A bis(methyl ether) – possibly meets the screening criteria for a PBT substance using mainly estimated data. The presence of this substance has been investigated in some recent studies of anaerobic transformation in freshwater aquatic sediment and sewage sludge, and anaerobic and aerobic soil transformation. Although inconclusive, the results suggest that it is a very minor degradation product. Given that a need for risk reduction measures has already been identified for some uses (which should reduce the environmental burden of the parent compound), no further specific work is recommended to address this issue at the present time (conclusion (i) on-hold).

The risk characterisation ratios for the marine environment indicate a possible risk from some applications. The need for further toxicity data with marine organisms should be evaluated once the implications of any risk reduction activities resulting from the assessment for fresh water and freshwater sediment are known (conclusion (i) on-hold).

(x) ii) There is at present no need for further information and/or testing, or for risk reduction measures beyond those which are being applied already.

This applies to the assessment of the risks to sewage treatment processes, the atmosphere and from secondary poisoning (based on the currently derived PNEC[3]) for all sources of tetrabromobisphenol-A.

For surface water this conclusion applies to the assessment of regional sources, and also for manufacture and processing of epoxy and polycarbonate resins, where

[3] The results from more recent mammalian toxicity tests are available but it is not possible to determine if these have any implications for the PNEC for secondary poisoning until full details of the studies are available and the validity of the data has been established by the relevant human health experts.

tetrabromobisphenol-A is used as a reactive flame retardant, and conversion sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

For the terrestrial compartment this conclusion applies to the assessment of risks from regional sources, and also from processing of epoxy and polycarbonate resins. In addition this conclusion also applies to sites manufacturing epoxy and/or polycarbonate resins where sewage sludge is not applied to agricultural land (Industry have indicated that this is the case at all of the known major epoxy resin and/or polycarbonate manufacturing sites in the EU). It is possible that tetrabromobisphenol-A may be degraded to bisphenol-A during anaerobic sewage sludge treatment processes (which could lead to bisphenol-A being applied to soil). The potential risks to soil have been assessed in the updated risk assessment for bisphenol-A, for both reactive and additive flame retardant uses (ECB, 2008). This indicated no risk to the soil compartment from these applications.

This conclusion also applies to the finding of the substance in the eggs of predatory birds.

Tetrabromobisphenol-A is not a PBT substance (it is vP).

(x) iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

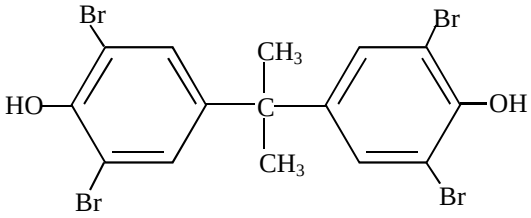
For surface water and sediment, this conclusion applies to compounding sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

For the terrestrial compartment, this conclusion applies to the use of tetrabromobisphenol-A as an additive flame retardant in ABS from compounding and conversion sites. The conclusion for conversion sites is dependent on whether or not sewage sludge from the site is applied to agricultural land (no risk is identified where sewage sludge is not applied to land). For ABS compounding sites a risk is identified regardless of the assumptions made over the spreading of sewage sludge.

1 GENERAL SUBSTANCE INFORMATION

1.1 IDENTIFICATION OF THE SUBSTANCE

This assessment considers the following commercial substance:

CAS No:	79-94-7
EINECS No:	201-236-9
IUPAC Name:	2,2', 6,6'-Tetrabromo-4,4'-isopropylidenediphenol (tetrabromobisphenol-A)
Molecular formula:	$C_{15}H_{12}Br_4O_2$
Molecular weight:	543.9 g/mole
Structural formula:	

Other names, abbreviations, tradenames and registered trademarks for the substance include the following.

2,2-bis(3,5-dibromo-4-hydroxyphenyl) propane	F-2016
3,3',5,5'-tetrabromobisphenol-A	F-2400
4,4'-isopropylidene-bis(2,6-dibromophenol)	F-2400E
phenol, 4,4'-isopropylidinebis, (dibromo-)	FR-1524
phenol, 4,4'-(1-methylethylidene)bis(2,6-dibromo-)	Fire Guard FG2000
tetrabromodihydroxy diphenylpropane	Firemaster BP 4A
TBBA	Saytex RB-100
TBBPA	Tetrabrom
BA-59P	Tetrabromodian

The common name tetrabromobisphenol-A or the abbreviation TBBPA will be used in this assessment.

1.2 PURITY/IMPURITIES, ADDITIVES

1.2.1 Purity/impurities

The purity of commercial tetrabromobisphenol-A has been reported as 98.5% (WHO, 1995). The main impurities are 0.1% water, a maximum of 60 mg hydrolysable bromine/kg and a maximum of 100 mg ionic bromide/kg (WHO, 1995). Recent tests carried out using composite samples from the main current suppliers of the substance report that the current purity of the substance is around 98.9% (Wildlife International, 2001a and 2001b) to 99.17% (Wildlife International 2002e), which is slightly higher than the value given in WHO (1995). Trace analysis of the current products indicates that the impurities include o,p'-tetrabromobisphenol-A (~0.05%) and tribromobisphenol-A (~0.79% to ~1.0%) (Wildlife International, 2001b and 2002e).

Brominated dibenzo-*p*-dioxins and furans may also be present at trace levels. The available data are discussed in Appendix A. In all cases the amounts found are below the levels specified in the German Dioxin Ordinance and the USEPA Dioxin Test Rule.

1.2.2 Additives

The commercially available form of tetrabromobisphenol-A has no stated additives.

1.3 PHYSICO-CHEMICAL PROPERTIES

The physico-chemical properties of tetrabromobisphenol-A are summarised in **Table 1.1**.

Table 1.1 Physico-chemical properties of commercial tetrabromobisphenol-A

Property	Value	Validity[a]
Chemical formula	$C_{15}H_{12}Br_4O_2$	1
Molecular weight	543.9 g/mole	1
Bromine content	58.8% by weight	1
Melting point	178°C; 181-182°C	2
Boiling point	~316°C (decomposes at 200-300°C)	2
Relative density	2.12; 2.18	2
Vapour pressure	$<1.19\times10^{-5}$ Pa at 20°C 6.24×10^{-6} Pa at 25°C	1 2
Water solubility	pH 5 - 0.148 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	1
Log octanol-water partition coefficient (log Kow)	5.90	1
Flammability	Not applicable – flame retardant	1
Autoflammability	Decomposes at 200-300°C	1
Explosive properties	None	1
Oxidising properties	None	1
Acid dissociation constants (pKa)	pKa_1= 7.5 pKa_2 = 8.5	4 4
Henry's Law constant	<0.1 Pa m^3/mole at 20-25°C	2
Conversion factor	1 ppm = 22.6 mg/m^3 at 20°C	1

Note: a) Validity markings. 1 - Valid without restriction. 2- Use with care. 3 - Not valid. 4 - Not assignable.

1.3.1 Physical state (at n.t.p.)

Tetrabromobisphenol-A is a white crystalline powder at 20^{o}C and 101,325 Pa (WHO, 1995).

1.3.2 Melting point

The melting point of tetrabromobisphenol-A has been reported to be 181-182^{o}C. A similar melting point of 178^{o}C is reported in IUCLID (2000).

1.3.3 Boiling point

The boiling point of tetrabromobisphenol-A is reported to be approximately 316^{o}C (WHO, 1995). However, the substance is likely to decompose over the temperature range 200-300^{o}C liberating Br_2/HBr gas as this reaction accounts for its flame-retarding properties, and so this boiling point could represent the decomposition temperature rather than the true boiling point of the substance. Further details of the method used to measure the boiling point of 316^{o}C are not available and so this hypothesis cannot be verified.

Using the Syracuse Research Corporation MPBPWIN program (version 1.28) a boiling point of 486^{o}C can be estimated for tetrabromobisphenol-A from its chemical structure.

1.3.4 Density

The relative density of tetrabromobisphenol-A has been quoted as 2.18 (WHO, 1995). A similar value of 2.12 at 20^{o}C has been quoted in IUCLID (2000).

1.3.5 Vapour pressure

The vapour pressure of tetrabromobisphenol-A at 20^{o}C has been investigated using the spinning rotor gauge method (Wildlife International, 2001a). The method used was based on the OECD 104 Vapour Pressure Curve method and the USEPA Product Properties Test Guideline OPPTS 830.7950. The substance used in the test was a composite sample from three current manufacturers of tetrabromobisphenol-A and the substance had a purity of 98.91%. Hexachlorobenzene (purity 99%) was used as a reference material in the study.

The limit of detection of the method for tetrabromobisphenol-A (defined as three times the standard deviation of the blank measurements) was determined as 3.57×10^{-6} Pa and the limit of quantification (defined as ten times the standard deviation of the blank measurements) was determined to be 1.19×10^{-5} Pa for tetrabromobisphenol-A. The vapour pressure for tetrabromobisphenol-A was below the limit of quantification of the method used i.e. $<1.19\times10^{-5}$ Pa at 20^{o}C.

The mean measured vapour pressure for the hexachlorobenzene reference material was 5.12×10^{-4} Pa, which is reasonably consistent with the published values for the vapour pressure of hexachlorobenzene of 2.6×10^{-3} Pa at 20^{o}C by the gas saturation method and 1.1×10^{-3} Pa at 20^{o}C by the vapour pressure balance method.

The vapour pressure of tetrabromobisphenol-A has been reported to be <1 mmHg at 20^{o}C (WHO, 1995). No further details of this study were reported. This value is equivalent to <133 Pa at 20^{o}C.

Watanabe and Tatsukawa (1989) reported a vapour pressure for tetrabromobisphenol-A at 25°C of 4.68×10^{-8} Torr, which is equivalent to 6.24×10^{-6} Pa. This was determined by a gas chromatography (GC) method, but few other details are available. The value is not inconsistent with the more recent determination using the spinning rotor method, but it is not possible to determine the reliability of this value. In particular, the nature of the substances used as references in the method is not given and so it is not clear if the method used was appropriate for a polar substance such as tetrabromobisphenol-A.

Wania (2003) reported the sub-cooled liquid vapour pressure to be 8.04×10^{-6} Pa at 25°C for tetrabromobisphenol-A. The vapour pressure was determined using a GC retention time method but further details are not currently available.

The vapour pressure is an important physico-chemical property for modelling the possible emissions of tetrabromobisphenol-A to the environment and also the subsequent distribution of the substance in the environment (See Section 3). For this reason, a reliable indication of the actual vapour pressure of the substance is desirable. One approach to this is to use quantitative structure-activity relationships (QSAR) to estimate the vapour pressure to support the available measured data. The Syracuse Research Corporation MPBPWIN (version 1.28) computer program has been used to estimate the vapour pressure of tetrabromobisphenol-A from its structure by the Modified Grain Method. The estimate was carried out three times, firstly allowing the program to estimate the melting point and boiling point, then using the measured melting point (see Section 1.3.2) and finally using the reported boiling point (see Section 1.3.3). The results are shown in **Table 1.2**.

Table 1.2 Estimated vapour pressure of tetrabromobisphenol-A

Input data		Calculated vapour pressure at 25°C
Melting point	**Boiling point**	
Estimated (206°C)	Estimated (486°C)	2.35×10^{-9} Pa (1.76×10^{-11} mmHg)
Measured (180°C)	Estimated (486°C)	4.73×10^{-9} Pa (3.55×10^{-11} mmHg)
Measured (180°C)	Measured (316°C)[a]	3.13×10^{-4} Pa (2.24×10^{-6} mmHg)

Note: a) The measured boiling point may represent the decomposition temperature rather than the true boiling point.

The predicted values using a boiling point of 486°C are consistent with the upper limit for the vapour pressure for tetrabromobisphenol-A as measured by the spinning rotor method but are well below that reported using a GC method. The value estimated using a boiling point of 316°C is higher than the upper limit for the measured vapour pressure, reflecting the fact that this may not be a true boiling point but a decomposition temperature.

For comparison, the vapour pressure of bisphenol-A is 5.3×10^{-6} Pa at 25°C (EC, 2003a).

Based on the available data, the vapour pressure of tetrabromobisphenol-A at ambient temperature will be assumed to be $<1.19\times10^{-5}$ Pa, and is probably considerably lower than this value. Where an actual value for the vapour pressure is needed the value of 6.24×10^{-6} Pa determined by Watanabe and Tatsukawa (1989) will be used in the environmental risk assessment, but it should be recognised that the reliability of this value is uncertain. The

implications of this value for the Henry's law constant, and hence subsequent environmental distribution, are considered in Section 1.3.14.1.

1.3.6 Solubility

The water solubility of tetrabromobisphenol-A has recently been determined using the OECD 105 method. The substance used was a composite sample from three manufacturers of the substance. A preliminary test was carried out by stirring an excess of the substance (nominal concentration 29 mg/l) in double distilled water for 2 days at 21°C. After this time the solution was centrifuged several times and the supernatants were analysed for tetrabromobisphenol-A. The concentration of tetrabromobisphenol-A in the dissolved phase was determined to be 0.077-0.081 mg/l. The pH of the solution was 6.6 (NOTOX, 2000).

The definitive test was carried out using the column elution technique (NOTOX, 2000). In this test, two columns were filled with inert carrier material onto which the test substance had been coated. The columns were then eluted with double distilled water at various flow rates at 21°C and the concentration of tetrabromobisphenol-A in the column effluent was determined by a high performance liquid chromatography (HPLC) method. The results of the experiment are shown in **Table 1.3**. The solubilities determined at the various flow rates were broadly similar, although there was a trend to lower values at lower flow rates. This trend could not be explained, and is the opposite to what would be expected if equilibrium was not reached. The overall mean value from the study is 0.063 mg/l, which agrees reasonably well with the value from the preliminary test.

Table 1.3 Measured water solubility from column elution experiments (NOTOX, 2000)

Flow rate (ml/hour)	Column	Effluent pH	Mean measured solubility
23	I	7.9	0.082 mg/l
24	I	7.9	0.066 mg/l
22	II	7.6	0.081 mg/l
23	II	7.9	0.070 mg/l
12	I	7.8	0.058 mg/l
12	I	7.9	0.053 mg/l
10	II	7.9	0.069 mg/l
10	II	7.9	0.056 mg/l
6	I	7.9	0.046 mg/l
5	II	8.1	0.048 mg/l
			Average value = 0.063 mg/l

A second similar generator column solubility study has recently been completed (Wildlife International, 2002f). This study differs slightly from the above study in that the solubility was determined in a series of buffered solutions (pH 5 (0.05 mole/l potassium hydrogen phthalate and 0.023 mole/l sodium hydroxide), pH 7 (0.05 mole/l potassium dihydrogen phosphate and 0.029 mole/l sodium hydroxide) and pH 9 (0.05 mole/l sodium borax and 0.014 mole/l hydrochloric acid)), as well as pure water, and the study was carried out at 25°C. The method used was based on OECD Test Guideline 105. The substance used in the test was again a composite sample from three manufacturers of the substance and had a purity of

99.17%. The results of this experiment are shown in **Table 1.4**. There was good agreement between the solubilities obtained at the two different flow rates and the mean solubility was 0.148 mg/l at pH 5, 1.26 mg/l at pH 7, 2.34 mg/l at pH 9 and 0.240 mg/l in the non-buffered water.

Table 1.4 Measured water solubility at various pH's using the column elution method (Wildlife International, 2002f)

PH	Flow rate (ml/minute)	Measured solubility (mg/l)		
		Range	Mean value[a]	Overall mean for both flow rates[a]
5	1	0.145-0.156	0.149±0.004	0.148±0.005
	0.5	0.139-0.154	0.146±0.006	
7	1	1.25-1.28	1.27±0.006	1.26±0.012
	0.5	1.25-1.26	1.26±0.006	
9	1	2.33-2.49	2.41±0.070	2.34±0.156
	0.5	2.03-2.51	2.27±0.20	
Pure (non-buffered) water (pH of water was 6.71; the pH of column effluent was 6.83-7.23 at a flow rate of 1 ml/minute and 6.79-7.12 at a flow rate of 0.5 ml/minute)	1	0.236-0.243	0.239±0.0024	0.240±0.0019
	0.5	0.240-0.242	0.241±0.0008	

Note: a) Values are reported as mean ± standard deviation.

As can be seen from the results of this study, the solubility of tetrabromobisphenol-A increases with increasing pH. The values obtained in this study using pure water (solubility 0.240 mg/l) are slightly higher than found in the NOTOX (2000) study (solubility around 0.063 mg/l) but these differences could, in part, be due to differences in the temperatures used in the two studies (the NOTOX (2000) study was carried out at 21^{o}C whereas the later study was carried out at 25^{o}C). Taken overall, both the NOTOX (2000) and Wildlife International (2002f) studies can be considered as valid studies that reflect the fact that the solubility of tetrabromobisphenol-A is dependent on, amongst other things, the pH of the water.

A further water solubility determination has been carried out using ^{14}C-labelled tetrabromobisphenol-A (Yu and Atallah, 1978). The radiochemical purity of the substance used was >98% and the substance was mixed with unlabelled tetrabromobisphenol-A to give the required specific activity. An excess of the test substance was shaken overnight with distilled water at 35^{o}C. The solution was then centrifuged for 1 hour at either 15^{o}C, 25^{o}C or 35^{o}C and the supernatant was analysed for tetrabromobisphenol-A by a radiochemical method. The average solubility determined for tetrabromobisphenol-A was 0.72 mg/l at 15^{o}C, 4.16 mg/l at 25^{o}C and 1.77 mg/l at 35^{o}C. This method is dependent on the centrifuging step being effective at removing all undissolved test material from the overlying water. Further, the experiment only appears to have allowed 1 hour for equilibrium to occur at the lower two temperatures. This may explain why variable results appear to have been obtained at the various temperatures (normally the water solubility would be expected to increase with increasing temperature). Therefore, the values obtained from this test should be considered as less reliable than the values obtained from the column elution method above. The pH of the water used in this study was not reported.

An apparent water solubility of 917 mg/l has been reported for tetrabromobisphenol-A (Ogino *et al.*, 1987). However the paper is in Japanese and so it has not been possible to check the details of this test. This value appears to be out of line with the other water solubility data available and so is not considered further in the assessment.

Using a log Kow value of 5.90 (see Section 1.3.7) a water solubility of 0.039 mg/l can be estimated for tetrabromobisphenol-A using the Syracuse Research Corporation WSKOW (version 1.30) estimation software. This is lower than, but of a similar order to, the value obtained in the column elution method for pure water (0.063 mg/l and 0.24 mg/l in the two determinations available).

Since tetrabromobisphenol-A can exist in an ionised form at pHs around 7 and above (see Section 1.3.14.2), the water solubility of tetrabromobisphenol-A would be expected to be dependent on the pH of the water. This is clearly confirmed in the Wildlife International (2002f) study reported above. The pH of the water used in the Yu and Atallah (1978) study was not reported but the values obtained in this study are consistent with those obtained in the Wildlife International (2002f) and NOTOX (2000) studies.

The effect of pH on the water solubility of tetrabromobisphenol-A has recently been investigated by Arnon *et al.* (2006). In this study the solubility of tetrabromobisphenol-A was determined using batch solubility tests. In all, five different buffer solutions were used with pH values of 7, 7.5, 8, 8.5 and 9, and five nominal concentrations were tested at each pH (nominal concentrations 100, 200, 300, 400 and 500 mg/l). Tetrabromobisphenol-A was added to a 20 ml glass vial as a solution in acetone and the solvent evaporated. After this 10 ml of the appropriate buffer was added and the tetrabromobisphenol-A and the solution were then shaken at 200 rpm for ten hours. After this time, the solutions were filtered (0.45 μm) and the last 1 ml of solution was analysed for the presence of tetrabromobisphenol-A using high-performance liquid chromatography. Under these conditions the solubility of tetrabromobisphenol-A was found to be <0.2 mg/l at pH 7, but the solubility increased markedly at higher pHs, reaching up to at least 500 mg/l at pH 9. The soluble fraction was also found to increase with the initial amount of tetrabromobisphenol-A added to the system. The solubility at pH 7 found in this test system is reasonably consistent with the values reported above at around pH 7. However, the solubility found at pH 9 in this study is two orders of magnitude higher than measured previously. Few other details of this study are given in the paper and so it is not possible to fully validate the results from this study, in particular the apparent dependence of the solubility on the initial concentration of tetrabromobisphenol-A is currently difficult to explain. Therefore these results will be considered to be less reliable than those obtained from the standard test methods outlined above.

Based on the available data, the most reliable value for the experimentally determined water solubility of tetrabromobisphenol-A is 0.148 mg/l at pH 5, 1.26 mg/l at pH 7, 2.34 mg/l at pH 9 and 0.063-0.240 mg/l in pure water.

In the environment, the buffering capacity of natural waters means that the results obtained in buffered solution have some relevance to the solubility of the substance in the environment and also the solubility of the substance in aquatic toxicity tests. Indeed, there is some evidence that the solubility of tetrabromobisphenol-A in some of the test media used for aquatic toxicity testing is around 0.5-1 mg/l (see Section 3.2), which is consistent with the recent solubility data obtained by the column elution method.

In terms of the environmental risk assessment, the water solubility is important for determining the distribution behaviour of the substance as it is used to define the Henry's law constant. This is discussed further in Section 1.3.14.1. When a specific value for the water solubility is required (for example in the EUSES modelling) a value of 0.24 mg/l at 25°C has been used, as obtained in the studies outlined above in pure water. It should be noted, however, that the assessment is not particularly sensitive to the value of the water solubility chosen.

1.3.7 Octanol-water partition coefficient (log Kow)

The octanol-water partition coefficient has been determined using ^{14}C-labelled tetrabromobisphenol-A (Yu, 1978). The radiochemical purity of the substance used was >98%. The experiment was carried out using two concentrations, with each concentration being tested in duplicate. The experiment was carried out by adding the required amount of test substance in a solvent to a centrifuge tube, evaporating the solvent and then adding 2 ml of n-octanol to dissolve the test substance. Distilled water (5 ml) was then added to the tube and each tube was shaken for 5 minutes and then centrifuged for 15 minutes. The organic and water phases were then analysed for tetrabromobisphenol-A by a radiochemical method. The mean Kow value determined was 34,644 (log Kow = 4.54).

The octanol-water partition coefficient for tetrabromobisphenol-A has recently been determined by a generator column method (Wildlife International, 2001b). The method used was based on the USEPA Product Properties Test Guideline OPPTS 830.7560. The substance used in the test was a composite sample from three manufacturers of tetrabromobisphenol-A, and had a purity of 98.91%. The main impurities present were 0.05% o,p'-tetrabromobisphenol-A, <0.01% 2,4,6-tribromophenol and 1.04% tribromobisphenol-A.

The glass column used in the test was around 20 cm long with an outside diameter of around 6 mm. The column was maintained at 25^{o}C throughout the experiment using a water jacket. The column was filled with an inert support material and a solution of the test substance in octanol (around 15 ml of a 8.295 g/l solution of the test substance) was used to charge the column. The column was then back-flushed with octanol-saturated water to remove any entrapped air. Octanol-saturated water was then allowed to flow through the column at a rate of 0.5 ml/minute overnight to equilibrate the system. Following the overnight equilibration period, the flow-rate of the octanol-saturated water was increased to 1 ml/minute and a further 1 hour was allowed for equilibration before the effluent from the column was collected in three consecutive 5 ml samples and analysed for the concentration of tetrabromobisphenol-A by a direct injection high performance liquid chromatography-mass spectrometry (HPLC-MS) technique. The mean (± standard deviation) measured concentration found in the column effluent was 0.0104±0.0008 mg/l. The measured concentration in the octanol phase was 8.295±0.140 g/l at the start of the experiment, the mean log Kow value determined was 5.90±0.034.

A log Kow of 3.25 has been reported for tetrabromobisphenol-A (Ogino *et al.*, 1987). However the paper is in Japanese and so it has not been possible to check the details of this test.

Watanabe and Tatsukawa (1989) reported a log Kow of 6.4 for tetrabromobisphenol-A determined by a HPLC method. No other experimental details of this study are available.

Other values for the octanol-water partition coefficient of <4 (Lee *et al.*, 1993 and Steinberg *et al.*, 1992) and 5.3 (WHO, 1995) have been reported for tetrabromobisphenol-A. No further details of how the values were determined are available.

A log Kow value of 5.9 will be used for tetrabromobisphenol-A in the risk assessment as it is from a well reported study and the generator column method used is an appropriate method to use for substances with high log Kow values (the OECD 107 shake flask method, which is similar to the method used in the Yu (1978) study, is recommended for log Kow values in the range -2 to 4, whereas the generator column method can be used for substances with log Kow values in the range 1 to >6). Similar to the case with water solubility, the log Kow value might be expected to depend on the pH as increasing pH leads to ionisation of the tetrabromobisphenol-A which may increase its solubility in the aqueous phase and decrease its solubility in the octanol phase (strictly the coefficient in this case is a distribution coefficient). Thus the log Kow value would be expected to decrease with increasing pH (indeed Kuch *et al.* 2004 have recently estimated that the log Kow value of tetrabromobisphenol-A would be around 5.34 at pH 4, 4.35 at pH 7 and 2.69 at pH 8; the actual method behind these estimates is unclear (it may have assumed a pKa of around 6.33, which is lower than reported in Section 1.3.14.2)). The actual pH of the aqueous phase in the log Kow determinations reported is not given.

1.3.8 Flash point

The substance is used as a flame retardant and so this parameter is not relevant. The substance does not have a flash point.

1.3.9 Autoignition

The material does not undergo autoignition but decomposes at elevated temperatures. The decomposition properties are consistent with the use of this material as a flame retardant.

1.3.10 Explosivity

Explosive properties are not expected on the basis of chemical structure and physical properties. Tetrabromobisphenol-A is not known to exhibit explosive properties with other materials.

1.3.11 Oxidising properties

Tetrabromobisphenol-A does not contain any structural alerts for oxidising effects and so is not considered to be an oxidiser.

1.3.12 Granulometry

The overall mass median diameter for two samples of tetrabromobisphenol-A has been determined as 31.81 μm (Inveresk, 2001) and 52.20 μm (Inveresk, 2002). The more recent study also reported that only approximately 4% of the particles had an aerodynamic diameter of <15 μm, i.e. towards the respirable range.

1.3.13 Surface tension

No value could be found for the surface tension of an aqueous solution.

1.3.14 Other physico-chemical properties

1.3.14.1 Henry's law constant

The Henry's law constant can be estimated from the vapour pressure and water solubility. For tetrabromobisphenol-A, there is no precise measured value available for the vapour pressure, and so a measured limit value of $<1.19\times10^{-5}$ Pa and a measured value of 6.24×10^{-6} Pa (see Section 1.3.5) will be considered here.

Based on these values and a water solubility of 0.063-0.240 mg/l for pure water (see Section 1.3.6), a Henry's law constant of <0.10 Pa m^3/mole or 0.014-0.054 Pa m^3/mole can be estimated for tetrabromobisphenol-A. However, as indicated in Section 1.3.6, the water solubility of tetrabromobisphenol-A is dependent on the pH, with the solubility increasing with increasing pH, and so the Henry's law constant for natural waters, particularly those with pHs of 7 or above, may be lower than estimated using the solubility in pure water.

Another estimate for the Henry's law constant has been obtained from the Syracuse Research Corporation HENRY (version 3.00) computer software. This estimates the Henry's law constant from chemical structure using a bond contribution method and a group contribution method. For tetrabromobisphenol-A only the bond contribution method could be used (values were missing for some groups present in tetrabromobisphenol-A) and the Henry's law constant was estimated as 2.2×10^{-8} Pa m^3/mole.

Clearly there is a large discrepancy between the values estimated from vapour pressure and water solubility and the value estimated from structure, however, all methods indicate that the actual Henry's law constant is <0.1 Pa m^3/mole, probably at most around 0.014-0.054 Pa m^3/mole and so this value will be used in the risk assessment.

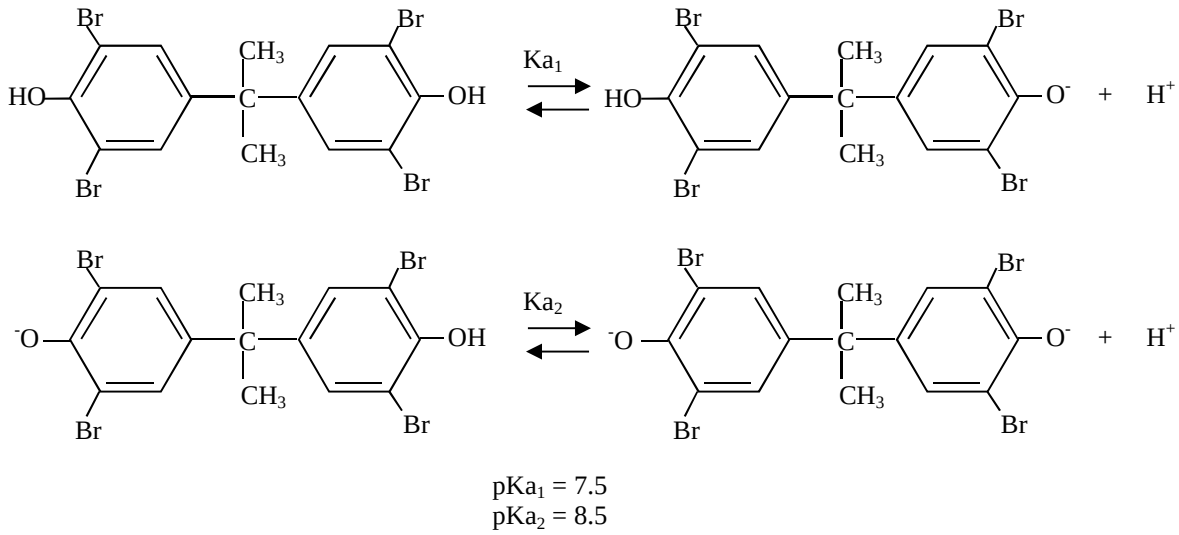
1.3.14.2 Acid dissociation constant

Tetrabromobisphenol-A has two acidic hydrogen atoms as shown in **Figure 1.1**. The pKa values are reported to be pKa_1 = 7.5 and pKa_2 = 8.5 (WHO, 1995). No further details of this study are available.

A further determination of the pKa values for tetrabromobisphenol-A has been recently carried out (Wildlife International, 2002c). The method used was based broadly on OECD Guideline 112. In this experiment the relative amounts of the dissociated and undissociated forms present in solution were determined at pHs covering the range 6.0 to 12.0 at 0.5 pH intervals. Only a single pKa value of 9.40 was found using this method. However, the analytical method used to determine the amounts of dissociated and undissociated acid present in solution involved solvent extraction (using hexane) of the undissociated form from the solution prior to analysis by HPLC. As acid-base equilibria are generally very rapidly attained, this method would cause the equilibrium to shift in solution as the undissociated form was removed. In addition, the analytical method would not distinguish between the two dissociated forms of tetrabromobisphenol-A (which would be a pre-requisite for determination of both pKa values). Thus, this study effectively determined the effect of pH

on the extraction of tetrabromobisphenol-A by hexane from solution (which is a function of the pKa values) rather than the actual pKa values and so the result is considered unreliable.

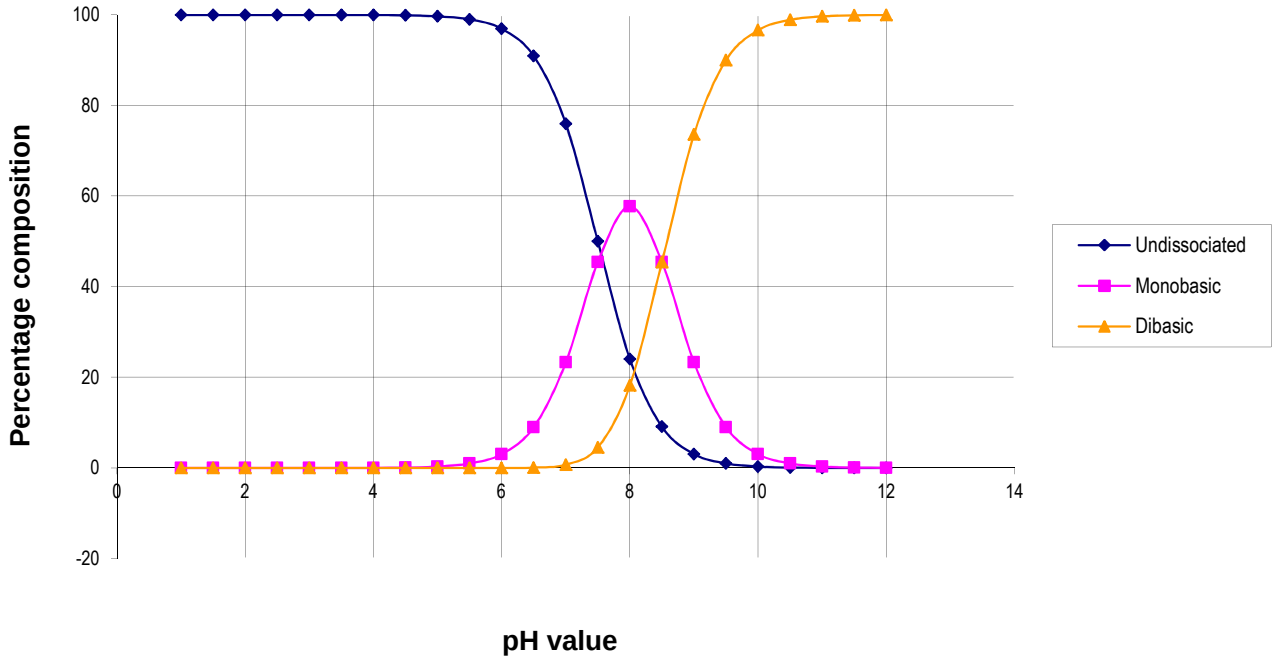
Figure 1.1 Acid dissociation constants for tetrabromobisphenol-A



$pKa_1 = 7.5$
$pKa_2 = 8.5$

In the absence of other reliable data, the values for pKa_1 and pKa_2 will be assumed to be 7.5 and 8.5 respectively. These pKa values mean that the ionised forms of tetrabromobisphenol-A will become prevalent in the environment at pHs >7-8. At lower pHs tetrabromobisphenol-A will be present essentially as the undissociated form. The expected distribution of the various species at various pHs is shown in **Figure 1.2** based on the pKa_1 and pKa_2 being 7.5 and 8.5. As can be seen from **Figure 1.2**, a significant fraction of the total tetrabromobisphenol-A is predicted to be present in an ionised form at pHs of 7 and above. Below this pH the undissociated form predominates.

Figure 1.2 Dissociation of tetrabromobisphenol-A at various pHs



The pH profile given in **Figure 1.2** is consistent with the available data on the variation of solubility with pH as the monobasic and dibasic forms of tetrabromobisphenol-A would be expected to be of a higher solubility than the undissociated form. (see Section 1.3.6).

1.3.15 Hazardous products formed under pyrolysis conditions

Under certain high temperature pyrolysis conditions, tetrabromobisphenol-A can form and release brominated dibenzofurans and dibenzo-*p*-dioxins. These reactions, and their environmental significance, are considered further in Section 2.3 and in detail in Appendix A.

1.4 CLASSIFICATION

1.4.1 Current classification

Tetrabromobisphenol-A is not currently classified for environmental or human health effects.

1.4.2 Proposed classification

The proposed classification for the environment is:

N; R50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

This proposal is based on the toxic effects seen in acute toxicity studies with fish and daphnia ($L(EC)_{50}$ <1 mg/l), the lack of biodegradation seen in standard ready biodegradation tests and the high bioconcentration factors (BCF>100) measured in fish.

No classification for human health is proposed.

2 GENERAL INFORMATION ON EXPOSURE

2.1 PRODUCTION

Tetrabromobisphenol-A is produced by the bromination of bisphenol-A in the presence of a solvent. The bromination reaction may be conducted in the presence of hydrocarbon solvent only or with water, 50% hydrobromic acid or aqueous alkyl monoethers. When methanol is used as solvent the fumigant methyl bromide is produced as a co-product. The production process is largely conducted in closed systems (WHO, 1995).

Tetrabromobisphenol-A is produced in the USA, Israel and Japan but not in the EU. The current total amount of tetrabromobisphenol-A produced is estimated at >120,000 tonnes/year (Hakk, 2001) and 150,000 tonnes/year (Arias, 2001). BKH (2000) reported that global demand for tetrabromobisphenol-A had increased from 50,000 tonnes/year in 1992 to 145,000 tonnes/year in 1998, with an average growth of 19% per annum. Global demand for tetrabromobisphenol-A was expected to grow by 8-9% per annum between 1998 and 2004.

In contrast to these figures, BSEF (2005a) estimate the worldwide market demand for tetrabromobisphenol-A to be 121,300 tonnes/year in 1999 and 119,700 tonnes/year in 2001, which suggest a static or slightly declining market over these years.

2.2 CONSUMPTION AND USES

2.2.1 Consumption, Import and Export

Table 2.1 gives details of consumption figures for tetrabromobisphenol-A as a raw chemical. From the table it appears that the consumption in the EU has been around 13,800 tonnes/year in the late 1990's but more recent figures show a sustained decline in use in the EU. For 2003, figures are available from two sources (EFRA, 2005 and EBFRIP, 2005). There is an apparent small discrepancy between the two sets of figures but both sources suggest the 2003 consumption of tetrabromobisphenol was around 6,500-7,500 tonnes/year. A similar EU consumption of around 6,200 tonnes/year is apparent for 2004. The decline in use of tetrabromobisphenol-A in the EU is attributed to a general move in the production of products such as printed circuit boards from the EU to other parts of the world. An EU consumption of 6,500 tonnes/year of tetrabromobisphenol-A will be used in the risk assessment, based on the most recent figures.

Leisewitz *et al.* (2000), quoting figures supplied by the Bromine Science Environmental Forum (BSEF), reported that the total market demand for tetrabromobisphenol-A in 1999 was 21,600 tonnes/year in the Americas, 13,800 tonnes/year in Europe, and 85,900 tonnes/year in Asia, giving a total consumption in these three areas of 121,300 tonnes/year. The equivalent figures for 2001 show a consumption of 18,000 tonnes/year in the Americas, 11,600 tonnes/year in Europe, and 89,400 tonnes/year in Asia, and 600 tonnes/year in the rest of the world, giving a total worldwide consumption of 119,700 tonnes/year (BSEF, 2005a).

As well as the substance itself, tetrabromobisphenol-A can be imported into a country in finished or partially finished products. Examples include plastic compound, printed circuit boards and finished electronic equipment. The tetrabromobisphenol-A in these products may be present as the substance itself or may be reacted into the polymer matrix. These imports

may be an important source of tetrabromobisphenol-A in the EU. Some information is available for imports into several EU countries from these types of sources and this is given below. It should be noted that the amounts imported into these countries are not necessarily from sources outside the EU.

Svensson and Hellsten (1989) carried out a survey of brominated flame retardant use in Sweden. They found that brominated flame retardants were not produced in Sweden, but were imported into the country by three main routes:

- as pure chemicals for further use in the plastics industry;
- as components (either reacted or as an additive) in plastic compounds and other semi-finished products;
- as components (either reacted or as an additive) in retail goods like computers, vehicles etc.

Table 2.1 Consumption of tetrabromobisphenol-A (tonnes/year)

Country	Consumption (tonnes/year)	Year	Reference
Australia	32 (including resins)	1998/1999	NICNAS, 2001
	37 (TBBPA derivatives)	1988/1999	NICNAS, 2001
Asia	85,900	1999	Leisewitz *et al.*, 2000; BSEF, 2005a
	89,400	2001	Birnbaum and Staskal, 2004; BSEF, 2005a
Japan	15,000		WHO, 1995
	12,000	1986	WHO, 1997
	14,000	1987	Watanabe and Tatsukawa, 1989
	14,400	1987	WHO, 1995
	18,000	1988	WHO, 1995
	23,000	1990	WHO, 1995
	3,000 (TBBPA epoxy oligomer)	1990	WHO, 1997
	24,500	1991	WHO, 1995
	23,000	1992	WHO, 1995
	22,000	1993	WHO, 1995
	8,500	1997	Japan Chemical Weekly, 1998
	24,000	1994	Danish Environmental protection Agency, 1999; WHO, 1997
	9,500 (TBBPA derivatives)	1994	Danish Environmental Protection Agency, 1999
	2,500 (TBBPA polycarbonate oligomer)	1994	WHO, 1997
	7,000 (TBBPA epoxy oligomer)	1994	WHO, 1997
	~40,000 (including derivatives)	~2000	Nagayama *et al.*, 2000
	32,300	2000	Ohta *et al.*, 2002
	31,000	2002	Ohta *et al.*, 2004a and 2004b

Table 2.1 continued overleaf.

Table 2.1 continued.

Country	Consumption (tonnes/year)	Year	Reference
USA	16,000		WHO, 1995
	16,000	1986	WHO, 1997
	18,000	1991	WHO, 1997
	21,600 (figure for 'Americas')	1999	Leisewitz et al., 2000; BSEF, 2005a
	18,000 (figure for 'Americas')	2001	Birnbaum and Staskal, 2004; BSEF, 2005a
Europe	12,500		OECD, 1994
	10,000		WHO, 1995
	13,150 3,659 (TBBPA derivatives)	1998	Danish Environmental Protection Agency, 1999
	2,150 (TBBA polycarbonate oligomer)	1998	Danish Environmental Protection Agency, 1999
	1,500 (TBBPA bis(2,3-dibromopropylether))	1998	Danish Environmental Protection Agency, 1999
	13,800	1999	RPA, 2001; Leisewitz et al., 2000, BSEF, 2005a
	11,600	2001	Birnbaum and Staskal, 2004; BSEF, 2005a
	8,200	2001	BSEF, 2005b
	7,000	2002	BSEF, 2005b
	6,500-7,500	2003	EFRA, 2005; EBFRIP, 2005; BSEF, 2005b.
	6,200	2004	BSEF, 2005b
UK	Up to 620	2001	BPF, 2001
Benelux, France, UK, Germany	9,700	1996	Danish Environmental Protection Agency, 1999
Germany	3,500-4,500	1997	Leisewitz *et al.*, 2000
	2700	1999	Leisewitz *et al.*, 2000
	500-1000 (TBBPA derivatives)	1999	Leisewitz *et al.*, 2000
The Netherlands	~200		Klingenberg, 1989
Norway	7.9 (9.5 imported and 1.6 exported)	1998	SFT, 1999
Sweden	~300	1988	Svensson and Hellsten, 1989
	~550	1988	Svensson, 1991
	~490 (including derivatives)	1993	KEMI, 1996; de Wit, 2000
	450 (including carbonate oligomer)	1994	de Wit, 2000
	258 (including carbonate oligomer)	1995	de Wit, 2000
	291 (including carbonate oligomer)	1996	de Wit, 2000
	303 (including carbonate oligomer)	1997	de Wit, 2000
	269 (including carbonate oligomer)	1998	de Wit, 2000
	427-439	2000	KEMI, 2002
	246	2004	KEMI, 2006

Table 2.1 continued overleaf.

Table 2.1 continued.

Country	Consumption (tonnes/year)	Year	Reference
Global	41,000		WHO, 1995
	121,300	1999	Leisewitz *et al.*, 2000; BSEF, 2005a
	150,000 (including derivatives)	2001	Arias, 2001
	>120,000		Hakk, 2001
	119,700	2001	BSEF, 2005a

Svensson and Hellsten (1989) estimated that in 1988, the total amount of brominated flame retardants imported in Sweden by these routes was around 1,400-2,000 tonnes/year. For tetrabromobisphenol-A it was estimated that around 300 tonnes/year were used in the manufacture of printed circuit boards within Sweden, with 150-200 tonnes/year being imported into Sweden in printed circuit boards manufactured elsewhere and a further 150-250 tonnes/year being imported in finished products.

A further estimate of the amounts of tetrabromobisphenol-A imported into Sweden in 1988 is given in Svensson (1991). Here it was estimated that 550 tonnes/year of tetrabromobisphenol-A was imported into Sweden as the pure compound, with around 600 tonnes/year being imported in glass-fibre epoxy laminate printed circuit boards.

de Wit (1999) reported that the amount of tetrabromobisphenol-A supplied to Sweden in products was around 334 tonnes in 1991.

Information from the Swedish Product Register for 2000 (KEMI, 2002) indicates that around 415-424 tonnes of tetrabromobisphenol-A were used as a raw material (flame retardant additive) in three plastic products, 11 tonnes were used in binders/adhesives agents in five products for office machinery and computers, and 1-4 tonnes were used for other uses (e.g. intermediates in plastic manufacture) in three plastic products. None of the products produced were reported to be used directly by consumers.

The amount of total brominated flame retardants imported into Denmark has been estimated to be around 320-660 tonnes in 1997 (Danish Environmental Protection Agency, 2001). Of this tetrabromobisphenol-A (and derivatives) accounted for around 180-360 tonnes. Tetrabromobisphenol-A (and derivatives) was found to be imported as a chemical (up to 2.1 tonnes/year), in plastic compound and masterbatch (around 34-42 tonnes/year), in semi-manufactured plastic products (around 2-5.2 tonnes/year), in laminates for printed circuit board production (100-160 tonnes/year) and in finished articles (the figure for this was not given in the paper but is presumably around 40-150 tonnes/year by difference). A large proportion of articles containing tetrabromobisphenol-A manufactured in Denmark were also subsequently exported. A detailed breakdown of the applications of imported tetrabromobisphenol-A and derivatives in Denmark is given in **Table 2.2.**

Table 2.2 Breakdown for use of tetrabromobisphenol-A and derivatives in Denmark in 1997 (Danish Environmental Protection Agency, 1999)

Application		**Consumption (tonnes/year)**
Printed circuit board assemblies	Epoxy laminates	92-150
	Paper/phenolic laminates	2.3-3.8
	Electronic component encapsulates	7.4-22
	Other plastic parts	<2
	Approximate total	100-180
Housings for electrical and electronic equipment	Computer monitors	35-52
	Notebook computers	2-3
	Printers	12-18
	Other office machines	5-7.4
	TV sets	1-2
	Other consumer electronics	0.5-2
	Medical and industrial electronics	1-4
	Small household appliances	0.5-1
	Approximate total	56-89
Other components of electric and electronic appliances	Switches, relay parts etc.	2-6
	Moulding fillers	-
	Wires	-
	Foam	-
	Other plastic parts	1-2
	Approximate total	3-8
Lighting	Sockets in lamps and fluorescent tubes	4-7
	Compact fluorescent tubes	-
	Plastic cover parts	<2
	Switches, electronic parts etc.	<2
	Approximate total	4-11
Wiring and power distribution	Rubber cables	-
	Other cables	-
	Wiring of houses	2-7
	Contactors, relays, switches etc. for automation and power distribution	2-8
	Approximate total	4-15

Table 2.2 continued overleaf.

Table 2.2 continued.

Application		Consumption (tonnes/year)
Textiles	Protective clothing	-
	Curtains, carpets and tents	-
	Furniture	-
	Foam and stuffing	-
	Approximate total	-
Building materials	Expanded polystyrene	-
	Extruded polystyrene foam	-
	Polyurethane foam	-
	Roofing foil	-
	Other uses	0-2
	Approximate total	0-2
Paints and fillers	Paint	-
	Fire proofing for wood	-
	Joint fillers etc.	-
	Approximate total	-
Transportation (parts and accessories)	Cars	12-36
	Lorries and buses	0.4-1.2
	Trains	0.3-4
	Other means of transport	1-10.5
	Approximate total	14-52
Overall total		180-360

Note: - = No use identified.

A mass balance for the amounts of tetrabromobisphenol-A present in finished products, either produced in or imported into Norway, has been reported by SFT (1999) for the year 1998. The net import of tetrabromobisphenol-A as the compound itself amounted to around 7.9 tonnes/year (9.5 tonnes/year imported and 1.6 tonnes/year exported), however this amount was much smaller than the amount estimated to be imported in finished products such as TVs, computers and other electrical equipment (138-195 tonnes/year), transport applications (5-35 tonnes/year), printed circuit boards (47-59 tonnes/year) and laminated prepregs (9-13 tonnes/year). The total net import of tetrabromobisphenol-A was therefore around 207-310 tonnes/year.

Hedelmalm *et al.* (1995) estimated that the amount of tetrabromobisphenol-A present in products in the Nordic countries was around 4,000 tonnes in 1994.

BKH (2000) estimated that the total demand for tetrabromobisphenol-A in the Netherlands in 2000 would be around 1,700 tonnes/year and the total demand in the EU would be around 40,000 tonnes/year.

A survey of the amount of tetrabromobisphenol-A present in several types of products in Germany has been carried out (Leisewitz *et al.*, 2000). It was estimated that around 3,200 tonnes/year of tetrabromobisphenol-A were used to make base material for printed circuit boards, and the amount of tetrabromobisphenol-A present in printed circuit boards in electronic scrap was around 4,200-5,100 tonnes/year. The difference between these two figures effectively represents the net import of tetrabromobisphenol-A in printed circuit boards in finished articles.

Although the above estimates clearly show that a large amount of tetrabromobisphenol-A is imported into EU countries in finished or partially finished products, it is not possible to estimate the total amount imported into the EU in products from these data as the available figures generally do not distinguish between imports from other countries within the EU and imports from outside the EU.

An estimate of the amount of tetrabromobisphenol-A imported into the EU in finished or partly finished products can be made by comparing the known consumption of tetrabromobisphenol-A in the EU (around 8,200-11,600 tonnes/year in 2001) with the total amount of tetrabromobisphenol-A supplied world-wide (around 120,000 tonnes/year for the same year; 2001 is used for this comparison as this is the most recent year for which estimates of both the EU and world-wide consumption are reported). Based on these figures the amount of tetrabromobisphenol-A consumed in the EU is only around 6.8-9.7% of the amount used world-wide. However, given that tetrabromobisphenol-A is widely used in electrical and electronic equipment, it would be expected that the EU demand for such products would be higher than implied by the consumption of tetrabromobisphenol-A alone (this is also born out by the fact that the recent decline in the use of tetrabromobisphenol-A has been attributed to a movement in the production of articles such as printed circuit boards from the EU to other parts of the world). Thus, if, as a worst case, it is assumed that the EU demand for electrical and electronic products (and hence tetrabromobisphenol-A) is around 1/3 of the world-wide total (there is no information available on the actual demand but a similar assumption was used in the Risk Assessment Report for octabromodiphenyl ether which has some similar uses to tetrabromobisphenol-A (EC, 2003b)), then the amount of tetrabromobisphenol-A present in new products in the EU can be estimated at around 40,000 tonnes/year. Thus, the import of tetrabromobisphenol-A into the EU in finished or partly finished products can be estimated to be around 33,500 tonnes/year, assuming that the EU consumption of the substance itself is 6,500 tonnes/year. Some of this may be imported as partly finished products such as polymer masterbatch and uncured epoxy resins (which need further processing (conversion or curing) in the EU before they are formed into the product), but the majority is likely to be in the form of finished products or components such as printed circuit boards. The actual split between partly finished and finished products is unknown. However, in order to try to take into account the possible releases from the further processing in the EU of partly finished products it will be assumed for the emission estimates that around 6,000 tonnes/year of tetrabromobisphenol-A (which corresponds to around the amount used directly in the EU) are in the form of partly finished products, with the remainder as finished products and components. Information on the actual amounts imported in partly finished or finished products would be useful to refine these assumptions.

In terms of trying to estimate how much tetrabromobisphenol-A may be imported into the EU in partially-finished or finished articles, it should be born in mind that the majority of tetrabromobisphenol-A is used as a reactive flame retardant and is chemically bound into the

polymer structure, and so only trace amounts of free tetrabromobisphenol-A will be present in the imported partially-finished or finished articles.

In summary, the following figures will be used in the risk assessment:

Tetrabromobisphenol-A imported into the EU as the substance	= 6,500 tonnes/year
Tetrabromobisphenol-A imported into EU as partly finished products (e.g. masterbatch, epoxy resins)	= 6,000 tonnes/year
Amount of tetrabromobisphenol-A imported into the EU in finished products and components	= 27,500 tonnes/year
Total	= 40,000 tonnes/year

These figures are based on data for 2003/2005. Earlier figures from the EU suggest that the consumption in the EU has dropped since the late 1990s, when consumption of tetrabromobisphenol-A itself was around 13,800 tonnes/year. As it is theoretically possible that the consumption in the EU could increase again in the future, the effect of such an increase on the overall conclusions of the assessment is considered in Appendix D.

2.2.2 Uses

The primary use of tetrabromobisphenol-A is as a reactive intermediate in the manufacture of flame-retarded epoxy and polycarbonate resins. It may also be used as an additive flame retardant, for example in the manufacture of acrylonitrile-butadiene-styrene (ABS) resins. Where tetrabromobisphenol-A is used as an additive flame retardant, it is generally used with antimony oxide for maximum performance (Hakk, 2001). Antimony oxide is generally not used in conjunction with tetrabromobisphenol-A in reactive flame retardant applications (Industry Consortium, 2002).

Tetrabromobisphenol-A is also used in the manufacture of derivatives. The main derivatives produced from tetrabromobisphenol-A are tetrabromobisphenol-A bis(methyl ether) (also known as tetrabromobisphenol-A dimethylether), tetrabromobisphenol-A dibromopropylether, tetrabromobisphenol-A bis(allylether), tetrabromobisphenol-A bis(2-hydroxyethyl ether), tetrabromobisphenol-A brominated epoxy oligomer, and tetrabromobisphenol-A carbonate oligomers (WHO, 1995). The main use of these derivatives is as flame retardants, usually in niche applications.

A breakdown of use world-wide was provided by Leisewitz *et al.* (2000), who indicated that around 70% is used for epoxy resins in printed circuit boards, 15% is used additively in HIPS for casing materials, 10% is used for the production of derivatives and 5% is used as additives for other polymers such as ABS and thermoplastic polyesters.

Industry has questioned the figures given above by Leisewitz *et al.* (2000) for the use of tetrabromobisphenol-A as an additive flame retardant in high impact polystyrene (HIPS) (Industry Consortium, 2003). They indicated that they are unaware that tetrabromobisphenol-A is or has ever been used as an additive in HIPS, and indicated that in their experience, tetrabromobisphenol-A is not an effective flame retardant for HIPS. Therefore, this use is not considered further in the risk assessment. The emissions from any additive use of tetrabromobisphenol-A not specifically covered in the assessment would be expected to be similar to those estimated for ABS.

Private information from Industry indicates that the ratio between reactive and additive flame retardant use in the EU is around 9:1, with ABS being the main additive use of tetrabromobisphenol-A. A recent survey by Industry has confirmed that this ratio is still applicable (EBFRIP, 2005). At present it is thought that derivatives of tetrabromobisphenol-A (see Section 2.2.2.3) are not manufactured in the EU and so this use is not considered explicitly in the assessment although default calculations are given for this use.

Tetrabromobisphenol-A is considered as an alternative additive flame retardant to octabromodiphenyl ether in ABS. The use of octabromodiphenyl ether in this application within the EU has fallen in recent years, and if this trend continues it is possible that the amount of tetrabromobisphenol-A used in this application in particular could increase in the future. This possibility is considered further in Appendix D.

The current uses and the potential emissions of tetrabromobisphenol-A are discussed further below.

2.2.2.1 Reactive flame retardants

The primary use of tetrabromobisphenol-A, accounting for approximately 90% of tetrabromobisphenol-A used, is as a reactive intermediate in the manufacture of epoxy and polycarbonate resins. When used as a reactive intermediate it becomes covalently bound in the polymer and is effectively lost. The only potential for exposure is from unreacted tetrabromobisphenol-A which may exist where an excess has been added during the production process.

When used as a reactive flame retardant in the production of epoxy resins, tetrabromobisphenol-A along with bisphenol-A, is reacted with epichlorohydrin. Commercial flame retardant epoxy resins contain up to approximately 20% bromine (the maximum bromine content that can be achieved in epoxy resins is 48% if no bisphenol-A is used in the formulation). The main use of these resins is in the manufacturing of rigid epoxy laminated printed circuit boards. There are estimated to be at least seven to ten major producers of flame retardant epoxy resins in Europe.

There are two main types of rigid or reinforced laminated printed circuit boards that are commonly used (Danish Environmental Protection Agency, 1999). These are usually either based on glass fibre reinforced epoxy resin (designated FR4) or cellulose paper reinforced phenolic resin (designated FR2), but a range of types are available.

The FR4-type laminate is by far the most commonly used laminate and is typically made by reaction of around 15-17% tetrabromobisphenol-A in the epoxy resin (Danish Environmental Protection Agency, 1999). The bromine content of these circuit boards has been given by Leisewitz *et al.* (2000) as around 18-20% on a resin weight basis or 9-10% on a laminate weight basis (the resin makes up around 50% of the total weight of the laminate). The most commonly used laminate is approximately 1.6 mm thick and the tetrabromobisphenol-A content has been estimated at around 0.42 kg/m^2 (Danish Environmental Protection Agency, 1999). This type of laminate is typically used in computers and telecommunications equipment.

According to Danish Environmental Protection Agency (1999), the FR2-type laminates may also contain tetrabromobisphenol-A, but in this case it acts as an additive flame retardant rather than a reactive flame retardant. The current suppliers of tetrabromobisphenol-A in the EU have, however, indicated that they are not aware of tetrabromobisphenol-A being used in FR2-type laminates (BSEF, 2006a), and this has been confirmed by the main global manufacturers of such laminates (IPC, 2006). This is considered further in the next section.

Glass-fibre reinforced laminates are produced by impregnating the glass-fibre fabric with the epoxy resin. The resin is then dried during which it hardens into an intermediate state (B-state; also known as prepregs). A copper foil is then applied using a hot-press process, during which the resin re-melts and is irreversibly and completely hardened under pressure and temperature.

Epoxy resins are also used as the base material for other types of printed circuit boards such as the composites CEM1, CEM3 (Leisewitz *et al.*, 2000). These composites consist of either a core of hard paper with epoxy resin (CEM1) or glass-fibre with epoxy resin (CEM3). In both cases the outer layers consist of glass-fibre/epoxy resin laminate. The bromine content of a CEM3-type composite is 4-7% in the resin.

As well as use in the printed circuit board laminate itself, epoxy resins containing tetrabromobisphenol-A are also used to encapsulate certain electronic components (e.g. plastic/paper capacitors, microprocessors, bipolar power transistors, IGBT (Integrated Gate Bipolar Transistor) power modules, ASICs (Application Specific Integrated Circuits) and metal oxide varistors) on the printed circuit board. The concentration of tetrabromobisphenol-A in the production of the resins used for encapsulation is relatively low, for example around 2% or 90 g/m^2.

It is also used as a reactive flame retardant in polycarbonate and unsaturated polyester resins. Polycarbonates are used in communication and electronics equipment, electronic appliances, transportation devices, sports and recreation equipment, lighting fixtures and signs. Unsaturated polyesters are used for making simulated marble floor tiles, bowling balls, glass-reinforced panels, furniture parts, sewer pipes coupling compound, automotive patching compounds, buttons, and for encapsulating electrical devices.

The production of base material for printed circuit boards in Germany in 1999 has been estimated at around 21,000 tonnes of laminate, which is equivalent to >10,000 tonnes of resin (the resin makes up around 50% of the weight of the laminate) (Leisewitz *et al.*, 2000). The FR4-type printed circuit boards account for >90% of the market in Germany and there are thought to be 4 resin manufacturers in Germany. The resin used in the printed circuit boards cannot be recycled, although the copper content can be recovered in primary copper smelters (recovery in secondary copper smelters is not carried out in Germany as flue gas purification is needed). Particle downcycling is carried out in a limited scale in Germany. This involves grinding waste from laminate and printed circuit board production and separating this into metal and plastic fractions. The plastic fraction can be used as a supplement or filler in other products made from flame-retarded thermosetting resins.

The most important application areas for FR4-type printed circuit boards are in telecommunications, computers, industrial controls and automotive electronics (Leisewitz *et al.*, 2000).

2.2.2.2 Additive flame retardant

As an additive flame retardant, tetrabromobisphenol-A is added to polymers to impart flame retardant properties. It does not react chemically with the other components of the polymer, and, therefore may leach out of the polymer matrix. Additive use accounts for approximately 10% of tetrabromobisphenol-A used. Its main use as an additive flame retardant is in acrylonitrile-butadiene-styrene (ABS) resins. Recommended starting levels of tetrabromobisphenol-A in ABS (medium to high impact) are 17.6-22.0%. ABS resins are used in automotive parts, pipes and fittings, refrigerators, other appliances, business machines, and telephones (WHO, 1995). The main applications where plastic containing tetrabromobisphenol-A may be used include TV-set backcasings and business equipment enclosures (RPA, 2001).

According to the BPF (2001) approximately 620 tonnes tetrabromobisphenol-A were used as an additive flame retardant in electric and electronic applications in the UK in 2001, often in conjunction with antimony trioxide as a synergistic system. The largest use was in television casings with approximately 450 tonnes of tetrabromobisphenol-A used per year. Other uses include: PCBs; PC monitor casings; components in printers; fax machines and photocopiers; vacuum cleaners, coffee machines and plugs/sockets. The total amount of plastics used in electrical/electronic applications is about 220,000 tonnes, of this amount about 20% will have flame retardants added. It is difficult to determine the exact number of sites used in polymer processing because of the changeable nature of the industry with processors sometimes taking on short term contracts. However, there are approximately 2,000 injection moulders in the UK.

As indicated in Section 2.2.2.1, it has been reported that tetrabromobisphenol-A is used as an additive flame retardant in FR2-type laminates for printed circuit boards (Danish Environmental Protection Agency, 1999). The typical usage rate given was around 4% of the laminate or around 0.036 kg/m^2. However, the major suppliers of tetrabromobisphenol-A in the EU have indicated that they are not aware of tetrabromobisphenol-A being used as an additive flame retardant in FR2-type laminates (BSEF, 2006a). They report that FR-2-type laminates are normally based on phenolic resin but may contain some epoxy resin to help processing and heat stability etc. It was thought possible that tetrabromobisphenol-A could be present in the epoxy resin, but in this case it would be a reactive flame retardant and not an additive flame retardant. Furthermore, IPC[4] (2006) has confirmed that tetrabromobisphenol-A is not used as an additive flame retardant in phenolic resins for copper clad laminates (FR-2 laminates). Therefore this application is not considered further in the assessment.

2.2.2.3 Derivatives

The total amount of tetrabromobisphenol-A derivatives used is less than the amount of tetrabromobisphenol-A used (approximately 25% on a weight basis). They are believed to be used in specialised (or niche) applications. (WHO, 1995)

[4] IPC is the only global trade association of the electronic interconnect sector, and represents more than 2,300 member companies including designers, board manufacturers, assembly companies, suppliers and original equipment manufacturers.

The derivatives may be used as either reactive or additive intermediates in polymer manufacture. In this risk assessment it is important to consider the potential generation of tetrabromobisphenol-A from the derivative.

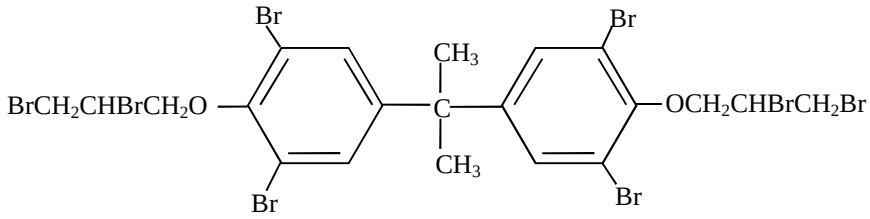
Industry have indicated that tetrabromobisphenol-A has been used in the past as an intermediate for manufacturing certain derivatives in the EU. However, no members of the Bromine Science and Environmental Forum (BSEF) Industry Consortium currently manufacture, nor intend to manufacture in the foreseeable future, such derivatives in the EU (Industry Consortium, 2003). It is also possible that derivatives of tetrabromobisphenol-A could be manufactured in the EU by companies that are not members of the consortium. The amount of free tetrabromobisphenol-A present as an impurity in the derivatives is thought to be <50 ppm (<0.005% by weight).

2.2.2.3.1 Tetrabromobisphenol-A bis(methyl ether)

Tetrabromobisphenol-A bis(methyl ether) (CAS Number 37853-61-5; the substance is the dimethyl ether derivative of tetrabromobisphenol-A and is sometimes known as dimethylated tetrabromobisphenol-A) has been found in the environment (see Section 3.1.1.2.2). The occurrence in the environment can possibly be explained by the O-methylation of tetrabromobisphenol-A by certain biological processes (see Section 3.1.0.6.2). It is not certain whether it is used itself as a flame retardant. There is some information to suggest that it has been used at low tonnage (<1,000 tones/year) as a flame retardant in expanded polystyrene (WHO, 1997).

2.2.2.3.2 Tetrabromobisphenol-A bis(2,3-dibromopropyl ether)

This substance (CAS Number 21850-44-2) is used as an additive flame retardant in polyolefins and copolymers such as high density polyethylene, low density polyethylene, polypropylene and polybutylenes. (OECD, 1994; WHO, 1995; Ash and Ash, 1997). The structure of tetrabromobisphenol-A bis(2,3-dibromopropyl ether) is shown below.



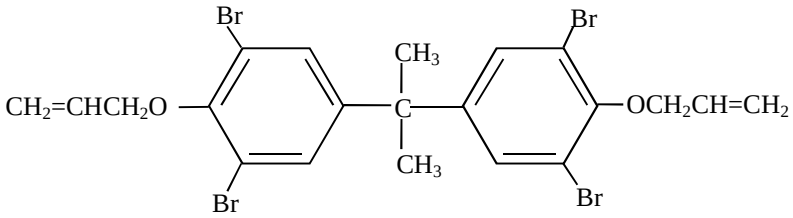
In polypropylene, Prins *et al.* (2000) indicated that a loading of 8-10% of the flame retardant meets the UL94 V-0 rating and the minimum amount necessary to meet the UL94 V-2 rating and Glow Wire rating is 1.5% of the flame retardant with 0.5% antimony trioxide and 1% of the flame retardant with 0.33% antimony trioxide respectively. Bar Yaakov *et al.* (2000) reported that 12% of the flame retardant with 4% antimony trioxide and 14.5% of the flame retardant with 5.2% antimony trioxide are used in formulations to meet the UL94 V-0 rating in polypropylene homopolymers and block copolymers respectively. They also reported that the UL94 V-2 rating is met using formulations containing 3% of the flame retardant with 1% antimony trioxide and 4.5% of the flame retardant with 1.5% antimony trioxide in polypropylene homopolymers and block copolymers respectively.

Flame retarded polypropylene is used in building applications (mainly in pipes for water discharge but also film and sheet for roofing), textiles, and in electrical and electronic applications such as wire nuts, lamp sockets, coil bobbins, connectors, wire and cable, housings of electrical appliances, TV yokes. Tetrabromobisphenol-A bis(2,3-dibromopropyl ether) is the most popular flame retardant for applications such as water discharge pipes passing the B1 class (DIN 4102) and also for lamp sockets meeting the UL94 V-2 or V-0 rating (Bar Yaakov *et al.*, 2000).

DeSchryver *et al.* (2002) reported that it could also be used in high impact polystyrene at 5% by weight (meets the UL94 V-2 or Glow Wire rating).

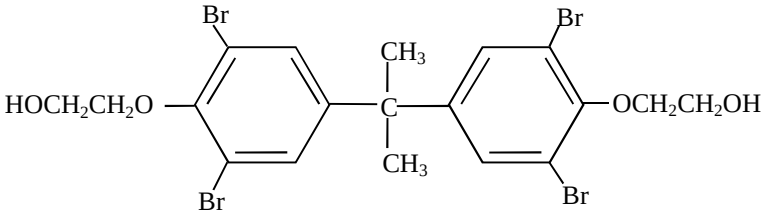
2.2.2.3.3 Tetrabromobisphenol-A bis(allyl ether)

This substance (CAS Number 25327-89-3) is used as a reactive flame retardant in polystyrene foams (expandable polystyrene (EPS)). (OECD, 1994; WHO, 1995; Ash and Ash, 1997). The structure of tetrabromobisphenol-A bis(allyl ether) is shown below.



2.2.2.3.4 Tetrabromobisphenol-A bis(2-hydroxyethyl ether)

This substance (CAS Number 4162-45-2) is used as an additive flame retardant in engineering polymers (e.g. polybutylene terephthalate and polycarbonate), epoxy resins, thermoset and thermoplastic polyesters, polyurethane, laminates for electronic circuit boards and adhesives and coatings (OECD, 1994; WHO, 1995; Ash and Ash, 1997). The structure of tetrabromobisphenol-A bis(2-hydroxyethyl ether) is shown below.

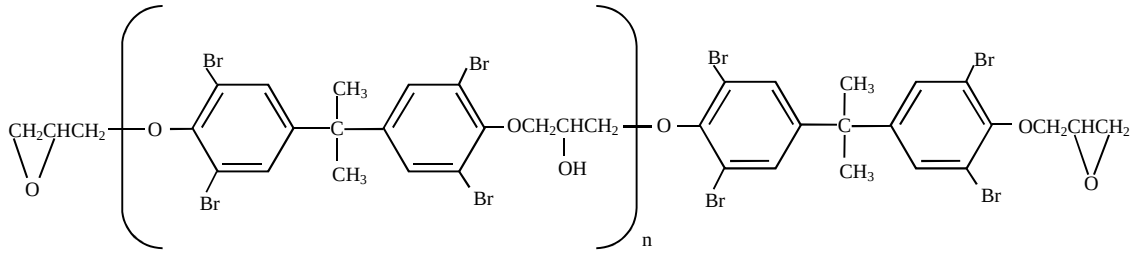


2.2.2.3.5 Tetrabromobisphenol-A brominated epoxy oligomer

Epoxy oligomers of tetrabromobisphenol-A are also known as tetrabromobisphenol-A diglycidyl ethers (CAS Number 68928-70-1). There are two chemically different types of brominated epoxy oligomers. One has two epoxy groups at the end of the molecule, which is similar to epoxy resins used for printed circuit boards (EP-type). The other has no reactive groups; this is tetrabromobisphenol-A epoxy end-capped with tribromophenol (EC-type). Both types of oligomer are reactive flame retardants. They are used in housings for business machinery and electrical/electronics parts by injection moulding from flame retardant compounds based upon high impact polystyrene (HIPS), ABS, ABS/polycarbonate, polybutylene terephthalate-alloys, polybutylene terephthalate and thermosetting resins. The

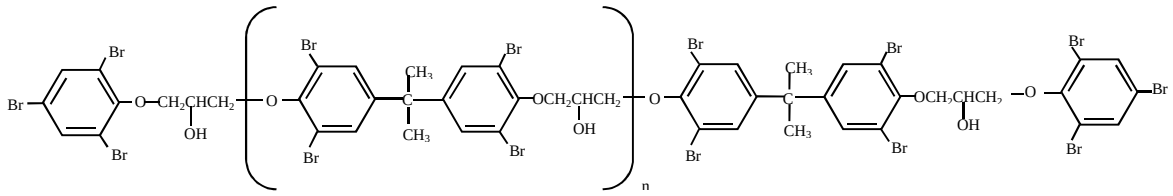
concentrations of the flame retardant in ABS are 21% of the EP-type and 19% of the EC-type. Brominated epoxy oligomers are used in combination with 5% of antinomy oxide. (WHO, 1995). The structures of the EP-type and EC-type tetrabromobisphenol-A brominated epoxy oligomers are shown below.

Example EP-type (epoxy-terminated) oligomer.



n = 0, 1, 2, 3, etc.

Example EC-type (tribromophenol end-capped)



n = 0, 1, 2, 3, etc.

As well as fully tribromophenol end-capped oligomers, some products are available with around 50% end-capping with tribromophenol (Plaitin *et al.*, 1998).

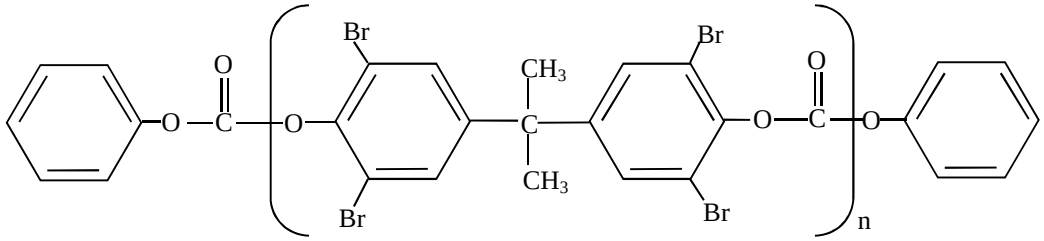
The molecular weights of the products vary between 700 and 50,000 g/mole, and differ depending on the application.

2.2.2.3.6 Tetrabromobisphenol-A carbonate oligomers

Tetrabromobisphenol-A carbonate oligomers are produced by reaction of tetrabromobisphenol-A with phosgene (OECD, 1994). In this respect they can be considered similar to the reactive use of tetrabromobisphenol-A in polycarbonates described above.

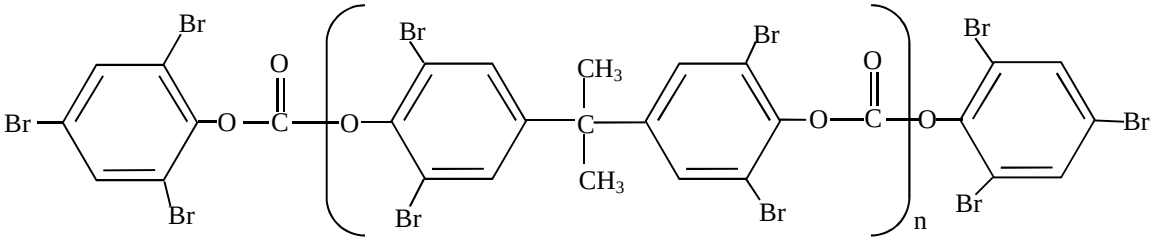
These oligomers are used as additive flame retardants in ABS and engineering thermoplastics such as polybutylene terephthalate, polycarbonate, polyethylene terephthalate and phenol-formaldehyde resins (OECD, 1994; WHO, 1995). Both phenoxy-terminated tetrabromobisphenol-A carbonate oligomers (CAS Number 94334-64-2) and tribromophenoxy-terminated tetrabromobisphenol-A carbonate oligomers (CAS Number 71342-77-3) are produced (WHO, 1995). The structures of these oligomers are shown below.

Phenoxy-terminated tetrabromobisphenol-A carbonate oligomer.



n = 3-5

Tribromophenoxy-terminated tetrabromobisphenol-A carbonate oligomer.



n = 3-5

Polybutylene terephthalate with 18% tetrabromobisphenol-A oligomer and 4% antimony trioxide is reported to meet the V-0 fire classification (OECD, 1994).

A tetrabromobisphenol-A diglycidyl ether - carbonate oligomer (CAS Number 32844-27-2) has also been reported.

Gouteux *et al.* (2006) has recently studied the products released from a sample of a tribromophenoxy-terminated tetrabromobisphenol-A carbonate oligomer under thermal stress. Details of the study are currently available only as an extended abstract. In the study, samples of the flame retardant were placed in a glass flask and heated up to around 100°C under a flow of nitrogen. Volatile products were collected and analysed, along with substances present on the glass surfaces of the system. No tetrabromobisphenol-A was detected in this experiment. The main products found were tribromophenol and pentabromoethylbenzene, but other substances such as dibromophenol and pentabromotoluene were also identified.

2.2.2.3.7 Others

OECD (1994) reported that a type of polyester fibre can be made from bis(hydroxyethyl) tetrabromobisphenol-A ethylene glycol by reaction with terephthalic acid and that flame retardant polyester-cotton blends containing 30% bromine, 45% polyester fibres and 25% cotton can be made from tetrabromobisphenol-A by reaction with terephthaloyl chloride in methylene chloride.

Ash and Ash (1997) indicated that tetrabromobisphenol-A diacrylate (CAS Number 55205-38-4) can be used in automotive coatings and wire and cable coatings. A

tetrabromobisphenol-A bis-(2-ethylether acrylate) derivative (CAS Number 6710-97-2) has also been reported.

The commercial significance of these products is unclear.

2.3 BREAKDOWN/TRANSFORMATION PRODUCTS

There is some evidence that shows that, under certain pyrolysis conditions, the presence of tetrabromobisphenol-A can lead to the formation of small amounts of brominated dibenzo-*p*-dioxins and dibenzofurans. This is discussed in detail in Appendix A. Generally, the amounts of these products formed from tetrabromobisphenol-A appear to be less than from some other brominated flame retardants such as the polybrominated diphenyl ethers (for example see EC, 2001). Factors that appear to affect the formation include the temperature and the residence time at the temperature. At high temperatures (e.g. around 800^{o}C) only trace amounts of mainly mono- and dibrominated dibenzo-*p*-dioxins and dibenzofurans appear to be formed.

Of possible environmental concern is the release of brominated dibenzo-*p*-dioxins and dibenzofurans from incineration of plastics containing tetrabromobisphenol-A and during accidental fires involving articles containing tetrabromobisphenol-A.

In the case of accidental fires, given the large amounts of toxic products known to be formed, notably chlorinated dibenzo-*p*-dioxins and dibenzofurans, but also non-halogenated products such as polycyclic aromatic compounds, the presence of tetrabromobisphenol-A is unlikely to significantly affect the total release of toxic products from fires as, in most cases, tetrabromobisphenol-A will only constitute a small proportion of the total halogenated material present in a fire.

Regulations on the design of municipal incinerators require a minimum incineration temperature of 850^{o}C for 2 seconds (EEC, 1989a and 1989b). A higher incineration temperature of 1,100^{o}C is required for hazardous waste incinerators where waste containing more that 1% halogens is incinerated (EEC, 1994).

Under the Pollution Prevention and Control (PPC) Regulations, incineration processes in England and Wales are regulated by the Environment Agency and the local authorities. The Environment Agency is responsible for regulating all plants that burn hazardous waste as well those other plants that burn non-hazardous waste at a rate of more than 1 tonne per hour. Local authorities regulate plants burning less than 1 tonne of waste per hour. With a few exceptions like clean wood waste and forestry waste, all incinerators are subject to the requirements of Directive 2000/76/EC (the Waste Incineration Directive) from 28th December 2005. Under this Directive, all plants must comply with limits of 0.1 ng/m^3 for dioxins and 10 mg/m^3 for dust irrespective of the size of the plant or the nature of the waste. In most cases this means the application of abatement for dioxins (e.g. activated carbon injection) and high efficiency dust abatement. The combination of these two measures results in dioxin levels below the prescribed limits.

Given the similarities between chlorinated and brominated dioxins and the mechanism of their formation, incinerator design and abatement technologies employed for chlorinated dioxins and furans should also be effective in limiting the emissions from the brominated analogues.

Other disposal/recycling practices for articles containing tetrabromobisphenol-A may have the potential to release polybrominated dibenzofurans and dibenzo-*p*-dioxins to the environment, and these are considered further in Appendix A.

2.4 LEGISLATIVE CONTROLS

In 1995 a Voluntary Industry Commitment for risk reduction of brominated flame retardants, including tetrabromobisphenol-A, was agreed within the OECD. The agreement required regular reporting of the risk reduction activities carried out by the global producers of tetrabromobisphenol-A. This initiative has now ended.

Directive 2002/96/EC[5] on Waste Electrical and Electronic Equipment (WEEE Directive) entered European law on the 13th February 2003 and should be implemented by Member States by the 13th August 2004. The Directive contains the following elements:

- Member States shall set up separate collection schemes and ensure the proper treatment, recovery and disposal of WEEE;
- The treatment, recovery and disposal of WEEE shall be financed by producers to create economic incentives to adapt the design of electrical and electronic equipment to the prerequisites of sound waste management;
- Consumers shall have the possibility to return their equipment free of charge. They need to be informed about the possibilities of return WEEE.

The Directive encourages producer responsibility for waste management, separate collection of WEEE, improved treatment and reuse/recycling, and improved dissemination to users. In implementing the Directive, producers are required to set up systems to treat WEEE which would include, amongst other things, separation of plastic containing brominated flame retardants from collected WEEE (RPA, 2001).

A further Directive (Directive 2002/95/EC) on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) also entered European law on the 13th February 2003. This Directive should be implemented by Member States by the 13th August 2004. According to this Directive, from 1st July 2006 manufacturers will be required to substitute certain heavy metals and certain brominated flame retardants (polybrominated biphenyls, pentabromodiphenyl ether, octabromodiphenyl ether and decabromodiphenyl ether (with a potential exemption of decabromodiphenyl ether following risk assessment results) in new electrical and electronic equipment. Tetrabromobisphenol-A is not included in this Directive.

In Denmark regulations are already in place on the management of waste from electrical and electronic products (Danish Environmental Protection Agency, 2001). According to the Ministry of Environment and Energy's Statutory Order No. 1067 of 22 December 1998, flame-retarded plastic has to be separated out from other waste from electrical and electronic equipment and this plastic has to be recycled, incinerated or deposited at approved facilities. In the case of recycling, the plastic has to be used for products for which special requirements

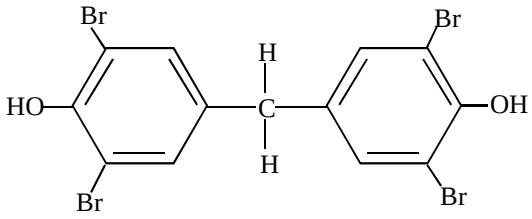
[5] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). Official Journal of the European Union, L37, 13/2/2003, pp24-38.

apply for fire safety reasons. There are around 25 companies that separate electronic waste in Denmark.

From 1st January 2004 waste (including products, materials and parts) containing more than 0.25% of tetrabromobisphenol-A will be classified as hazardous waste in Norway (within the rest of the EU this will be classified as waste only) (Wendschlag, 2004).

2.5 NATURAL SOURCES

A large number of organobromine compounds are known to be produced naturally in the environment, many by marine organisms. Indeed at least 50 simple bromophenols are known to occur naturally, and several natural diphenyl methanes have also been discovered (Gribble *et al.*, 2000). In particular, the following substance (bis(3,5-dibromo-4-hydroxyphenyl)methane) that is structurally similar to tetrabromobisphenol-A has been found to be produced by the segmented marine worm *Thelepus setosus*.



Tetrabromobisphenol-A itself has not yet been identified as being produced by natural sources and so this will be considered to be an insignificant process for tetrabromobisphenol-A in this assessment.

3 ENVIRONMENT

3.1 EXPOSURE ASSESSMENT

3.1.0 General discussion

Tetrabromobisphenol-A is not currently produced in the EU though there has been production in the past and this is considered in Section 3.1.0.1. Currently environmental releases will occur as a result of the processing, use and disposal of tetrabromobisphenol-A and plastics containing tetrabromobisphenol-A, and these are quantified in Sections 3.1.0.2 to 3.1.0.4.

The emissions have been estimated using industry-specific information wherever possible, and these emissions have been taken forward to the PEC calculations and Risk Characterisation. For some lifecycle stages, emissions have also been estimated using the default methods from Appendix 1 of the Technical Guidance Document. These are identified as such in the following Sections and are provided mainly for information, but are used in the PEC calculations for lifecycle stages where insufficient industry-specific information is available to estimate the emission by other methods.

Many of the methods used to estimate emissions from polymers depend on the vapour pressure. For tetrabromobisphenol-A, the only validated vapour pressure data comes from a study where only the upper limit of the vapour pressure was determined (vapour pressure $<1.19\times10^{-5}$ Pa at 20^{o}C). In the calculations a value of 6.24×10^{-6} Pa at 25^{o}C has been used. The reliability of this value is uncertain, and there is evidence from modelled data that the actual vapour pressure could be much lower than this value. This, therefore, introduces added uncertainty over the emission estimates obtained.

3.1.0.1 Releases from production

According to information supplied by the producers of tetrabromobisphenol-A (personal communication) it is not currently produced in the EU. One producer reports that production did take place in the EU from 1989 to 2000. Production at this site has now ceased for commercial reasons.

While there is not currently any production in the EU, it is technically feasible that production could restart if commercial conditions dictated. Therefore, a local release scenario is considered in this assessment to allow for this. Based upon the information supplied by Industry for production in the EU between 1989 and 2000, a representative value for yearly production would appear to be around 4,000 tonnes.

Default emission estimate

An estimate of emissions to waste water can be obtained using the default values from the Technical Guidance Document. Assuming Industry Category (IC)=11 (polymers industry) and Use Category (UC)=22 (flame retardants and fire preventing agents), the default emission factors for production are given in Table A1.1 of Appendix 1 of the Technical Guidance Document. For tetrabromobisphenol-A the vapour pressure is <1 Pa giving a default release of 0 to air (production in dedicated equipment (Main Category (MC)=1c)) and 0.003 (0.3%) to waste water. The default number of days production is 300 days per year

(Table B1.4). Based upon these default release estimates the daily release of tetrabromobisphenol-A is 0 kg/year to air and 12,000 kg/year or 40 kg/day to waste water.

Industry-specific information

Dust emissions from the plant were measured in 1998 as 0.031 g/hour. No information on possible releases to other media such as water was available. As the substance has a relatively high specific gravity, it is probably reasonable to assume that dust emissions will rapidly settle out of the atmosphere and ultimately end up going to waste water by washing of floors and equipment etc., or being disposed of to solid waste. Assuming continuous production and that all releases ultimately end up going to local waste water gives a daily release of tetrabromobisphenol-A to waste water of 0.744 g/day (7.44×10^{-4} kg/day). Assuming 300 days production, this figure is equivalent to a yearly emission of 0.223 kg/year.

A report investigating the emissions from the production of brominated flame retardants in the EU (EEC, 1993) gave the following release estimates for tetrabromobisphenol-A from production:

Air	0.07 kg/tonne (as particulates)
Water	<0.5 kg/tonne (from washing out of reaction vessel after each batch) 0.045-<0.45 kg/tonne (product cake washing)
Solid wastes	<10 kg/tonne (total waste; tetrabromobisphenol-A will make up only part of this)

The particulate emissions are likely to settle rapidly out of the atmosphere and ultimately end up going to waste water or solid waste. Assuming the particulate emissions all eventually enter waste water, the maximum estimated emission to waste water based on the data reported in ECC (1993) is 1.02 kg/tonne. Applying this to a tonnage of 4,000 tonnes gives an emission of 4,080 kg/year (13.6 kg/day based upon 300 days production).

As there is no production of tetrabromobisphenol-A currently in the EU, these emission estimates, and the subsequent local PEC calculations, are for illustrative purposes only and will not be considered further in the risk characterisations. It is clear from the above estimates, that the actual emissions from the former production site in the EU were less than would be predicted from the default values in the Technical Guidance Document. An emission figure of 0.744 g/day or 0.223 kg/year for the former production site in the EU has been provided based on dust emissions to air, but no information has been given on emissions to water from the process. As EEC (1993) indicated that washing out of the reactor vessels between batches could be a source of release of brominated flame retardants in general during their production (it was reported that the flame retardant products can adhere to the sides of the reaction vessel and are removed by washing with water containing a surfactant), the emissions from a production site will be assumed to be 4,080 kg/year or 13.6 kg/day over 300 days to waste water in the illustrative local PEC calculations.

3.1.0.2 Release from use (processing)

3.1.0.2.1 Production of tetrabromobisphenol-A derivatives

Default emission estimate

As indicated in Section 2.2.2.3, a number of derivatives of tetrabromobisphenol-A are produced as flame retardants. Information on the production of these derivatives is scarce and the situation with regards to the current production of these derivatives in the EU is confidential and unclear, although the Industry Consortium for tetrabromobisphenol-A have indicated that none of its members currently manufacture such derivatives in the EU (Industry Consortium, 2003). World-wide, the use of these derivatives appears to be increasing, and given that brominated flame retardants are produced at some sites in the EU already, it cannot be ruled out that production of these derivatives will not occur in the future. Therefore, in order to take into account this possibility, an emission estimate will be made for an example generic site producing any one of the tetrabromobisphenol-A derivatives. If tetrabromobisphenol-A is used for this purpose in the EU in the future, information on the release of tetrabromobisphenol-A from the process would be desirable.

The example calculation will assume that the site uses 500 tonnes/year of tetrabromobisphenol-A to produce a derivative (the actual amount of derivative produced at a site of this size will depend on the actual derivative but will be >500 tonnes/year). In the absence of any information on the actual emissions from the process, the emissions will be estimated using the default emission factors from the Technical Guidance Document. The production of tetrabromobisphenol-A derivatives can be considered to be the processing step in IC=3 (chemical industry: chemicals used in synthesis). Assuming MC=3 (default), the appropriate emission factors from Table A3.3 of Appendix 1 of the Technical Guidance Document are 0.00001 to air (0.001%) and 0.007 (0.7%)[6] to waste water, and the number of days of emission can be estimated as 200 days/year from Table B3.2. The following emissions can therefore be estimated for a generic site:

Emission to air = 5 kg/year = 0.025 kg/day over 200 days.
Emission to waste water = 3,500 kg/year = 17.5 kg/day over 200 days.

Industry-specific information

No information is currently available.

3.1.0.2.2 Reactive flame retardant use

The total amount of tetrabromobisphenol-A assumed to be used in Europe for this assessment is approximately 6,500 tonnes/year. Of this amount, 90% or 5,850 tonnes/year is assumed to be used as a reactive flame retardant in epoxy resins and other resins. When used as a reactive flame retardant, tetrabromobisphenol-A effectively acts as monomer and is incorporated into the polymer structure during the polymerisation reaction. Once incorporated into the polymer backbone, emissions of tetrabromobisphenol-A cannot occur during any subsequent processing steps of the polymer.

[6] Strictly speaking a higher default emission factor of 0.02 (2%) should apply to a tonnage of 500 tonnes. However as this is an hypothetical calculation the lower factor was chosen as this is thought to be more appropriate for an existing substance and, in addition, the actual tonnage is unknown.

The commercially produced resins typically contain around 20% bromine (see Section 2.2), which is equivalent to a tetrabromobisphenol-A content, reacted in the polymer backbone, of around 34% (tetrabromobisphenol-A has a bromine content of 59%). Hence, the amount of epoxy or other resins that are made each year in the EU from tetrabromobisphenol-A is around 17,200 tonnes/year.

Default emission estimate

The use of tetrabromobisphenol-A as a reactive flame retardant in epoxy and other resins is related to IC=11 (polymers industry), where tetrabromobisphenol-A effectively becomes the monomer (UC=43) in the polymerisation reaction. Default emission factors for this process can be obtained from Table A3.10 of Appendix 1 of the Technical Guidance Document. For a substance with a vapour pressure <1 Pa and a water solubility <10 mg/l the release factors to air and water for a monomer are 0.00001 (0.001%) and 0.00001 (0.001%) respectively.

The amount of resin produced at a local site and the number of days processing can be estimated from Table B3.9 of Appendix 1 of the Technical Guidance Document. Based on a regional tonnage of 1,720 tonnes/year for the resin (i.e. applying the 10% rule), the amount of resin produced at a site would be 258 tonnes/year over 103 days. The amount of tetrabromobisphenol-A used to produce this quantity of resin would be around 88 tonnes.

Based on the above figures, the following default release estimates can be calculated:

Local release:	0.0085 kg/day over 103 days to air
	0.0085 kg/day over 103 days to waste water
Regional release:	5.9 kg/year to air
	5.9 kg/year to waste water
Total EU release:	58.5 kg/year to air
	58.5 kg/year to waste water

Industry-specific information

Manufacture of epoxy and polycarbonate resins

In the production of flame-retarded epoxy or polycarbonate resins, tetrabromobisphenol-A effectively replaces some or all of the bisphenol-A in the polymerisation processes. Thus, information on the emissions of bisphenol-A from the process may also be useful in estimating the possible emissions of tetrabromobisphenol-A from the process. The emissions of bisphenol-A have been considered in detail in the Risk Assessment Report for that substance (EC, 2003a) and the following information from that report is of use here.

Approximately 171,000 tonnes/year of bisphenol-A are used to produce epoxy resins in the EU, with around 90% of the production occurring at 8 known sites. There are a number of different epoxy resins produced, which vary in the starting constituents, however diglycidyl ethers of bisphenol-A derived from bisphenol-A and epichlorohydrin are still among the most widely used epoxy resins.

Site-specific emission information for bisphenol-A was obtained for 6 sites producing epoxy resins. There were reported to be no emissions to air and water from 3 of the sites, one site

gave the daily emission of bisphenol-A in the effluent from the waste water treatment plant as <0.075 kg/day, another plant gave overall emissions of bisphenol-A to air as 25 kg/year and the emissions to waste water as 0.24 kg/day, and the final plant gave an emission of 0.72 kg/day from the waste water treatment plant.

Polycarbonate resins are produced from bisphenol-A at 5 sites in the EU. Production of bisphenol-A is also carried out at these sites and the emissions from the polycarbonate production were not identified separately.

From the above information on bisphenol-A it is clear that the number of sites producing epoxy and polycarbonate resins in the EU is small. The emission of bisphenol-A from these sites is generally reported to be low, but was measurable at several sites indicating that emission of tetrabromobisphenol-A could also be expected from the process.

In addition to this information, Industry has recently carried out a survey of releases of tetrabromobisphenol-A itself from the processes. The results from the survey are considered confidential and did not cover all known sites producing brominated epoxy resins in the EU. Little actual information on releases to the environment from the process was reported. The survey generally indicated that emissions to waste water would be expected to be small as the process is essentially a dry process, but emissions to air were reported to occur from some loading operations.

A further survey of users of tetrabromobisphenol-A for the manufacture of epoxy resins has been carried out (EBFRIP, 2005). This survey investigated whether the process was a wet or dry process and the fate of any sludge from the process (no actual emission figures were collected). Two main processes are used to produce brominated epoxy resins within Europe. The first is a dry or “fusion” process that does not use water (and does not generate waste water effluents). The second is a wet or “taffy” process that does produce water effluent (brine). Information was provide for eight of the eleven known companies within the EU that use tetrabromobisphenol-A as a reactive flame retardant for the production of epoxy resins (one of the companies used tetrabromobisphenol-A at more than one site). A dry process only was used by several of the companies. These sites had no water effluent from the process and hence no waste water treatment sludge containing tetrabromobisphenol-A was generated. Some of the companies used both the wet and dry process and so may have emissions to waste water. The sludge generated at these companies from treatment of the waste water was not applied to agricultural land. Some of the companies use the wet process alone. The sludge generated from the treatment of the waste water at these sites was again not applied to agricultural land.

A follow-up survey has been carried out on the fate of sewage sludge at the small number of sites not covered by the above survey (BSEF, 2006b). This indicated that none of the companies applies sewage sludge of agricultural land. It should be noted that the EBFRIP (2005) and BSEF (2006b) surveys between them now cover the fate of sewage sludge at all customer sites supplied by the main EU importers of tetrabromobisphenol-A (the importers are all members of both EBFRIP (the European Brominated Flame Retardants Industry Panel) and BSEF (the Bromine Science and Environmental Forum)). However, it is possible that there may be other sites within the EU that use tetrabromobisphenol-A as a reactive flame retardant that are supplied by companies other than EBFRIP/BSEF member companies, and the fate of sewage sludge at such sites is currently unknown.

A detailed monitoring study of emissions has also recently been carried out at one of the sites identified in the EBFRIP (2005) survey. Details of the survey are confidential (details are given in the confidential annex) but a brief summary of the main findings is given in Appendix F. These data have been considered later in the PEC calculations for this site.

In addition to reactive use in brominated epoxy resin manufacture a further, confidential, reactive use was identified in the EBFRIP (2005) survey. A detailed monitoring survey of the emissions from this site has been carried out (the details are confidential but a brief summary of the main findings is given in Appendix F) and this has been used as the basis of the PEC calculations for this use (it is understood that there is only one site in the EU carrying out this process).

In the absence of specific release information for tetrabromobisphenol-A for all sites in the EU, the emissions from production of flame-retarded epoxy and polycarbonate resins will be estimated using the default emission factors of 0.001% to air and 0.001% to water outlined above. However, to recognise the fact that the number of sites carrying out this operation in the EU appears to be small, the 10% rule will not be applied in determining the amount of tetrabromobisphenol-A used on each site. Instead, Table B3.9 of Appendix 1 of the Technical Guidance Document will be applied to the total amount of tetrabromobisphenol-A used in the process in the EU. This gives the fraction of main source as 0.1 (i.e. the amount of tetrabromobisphenol-A used at a site as 585 tonnes/year) and the number of days of operation as 300. The daily amount of tetrabromobisphenol-A used on a site obtained from these figures is 2 tonnes/day. This figure is similar to, but slightly lower than, the daily usage that can be estimated from the information provided in the industry surveys of the use in this application (mean daily usage is around 2.7 tonnes/day). Therefore for this assessment the mean daily usage of 2.7 tonnes/day will be used for the generic site. The resulting emissions estimated from production of epoxy and polycarbonate resins (generic site) are given below. The available site-specific information is considered further in Appendix F.

Local release:	0.027 kg/day over 300 days to air
	0.027 kg/day over 300 days to waste water
Regional release:	5.9 kg/year to air
	5.9 kg/year to waste water
Total EU release:	58.5 kg/year to air
	58.5 kg/year to waste water

To put these emissions into context, the total EU emissions of bisphenol-A from production of epoxy resin production are around 403 kg/year to receiving water (after treatment). The estimated removal during waste water treatment for bisphenol-A was 88%, and so this figure is very approximately equivalent to an emission of the order of 3,300 kg/year to waste water prior to treatment (there are large errors in this extrapolation). As the use of tetrabromobisphenol-A in epoxy resins (5,850 tonnes/year) is around 3.4% of the amount of bisphenol-A used in epoxy resins (171,000), then the pro-rata total EU emission to waste water for tetrabromobisphenol-A would be expected to be of the order of 110 kg/year to waste water. This is in reasonably good agreement with the default emissions estimated above.

Curing and further processing of epoxy and polycarbonate resins

The emissions of tetrabromobisphenol-A from the subsequent processing of epoxy and polycarbonate resins depend on the residual monomer content of the resin. The residual monomer content of tetrabromobisphenol-A is uncertain. EC (2003a) indicates that the residual monomer content of bisphenol-A in epoxy resins is a maximum of 1,000 ppm (or 0.1% by weight) when produced, and this level is further reduced when the epoxy resin is cured. It can be assumed that the residual levels of tetrabromobisphenol-A in the produced epoxy and polycarbonate resin will be similarly low. This is confirmed by recent information provided by Industry as part of a survey into the use in this area which indicated that the residual content of some epoxy resin products is <200 ppm (or <0.02% by weight).

If the initial amount of tetrabromobisphenol-A added to the resin is assumed to be 34%, and the residual monomer content of the resin is less than 0.02%, then the amount of tetrabromobisphenol-A reacted into the polymer backbone is (33.98×100)/34 = 99.94% of that used, and the amount of residual monomer in the polymer is <0.06% of the tetrabromobisphenol-A used.

Sellström and Jansson (1995) determined the amount of unreacted tetrabromobisphenol-A that could be extracted from a printed circuit board sample. The sample was an epoxy laminate coated with copper and was bought from a store in Sweden. A file was used to remove a 0.5 g sub-sample of filings and this sub-sample was extracted with 10 ml of water containing NaOH (0.01 M) and NaCl (1 M) over 20 hours. No recovery experiments were carried out in this study and so the efficiency of the method used to extract tetrabromobisphenol-A from the polymer is not known. The amount of unreacted tetrabromobisphenol-A found to be present in the filings using this method was 700 µg/kg filings (if the efficiency of the extraction method was <100% then the actual amount of free tetrabromobisphenol-A would be higher than this figure). The printed circuit board was thought to contained around 8-12% bromine (which is equivalent to 14-20% of tetrabromobisphenol-A used in its manufacture). Thus it was concluded that there was at least 3.5 mg of free tetrabromobisphenol-A present in the polymer for every kg of tetrabromobisphenol-A used. This figure is equivalent to a residual monomer content of 3.5×10^{-4}% of the tetrabromobisphenol-A used. This figure is lower than, but consistent with, the data reported above. It should be noted, however, that this estimate depends crucially on the extraction efficiency of the method used. If the extraction efficiency was less than 100% then the actual residual monomer content of the sample could be higher than indicated here.

A residual monomer content of <0.02% by weight in the resin or <0.06% of the amount of tetrabromobisphenol-A used to make the resin (figures based on the information recently reported by Industry) will be assumed in the assessment.

A rough estimate for the emissions of this residual monomer content during curing and subsequent processing can be obtained using the emission factors for polymer processing (conversion) from the Use Category Document on plastics additives (OECD, 2004). From this document, both thermosetting epoxy resins and thermoplastic polycarbonate resins containing flame retardants are cured (in the case of epoxy resins) or processed using processes in closed systems (as defined in OECD (2004)) and an emission factor of 0.02% assuming no fume elimination equipment is used (see also Section 3.1.0.2.3).

According to OECD (2004) the worst case amount of epoxy resin and polycarbonate resin processed on a site is 80 tonnes/year and 69 tonnes/year respectively. The number of days on which processing of the resin would occur can be estimated as 32 and 28 respectively using Table B3.9 of Appendix 1 of the Technical Guidance Document. Assuming all this resin is flame-retarded and that the resin has a residual tetrabromobisphenol-A monomer content of 200 ppm, the maximum emission of tetrabromobisphenol-A from a resin processing site would be 0.0032 kg/year (or 1.0×10^{-4} kg/day over 32 days) for an epoxy resin processing site and 0.0028 kg/year (or 1.0×10^{-4} kg/day over 28 days) for a polycarbonate processing site.

The regional and continental emission of tetrabromobisphenol-A from further processing of epoxy and polycarbonate resins can be estimated assuming that the residual monomer content is a maximum of 0.06% of the tetrabromobisphenol-A used. Therefore, if the total amount of tetrabromobisphenol-A used in the EU in this area is 5,850 tonnes/year, the maximum amount present as residual monomer will be 3.51 tonnes/year. Assuming the emission factor for the residual monomer during further processing is 0.02% gives a total EU emission from this source of 0.70 kg/year. The regional emission can be assumed to be 10% of this value, 0.070 kg/year.

As discussed in Section 2.2.1, a further 6,000 tonnes/year of tetrabromobisphenol-A could be assumed to be imported into the EU in semi-finished products that require further processing or curing. If it is assumed that 90% of this is used as a reactive flame retardant, then the amount of residual monomer present in the resin would be 3.24 tonnes/year. Assuming an emission factor of 0.02% would give a total EU emission of 0.65 kg/year from this source. The regional emission would be 10% of this value, 0.065 kg/year.

Thus, taking into account the amount of resin produced in the EU and the amount that may be imported into the EU, the total EU emission from processing or curing of the resin would be 1.35 kg/year. The regional emissions will be 10% of this value, 0.14 kg/year.

According to OECD (2004), these releases are initially to air as hot gases. For substances with low vapour pressures such as tetrabromobisphenol-A the possibility of condensation as the gas cools needs to be considered. This may lead to some of the releases initially to air entering other waste streams such as waste water as a result of washing floors and equipment etc. The Use Category Document gives no guidance as to the fraction of the air release that could eventually end up in waste water. As a worst case approach it could be assumed that 50% of the release to air would eventually reach waste water. In the absence of any other information, this assumption will be used later in the PEC calculations.

3.1.0.2.3 Additive flame retardant use

The total amount of tetrabromobisphenol-A assumed to be imported into the EU is in the region of 6,500 tonnes/year. Around 10% of this, or 650 tonnes/year, is used in additive flame retardant applications (see Section 2.2). The main area of use is in ABS resins. There are reports in the literature of other possible additive uses of tetrabromobisphenol-A (for example in HIPS and phenolic resins, see Section 2.2), but Industry have indicated that, as far as they are aware, no use of tetrabromobisphenol-A in these applications currently occurs in the EU and so these applications are not considered further in the risk assessment. The amount of tetrabromobisphenol-A added to the polymers is around 20% by weight in ABS. Therefore the amount of ABS polymer produced containing tetrabromobisphenol-A is in the region of 3,250 tonnes/year in the EU as a whole.

Default emission estimate

Appendix 1 of the Technical Guidance Document gives default release estimates for substances used in the polymers industry (IC=11). The release factors for flame retardants (UC=22) during the polymer processing step for thermoplastics are 0.0005 (0.05%) to air (boiling point >300^{o}C; vapour pressure <1 Pa) and 0.0005 (0.05%) to waste water (Table A3.11 of Appendix 1 of the Technical Guidance Document).

Assuming that the amount of polymer produced in the EU containing tetrabromobisphenol-A as an additive is 3,250 tonnes/year, then the amount of polymer produced in a region would be 10% of this value, 325 tonnes/year. Using Table B3.9 of Appendix 1 of the Technical Guidance Document, the amount of polymer containing tetrabromobisphenol-A produced on a site would be around 81 tonnes/year over 33 days. The amount of tetrabromobisphenol-A used to make this amount of plastic would be 16.2 tonnes.

Based on the above figures, the following default release estimates can be calculated:

Local release:	0.25 kg/day over 33 days to air
	0.25 kg/day over 33 days to waste water
Regional release:	32.5 kg/year to air
	32.5 kg/year to waste water
Total EU release:	325 kg/year to air
	325 kg/year to waste water

Industry-specific information

The Use Category Document on plastic additives (OECD, 2004) considers the possible release of flame retardant additives from use in plastics. Around 75,000 tonnes/year of ABS are produced in the United Kingdom in closed (around 92% of total) and open systems (around 8% of total), depending on the processing method used to produce the final product.

Processes using closed systems (as defined in OECD (2004)) include blow moulding, injection moulding, compression moulding, profiles and other extrusion processes, and foaming. Processes using open systems include calendering, fabric coating, casting, thermoforming and filament winding/pultrusion. Partially open systems include processes such as wire and cable production, fibre production, extrusion coating and film production.

Table 3.1 shows the estimated worst case amount of ABS plastic processed at a site using closed system processes. This is taken from OECD (2004) and is based on the total production volume for ABS polymer in the United Kingdom, along with information on the number and size distribution of the polymer processing sites. It is thought that this figure will be representative of the situation throughout the EU. This figure, along with knowledge of the amount of flame retardant used in the polymer, has been used to estimate the amount of tetrabromobisphenol-A used at a worst case site. The estimate assumes that all the polymer produced at the site contains tetrabromobisphenol-A. The number of days on which processing occurs is estimated from Table B3.9 of Appendix 1 of the TGD.

Table 3.1 Estimated amounts of tetrabromobisphenol-A used at polymer processing sites

Type of polymer	Amount of polymer processed (OECD, 2004)	Tetrabromobisphenol-A content of polymer	Amount of tetrabromobisphenol-A processed at site	Estimated number of days of operation per year
ABS	428 tonnes/year	20%	85.6 tonnes/year	171

Further information supplied by the British Plastics Federation (BPF, 2001) suggests that 620 tonnes of tetrabromobisphenol-A were used in the UK as an additive flame retardant in 2001. The main materials in which it was used as an additive were given as ABS (acrylonitrile butadiene styrene), impact modified polystyrene (the Industry Consortium for Tetrabromobisphenol A have indicated that, as far as they are aware, tetrabromobisphenol-A is not used in impact modified polystyrene (Industry Consortium, 2003)) and sometimes with polypropylene in electronic applications. The total amount of plastics used in electrical/electronic applications was about 220,000 tonnes in the United Kingdom, of which about 20% had flame retardants added (44,000 tonnes). The main form of polymer processing used in the electronic industry is injection moulding. In the UK there are approximately 2,000 injection moulders. It is hard to estimate how many of these will be involved in supplying components to the electronic industry due to the changeable nature of contracts and demand. However from a random sample of companies it was estimated that approximately 950 injector moulders supply to the electronics industry. If it is assumed that only 20% of these companies are using flame retardants the total number of sites using brominated flame retardants is approximately 190 in the UK. Assuming that the only brominated flame retardant in use is tetrabromobisphenol-A and that equal quantities are used at each site the amount used per site is 3.26 tonnes/year based on the 2001 figure. It should be noted that use is unlikely to be equally divided between sites.

Industry has indicated that use of tetrabromobisphenol-A in ABS in the EU may be limited to a few larger producers (BSEF, 2006b). With this in mind, the amount/site estimated in **Table 3.1** will be used as the basis for the emission estimates in the following Sections.

Raw materials handling (formulation - step 1)

Tetrabromobisphenol-A is a solid at room temperature and so may generate a dust during handling of the raw material. The average of the median particle sizes[7] from two samples is 42 μm.

OECD (2004) gives an emission factor for loss of dust during raw material handling of 0.21% for powders. The release figure of 0.21% is made up of three components. Firstly, it is assumed that the substance is handled in sacks or bags and some losses due to wear and tear occur. This loss has been estimated as 0.1%, independent of particle size. Secondly, it is assumed that there are problems due to the presence of attractive forces between the individual particles. The origin of these forces could be mechanical interlocking, interfacial and capillary forces between adsorbed layers etc., and for very fine particles, van der Waals

[7] As the particle size values are medians, there will be components of the sample both smaller and larger than this. This means that some components of the material will be below the threshold of 40 μm used in OECD, 2004 for distinguishing levels of dust release. At present there is no information on the relative amounts above and below the threshold, but as the average of the median values is above the threshold the values for >40 μm have been used. This part of the life cycle currently indicates a possible risk based on the emission factors for particulates >40 μm; higher emission estimates would be obtained for particles <40 μm.

forces can be significant. It has been shown that such attractive forces could become significant for particles associated with adsorbed water when diameters are less than 50 μm, and for dry particles which are about two orders of magnitude smaller. Practical experience has shown that agglomeration effects are significant for particles of diameter <40 μm and such particles will not empty cleanly from a bag. For particles >40 μm diameter, retention in the bag is not significant and losses are expected to be at minimal levels e.g. 0.01% (OECD, 2004). The third source of release during handling is from dust generation. This is estimated to be around 0.1% for substances with particle sizes >40 μm (OECD, 2004).

As the substance has a low vapour pressure, volatile losses during handling at ambient temperatures are likely to be negligible.

Using a release figure of 0.21% during raw materials handling, the following emission estimates can be obtained for the various polymer processing sites considered:

ABS site 180 kg/year or 1.05 kg/day to solid waste/waste water over 171 days

The total EU usage of tetrabromobisphenol-A in this application is 650 tonnes/year. The EU-wide release from raw materials handling can therefore be estimated at 1,365 kg/year. According to the Technical Guidance Document, the regional release will be 10% of this figure, around 137 kg/year.

These losses will initially be to the atmosphere, but it is expected that the dust will rapidly settle and so losses will be mainly to solid waste, which may be disposed of, or washed to waste water. As a worst case it will be assumed that the release eventually enters the waste water stream.

Compounding (formulation - step 2)

The compounding stage (where the additive is first mixed into the polymer material) is also susceptible to dust generation but losses are thought to be lower than during the previous handling stage. Losses mainly occur early in the mixing cycle and localised containment may be used to recover the material for recycling. It is thought that losses at this stage are at least an order of magnitude lower than during the original handling stage above, and a worst case scenario may be of the order of 0.01%. Release will again be initially to the atmosphere but the particles would be expected to settle and so losses might ultimately be to solid waste or waste water. As the compounding process generally involves mixing at elevated temperatures, as well as particulate losses, there will be a further 0.002% loss due to the volatility of the flame retardant (tetrabromobisphenol-A, with a vapour pressure of around 6.24×10^{-6} Pa or less, is considered to be in the low volatility additive class defined in OECD (2004)).

Using these release figures, the following emission estimates can be obtained for the various polymer processing sites considered during the compounding step:

ABS site 8.56 kg/year or 0.050 kg/day to solid waste/waste water over 171 days
1.71 kg/year or 0.010 kg/day to air as vapour over 171 days

The total EU usage of tetrabromobisphenol-A in this application is 650 tonnes/year. The EU-wide release from the compounding stage can therefore be estimated at 65 kg/year as

particulates to solid waste/waste water and 13 kg/year to air as vapour. According to the Technical Guidance Document, the regional release will be 10% of these figures, around 6.5 kg/year as particulates to solid waste/waste water and 1.3 kg/year to air as vapour.

As a worst case it will be assumed that the particulate emissions are eventually emitted to waste water.

A detailed monitoring study of emissions has also recently been carried out at a compounding site using tetrabromobisphenol-A as an additive flame retardant. Details of the survey are confidential (details are given in the confidential annex) but a brief summary of the main findings is given in Appendix F. The data from the survey are generally in very good agreement with the default emission estimates given above, and confirm that the default scenario for this use is appropriate to some sites within the EU. The site-specific data for this site have been considered later in the PEC calculations. In addition, it has been confirmed that sewage sludge from the major ABS compounding sites in the EU that are supplied by EBFRIP/BSEF member companies do not apply sewage sludge from the site onto agricultural land (BSEF, 2006b). This is considered further in relation to the PEC calculations for the soil compartment.

Conversion (processing)

As discussed above, plastics containing tetrabromobisphenol-A are generally processed, or converted into the final shape/product, using closed systems as defined in OECD (2004). The processes involved typically include injection moulding for thermoplastic resins such as ABS. As a worst case, OECD (2004) recommends an emission factor of 0.002% for injection moulding of an additive in the low volatility class appropriate for tetrabromobisphenol-A. This factor applies to sites where fume elimination equipment is in operation. However, OECD (2004) also recommends that this factor is increased by a factor of 10 for smaller sites (processing <750 tonnes/year of plastic) as fume elimination equipment may not necessarily be used at such sites. Therefore, emissions from sites with (emission factor 0.002%) and without (emission factor 0.02%) fume elimination equipment will be considered. The estimated emissions are shown below.

Sites with fume elimination equipment:

ABS site 1.71 kg/year or 0.010 kg/day over 171 days

Sites without fume elimination equipment:

ABS site 17.1 kg/year or 0.10 kg/day over 171 days

The total EU usage of tetrabromobisphenol-A in this application is 650 tonnes/year. The EU-wide release from the conversion stage can therefore be estimated at 13 kg/year assuming all sites have fume elimination equipment and 130 kg/year assuming no sites have fume elimination equipment. The actual overall proportion of tetrabromobisphenol-A that is processed at sites with and without fume elimination equipment is not known, but the use of such equipment is relatively common place, particularly at large sites, and is becoming increasingly common at other sites. The regional release will be 10% of these figures, around 1.3 kg/year assuming all sites have fume elimination equipment or 13 kg/year assuming no sites have fume elimination equipment.

As discussed in Section 2.2.1, a further 6,000 tonnes/year of tetrabromobisphenol-A could be assumed to be imported into the EU in semi-finished products such as masterbatch, that require further processing (conversion) in the EU. If it is assumed that 10% of this is used as an additive flame retardant, then the total EU emission from this source would be 12 kg/year assuming all sites have fume elimination equipment or 120 kg/year assuming no sites have fume elimination equipment. The regional emissions would be 10% of these values, 1.2 and 12.0 kg/year respectively.

The total EU emission from conversion of polymers, taking into account the amount of tetrabromobisphenol-A possibly imported into the EU in partly finished products such as masterbatch, can therefore be estimated at 25 kg/year assuming all sites have fume elimination equipment or 250 kg/year assuming no sites have fume elimination equipment. The regional emissions would be 10% of these values, 2.5 kg/year or 25 kg/year respectively.

According to OECD (2004), these releases are initially to air as hot gases. For substances with low vapour pressures such as tetrabromobisphenol-A the possibility of condensation as the gas cools needs to be considered. This may lead to some of the releases initially to air entering other waste streams such as waste water as a result of washing floors and equipment etc. OECD (2004) suggests that, as a worst case approach, it could be assumed that 50% of the release to air would eventually reach waste water. In the absence of any other information, this assumption will be used later in the PEC calculations.

Industry have recently indicated that the majority of ABS containing tetrabromobisphenol-A is processed (converted) by injection moulding to form “appearance” parts (enclosures) such as electrical equipment cabinents (EBFRIP, 2007). It was estimated that around 99% of the total ABS containing tetrabromobisphenol-A is processed by injection moulding. The remaining 1% is processed (converted) by extrusion.

The emission factors for conversion given in OECD (2004) are thought to be most appropriate for conversion processes such as extrusion. The method given in OECD (2004) assumes that there is no emission in the extruder itself, but that a short exposure of hot material to the atmosphere takes place as the product leaves the extruder die, resulting in a potential source of emission. OECD (2004) indicates that injection moulding is, in principle, comparable to extrusion except that the cooling process takes place in a closed space (the mould) resulting in a lower, or no, potential for evaporation. However, OECD (2004) recommends that a similar emission factor as for extrusion is used in the absence of any further information.

EBFRIP (2007) have provided further, qualitative, information on the potential for emissions from conversion using injection moulding. The information provided suggested that it is not common for the injection moulder barrel to be vented (but it was not completely ruled out that venting may occur in some situations) and that the moulding temperature is controlled at around 60-70°C. It was reported that there is no visible fuming from an injection moulding cycle as the only contact between molten polymer and the air where fumes could be emitted is from the small surface area of the advancing polymer melt[8] as it fills the mould, but it was

[8] EBFRIP (2007) did not indicate the melt-temperature used for ABS in injection moulding. Kulich *et al.* (1991) describes the typical conditions used in injection moulding of ABS. The melt temperature ranges from 218 to 268°C. The melt is injected under pressure into the mould, with typical mould temperatures from 27-66°C (or 60 to 82°C for high heat grades).

noted that the melt cools quickly, under pressure, to a temperature of around 70°C before injection.

The only point in the cycle where fuming can be observed is when the injection moulder barrel is purged prior to shut-down. In this operation the barrel would be clamped back from the mould and the remaining polymer in the barrel discharged to air. The volume of polymer discharged in this manner was reported to be minimal (2-3 shots[9] maximum) to minimise waste/costs.

EBFRIP (2007) indicated that mould cleaning would not be done by washing with water, but rather with solvent and cleaning tissues. Generally there would be negligible deposits of tetrabromobisphenol-A or other additives on the mould because such a build-up would quickly have adverse impacts on the surface finish of the moulding, and it is slow and expensive to stop and clean the mould.

Overall, the information from EBFRIP (2007) suggests that the actual emissions from injection moulding could be lower than expected from extrusion, and hence the emissions estimated above may overestimate the actual emissions from injection moulding. However, EBFRIP (2007) did not provide any further quantative information which could be used to derive more refined emission estimates from injection moulding. In addition, EBFRIP (2007) indicates that a very small amount of ABS containing tetrabromobisphenol-A is converted using extrusion processes, for which the methodology in OECD (2004) may be more appropriate. Therefore the emission estimates obtained using OECD (2004) above are taken forward to the PEC calculations for conversion.

OECD (2004) indicates that for some plastics, compounding and conversion could occur at the same site and, if so, the emissions from both stages should be added together. For tetrabromobisphenol-A Industry have confirmed that none of the known compounding sites carry out conversion at the same site (EBFRIP, 2007). Therefore a scenario for a combined compounding/conversion site is not considered in this risk assessment.

3.1.0.3 Releases over lifetime of products

It is possible that tetrabromobisphenol-A could leach from or volatilise from polymers over their lifetime in products. This is particularly the case when tetrabromobisphenol-A is used as an additive flame retardant, but is also possible if when it is used as a reactive flame retardant it is not completely reacted into the polymer backbone. The actual residual monomer concentration of tetrabromobisphenol-A in polymers where it is used as a reactive flame retardant is likely to be less than 200 ppm or 0.02% by weight of the resin (<0.06% by weight based on the mass of tetrabromobisphenol-A used to make the resin) (see Section 3.1.0.2.1).

When considering the releases over the lifetime of products it needs to be considered that products containing tetrabromobisphenol-A (either as an additive or reacted into the polymer backbone) could be imported into the EU as well as being produced in the EU. For tetrabromobisphenol-A, the amount imported in finished or semi-finished products could be significant (see Section 2.2.1) and the total amount of tetrabromobisphenol-A that is

[9] This term was not explained in EBFRIP (2007). Xanthos and Todd (1996) indicate that the injection unit capacity of the injection moulding machine is described by the shot size. The shot size is the maximum volume of melt that can be injected into the mould in a single cycle. It is determined by the diameter of the reciprocating screw injector and the distance over which it is designed to reciprocate (typically abour three screw diameters).

estimated to be present (either as an additive or reacted into the polymer backbone) in new products in the EU is approximately 40,000 tonnes/year.

It will further be assumed that 90% of the tetrabromobisphenol-A in finished products is used in reactive applications and 10% is used in additive applications (see Section 2.2.2). Thus the amount of tetrabromobisphenol-A present as an additive in finished products is 4,000 tonnes/year. For the reactive use, tetrabromobisphenol-A can only be released from the product if it is present as residual monomer. Using the same approach as taken in Section 3.1.0.2.2, assuming that a maximum of 0.06% of the tetrabromobisphenol-A used as a reactive flame retardant is available as residual monomer and not bound into the polymer backbone, the maximum amount of residual monomer present in finished articles where tetrabromobisphenol-A is used as a reactive flame retardant would be 21.6 tonnes/year.

3.1.0.3.1 Leaching loss

Reactive flame retardant applications

Although leaching of residual tetrabromobisphenol-A from polymers is theoretically possible over the service life of products, given that the major use of plastics flame retarded with tetrabromobisphenol-A appears to be in electrical or electronic applications which will not come into contact with water, the actual amount leached from the products over their use lifetime will be very low.

Additive flame retardant applications

Similar to the case with reactive flame retardant applications, although the leaching of tetrabromobisphenol-A from products where it is used as an additive flame retardant is theoretically possible, as most of the plastics are used in electrical or electronic applications they are unlikely to come into contact with water and so the actual amount of tetrabromobisphenol-A leached from products over their use lifetime will be very low.

3.1.0.3.2 Volatile loss

Reactive flame retardant applications

Wolf *et al.* (2000) found that no brominated substances were released from an epoxy resin printed circuit board using a purge and trap screening method. The printed circuit board was known to be flame retarded with tetrabromobisphenol-A. The test used a ground 100 mg sample of the circuit board that was placed in a flask and slowly heated to a temperature of around 100^{o}C over 12 minutes. The volatile products emitted from the polymer were purged under a nitrogen stream (2 l/minute) and collected for analysis. The short duration of this experiment means that it is not possible to deduce anything about the possible volatile emissions of tetrabromobisphenol-A over the lifetime of the polymer product.

de Boer *et al.* (1998) reported that tetrabromobisphenol-A was present at a concentration of 266 mg/kg in the printed circuit board from a television set, but that it could not be detected in air inside or outside the television set.

ERGO (2002) investigated the emissions of tetrabromobisphenol-A from operating computer monitors over an extended time period. Full details of this study are given in the next section.

Tetrabromobisphenol-A was detected in air outside the monitor only in the experiments with monitors that contained tetrabromobisphenol-A as an additive flame retardant in the housing. No tetrabromobisphenol-A was detected in the control experiment using a monitor that contained bromine only in the printed circuit boards (presumed to be reactively flame retarded with tetrabromobisphenol-A) within the monitor.

The above experimental data show that the potential for volatilisation of tetrabromobisphenol-A from plastics where it is used as a reactive flame retardant is very low. The reason for this is that the vast majority of the tetrabromobisphenol-A used is reacted into the polymer matrix and so is not available for release. However, any tetrabromobisphenol-A present as residual monomer could be volatilised from the polymer over extended time periods.

Information on the loss from volatilisation of tetrabromobisphenol-A from use as an additive flame retardant in computer monitors is given in the next Section. It appears relevant to assume that a similar loss could occur for the residual tetrabromobisphenol-A monomer content of polymers where it is used as a reactive flame retardant. Thus a release factor of 8.0×10^{-5}% per year will be assumed for the residual monomer content of reactively flame retarded polymers (see following Section for derivation of this figure).

As discussed above, the amount of residual monomer present in new finished products flame retarded with reactive tetrabromobisphenol-A is estimated to be around 21.6 tonnes/year. Therefore, when considered over a 10 year lifetime, the total amount of tetrabromobisphenol-A present at any one time in the EU in finished products as residual monomer is 216 tonnes. Assuming a yearly emission of 8.0×10^{-5}% as a result of volatilisation, the total EU release of tetrabromobisphenol-A as residual monomer can be estimated at 0.17 kg/year. The regional release would be 10% of this figure, 0.017 kg/year.

Additive flame retardant applications

Wolf *et al.* (2000) investigated the brominated chemicals and other substances that were released from ABS polymer containing tetrabromobisphenol-A using a purge and trap screening method. The test used a ground 100 mg sample of the polymer that was placed in a flask and slowly heated to a temperature of around 100^{o}C over 12 minutes. The volatile products emitted from the polymer were purged under a nitrogen stream (2 l/minute) and collected for analysis. In all, four ABS samples were investigated. None of the samples were found to emit tetrabromobisphenol-A, but one of the samples emitted detectable amounts of dibromophenol. The short duration of this experiment means that it is not possible to deduce anything about the possible volatile emissions of tetrabromobisphenol-A over the lifetime of the polymer product.

Luijk and Govers (1992) investigated the stability of ABS containing 25.7% tetrabromobisphenol-A by thermogravimetry over the temperature range 25 to 725^{o}C. In this experiment, a sample (4 mg) was heated at a rate of 5^{o}C/minute in both an inert argon atmosphere and in an air atmosphere. The results of this analysis showed that the initial stage of thermal degradation of the ABS occurred in the temperature range 350 to 450^{o}C. The results also showed that tetrabromobisphenol-A evaporated from the polymer in the temperature range 200 to 325^{o}C, before the degradation of the polymer matrix occurred. The char formed was burnt in the temperature range 450 to 550^{o}C.

McPherson *et al.* (2004) found tetrabromobisphenol-A to be present in dust from the tops of monitors and central processing units from computers in the United States. Wipe samples were collected from sixteen computers from a variety of public locations across the United States in March 2004. Tetrabromobisphenol-A was found to be present in fifteen out of the sixteen samples collected in amounts corresponding to <0.006 pg/cm^2 to 2.42 pg/cm^2. However, it should be noted that the procedural blank samples contained tetrabromobisphenol-A corresponding to a level of around 0.006-0.071 pg/cm^3. This blank level was similar to or higher than the level found in eleven of the fifteen positive samples, and only four of the wipe samples had levels higher than the blank level (these samples had respectively 0.11 pg/cm^2, 0.089 pg/cm^2, 1.76 pg/cm^2 and 2.42 pg/cm^2).

The above experimental data do not allow an estimate for the release of tetrabromobisphenol-A from polymers during normal use conditions. However, a further study has been undertaken (ERGO, 2002; Herrmann *et al.*, 2003) from which it is possible to estimate a representative emission rate. In this study, the emissions of tetrabromobisphenol-A from two new 15 inch (38 cm) computer monitors which contained tetrabromobisphenol-A as an additive flame retardant in the housing (the levels present were determined to be 12.4% and 12.7% in the two monitor housings respectively) were determined under normal operating conditions over a prolonged time period. A third monitor that contained no additive tetrabromobisphenol-A in the housing (the concentration of tetrabromobisphenol-A in the housing was determined to be <0.1% but the monitor did have bromine in the printed circuit board) was used as a control. The tests were carried out in steel chambers of volume 0.51 m^3. An air exchange rate of 2 chamber volumes per hour was used in the test. This resulted in an air velocity directly above the monitor of 0.11-0.16 m/s. The monitors were operated continuously in the test chambers for several weeks and all energy saving features on the monitors were disabled during the test. During the experiment the air temperature in the chamber above the monitor was between 25.1^{o}C and 26.7^{o}C and the air temperature in the monitor housing was between 41^{o}C and 55^{o}C. At various times during the test, the tetrabromobisphenol-A concentration in the air was determined in two individual samples collected over a 20-24 hour period on two consecutive days (total volume of air sampled at each occasion was ~20 m^3). In addition, wipe samples taken from the inner surfaces of the chamber (temperature 21.6-22.9^{o}C) and also from a "fogging plate" within the chamber (maintained at 10.8^{o}C) were also collected and analysed for tetrabromobisphenol-A. The results of this experiment are shown in **Table 3.2**.

The results show that tetrabromobisphenol-A was emitted from both the monitors where it was used as an additive flame retardant, but could not be detected in the experiment where it was used as a reactive flame retardant only. The agreement between the data obtained for the two monitors where it is used as an additive flame retardant was excellent. The data also appear to show a slight downward trend of the emission with time, although there are relatively few data points available to determine if this is a statistically significant effect.

Table 3.2 Volatile loss from computer monitors under normal use conditions (ERGO, 2002)

Monitor	Tetrabromobisphenol-A content of housing	Total Bromine content of circuit boards in monitor	Measured concentration of tetrabromobisphenol-A in chamber air[a]										
			Day 1	Day 2	Day 9	Day 10	Day 16	Day 17	Day 36	Day 43	Day 71	Day 72	Day 219
Monitor 1	12.4%	Small board - 7.3% Large board - 6.1%	1.2 ng/m^3	1.2 ng/m^3	1.2 ng/m^3	1.1 ng/m^3			0.9 ng/m^3	0.9 ng/m^3	0.8 ng/m^3	0.8 ng/m^3	
Monitor 2	12.7%	Small board - 5.1% Large board - 5.2%	0.9 ng/m^3	2.0 ng/m^3	1.1 ng/m^3	1.2 ng/m^3	1.1 ng/m^3	1.1 ng/m^3					
Control monitor	<0.1%	Small board - 4.8% Medium board - 6.0% Large board - 5.9%	<0.05 ng/m^3	<0.05 ng/m^3	<0.05 ng/m^3	<0.05 ng/m^3	<0.05 ng/m^3	<0.05 ng/m^3					<0.05 ng/m^3

Note: a) The background (blank) concentration in air in the chambers was <0.05 ng/m^3 in all experiments.

Tetrabromobisphenol-A was also found in small amounts in the wipe samples taken at the end of the experiments using the monitors where tetrabromobisphenol-A was used as an additive flame retardant. For monitor 1, the wipe samples taken on day 17 showed tetrabromobisphenol-A levels of <30 $\mu g/m^2$ on the fogging plate and 2.5 $\mu g/m^2$ on the ceiling of the test chamber. For monitor 2, the wipe samples taken on day 140 showed tetrabromobisphenol-A levels of 132 $\mu g/m^2$ on the fogging plate, 6.5 $\mu g/m^2$ on the ceiling of the test chamber and 569 $\mu g/m^2$ on the bottom of the test chamber (this latter value was thought to have been influenced by the presence of polymer particles from the monitor in the sample). The wipe samples from the end of the control experiment generally contained no tetrabromobisphenol-A (<2 $\mu g/m^2$) but one sample from the bottom of the chamber taken on day 140 contained a small amount of tetrabromobisphenol-A (3.4 $\mu g/m^3$).

The final part of the study determined the concentrations of tetrabromobisphenol-A in a typical office (size was 6.6 m × 4.6 m × 2.6 m) in which a newly installed monitor containing tetrabromobisphenol-A in the housing was running under "real life" conditions for several weeks. At various times during the experiment, the air in the office was sampled over a period of one working day (12 hours) according to the German guideline VDI 4300 in which the room is aired for 15 minutes by opening a window on the evening before sampling and the window is then closed before and during the sampling on the next day. In this experiment, the concentration of tetrabromobisphenol-A in the air before running the monitor was <0.05 ng/m^3 and the concentration in air during the time the monitor was running was 2.3 ng/m^3 on day 1, 0.5 ng/m^3 on day 30, 0.1 ng/m^3 on day 68 and 0.2 ng/m^3 on day 117. These results again confirm that only a small amount of tetrabromobisphenol-A is lost from the computer monitor over extended time periods.

From the data reported in **Table 3.2** it is possible to estimate the daily emission rate of tetrabromobisphenol-A from a computer monitor. The typical concentration in the chamber air during this experiment with monitors containing additive tetrabromobisphenol-A was around 1.1 ng/m^3. Since the air replacement volume in the test was around 20 m^3/day, the amount of tetrabromobisphenol-A emitted from the monitor can be estimated at around 22 ng/day.

In addition to this it also needs to be considered that tetrabromobisphenol-A was found on the various internal surfaces of the test chamber. The interpretation of these data is not straightforward and some of the samples (notably one sample from the bottom of the test chamber for monitor 2) may have been influenced by the presence of polymer particles from the monitor. Thus, it is recognised that the following analysis of the data in terms of estimation of the amount of tetrabromobisphenol-A emitted is somewhat speculative and uncertain. However, it is important to consider the amount of tetrabromobisphenol-A on the walls of the test chamber, and in particular the "fogging plate", as these were at a lower temperature than the monitor housing and so some of the tetrabromobisphenol-A emitted from the monitor could have condensed onto the walls rather than passing out of the chamber in the air stream.

The test chambers used had dimensions of 0.8 m × 0.8 m × 0.8 m and so the total internal surface area of the chambers was 3.84 m^2. Using the measured concentrations in the ceiling wipe samples (2.5 $\mu g/m^2$ for monitor 1 after 17 days and 6.5 $\mu g/m^2$ for monitor 2 after 140 days) as being representative for all internal surface areas of the chamber, the total amount of tetrabromobisphenol-A present on the internal chamber walls can be estimated as

around 9.6 μg after 17 days for monitor 1 and 25 μg after 140 days for monitor 2. The surface area of the "fogging plate" used in the experiment was 0.09 m^2. Using the concentrations found in wipe samples on the "fogging plate" (<30 $\mu g/m^2$ after 17 days for monitor 1 and 132 $\mu g/m^2$ after 140 days for monitor 2) the total amount of tetrabromobisphenol-A present on the fogging plate can be estimated as <2.7 μg after 17 days for monitor 1 and 12 μg after 140 days for monitor 2). Thus the total amount of emitted tetrabromobisphenol-A present on the internal surfaces of the test chambers is estimated at approximately 10 μg after 17 days for monitor 1 and 37 μg after 140 days for monitor 2. Assuming the deposition/condensation rate was constant with time during the experiment, the daily amount of tetrabromobisphenol-A deposited on the internal surfaces can be estimated as around 588 ng/day for monitor 1 and 260 ng/day for monitor 2.

Combining the total amount emitted to surface and air, it can be seen that the maximum amount of tetrabromobisphenol-A estimated to be emitted during this experiment is around 610 ng/day.

In order to convert this emission amount to an emission factor that could be applied to other computer equipment, it needs to be related to the mass of tetrabromobisphenol-A present in the monitor housing. The concentration of tetrabromobisphenol-A present in the monitor housing was 12.4-12.7%. The mass of plastic present in the monitor was around 1.9 kg in the casing and 0.35 kg in the base (BSEF, 2002a). On this basis, the mass of tetrabromobisphenol-A present in the monitor would be around 0.28 kg, and so the amount of tetrabromobisphenol-A emitted from the monitor of 610 ng/day can be used to estimate an approximate daily emission factor of 2.2 μg/kg tetrabromobisphenol-A (which is equivalent to 2.2×10^{-7}% per day or 8.0×10^{-5}% per year).

The volatile emissions of brominated flame retardants (including tetrabromobisphenol-A) from a variety of products have been determined by Kemmlein *et al.* (2003a and 2003b) and Hahn *et al.* (2004). The tests were carried out using 0.02 m^3 and 1 m^3 emission test chambers, and in some case 1 litre cells, and were generally carried out for around 93-153 days at 23°C and 50% relative humidity. The air flow rates used in the experiment were 1 m^3/hour in the 1 m^3 chamber, 0.128 m^3/hour in the 0.02 m^3 chamber and 0.022 m^3/hour in the 1 litre cells, giving 1, 5.6 and 22 air exchanges per hour in the three chamber types respectively. The emissions of tetrabromobisphenol-A from two PCs (both including the PC base unit and monitor, and one including also a printer) were determined using the 1 m^3 test chamber. In addition, the emissions of tetrabromobisphenol-A from an old monitor housing and a PC circuit board and casing were determined using the 0.02 m^3 test chamber (the experiments with the circuit board and casing were carried out at 60°C as well as 23°C).

The emission rates for volatile loss found in most experiments were too low to be determined by the method used. However an emission rate of 0.37 ng/m^2/hour was determined for tetrabromobisphenol-A from an old housing (made from ABS with a bromine content of 5.9%) from the data processing field based on the amount of Tetrabromobisphenol-A found on the inside wall of the test chamber.

It is difficult to compare the emission rate obtained by Kemmlein *et al.* (2003a and 2003b) directly with those derived above from the ERGO (2002) study owing to the different temperatures used. The surface area of the sample used in the Kemmlein *et al.* (2003a and 2003b) study appears to have been 0.098 m^2. The actual exposed surface area in the ERGO (2002) study was not given but the size of the monitor used was given as 38 cm. This

measurement refers to the size of the cathode ray tube, measured across its diagonal. If it is assumed that a monitor of this size can effectively by represented by a five faced box with sides of 30 cm length, the total surface area of the outside of the monitor can be estimated to be around 0.45 m^2 (or 0.9 m^2 if the internal surface area is also considered). On this basis, the emission figure of 0.37 ng/m^2/hour measured by Kemmlein *et al.* (2003a and 2003b) would lead to a total emission of the order of 0.17-0.33 ng/hour or 4-8 ng/day for a monitor of this size. This value agrees well with the value of 22 ng/day for the monitor derived from the ERGO (2002) data above, particularly when the higher temperature of the ERGO (2002) study is taken into account.

The emission factor of 8.0×10^{-5}% per year derived from the ERGO (2002) data above will be used in the risk assessment to estimate the likely volatile loss of tetrabromobisphenol-A from electronic equipment in use.

The amount of additive tetrabromobisphenol-A present in new goods in the EU is estimated at 4,000 tonnes/year (see above). Considering a 10 year lifetime, the total amount of tetrabromobisphenol-A present at any one time in the EU as an additive is therefore 40,000 tonnes/year. Assuming a yearly release of 8.0×10^{-5}% due to volatilisation, the total EU release of tetrabromobisphenol-A from additive flame retardant use would be 32 kg/year. The regional release would be 10% of this figure, 3.2 kg/year.

It is recognised that there are some uncertainties inherent in extrapolating the data from ERGO (2002) to an emission factor, particularly in terms of the interpretation of the surface wipe sample data and the possible reduction in emission rate with time (which is not taken into account in the estimated factor). However, it is thought that the methods outlined above can be used to obtain "order of magnitude" estimates for the total amount of tetrabromobisphenol-A volatilised from plastics over their lifetime. The only other method available for estimation of these releases is a more general method (not specific for tetrabromobisphenol-A) that relies on the vapour pressure to effectively scale the known emissions for a reference substance (such as 2-(diethylhexyl) phthalate) to estimate those for the substance under consideration (OECD, 2004). Using this method and a vapour pressure of 6.24×10^{-6} Pa for tetrabromobisphenol-A, a yearly emission factor of 0.051% can be estimated. This factor is applicable to thin films and is substantially higher than the factor derived above. However, it should be born in mind that this emission factor applies to thin films rather than "thicker" plastic housings, and also depends on the vapour pressure. As discussed in Section 1.3.5 it is clear that the vapour pressure of tetrabromobisphenol-A is very low, and probably lower than the value assumed in the calculation. For these reasons this estimated emission factor of 0.051% is not used in the assessment to estimate the emissions of tetrabromobisphenol-A from plastic products.

3.1.0.3.3 Waste remaining in the environment

As well as volatilisation and leaching losses of tetrabromobisphenol-A from products and articles, tetrabromobisphenol-A may also enter into the environment as a result of "waste" from the products themselves during their useful lifetime, and during disposal. Such waste could include erosion/particulate losses of polymeric products during their use, and there is also potential for this type of particulate release when products are dismantled or disposed of at the end of their useful life. This latter source of emission is considered more fully in Section 3.1.0.3.4.

When considering these emissions over the lifetime of a product, products with outdoor uses are most likely to be sources of this type of waste due to weathering and wear. As the vast majority of tetrabromobisphenol-A is used in electrical and electronic equipment, the potential for this type of polymeric release over the lifetime of the product is low.

At present there is no agreed methodology given in the Technical Guidance Document for assessing the risks from this type of waste. However, a methodology was outlined in the draft risk assessment report for di-(2-ethylhexyl)phthalate (DEHP) (ECB, 2000) and a similar approach is taken here. The estimates obtained are open to a high degree of uncertainty.

Details of the approach used previously for other plastics' additives

In the draft DEHP risk assessment, "waste remaining in the environment" was identified to be produced from the following applications of PVC polymers (ECB, 2000).

Car undercoating.
Roofing material.
Coil coating.
Fabric coating.
Cable and wires.
Hoses and profile.
Shoe soles.

The emission factors used for these types of losses in the draft DEHP risk assessment were around 2-10% over the lifetime of the product, with higher factors being applied to articles subject to high wear rates such as car underbodies and shoe soles, and 2% during disposal operations. The assumptions behind the derivation of these factors were not given in the report. These releases were thought to occur mainly to urban/industrial soil. In the draft DEHP assessment it was assumed that 75% of the emissions would be to industrial/urban soil and 0.1% would be to air, with the remainder occurring to surface water (and hence sediment).

Approach taken for tetrabromobisphenol-A

In the absence of any other data, a similar approach to that used for DEHP is used here for tetrabromobisphenol-A as a worst case, using the same emission factors as used for DEHP. Only outdoor applications are considered to contribute significantly to the waste over the lifetime of articles. Where tetrabromobisphenol-A is used as a reactive flame retardant, only the substance present as residual monomer is assumed to be available for release.

The actual amount of tetrabromobisphenol-A present in plastics for outdoor applications is unknown, but, given that the major use is in plastics for electrical and electronic applications, and in particular printed circuit boards, the amount subject to wear and weathering will be very small. For the calculation it will be assumed that a nominal amount of 0.1% of the total amount of tetrabromobisphenol-A used as an additive will be present in plastics where wear and weathering could occur over the products' lifetime. No loss through wear and weathering over the products' lifetime will be assumed for applications where tetrabromobisphenol-A is used as a reactive flame retardant (mainly printed circuit boards).

The approach assumes the following.

- The quantity of articles/products containing tetrabromobisphenol-A disposed of each year is equal to the quantity of new articles/products containing tetrabromobisphenol-A produced or imported each year.
- The emission factors estimate the total release over the entire service life of the product/article (i.e. for low wear articles, 2% of the product is worn away as particles/dust over the lifetime of the product).
- For products where tetrabromobisphenol-A is used as a reactive flame retardant, only the tetrabromobisphenol-A present as residual monomer is available for release.
- The emissions over the service life are likely to be mainly to soil, with smaller amounts going to surface water (and hence sediment) and air. In the absence of any further information, and to be consistent with the approach taken previously with DEHP, it will be assumed that these emissions are split 75% to soil, 24.9% to surface water and 0.1% to air.

In the calculations, the amount of tetrabromobisphenol-A lost by volatilisation over the service life is also taken into account to avoid double counting

There are many uncertainties inherent in these emission estimates, and the approach taken may overestimate the actual releases and hence risk from this source. Further, since this type of waste is essentially polymeric particles containing tetrabromobisphenol-A, it is not known if this is in a form that is "available" in the environment and so would lead to actual exposure of organisms to tetrabromobisphenol-A.

The amount of "waste remaining in the environment" over the lifetime of products can therefore be tentatively estimated as follows.

	Additive use	Reactive use
Amount of tetrabromobisphenol-A present in new products (or as residual monomer) =	4,000 tonnes/year	21.6 tonnes/year
Amount lost through volatilisation over the service life =	0.032 tonnes/year	1.7×10^{-4} tonnes/year
Total amount remaining in products =	4,000 tonnes/year	21.6 tonnes/year
Estimated fraction of products used for outdoor applications =	0.1%	0%
Amount of tetrabromobisphenol-A in products for outdoor applications =	4.00 tonnes/year	0 tonnes/year
Estimated loss as "waste remaining in the environment" over product lifetime =	2%	2%
Emission of tetrabromobisphenol-A as "waste remaining in the environment" over product lifetime =	0.080 tonnes/year	0 tonnes/year
Total amount of tetrabromobisphenol-A remaining in plastics for recycling or disposal =	4,000 tonnes/year	21.6 tonnes/year

The total estimated amount of tetrabromobisphenol-A emitted as "waste remaining in the environment" over the lifetime of products is therefore estimated as 0.080 tonnes/year for the EU as a whole. The regional amount will be taken as 10% of this figure. It will be assumed

that this release is to industrial/urban soil, air and surface water (and hence sediment) as follows:

	Total EU (kg/year)	Region (kg/year)
75% to industrial/urban soil	60	6
0.1% to air	0.08	0.008
24.9% to surface water	20	2

3.1.0.3.4 Releases during recycling and disposal

There are two aspects of recycling that could potentially result in emissions of tetrabromobisphenol-A to the environment. These are (a) the collection, separation and shredding/regrinding of plastic containing tetrabromobisphenol-A from the other components of the products being recycled and (b) the remelting and reshaping of the collected plastic.

Reactive flame retardant applications

Epoxy resins used in printed circuit boards cannot be remelted and so are not normally recycled. The copper fraction of printed circuit boards can be recovered and the environmental impact of this process is considered in Appendix A.

In Germany, regrinding of waste from laminate and printed circuit board production is carried out to a limited extent (Leisewitz *et al.*, 2000). This process separates the waste into metal and plastic fractions. The copper from the metal fraction can be recovered and the plastic fraction (including the flame retardant) can be used as a supplement or filler in other products made from flame retarded resins. No information on the emissions from this process are available. However, particulate emissions from general disposal operations are considered in Section 3.1.0.5.

The potential for emissions of tetrabromobisphenol-A from the collection, separation and regrinding of printed circuit boards (or other plastic articles that contain tetrabromobisphenol-A reacted into the polymer backbone) would appear to be limited owing to the relatively low residual or free tetrabromobisphenol-A content of the polymer (less than 200 ppm (<0.02%) based on the mass of resin.

Additive flame retardant applications

Recycling of plastics containing additive flame retardants is not routinely carried out in the EU. This is likely to change in the future, owing to initiatives such as the WEEE Directive (see Section 2.4). As the remelting and reshaping of thermoplastics is in principle similar to their production, then the emissions of tetrabromobisphenol-A from this stage of the recycling process will in principle be similar to those during the conversion stage identified in Section 3.1.0.2.3.

The other aspect of recycling where emissions could occur is in the collection, separation and shredding/regrinding of plastics present in waste electrical and electronic equipment. Tetrabromobisphenol-A has been measured in the air (see Section 3.1.3.2) and in the blood of workers (see Section 3.1.4.2) at such facilities.

A study of the mass-flow of tetrabromobisphenol-A at an electronic equipment recycling facility in Japan has been made (Tamade *et al.*, 2002). The facility was built in 2000 and had a throughput of 75 tonnes over ten and a half hours. The recycling facility had an adjoining incineration plant with a capacity of 150 tonnes per 24 hours. The incineration plant burnt residues and refuse derived fuel (RDF) from the recycling facility, and was also using the exhaust from the recycling facility as its combustion air.

As part of the study, the concentration of tetrabromobisphenol-A present in TV back covers, dust collected from inside the TVs and dust from the air conditioning units within the recycling facility was determined. The mean level of tetrabromobisphenol-A present in the back covers of TVs was 8.1 g/kg, the mean level found in dust from inside the TVs was 17 mg/kg and the mean level in dust from the air conditioning unit was 0.15 mg/kg. The amount of tetrabromobisphenol-A present in the TV back casing and dust from inside the TVs was found to be increase as the age of the TVs decreased (the mean level found in the back casing was 0.011 g/kg, 3.4 g/kg and 21 g/kg in TVs from the second half of the 1980's, first half of the 1990's and second half of the 1990's respectively; the corresponding levels in dust from inside the TVs were 4.1 mg/kg, 11 mg/kg and 37 mg/kg respectively. This implies an increasing usage of tetrabromobisphenol-A in modern TVs over those produced in the late 1980's and early 1990's.

The mass balance determined during the recycling process indicated the exhaust from the molder contained higher amounts of tetrabromobisphenol-A than the exhaust from the rough crusher and fine crusher. The tetrabromobisphenol-A input into the facility was estimated to be 1.1 kg/hour and the total present in exhausts from the various units in the facility was around 22.8 mg/hour (fed to the incinerator) plus around 0.13 mg/hour fed directly to the atmosphere. The mass balance also showed that the amount of tetrabromobisphenol-A leaving the incinerator (as bottom ash, flue gas and fly ash) was around 1/500 to 1/9,000 of that entering the incinerator.

In summary, the total air emission from this plant was 22.9 mg/hour (183 mg/day assuming an eight-hour day) prior to incineration and the total emission (to air, in bottom ash, in flue gas and in fly ash) was around 0.13-0.18 mg/hour (1.0-1.4 mg/day assuming an eight-hour day) after passing through the incinerator. These data will be considered later to estimate the local PECs in air and soil (through atmospheric deposition) from such a plant.

It is also possible to estimate the total regional and continental emissions from this processes if the following (large number of) assumptions are made. As the tetrabromobisphenol-A input into the recycling plant at the time of the measurements was around 1.1 kg/hour, it is possible to estimate an emission factor of 20.8 mg/kg for a plant without incineration and up to 0.16 mg/kg for a plant with incineration. At present the total amount of plastic containing tetrabromobisphenol-A recycled in the EU is unknown but is expected to be small. However, the WEEE Directive (see Section 2.4) sets a recycling target of around 65% for IT and communications equipment and so it is possible that larger amounts of plastic containing tetrabromobisphenol-A could be recycled in the future. It should be noted that "recycling" in the WEEE Directive covers re-use and other recycling options as well as recycling in the sense being discussed here (collection, separation and shredding/regrinding, with subsequent remelting and reshaping). In order to obtain an "order of magnitude" estimate of the possible future emissions of tetrabromobisphenol-A from this source, the following assumptions and calculations have been made.

- The quantity of articles/products containing tetrabromobisphenol-A disposed of or recycled each year is equal to the quantity of new articles/products containing tetrabromobisphenol-A produced or imported each year. This would give an estimate of 4,000 tonnes/year for tetrabromobisphenol-A as an additive flame retardant in plastic products.
- The recycling rate is a around 65%. This would mean that around 2,600 tonnes/year of tetrabromobisphenol-A additive in articles would be subject to recycling.

Using the figure of 2,600 tonnes/year as the estimate for the amount of tetrabromobisphenol-A that may be subject to recycling in the future, the total emission (mainly to air) from recycling plants could be estimated as 0.42-54.8 kg/year using the emission factors derived above.

Another study of the emissions from an electronics recycling plant in Japan has been carried out by Takigami *et al.* (2006). Details of the study are currently only available as an extended abstract. Air monitoring for tetrabromobisphenol-A was carried out at a location where dismantling and shredding of television sets was carried out. Approximately 600 television sets were dismantled at the plant each day, and the plant operated for 250 days per year. Part-way through the study, further emission control measures were introduced into the dismantling plant to reduce particulate/dust emissions, and the study considered the situation both before and after the introduction of the control measures. The control measures introduced included the use of a vacuum cleaner to collect the dust inside the televisions during removal of the backs of the televisions, and use of a portable dust collector. The air sampling was carried out during January to February 2005. The concentration of tetrabromobisphenol-A in air of the dismantling hall both before and after introduction of the new emission control measures was around 50 ng/m^3 (value read from graph). The concentration in air during the shredding processes were found to be one or two orders of magnitude higher than found in the dismantling hall. However, the concentration in treated air after dust collection was reduced markedly (by four or five orders of magnitude; the actual concentrations found are not reported in the paper).

It should be noted that the representativeness of these data with regards to the current situation in the EU is unknown and so the actual emissions and PECs calculated from these data should be treated as indicative. It should also be noted that, as the emissions are likely to be particulate in nature there may be potential for dusts to settle in the facility and be subsequently washed into the waste water stream. It is not currently possible to estimate the significance of this source.

Ultimate disposal

Most tetrabromobisphenol-A is used in plastics that are used in electrical and electronic equipment. The amounts of waste plastics generated from electrical and electronic equipment have been estimated for several EU countries in the late 1990s (Menad *et al.*, 1998) and are shown in **Table 3.3**. These show that a large amount of plastic waste is generated from this source in the EU.

Plastics are thought to make up around 15-30% of the total scrap from electronic equipment, with the remainder consisting of 40-50% glass, and 20-30% metals (Menad *et al.*, 1998). It was estimated that a personal computer may contain 1.7 kg of total flame retardants, with

70% of this in the cabinet and the remainder being in the printed circuit board. Similarly, it was estimated that the plastic cover of a television may contain 2 kg of flame retardant.

Menad *et al.* (1998) reported figures from The Association of Plastics Manufacturers in Europe which indicated that around 200,000 tonnes of plastics used in electrical and electronic equipment contain flame retardants and this corresponded to around 17% of the plastics consumed in this area.

Table 3.3 Estimated amounts of plastic wastes from disposal of electrical and electronic equipment

Country	Estimated amount (tonnes/year)
Austria	15,000
Belgium/Luxembourg	25,000
Denmark	25,000
Finland	9,000
France	98,000
Germany	127,000
Greece	4,000
Ireland	2,000
Italy	75,000
Netherlands	29,000
Norway	3,000
Portugal	6,000
Spain	52,000
Sweden	13,000
United Kingdom	93,000
Total EU	576,000

Solid waste is also generated during the production of printed circuit boards (Danish Environmental Protection Agency, 1999). It has been estimated that around 15-25% of the laminate produced is disposed of to solid waste as off-cuts, drillings etc.

It has been estimated that around 70,000 tonnes of printed circuit board material are scrapped each year in Germany. Of this, approximately 90% of the total resin is incinerated or deposited in landfills.

Peltola (2002) has recently determined the concentration of tetrabromobisphenol-A in bottom ash from two municipal incinerators in Finland. The detection limit of the method use was 0.2-0.3 μg/kg and tetrabromobisphenol-A was not detected in either sample.

The plastics containing tetrabromobisphenol-A will usually be disposed of either to landfill or by incineration. It is expected that the emissions of tetrabromobisphenol-A from incineration processes will be near zero, although the question of formation of brominated dibenzo-*p*-dioxins and dibenzofurans has been raised as a potential problem (this is covered in more detail in Section 2.3 and Appendix A). When plastic containing tetrabromobisphenol-A, either as an additive or as residual monomer, is disposed of to

landfill, in theory it could volatilise to the atmosphere or leach out of the plastic into groundwater.

Using the assumption that the amount of plastic containing tetrabromobisphenol-A produced each year replaces that disposed of each year then the total amount of tetrabromobisphenol-A disposed of each year as an additive or residual monomer in plastic products is currently up to around 4,022 tonnes/year (although this may change in the future owing to the implementation of the WEEE Directive; see Section 2.4).

A substance flow analysis of brominated flame retardants (including tetrabromobisphenol-A (this was defined in the study as tetrabrombisphenol-A and its derivatives)) in waste TV sets has recently been carried out in Japan (Tasaki *et al.*, 2004). The study investigated the effects on the amounts of the flame retardants that would likely be disposed of in television sets in future years. In order to determine the base-line situation the study investigated the amounts and types of flame retardants that were present in television casings (both front and rear covers). Decabromodiphenyl ether was found to have been first used in the late 1980's for the rear covers of TVs, and in front covers starting from around 1993-1996, but that there was a move in the late 1990s from this flame retardant to tetrabromobisphenol-A-based flame retardants (including its derivatives). Little or no substitution with non-brominated flame retardants was seen (as of 2002). Based on these findings, three scenarios were constructed: 1) business as usual scenario, where the composition of TV sets found in the late 1990s would continue into the future; 2) non-polybrominated diphenyl ether scenario, where the substitution of decabromodiphenyl ether with tetrabromobisphenol-A-based flame retardant would continued, with total replacement by 2001; and 3) non-brominated flame retardant scenario, where from 2003 the brominated flame retardants would be progressively substituted by non-brominated flame retardants, with complete substitution by 2006. The average lifetime of a TV set in Japan used in the study was 9.8 years based on an analysis of data from survey results of the number of TVs remaining in households. The results of the analysis were determined in terms of the amount of total bromine present in waste TVs. For the business as usual scenario, the amounts of bromine present in waste TVs was estimated to be 246 tonnes in 1995 and this was predicted to rise to 1,204 tonnes in 2000, 2,598 tonnes in 2005, 3,620 tonnes in 2010, 4,091 tonnes in 2015 and 4,463 tonnes in 2020. Tetrabromobisphenol-A-based compounds were estimated to account for 2.8% of the total bromine in 1995, rising to 3.2% in 2000, 12% in 2010 and 13% in 2020. An important driving force behind the predicted increases was the current increase in size of TV sets. For the non-polybrominated diphenyl ether scenario, the amount of decabromodiphenyl ether present in waste TV sets was predicted to peak in 2005 and the amount of tetrabromobisphenol-A-based compounds increased after this time (the amount of decabromodiphenyl ether in waste was predicted to become lower than the amount of tetrabromobisphenol-A-based compounds in 2008). In the non-brominated flame retardant scenario, the amount of bromine in waste TVs was predicted to peak in 2009 and then decrease markedly (falling to around 10% of its 2000 level by 2010). The amount of tetrabromobisphenol-A-based compounds in waste TVs was predicted to peak around 2011 (approximately 1,700 tonnes as bromine).

Morf *et al.* (2005) reported the results of a substance flow analysis of tetrabromobisphenol-A in recycled waste electrical and electronic equipment in Switzerland. Based on earlier work it was estimated that around 66% of all tetrabromobisphenol-A imported into Switzerland was disposed of through waste electrical and electronic equipment in the late 1990s. The average concentration of tetrabromobisphenol-A as an additive in small sized waste electrical and

electronic equipment (consisting of household appliances, office and communication appliances (such as personal computers, monitors, printers, telephones, fax and photocopy machines), entertainment electronics (such as television sets, videos, camcorders, radios etc.) and other small sized electrical equipment at a modern recycling plant was found to be 1,420 mg/kg in 2003. The tetrabromobisphenol-A concentration in separately analysed fractions was found to be around 5 mg/kg in copper cable scrap, 43 mg/kg in printed circuit boards, 80 mg/kg in wood television housings, 23,000 mg/kg in plastic television/personal computer housings, and 7,300 mg/kg in television rear covers.

The study also determined the mass transfer coefficient for tetrabromobisphenol-A into the various output fractions from the plant. The total input of tetrabromobisphenol-A into the plant during the three day study period was estimated to be around 326 kg. The mass transfer coefficients were estimated as follows for the various output fractions from the recycling process: 0.032 to fine particulates, 6×10^{-5} to copper cables, 5×10^{-4} to printed circuit boards, 0.35 to plastics and wooded castings, 0.57 to fine-graded plastics fractions and 0.047 to fine-graded metal fractions. The study did not determine quantitatively the fate of these output fractions. At the plant in question, the metals in iron and metal scrap, and printed circuit boards, were recovered in ferrous and non-ferrous metal processes with state-of-the art air pollution control systems. The plastics fractions were treated in state-of-the-art municipal waste incineration plants.

An estimate for the amount of tetrabromobisphenol-A released annually to the environment in Switzerland has been made in a further study by Morf *et al.* (2006). Details of the study are currently available as an extended abstract only. The estimate was based on a substance-flow analysis for the late 1990s. At that time, around 1,130 tonnes of tetrabromobisphenol-A-based flame retardants were imported into Switzerland in semi-finished or finished products. Of this amount, 570 tonnes were consumed in Switzerland, with the remainder being re-exported. Of the 570 tonnes consumed, almost all was in electrical and electronic equipment (83% in computers and 11% in consumer electronic equipment). The amount of tetrabromobisphenol-A present in consumed products at steady state was estimated to be 5,600 tonnes/year. The estimated amount of tetrabromobisphenol-A in waste products was estimated to be 400 tonnes/year, and it was thought that around 68% of this was destroyed by incineration, with about 21% being exported and around 11% disposed of to landfill. It was estimated that around 0.3 tonnes of tetrabromobisphenol-A was emitted into the environment each year from products in use (diffuse sources). It should be noted that this study makes no distinction between additive and reactive use of tetrabromobisphenol-A and so the figures could refer to the amount of tetrabromobisphenol-A bound into the polymer backbone.

A study of the levels of tetrabromobisphenol-A in automobile shredder residue has been carried out by Sakai *et al.* (2006). The results are currently only available in an extended abstract. In Japan, around 4 million cars are disposed of each year. Around 75-80% of the end-of-life vehicle is recycled but the remainder (known as automobile shredder residue or ASR) is disposed of to landfill. In this study, around 15 tonnes of ASR was collected from a recycling company and a subsample of 107 kg was taken for analysis. The ASR sample was sieved (5-mm) and manually separated into individual components such as plastics, rubber, polyurethane foam, textile, wire, metals etc. Each component was weighed, crushed into <1 mm particles, and then remixed based on the original percentage composition. This remixed sample was then crushed into <0.25 mm particles for use in the analysis. The concentration of tetrabromobisphenol-A present in the ASR was 15 mg/kg.

No experiments have been carried out on the leachability of tetrabromobisphenol-A from polymers in landfills, but given that the substance is reasonably soluble in water (solubility ~0.063-2.34 mg/l) leaching over extended timeperiods is a possibility. This is supported by the experiments of Sellström and Jansson (1995) reported in Section 3.1.0.3.1, that demonstrate that tetrabromobisphenol-A could be extracted from printed circuit boards under laboratory conditions using a strongly alkaline (0.01 M NaOH) solution.

Several studies have investigated the presence of tetrabromobisphenol-A in landfill leachate. The results from these studies are reported in Section 3.1.1.2.1. Tetrabromobisphenol-A has been found in some, but not all leachate samples at low levels. In some studies the tetrabromobisphenol-A found was associated with the particulate phase.

If leaching of tetrabromobisphenol-A from plastic does occur in landfills it is likely to strongly adsorb onto soil and this will significantly lower its potential for reaching ground water. In addition, the substance has been shown to degrade under anaerobic conditions, which should again reduce its potential for reaching groundwater. Similarly the low vapour pressure of the substance would limit its volatility from landfills.

It is not currently possible to quantify the actual releases of tetrabromobisphenol-A from landfills but, although such releases have been shown to occur, they are generally expected to be low.

3.1.0.4 Other sources of release

3.1.0.4.1 Use of tetrabromobisphenol-A derivatives

The free or unreacted tetrabromobisphenol-A content of the flame retardant derivatives made from tetrabromobisphenol-A is reported to be <50 ppm (<0.005% by weight) (Industry Consortium, 2003). Therefore the environmental release of tetrabromobisphenol-A during the use of its derivatives is considered to be negligible.

3.1.0.4.2 Paper recycling

Kuch *et al.* (2001) (as reported in Metzger and Kuch (2003)) indicated that tetrabromobisphenol-A has been found in toilet paper at concentrations up to 25 µg/kg dry weight. They found that the level in recycled paper was generally higher than in non-recycled paper and postulated that the contamination may have arisen from the inks used for printing or from special flame-protected papers used for recycling.

Industry (BSEF, 2002b) have indicated that minor amounts of tetrabromobisphenol-A may have been used in the past in the production of thermal papers and that, if such papers entered the recycling process for normal paper, the final recycled paper may contain small amounts of tetrabromobisphenol-A. It is understood that tetrabromobisphenol-A is no longer used in this application.

3.1.0.4.3 Recycled aluminium production

Sinkkonen *et al.* (2003a) investigated the behaviour of tetrabromobisphenol-A during recycled aluminium production. An earlier screening study (Sinkkonen *et al.*, 2003b) had indicated that brominated flame retardants were present in samples of scrap materials used in

recycled aluminium smelters. The samples included plastics used in electronic equipment, filter dust from an electronics crusher, cyclone dust from an electronics crusher and light fluff from a car chopper. Tetrabromobisphenol-A was found to be present in some of the scrap samples. Sinkkonen *et al.* (2003a) analysed the levels of tetrabromobisphenol-A present in the ash from a recycled aluminium smelter in Finland. The smelter used shredded mixed metal scrap (from old cars and electronic equipment etc.) and in all four ash samples from various parts of the process were analysed (collected from the respective flue gas filter units). Several halogenated bisphenol-derivatives were identified in some of the samples and it was thought that these were possibly formed from the degradation of tetrabromobisphenol-A during the smelting process. Tetrabromobisphenol-A itself was also found in some ash samples at low levels (388 µg/kg).

3.1.0.4.4 Formation in the environment

Peterman *et al.* (2000), in a brief report available in abstract form only, indicated that tetrabromobisphenol-A could be formed from the bromination of bisphenol-A in drinking water. The report suggested that this may occur if drinking water was stored in polycarbonate containers which had been sanitised with bromine and ozone. In terms of a source of tetrabromobisphenol-A in the environment, this can be considered to be negligible as water supplies are not routinely brominated.

Several derivatives of tetrabromobisphenol-A are used as flame retardants (see Section 2.2.2.3). Some of these are simple ether derivatives of tetrabromobisphenol-A, for example the bis(allyl ether), the bis(2-hydroxyethyl ether) and the bis(2,3-dibromopropyl ether), and would appear to have some potential to re-form tetrabromobisphenol-A through biodegradation processes in the environment. These types of reactions do not appear to have been studied for these flame retardants, and so the significance of these processes in terms of the formation of tetrabromobisphenol-A in the environment cannot be assessed.

3.1.0.5 Summary of environmental releases of tetrabromobisphenol-A

The releases to the environment estimated over the whole life-cycle of tetrabromobisphenol-A are summarised in **Table 3.4**.

Table 3.4 Summary of estimated environmental release for tetrabromobisphenol-A

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	1,120	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			

Table 3.4 continued overleaf.

Table 3.4 continued.

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
"Waste remaining in the environment"	Particulate loss over lifetime of products				0.008	0	2	6	0.072	0	18	54
Release during recycling and disposal	Collection, separations and shredding/regrinding of plastic[g]	1.0×10^{-6}-1.83×10^{-4}		300	0.042-5.48				0.38-49.3			
Use of tetrabromobisphenol-A derivatives as flame retardants					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

Note: a) Continental emissions = total EU emissions - regional emissions.
b) A 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 as no sites are 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.

3.1.0.6 Degradation

It should be noted in this (and the following) sections that many of the tests have been carried out using non-standard (i.e. non-OECD) test guidelines. Such studies are considered as valid with restrictions. Where the study follows closely a specific guideline, this is noted in the text.

3.1.0.6.1 Abiotic degradation

Indirect photooxidation

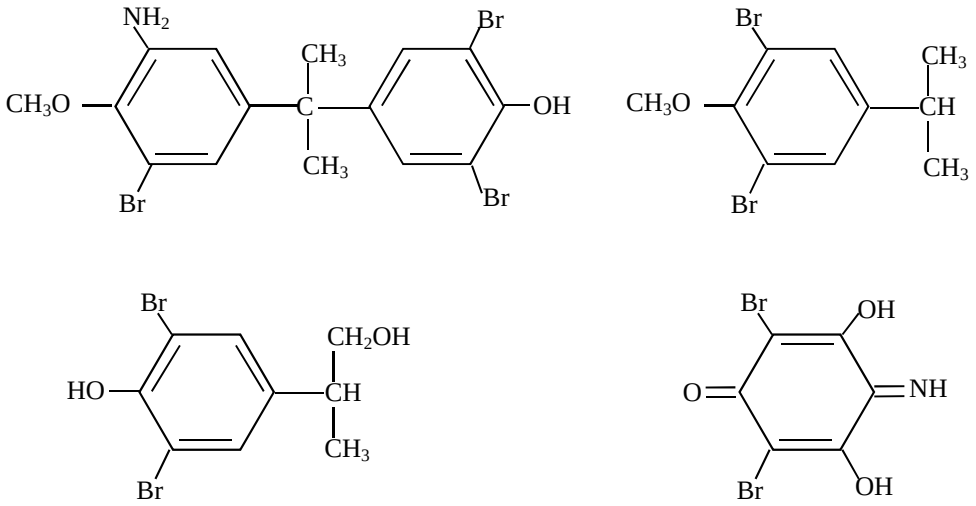
A rate constant for the reaction of tetrabromobisphenol-A with atmospheric hydroxyl radicals has been estimated as 2.96×10^{-12} cm^3 $molecule^{-1}$ s^{-1} using the Syracuse Research Corporation AOP (version 1.86) estimation program. This program estimates the rate constant from chemical structure using the group contribution method recommended in the Technical Guidance Document. Assuming an atmospheric concentration of hydroxyl radicals of 5×10^5 molecules/cm^3, an atmospheric half-life of around 130 hours can be estimated.

There is no information available on the possible atmospheric degradation products and so it is not possible to assess the risks that these might present to the atmosphere.

Direct photodegradation

The photodegradation of ^{14}C-labelled tetrabromobisphenol-A (radiochemical purity >98%) adsorbed onto silica gel has been studied using UV-light of 254 nm wavelength (Yu, 1979). The test substance was added to the surface of a silica gel plate (thickness 0.25 mm) dissolved in acetone and then, once the acetone had evaporated, was exposed to the UV-light for various time periods. The identities of the products formed were determined by thin layer chromatography (TLC) or by mass spectrometry. Tetrabromobisphenol-A was found to degrade rapidly and the degradation curve was biphasic. The initial decrease in concentration was rapid, with a half-life of 0.12 days. After around six hours of exposure the rate of degradation appeared to decrease and the half-life for the second phase was estimated to be 1.1 days. At least eight degradation products were found by TLC, and four of these products were identified by mass spectrometry. The identified products are shown in **Figure 3.1**. All degradation products were transitory, reaching their maximum level after about one day of irradiation and then decreasing upon further irradiation. As UV-radiation was used in these experiments, the significance of the results to the behaviour of tetrabromobisphenol-A in the environment is uncertain.

Figure 3.1 Products formed during UV-irradiation of tetrabromobisphenol-A



The calculated half-life for degradation of tetrabromobisphenol-A by UV-light in water was reported to be 10.2 days in spring, 6.6 days in summer, 25.9 days in autumn and 80.7 days in winter (WHO, 1995). These estimates were based on an unpublished report (Bayer, 1990) and, since no further details are available, the reliability of these estimates cannot be determined.

Tetrabromobisphenol-A has been reported to be easily degradable using UV light (Sjödin, 2000). In the solid state, 2,4,6-tribromophenol was reported to be one of the major photodegradation products. In water, the photodegradation was reported to be strongly dependent on pH and the main products formed were isopropyl-substituted phenol products. Few other details of these studies are currently available. As this experiment used UV-radiation, the significance of the findings to the behaviour of tetrabromobisphenol-A in the environment is unclear.

Eriksson and Jacobsson (1998) found that tetrabromobisphenol-A was photodegraded when adsorbed onto the surface of quartz cuvettes. The experiment used UV-light of wavelength >290 nm both in the absence of, and in the presence of, hydroxyl radicals. Tetrabromobisphenol-A was found to degrade completely within 5-6 days exposure. The main breakdown product found was 2,4,5-tribromophenol, which also degraded under the experimental conditions used. A number of other products (at least 20) were also formed and some of these were tentatively identified as di- and tribromobisphenol-A, dibromophenol, 2,6-dibromo-4-(bromoisopropylene)phenol, 2,6-dibromo-4-(dibromoisopropylene)phenol and 2,6-dibromo-1,4-hydroxybenzene.

A further photolysis experiment with tetrabromobisphenol-A has recently been carried out by Eriksson *et al.* (2004). In this study aqueous solutions of tetrabromobisphenol-A were exposed to simulated solar light (a 20 W fluorescent tube; λ >290 nm) in glass vessels at various pHs (in the range 5.5 to 11). The half-lives of tetrabromobisphenol-A under the conditions (initial concentration 5 µmol/l) used were around 16 minutes at pH 10, 17 minutes at pH 9, 18 minutes at pH 8.1 and pH 7.9, 24 minutes at pH 7.4, 30 minutes at pH 7.1, 41 minutes at pH 6.9, 99 minutes at pH 6.1 and 350 minutes at pH 5.5. The major degradation products found in this study were 4-hydroxyl-2,6-dibromophenol, 4-isopropyl-2,6-

dibromophenol, 4-isopropylene-2,6-dibromophenol, 4-isopropyl-2,6-dibromophenol and 4-(2-hydroxyisopropyl)-2,6-dibromophenol. The same results are also reported by Cantillana *et al.* (2004) but here it is reported that the initial concentration of tetrabromobisphenol-A was <0.1 µmol/l.

Debrauwer *et al.* (2005) have also investigated the products from photolysis of tetrabromobisphenol-A. In this study a 0.5 g/l solution of tetrabromobisphenol-A in acetonitrile was exposed to solar light for five days. The main polar degradation products formed included 2,6-dibromophenol, 3-hydroxy-4-isopropylene-2,6-dibromophenol, and tribromophenol. Only trace amounts of debrominated derivatives of tetrabromobisphenol-A were found (e.g. tribromobisphenol-A, dibromobisphenol-A, bromobisphenol-A and bisphenol-A). A number of other, high molecular weight degradation products were also evident including 2,2'-dihydroxy-3,3'-dibromo-5,5'-di(3,5-dibromo-4-hydroxycumyl)-biphenyl and 2,6-dibromo-4-(3',5'-dibromo-4'-hydroxycumyl)-1-(3'',5''-dibromo-4''-hydroxy-phenoxy)-benzene. These high molecular weight degradation products were thought to be formed as a result of coupling of several tetrabromobisphenol-A and/or 2,6-dibromophenol units

Hydrolysis

No information is available on the hydrolysis of tetrabromobisphenol-A under environmentally relevant conditions. Based on its chemical structure, tetrabromobisphenol-A would not be expected to hydrolyse rapidly in the environment.

Summary of abiotic degradation

Tetrabromobisphenol-A is likely to react readily with atmospheric hydroxyl radicals with a half-life of around 130 hours. The available information indicates that tetrabromobisphenol-A is also susceptible to direct photodegradation using UV-radiation (e.g. 254 nm and >290 nm), leading to a variety of products, but the significance of the process in the environment is not clear. Hydrolysis of tetrabromobisphenol-A is not expected to be a significant process in the environment.

Table 3.5 outlines the reaction rate constants for these processes that will be used later in the environmental modelling for tetrabromobisphenol-A.

Table 3.5 Summary of abiotic reaction rate constants for tetrabromobisphenol-A

Process	Reaction rate constant	Estimated half-life
Atmospheric photooxidation by hydroxyl radicals	2.96×10^{-12} cm^3 $molecule^{-1}$ s^{-1}	130 hours
Photodegradation in air, water, sediment and soil	0	
Hydrolysis	0	

3.1.0.6.2 Biodegradation

Aerobic conditions

Standard ready and inherent biodegradation tests

Tetrabromobisphenol-A has been tested in a MITI ready biodegradation test (CITI, 1992). A mixed inoculum derived from sewage sludge, surface water and sediment samples from ten locations in Japan was used. The concentration of the substance used was 100 mg/l and this was incubated with 30 mg/l activated sludge suspended solids for 14 days at 25^{o}C. The biodegradation was monitored both by biochemical oxygen demand (BOD) and parent compound analysis by a gas chromatographic method. No biodegradation was found (average percentage biodegradation was 0% based on BOD and 0.7% based on parent compound analysis). Therefore the substance was not readily biodegradable in this test. Few other test details are available for this study and so it is not possible to fully validate the test.

Soil systems

The biodegradation of tetrabromobisphenol-A under aerobic conditions has been studied in three different natural soil types (Springborn Life Sciences, 1989e). The substance tested was ^{14}C-labelled tetrabromobisphenol-A that was mixed with unlabelled tetrabromobisphenol-A (purity 99.06%). The soils used in the study were a sandy loam, clay loam and a silty loam. The tests were carried out in 250 ml flasks with each flask containing 50 g dry weight of soil. The test substance was added to the soil as a solution in acetone to give a final concentration of 10 mg/kg dry weight. The soils in the test had a moisture content ~40% of their field capacity. The flasks were incubated in the dark at 21.5^{o}C for 64 days. No control vessels appear to have been run.

At the end of the incubation, the soil and gaseous traps (CO_2 and volatile compounds) were analysed for the presence of radioactivity. The results are shown in **Table 3.6**. The soil samples were also extracted by Soxhlet extraction with acetone for sixteen hours followed by thin layer chromatography (TLC) analysis, using a 7:3 mixture of hexane:ethyl acetate as solvent, in order to identify any metabolites formed. The result of this analysis is shown in **Table 3.7**.

As can be seen from **Table 3.6**, the recovery of radioactivity from the study was generally good (~80%), except for the silty loam soil (~60%) and most of the radioactivity was present in the solid phase. The radioactivity in the volatile traps was almost exclusively CO_2, but the small amount detected (≤5.5%) indicated that little or no mineralisation had occurred during the test

Table 3.6 Aerobic degradation of ^{14}C-labelled tetrabromobisphenol-A in three soil types after 64 days

Soil type	Soil properties							Distribution of recovered radioactivity (as % of that initially applied			
	CEC[a]	O.C.[b]	pH	FMC[c]	Sand	Silt	Clay	Rep.[d]	Soil	Volatile traps/CO_2	Total
Sandy loam	10.8	4.4%	7.0	74.8%	83%	13%	4%	1	79.0%	1.4%	80.4%
								2	60.4%	1.7%	62.1%
								3	89.1%	2.7%	91.8%
								4	75.9%	3.6%	79.5%
								Mean	76.1%	2.4%	78.5%
Silty loam	6.0	0.8%	6.2	43.9%	16%	58%	26%	1	62.4%	3.7%	66.1%
								2	50.0%	4.3%	54.3%
								3	54.2%	4.6%	58.8%
								4	54.1%	5.1%	59.2%
								Mean	55.2%	4.4%	59.6%
Clay loam	19.6	1.8%	7.6	75.9%	43%	24%	33%	1	65.6%	5.9%	71.5%
								2	69.4%	5.4%	74.8%
								3	95.3%	5.4%	100.7%
								4	72.3%	5.3%	77.6%
								Mean	75.7%	5.5	81.2%

Notes: a) Cation exchange capacity (meq/100 g).
b) Organic carbon concentration.
c) Field moisture capacity.
d) Replicate experiments.

Table 3.7 Products from aerobic degradation of ^{14}C-labelled tetrabromobisphenol-A after 64 days

Identity	Amount (as % of radioactivity recovered from TLC plates after Soxhlet extraction of soil)		
	Sandy loam	Silty loam	Clay soil
Polar	3.5-12.3%	27.4-28.3%	18.0-18.7%
Low Rf[a]	1.8-3.0%	19-22.0%	13.3-15.1%
Unknown A	0%	0-7%	0%
Unknown B	4.2--6.5%	7.4-8.2%	11.0%
Tetrabromobisphenol-A	74.3-81.9%	35.9-40.1%	41.1-43.2%
Unknown C	5.7-6.2%%	1.5-3.1%	8.8-16.2%
Dimethyl and diethyl tetrabromobisphenol-A derivatives	0-0.5%	0%	0.4-1.3%
High Rf[b]	0-0.2%	0%	0-1.9%

Notes: a) A low Rf indicates products that are more polar than tetrabromobisphenol-A in TLC analysis.
b) A high Rf indicates products that are less polar than the tetrabromobisphenol-A dimethyl and diethyl derivatives in TLC analysis.

For the TLC analysis, the extraction method used recovered around 52.4-86.1% of the radioactivity from the sandy loam soil, around 45.5-48.6% of the radioactivity from the silty loam soil and only 10.1-18.6% of the radioactivity from the clay loam soil. Thus a substantial fraction of the total radioactivity, and hence metabolites, was not analysed with the method used. The results of the TLC analysis (**Table 3.7**) indicate that after 64 days incubation, ~74.3-81.9% of the extracted radiolabel was unchanged tetrabromobisphenol-A in the sandy loam soil, ~35.9-40.1% of the extracted radiolabel was unchanged tetrabromobisphenol-A in the silty loam soil and ~41.1-43.2% of the extracted radiolabel was was unchanged tetrabromobisphenol-A in the clay loam soil. Two main degradation products were found (designated unknown B and unknown C), along with small amounts of a third product (unknown A) in some replicates, but the identities of these products was not determined in the study. The TLC analysis indicated that unknown A and unknown B were more polar than tetrabromobisphenol-A, whereas unknown C appeared to be less polar than tetrabromobisphenol-A. Two expected metabolites of tetrabromobisphenol-A (O,O'dimethyltetrabromobishphenol-A and O,O'-diethyltetrabromobisphenol-A) were also analysed for in the TLC method used, but these were found only in trace amounts. A substantial fraction of the radioactivity was also present as highly polar metabolites, which were not separated by the TLC method used (they remained at the origin of the TLC plate).

A further study investigating the degradation of tetrabromobisphenol-A in soil under both aerobic and anaerobic conditions is available (Wildlife International, 2006c; the results for the anaerobic part of the study are given later in the Section on anaerobic degradation). The test method was based on the OECD 307 test guideline. The substance tested in this study was uniformly ring labelled ^{14}C-tetrabromobisphenol-A (radiochemical purity 99.6%). Four soils were used in the study. The relevant properties of the soils are summarised in **Table 3.8**.

The soils were stored under refrigerated conditions until required. At this time, the soils were adjusted to the moisture contents at $^{1}/_{3}$ bar indicated in **Table 3.8**. and incubated under aerobic conditions (head space continuously purged with air) for seven days prior to the start of the test.

The test chambers used were 500 ml wide-mouth amber glass bottles containing the equivalent of 100 g of dry soil. The test was started by adding tetrabromobisphenol-A (as a solution in ethanol) to the surface of the soil. The initial nominal concentration of tetrabromobisphenol-A was 50 µg/kg dry soil. The amount of ethanol added to the soil was around 50 µl/100 g dry soil. Control soils, that just received the equivalent amount of ethanol, were also prepared. All incubations were carried out in the dark at approximately 20°C. For the aerobic part of the test, the chambers were incubated under aerobic conditions for up to six months.

Table 3.8 Soils used to investigate the aerobic (and anaerobic) degradation of tetrabromobisphenol-A (Wildlife International, 2006c)

Soil parameter		Soil properties			
		a	b	c	d
Designation		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
Composition		88.1% sand 1.0% silt 10.9% clay	61.9% sand 15.5% silt 22.6% clay	9.5% sand 63.9% silt 26.6% clay	14.9% sand 51.2% silt 33.9% clay
pH		7.0	6.8	7.5	5.7
Cation exchange capacity		11.4	19.0	26.6	25.4
Moisture content by weight at $^1/_3$ bar[a]		9.0%	19.3%	40.1%	34.4%
Organic carbon content		1.2%	2.1%	5.5%	2.2%
Microbial biomass	Freshly collected soil	110 µg/g	254 µg/g	696 µg/g	131 µg/g
	At start of test	- 35 µg/g (control soil) 22 µg/g (treated soil)	144 µg/g (control soil) 155 µg/g (treated soil)	900 µg/g (control soil) 875 µg/g (treated soil)	127 µg/g (control soil) 122 µg/g (treated soil)
	On day 97 of test	165 µg/g (contol soil) 190 µg/g (treated soil)	313 µg/g (control soil) 298 µg/g (treated soil)	743 µg/g (control soil) 678 µg/g (treated soil)	146 µg/g (control soil) 149 µg/g (treated soil)

Notes: a) The water contents were adjusted to, and maintained at, these values throughout the aerobic test.

In all, eighteen aerobic test chambers were constructed for each soil to determine transformation products. Two test chambers for each treatment were analysed for the presence of tetrabromobisphenol-A and degradation products immediately after spiking with the test substance, and two test chambers for each soil type and each incubation condition were analysed at monthly intervals thereafter until the end of the study (the mineralization products formed under anaerobic conditions were only determined at the end of the experiments). Additional test chambers, including control test chambers, were also run in order to determine the soil characteristics (pH, microbial biomass etc.) during the test.

Various analytical methods were used to determine the degradation products formed. For the aerobic incubations, the parent compound and any degradation products were extracted from the soil using acidified methanol (each soil was extracted three times using around 200-250 ml of the acidified methanol with five minutes sonication in an ultrasonic bath followed by thirty minutes shaking for each extraction). The extracts were then concentrated and subject to analysis for total radioactivity and were also analysed for the presence of parent compound and degradation products by both HPLC analysis (where possible) and also TLC analysis. Mineralization products (i.e. $^{14}CO_2$) were also collected and analysed during the incubations using carbon dioxide traps followed by liquid scintillation counting. The results from this study are summarised in **Table 3.9**.

Table 3.9 Aerobic degradation of tetrabromobisphenol-A in four soils (Wildlife International, 2006c)

Time (months)	Parameter	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
0 (start of test)	Soil extract[b]	98.5% [92.5%][d]	94.9% [90.7%][d]	94.9% [89.2%][d]	93.7% [89.6%][d]
	Soil bound[c]	1.8%	5.7%	4.9%	6.2%
	Total ^{14}C recovery	100.3%	100.6%	99.7%	99.9%
1	$^{14}CO_2$[a]	8.5%	11.8%	13.7%	9.8%
	Soil extract[b]	18.9% [10.1%][d]	11.9% [4.7%][d]	11.1% [5.0%][d]	18.6% [10.3%][d]
	Soil bound[c]	55.3%	74.8%	83.6%	64.9%
	Total ^{14}C recovery	82.7%	98.5%	108.4%	93.3%
2	$^{14}CO_2$[a]	11.4%	13.8%	15.0%	13.4%
	Soil extract[b]	14.0% [6.2%][d]	8.5% [2.9%][d]	8.8% [3.9%][d]	13.4% [6.6%][d]
	Soil bound[c]	69.9%	64.4%	70.1%	68.6%
	Total ^{14}C recovery	95.3%	86.7%	93.9%	13.4%
3	$^{14}CO_2$[a]	13.6%	16.4%	17.4%	16.0%
4	$^{14}CO_2$[a]	15.2%	18.5%	19.1%	18.0%
	Soil extract[b]	10.7% [3.0%][d]	6.5% [1.8%][d]	7.0% [1.3%][d]	9.3% [3.5%][d]
	Soil bound[c]	59.6%	64.9%	73.1%	63.6%
	Total ^{14}C recovery	85.4%	89.9%	99.1%	90.9%
5	$^{14}CO_2$[a]	16.3%	20.0%	20.6%	20.0%
	Soil extract[b]	10.1% [2.9%][d]	6.3% [1.7%][d]	6.8% [1.9%][d]	10.0% [3.3%][d]
	Soil bound[c]	63.5%	60.0%	80.4%	63.2%
	Total ^{14}C recovery	89.9%	86.3%	107.8%	93.2%
6	$^{14}CO_2$[a]	17.5%	21.3%	21.6%	21.2%
	Soil extract[b]	8.7% [2.0%][d]	6.1% [1.7%][d]	6.6% [1.7%][d]	8.0% [2.4%][d]
	Soil bound[c]	56.0%	63.7%	75.8%	61.7%
	Total ^{14}C recovery	82.2%	91.1%	104.0%	90.9%

Notes: a) This represents the ^{14}C collected in the carbon dioxide traps, charcoal traps, and blank traps used in the collection system. The vast majority of the ^{14}C was associated with the carbon dioxide traps.
b) ^{14}C-Label that was extracted from the soil using acidified methanol.
c) ^{14}C-Label that was not extracted from the soil using acidified methanol.
d) The figures in [ ] refer to the amount of radiolabel that was determined to be unchanged ^{14}C-tetrabromobisphenol-A.

It is noticeable that the amount of radioactivity that could not be extracted from the soil increased with increased incubation time, and by 6 months around 56-76% of the radioactivity could no longer be extracted from the soil. The identity of this radioactivity is unknown, for example it could represent unchanged tetrabromobisphenol-A that became increasingly strongly bound to the soil during the experiment (and so could not be removed from soil by the relatively mild extraction process used in the analytical method (the soil was extracted at room temperature using acidified methanol – five minutes sonication followed by thirty minutes shaking) or may represent degradation products that are more strongly bound to the soil than tetrabromobisphenol-A/radiolabel that was incorporated into the soil biomass.

The scientists that carried out these tests have been contacted in relation to this aspect of the test, but no further information on the identity of the soil-bound radiolabel is available.

Based on these results, the study concluded that the DT_{50} (the time for disappearance of 50% of the starting material) for tetrabromobisphenol-A from the soils was around 5.3-7.7 days. However, given that it is possible that much of this disappearance may result from increased binding of tetrabromobisphenol-A to the soil, these DT_{50} values may represent an adsorption process rather than a degradation process. More relevant to the risk assessment is the mineralization half-life or DT_{50}. As can be seen, the amount of ^{14}C found as mineralization products increased slowly during the test, reaching around 18-22% after 6 months incubation. Based on these results it can be concluded that mineralization half-life is >6 months.

The extractable products found in this study are summarised in **Table 3.10**.

Table 3.10 Products identified in the soil extracts during the aerobic degradation of tetrabromobisphenol-A in four soils (Wildlife International, 2006c)

Time (months)	Parameter[a]	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
0 (start of test)	Polar				
	Bisphenol-A				
	Unknown 4	0.7%			
	Unknown 3	4.3%	4.2%	5.7%	4.3%
	Tetrabromobisphenol-A	92.5%	90.7%	89.2%	89.6%
	Unknown 2	1.1%			
	Unknown 1				
	Origin				
	Total	98.5%	94.9%	94.9%	93.7%
1	Polar	0.1%	0.1%	0.0%	0.3%
	Bisphenol-A	0.4%	0.4%	0.0%	1.3%
	Unknown 4	0.3%	0.4%	0.2%	0.6%
	Unknown 3	0.7%	0.6%	0.5%	1.2%
	Tetrabromobisphenol-A	10.1%	4.7%	5.0%	10.3%
	Unknown 2	4.0%	3.5%	4.3%	3.5%
	Unknown 1	3.2%	2.2%	1.4%	1.3%
	Origin	0.1%	0.1%	0.0%	0.1%
	Total	18.9%	11.9%	11.1%	18.6%

Table 3.10 continued overleaf.

Table 3.10 continued.

Time (months)	Parameter[a]	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
2	Polar	0.0%	0.1%	0.1%	0.3%
	Bisphenol-A	0.2%	0.3%	0.6%	1.0%
	Unknown 4	0.2%	0.1%	0.2%	0.3%
	Unknown 3	0.6%	0.4%	0.7%	0.9%
	Tetrabromobisphenol-A	6.2%	2.9%	3.9%	6.6%
	Unknown 2	4.4%	3.3%	2.8%	3.4%
	Unknown 1	2.4%	1.2%	0.4%	0.8%
	Origin	0.1%	0.1%	0.1%	0.1%
	Total	14.0%	8.5%	8.8%	13.4%
4	Polar	0.2%	0.1%	0.0%	0.3%
	Bisphenol-A	0.4%	0.2%	0.0%	0.5%
	Unknown 4	0.3%	0.2%	0.2%	0.4%
	Unknown 3	0.3%	0.4%	0.5%	0.5%
	Tetrabromobisphenol-A	3.0%	1.8%	1.3%	3.5%
	Unknown 2	2.8%	1.7%	2.5%	2.6%
	Unknown 1	3.6%	2.0%	2.5%	1.6%
	Origin	0.2%	0.1%	0.0%	0.0%
	Total	10.7%	6.5%	7.0%	9.3%
5	Polar	0.1%	0.0%	0.1%	0.1%
	Bisphenol-A	0.2%	0.1%	0.1%	0.4%
	Unknown 4	0.2%	0.1%	0.3%	0.6%
	Unknown 3	0.3%	0.2%	0.2%	0.5%
	Tetrabromobisphenol-A	2.9%	1.7%	1.9%	3.3%
	Unknown 2	2.9%	1.9%	1.9%	2.8%
	Unknown 1	3.5%	2.0%	2.3%	2.3%
	Origin	0.0%	0.1%	0.1%	0.0%
	Total	10.1%	6.3%	6.8%	10.0%

Table 3.10 continued overleaf.

Table 3.10 continued.

Time (months)	Parameter[a]	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
6	Polar	0.0%	0.0%	0.0%	0.1%
	Bisphenol-A	0.2%	0.2%	0.1%	0.5%
	Unknown 4	0.2%	0.2%	0.2%	0.3%
	Unknown 3	0.2%	0.2%	0.3%	0.4%
	Tetrabromobisphenol-A	2.0%	1.7%	1.7%	2.4%
	Unknown 2	2.0%	1.4%	2.3%	2.3%
	Unknown 1	3.9%	2.2%	1.9%	2.1%
	Origin	0.2%	0.1%	0.0%	0.0%
	Total	8.7%	6.1%	6.6%	8.0%

Note: a) The identities of some of the degradation products were not established in this study. With the exception of time 0, all the data refer to the results of TLC analysis. The peaks found were grouped based on their retention times, and then compared with the retention times for tetrabromobisphenol-A and bisphenol-A. Thus the origin (0-28 mm on the chromatogram), unknown 1 and unknown 2 (28-55 mm on the chromatogram) represents products that are less polar than tetrabromobisphenol-A, unknown 3 and unknown 4 (75-120 mm on the chromatogram) represent products with a polarity intermediate between tetrabromobisphenol-A and bisphenol-A, and polar (145-190 mm on the chromatogram) represents products that are more polar than bisphenol-A.

The degradation products were not unambiguously identified in the study as the concentrations present were low, meaning that HPLC analysis could not be used. Instead, the products formed were grouped in terms of their polarity in relation to either bisphenol-A and tetrabromobisphenol-A based on their behaviour during TLC analysis. The results of this analysis are rather inconclusive, with indications of products of polarity intermediate between tetrabromobisphenol-A and bisphenol-A (unknown 4 and unknown 3) and also products less polar than tetrabromobisphenol-A (unknown 1 and unknown 2) being formed. It could be speculated that unknown 1 and unknown 2 are possibly methylether-derivatives of tetrabromobisphenol-A, and unknown 3 and unknown 4 are mono- to tribromobisphenol-A derivatives, but there is no firm evidence for this from this study. A further confounding aspect of this study is that no information is available on the ^{14}C-products from a control soil (i.e. no controls using sterilised soils appear to have been run), meaning that it is difficult to put the relatively small amounts of radioactivity found as some products into context. It should also be noted that another limitation with this study is that the test substance (as a solution in ethanol) was applied only to the surface of the soil. Therefore complete mixing of the substance within the bulk of the soil cannot be guaranteed. The OECD 307 method indicates that when the test substance is added as a solution in a solvent, the substance should firstly be added to a sub-sample of the soil, the solvent allowed to evaporated, and then the spiked sub-sample of soil should be thoroughly mixed into the bulk of the soil.

It should be noted that the interpretation of both the Springborn Life Sciences (1989e) study and the Wildlife International (2006c) studies is difficult owing to the large amount of radiolabel that was not extractable from the soil. Different extraction methods were also used in the two studies (the Springborn Life Sciences (1989e) study used soxhlet extraction with acetone for sixteen hours compared with room temperature extraction with acidified methanol used in the Wildlife International (2006c) study). No further information on the soil-bound residues is available.

Sediment systems

The degradation of ^{14}C-labelled tetrabromobisphenol-A has been studied in an aerobic sediment-water system (Springborn Laboratories, 1989d). The substance tested had a radiopurity of 96.0%. Stock solutions of the test substance were prepared in acetone and acetone at ~0.5 ml/kg dry sediment was present in the test media.

The sediment used was a natural river sediment. It had a total organic carbon content of 6.8%, a pH of 5.5 and field moisture capacity of 15.9%, and was composed of 92% sand, 6% silt and 2% clay. The test system consisted of approximately 40 ml sediment (~20 g dry weight) in 135 ml river water. The tetrabromobisphenol-A solution was added to the water-phase at concentrations of 10, 100 and 1,000 µg/l. The flasks were then incubated in the dark at 25^{o}C for up to 56 days. Oxygen was bubbled through the test vessels daily for 5 minutes to maintain aerobic conditions. A sterile sediment (containing $HgCl_2$) control was also run, but no solvent or non-sterile control appears to have been used. Each treatment was carried out in triplicate. The pH of individual vessels ranged from 5.2-6.6 (mean 5.7) and the measured dissolved oxygen level was always >6.4 mg/l, indicating that aerobic conditions had been maintained. Flasks were sampled on days 0, 4, 7, 10, 14, 21, 28, 42 and 56. Analyses were carried out for the presence of radioactivity in the solid (combustion analysis) and water phase, and also in the volatile products collected from the system. The results of these analyses are shown in **Table 3.11**.

Only a very small fraction of the total radioactivity applied to the system was present as volatile products, indicating that mineralisation of tetrabromobisphenol-A was incomplete. The majority of the ^{14}C was found associated with the sediment phase. At the end of the test, samples of the sediment were Soxhlet extracted with acetone for sixteen hours and subject to HPLC analysis with radiometric detection. The results of these analyses are also shown in **Table 3.11**. These show that 44.7%-64.2% of the radioactivity recovered from the sediment-phase was still present as tetrabromobisphenol-A. The estimated time to 50% degradation (DT_{50}; this would be equivalent to the half-life for a first order degradation process) for primary degradation of tetrabromobisphenol-A based on these data was 48 days at an initial concentration of 10 µg/l, 69 days at an initial concentration of 100 µg/l and 84 days at an initial concentration of 1,000 µg/l. The corresponding DT_{50} in the sterile controls was ~1,300 days (a small but measurable number of active cells were found in the sterile controls), indicating that the degradation seen was as a result of biotic activity. The DT_{50} determined at the various concentrations was found to be related to the microbial numbers present in the test system, and indicates that the higher concentrations tested may have been slightly inhibitory to the microbial populations present.

As can be seen from **Table 3.11** the overall recovery of ^{14}C from this experiment was rather low (averaging around 50%), and so the DT_{50}s/half-lives estimated from the data should be treated with caution.

Table 3.11 Degradation of ^{14}C-labelled tetrabromobisphenol-A in aerobic sediments over 56 days

Initial TBBPA concentration	No. of microorganisms at day 56 (CFU/ml)[a]	Time period (days)	Radioactivity recovered (as % of total applied)			% of recovered ^{14}C as TBBPA[c]
			Volatile traps/CO_2[b]	Aqueous phase[b]	Solid phase[b]	
10 µg/l	4.8×10^4	0	ND	5.2%	15.2%	91.8%
		4	ND	11.2%	63.0%	91.3%
		7	ND	3.6%	55.5%	89.3%
		10	ND	0.3%	43.0%	92.9%
		14	2.6%	0.7%	144%	82.2%
		21	ND	0.4%	62.9%	62.9%
		28	ND	ND	56.8%	39.1%
		42	ND	ND	74.9%	60.5%
		56	1.6%	ND	51.7%	44.7%
100 µg/l	2.5×10^3	0	ND	3.4%	10.0%	98.4%
		4	ND	3.0%	38.5%	100%
		7	0.7%	3.1%	-	97.9%
		10	ND	1.9%	45.9%	100%
		14	0.2%	2.1%	49.1%	100%
		21	ND	1.5%	44.3%	78.7%
		28	0.7%	1.0%	44.2%	79.2%
		42	0.3%	0.7%	41.5%	60.7%
		56	0.5%	0.4%	26.3%	64.2%
1,000 µg/l	1.5×10^3	0	ND	1.4%	12.7%	100%
		4	ND	1.5%	41.6%	100%
		7	ND	1.4%	50.3%	84.0%
		10	ND	1.3%	43.8%	75.5%
		14	0.1%	2.0%	41.1%	77.7%
		21	0.1%	0.7%	38.4%	76.5%
		28	0.6%	0.5%	37.0%	66.7%
		42	0.1%	0.2%	30.5%	67.0%
		56	2.1%	0.4%	36.4%	60.8%

Notes: a) Mean number of viable colony forming units present in the sediment/water system at the end of the study.
b) Based on total ^{14}C present in the solid phase (combustion analysis), water phase expressed as a percentage of the radioactivity added to the system or collected in the volatile traps.
c) Based on HPLC analysis of the acetone extracts expressed as a percentage of ^{14}C recovered.

Other systems

Allard *et al.* (1987) investigated the O-methylation of tetrabromobisphenol-A using two strains of bacteria that were known to be capable of O-methylating other phenolic compounds. The bacteria used were a gram positive *Rhodococcus* sp. and a gram negative *Acinetobacter* sp. The tests were carried out in bottles containing 3 ml of cell suspension (the

cell suspension contained 10^8 cells/ml for *Rhodococcus* sp. and 10^9 cells/ml for *Acinetobacter* sp.). In experiments with *Rhodoccus* sp. O-methylation was found to occur at a rate of 4.7×10^{-10} µg hour^{-1} [cells per ml]$^{-1}$, giving an overall 60% yield of the product. No O-methylation occurred with the *Acinetobacter* sp.

Reactions of this type may explain the presence of the bis-O-methyl ether derivative of tetrabromobisphenol-A found in some surveys of environmental levels (see Section 3.1.1.2.2).

Anaerobic conditions

Sewage sludge

The ability of bench-scale reactor systems to degrade a waste mixture from a production site has been investigated (Brenner *et al.*, 2006). The reactor systems used were based on the conventional (aerobic) activated sludge process and the contact (anaerobic) process. The feed for the reactors consisted of a tetrabromobisphenol-A waste stream (containing approximately 40% tetrabromobisphenol-A, 20% 2,4,6-tribromophenol, 8% 2,4-dibromophenol together with other materials), and contaminated sediments. This solid waste was mixed with water at a dose rate of 0.5 g solid waste/litre and adjusted to a pH of 8.5 (in order to maximise the solubility of tetrabromobisphenol-A) before being fed to the reactors. The concentration of tetrabromobisphenol-A and 2,4,6-tribromophenol in the feed to the reactors was approximately 230 mg/l and 120 mg/l respectively. A total of five different reactors were operated under different conditions (aerobic or anaerobic) using various carbon sources to serve as an electron donor (the electron donors were added to the feed at a concentration of 400 mg total organic carbon/l). Essential nutrients (nitrogen and phosphorus salts at 70 mg N/l and 16 mg P/l) were also added to the reactor feed. The conditions used are summarised in **Table 3.12**.

The reactors were initially seeded with sludge from a municipal waste water treatment plant (concentration 2.5 g/l which is typical of activated sludge systems) along with a sediment contaminated with tetrabromobisphenol-A and 2,4,6-tribromophenol. The reactors were operated using a draw and fill procedure (no details are given on the frequency of this procedure or the typical residence time within the reactors). During the experiment, the reactors were gently agitated using mechanical mixers. Anaerobic conditions were maintained by continuously bubbling nitrogen gas through the system (the conditions were also monitored by a redox electrode). For the aerobic reactor, continuous aeration was provided. The aerobic/anaerobic reactor was continuously cycled between aerobic and anaerobic conditions by turning on and off the air supply (thirty minutes aeration followed by 3.5 hours anaerobic conditions; nitrogen was constantly bubbled through the reactor during both the aerobic and anaerobic phases) for a total of six cycles per day.

Evaluation of debromination efficiency of the systems was determined by monitoring for bromide ion in the reactor mixed liquor using a bromide selective electrode. In addition, more detailed analysis was carried out for parent compound and a possible degradation product (bisphenol-A). No evidence for the degradation of tetrabromobisphenol-A under either aerobic or anaerobic conditions was seen in any of the reactors, and no bisphenol-A was detected during the study. In contrast, tribromophenol was easily degraded in the aerobic reactor. It should be noted that the sensitivity of the analytical methods used (both to determine bromide ion and bisphenol-A) is unclear from the paper.

Table 3.12 Summary of bench-scale reactors used to study the degradation of tetrabromobisphenol-A (Brenner *et al.*, 2006)

Conditions	Electron acceptor	Electron donor (carbon source)	Reactor liquid volume (litres)	Operation period (months)
Anaerobic	Tetrabromobisphenol-A	Solid waste organics	3	6
Anaerobic	Tetrabromobisphenol-A	Glucose/sucrose	4	6
Anaerobic	Tetrabromobisphenol-A	Peptone, triptone, yeast extract	1	4
Aerobic	Oxygen	2,4,6-Tribromophenol	4	4
Aerobic/anaerobic	Oxygen/ tetrabromobisphenol-A	Sucrose/acetate	4	2

A further study to investigate the anaerobic degradation of tetrabromobisphenol-A in sewage sludge has been carried out by industry.

The study investigated the mineralization and transformation of ^{14}C-labelled tetrabromobisphenol-A in anaerobic digester sludge (Wildlife International, 2006a). The protocol used was based on OECD Guideline 308. The substance tested had a radiochemical purity of 99.6% and was uniformly labelled in both phenyl rings.

The anaerobic digester sludge was collected from a municipal waste water treatment plant. The sludge was collected through a 6.3 mm sieve and had a pH of 7.1 and contained 44 g of solids per litre. The test vessels used consisted of 100 ml of either live (biotic) or sterile (abiotic) digester sludge and 100 ml of mineral salts solution in a 500 ml glass bottle. The solids contents of the test vessels were determined to be 23 g/l for the biotic vessels and 25 g/l for the abiotic vessels. The nominal tetrabromobisphenol-A concentration used was 50 µg/l and the test substance was added as a solution in ethanol (22.5 µl of the ethanol solution was added to each test vessel). The experiments were carried out at 35°C in the dark for up to 120 days. Nitrogen was continuously purged through the headspace of the test vessels at a slow rate.

Parallel sets of vessels were used for both the biotic and abiotic experiments in order that both mineralization ($^{14}CO_2$, $^{14}CH_4$ and other volatile radiolabelled products) and initial transformation products could be determined.

The apparatus used to determine the mineralization and other volatile products consisted of a set of CO_2 traps followed by a combustion furnace (to oxidize $^{14}CH_4$ and other volatile radiolabelled products to $^{14}CO_2$) followed by a final set of CO_2 traps. The $^{14}CO_2$ traps were analysed on days 7, 14, 28, 42, 56, 70, 84, 98, 112 and 120 of the experiment. The experiments investigating mineralization were carried out in duplicate.

For the experiments investigating the initial transformation products, a total of fourteen test vessels were prepared for each of the biotic and abiotic experiments, and two test vessels from each test system were analysed at days 0, 7, 14, 28, 42 and 56, with a further two test vessels from the biotic test system being analysed on day 120. For the analysis, the water and solid phases were separated and analysed separately. With the exception of the samples collected at day 120, the water phase was found to contain <10% of the radioactivity and so

the degradation products present were not analysed in detail for this phase. At day 120 the water phase contained slightly greater than 10% of the radioactivity.

Prior to the start of the test, a sample of the inoculum was analysed for the presence of tetrabromobisphenol-A. No tetrabromobisphenol-A was detected in either the water phase or the sludge solids (the detection limits were around 2 µg/l for the water phase and 15 µg/kg dry weight for the sludge solids).

Very little mineralization was evident in the test, with the mean cumulative total radioactivity collected in the mineralization and volatiles traps being 1.1% and 0.9% of the dosed radioactivity in the biotic and abiotic systems respectively.

The results of the analysis for the initial transformation products from the biotic experiments is summarised in **Table 3.13**, and shown in **Figure 3.2**. As can be seen degradation appears to occur via three intermediate products to eventually form bisphenol-A. The total yield of bisphenol-A was around 48% after 120 days. The DT_{50} (equivalent to a half-life for a first order process) for tetrabromobisphenol-A was estimated to be around 19 days under these conditions. The overall mass balance from this study was good.

Further work has been carried out to try to better establish the identities of the intermediate degradation products (Wildlife International, 2006f). The approach taken assumed that the most likely intermediary degradation products of tetrabromobisphenol-A are tribromobisphenol-A, dibromobisphenol-A, bromobisphenol-A and bisphenol-A and so reference standards for three of these four products (reference standards were not available for bromobisphenol-A) were used in the method. In addition, analyses were also performed to evaluate the potential presence of both the mono- and dimethylethers of tetrabromobisphenol-A. The analytical method used was a screening approach utilising an HPLC/MS/MS method for selected extracts from the sludge obtained in the original degradation study. However, as this analysis was not based on determination of ^{14}C, and no clean up had been applied to the extract, (or could be used owing to the small amount of extract available), the analysis was severely compromised by the generally high background contamination in the extract when analysed by HPLC/MS/MS. Therefore it was not possible to conclude on the identities of the degradation products found. However, it was found that some extracts contained products with retention times of close similarity to one or more of the reference standards (for example dibromobisphenol-A, tribromobisphenol-A and also in some cases the mono- and dimethylether of tetrabromobisphenol-A), but other, unidentified, peaks were also present in the chromatograms (it is not entirely clear from the paper whether these are potential degradation products of tetrabromobisphenol-A or other substances that were extracted from the sludge unrelated to tetrabromobisphenol-A).

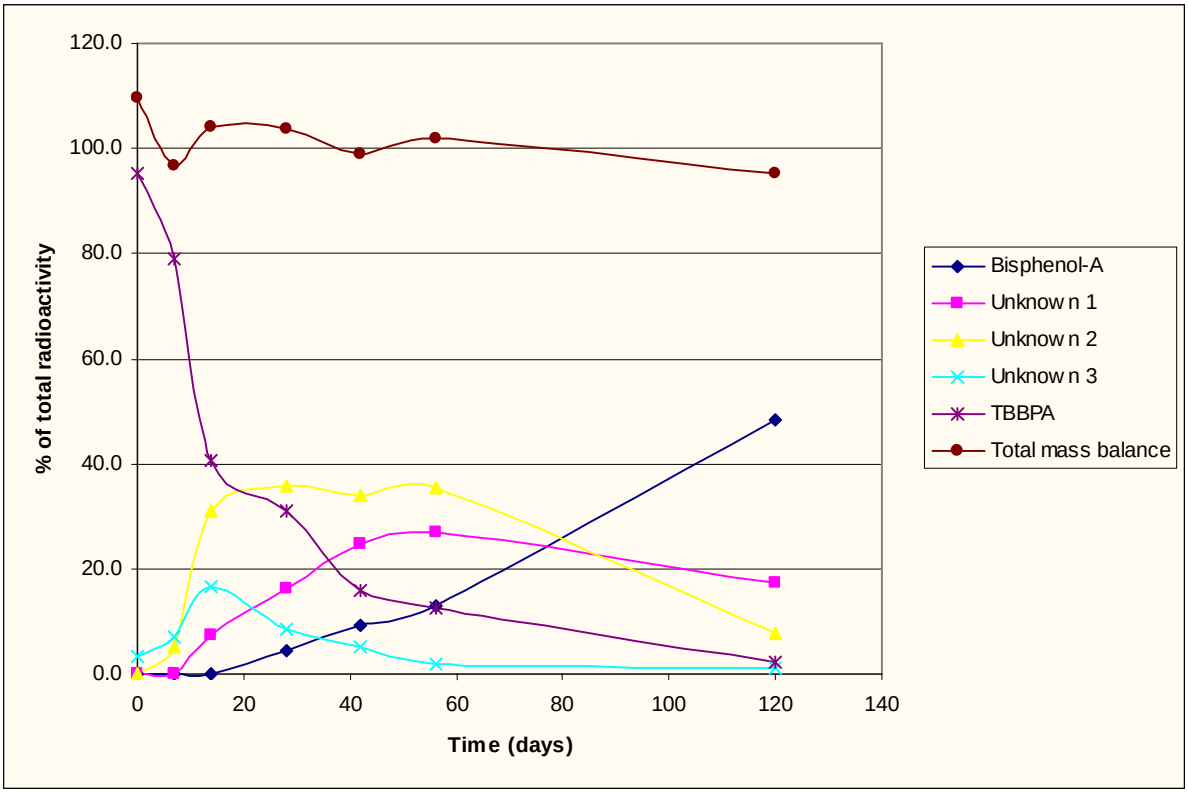
Little degradation was seen in the abiotic experiments, for example around 92% of the initial radioactivity added to the system was found to be present as unchanged tetrabromobisphenol-A at 56 days, and around 68% of the initial radioactivity was found to be present as unchanged tetrabromobisphenol-A at day 120 in the mineralization experiment.

Table 3.13 Summary of degradation in anaerobic sewage sludge

Time (days)	% Radioactivity								Total mass balance (%)
	Bisphenol -A	Unknown 1[b]	Unknown 2[b]	Unknown 3[b]	TBBPA	Other 14C			
	Sludge	Sludge	Sludge	Sludge	Sludge	Water layer	Unextracted sludge[a]	Gases	
0	0.0	0.0	0.0	3.5	95.3	5.0	5.9	0.0	109.7
7	0.0	0.0	5.2	6.9	78.9	1.6	3.9	0.1	96.6
14	0.0	7.4	30.9	16.5	40.7	3.3	5.0	0.2	104.0
28	4.3	16.1	35.7	8.5	30.9	3.8	4.3	0.3	103.9
42	9.2	24.8	33.9	5.0	16.0	5.9	3.8	0.4	99.0
56	12.9	26.9	35.4	1.9	12.5	6.6	5.2	0.4	101.8
120	48.4	17.2	7.8	1.0	2.3	13.2	4.2	1.1	95.2

Notes: a) Radiolabel that could not be extracted from the sludge.
b) The identities of some of the degradation products were not established in this study. The peaks found in HPLC analysis (using a radiochemical detector) were grouped based on their retention times, and then compared with the retention times for tetrabromobisphenol-A and bisphenol-A. Thus unknown 1, unknown 2 and unknown 3 are products with a polarity intermediate between tetrabromobisphenol-A and bisphenol-A.

Figure 3.2 Degradation of tetrabromobisphenol-A in anaerobic sewage sludge



Gerecke *et al.* (2006) has investigated the anaerobic degradation of tetrabromobisphenol-A (and two other brominated flame retardants (decabromodiphenyl ether (decaBDE) and hexabromocyclododecane (HBCD)) in digested sewage sludge. The tetrabromobisphenol-A used in the study had a purity of 97%. Experiments were carried out using a mixture of tetrabromobisphenol-A with the two other brominated flame retardants (decaBDE and

HBCD) along with three other brominated compounds as primers (2,6-dibromobiphenyl, 4-bromobenzoic acid and/or decabromobiphenyl). These mixtures were tested both with added nutrients (yeast and starch) and without added nutrients. A second experiment was carried out using tetrabromobisphenol-A alone in the presence of nutrients. Sterilized sludge was used as a negative control and a racemic mixture of (±)-α-hexachlorocyclohexane was used as a substrate in the positive controls.

The anaerobic reactors used consisted of 300 ml glass serum bottles containing a 1 cm layer of glass beads. These were spiked with solutions of the test substance(s) in an organic solvent and the solvent was allowed to evaporate overnight. The amount of test substance(s) added was 9-11 nmol/reactor for each substance used (flame retardant and primer). Starch (20 mg) and yeast (50 mg) were then added to the bottles and the bottles were immediately filled with 20 ml of freshly collected digested sewage sludge from a sewage treatment plant in Dübendorf, Switzerland, that serves 45,000 people. The sewage sludge was taken from the mesophilic stabilizer operated at 37°C and had a pH of 7.6 and a solids content of 3%. The anaerobic reactors were then tightly capped and incubated at 37°C in the dark for up to 6 days. At various timepoints, bottles were opened and analysed for tetrabromobisphenol-A.

The degradation half-life for tetrabromobisphenol-A was found to be 0.59 days (first order rate constant 1.2±0.06 day^{-1}) when tested as a mixture with decaBDE and HBCD in the presence of the three primer compounds and nutrients. Similar degradation half-lives were found in the experiments where tetrabromobisphenol-A was tested alone without other flame retardants/primers (first order rate constant 1.3±0.16 day^{-1}; half-life 0.53 days) or tested as a mixture with other flame retardants/primers in the absence of added nutrients (first order rate constant 1.3±0.09 day^{-1}; half-life 0.53 days). In the sterile controls, the concentrations were found to be slightly lower than the initial concentration on day two and day six of the experiment, however the degradation rate constant derived from the data was not significantly different from zero.

Gerecke *et al.* (2006) also carried out a preliminary study investigating the degradation of tetrabromobisphenol-A in a full-scale anaerobic digester. For this study, grab samples of sewage sludge were taken at the inlet and outlet of the mesophilic digester at the sewage treatment plant at Dübendorf, as well as samples from the mesophilic digester/reactor itself. The concentration of tetrabromobisphenol-A was determined to be 1.9 nmol/l in the inlet sample, 0.4 nmol/l in the digester/reactor, and 0.3 nmol/l in the outlet. The residence time in the reactor was 28 days. Although these data are suggestive that degradation of tetrabromobisphenol-A was occurring in the digester/reactor, it should be born in mind that these results are based on single grab samples of the inlet, reactor and outlet, and the temporal variability in the concentrations measured is not known.

Soil systems

The biodegradation of tetrabromobisphenol-A under anaerobic conditions has been studied in three different natural soil types (Springborn Life Sciences, 1989d). The substance tested was ^{14}C-labelled tetrabromobisphenol-A that was mixed with unlabelled tetrabromobisphenol-A (purity 99.06%). The soils used in the study were the same sandy loam, clay loam and a silty loam soils used in the aerobic study discussed above. The tests were carried out in 250 ml flasks with inlet and outlet ports for nitrogen gas exchange and each flask contained 50 g dry weight of soil. The test substance was added to the soil as a solution in acetone to give a final concentration of 10 mg/kg dry weight. The soil was then mixed and tap water was

added to provide a depth of 2-3 cm over the soil. Finally the flasks were flushed with nitrogen (the flasks were flushed daily with nitrogen throughout the test to maintain anaerobic conditions and to allow collection of any gaseous degradation products). The flasks were incubated in the dark at 21.4°C for 64 days. No control soils appear to have been run.

At the end of the test, water, soil (combustion analysis) and gaseous traps were analysed for the presence of radioactivity. The results are shown in **Table 3.14**. The soil samples were also extracted by Soxhlet extraction with acetone for 16 hours followed by TLC analysis, using a 7:3 mixture of hexane:ethyl acetate as solvent, in order to identify any metabolites formed. The results of this analysis are shown in **Table 3.15**.

As can be seen from **Table 3.14**, the recovery of radioactivity from the study was generally good (>85%) and most of the radioactivity was present in the solid phase. A small amount of radioactivity was recovered from the water phase. The radioactivity in the volatile traps was almost exclusively CO_2, but the small amount detected indicated that little or no mineralisation had occurred during the test

Table 3.14 Anaerobic degradation of ^{14}C-labelled tetrabromobisphenol-A in three soil types after 64 days

Soil type	Soil properties							Distribution of recovered radioactivity (as % of that initially applied				
	CEC[a]	O.C.[b]	pH	FMC[c]	Sand	Silt	Clay	Rep.[d]	Water	Soil[e]	Volatile traps/ CO_2	Total
Sandy loam	10.8	4.4%	7.0	74.8%	83%	13%	4%	1	0.6%	116.4%	0.04%	117.0%
								2	0.5%	100.6%	0.02%	101.1%
								3	0.5%	84.0%	0.03%	84.5%
								4	0.4%	100.9%	0.03%	101.3%
								Mean	0.5%	100.5%	0.03%	101.0%
Silty loam	6.0	0.8%	6.2	43.9%	16%	58%	26%	1	3.2%	78.9%	0.34%	82.4%
								2	1.8%	83.1%	0.26%	85.2%
								3	2.5%	86.8%	0.43%	89.7%
								4	2.3%	83.3%	0.38%	86%
								Mean	2.5%	83.0%	0.35%	85.8%
Clay loam	19.6	1.8%	7.6	75.9%	43%	24%	33%	1	1.6%	82.1%	0.10%	83.8%
								2	1.4%	85.8%	0.05%	87.3%
								3	2.1%	81.2%	0.10%	83.4%
								4	3.2%	82.7%	0.13%	86.0%
								Mean	2.1%	82.9%	0.095%	85.1%

Notes: a) Cation exchange capacity (meq/100 g).
b) Organic carbon concentration.
c) Field moisture capacity.
d) Replicate experiments.
e) Based on combustion analysis of the soil after removal of the water phase.

The recovery of ^{14}C from the soil by solvent extraction was generally good for the sandy loam and clay loam (mean recovery was around 87.5% and 104.7% of the initially applied

radioactivity) but was low for the silty loam (mean recovery was around 48.3% of the initially applied radioactivity). The results of the TLC analysis (**Table 3.15**) indicate that after 64 days incubation, ~44-57% of the extracted radioactivity was as unchanged tetrabromobisphenol-A in the sandy loam soil, ~53-65% of the extracted radioactivity was as unchanged tetrabromobisphenol-A in the silty loam soil and ~90-91% of the extracted radioactivity was as unchanged tetrabromobisphenol-A in the clay loam soil. Three main degradation products were found but these were not identified in the study. Unknown A and unknown B appeared to be more polar than tetrabromobisphenol-A in the TLC analysis, whereas unknown C appeared to be less polar than tetrabromobisphenol-A. Two expected metabolites of tetrabromobisphenol-A (O,O'dimethyltetrabromobisphenol-A and O,O'-diethyl-tetrabromobisphenol-A) were also analysed for but these were found only in trace amounts.

Table 3.15 Products from anaerobic degradation of ^{14}C-labelled tetrabromobisphenol-A after 64 days

Identity	Amount (as % of radioactivity recovered from TLC plates after Soxhlet extraction of soil)[c]		
	Sandy loam	Silty loam	Clay loam
Polar	2.2-3.4%	12.5-18%	1.1-2.1%
Low Rf[a]	1.8-2.0%	8.6-12.1%	1.6-1.9%
Unknown A	24.6-36.8%	0%	0%
Unknown B	12.1-13.0%	7.3-8.4%	2.5-3.1%
Tetrabromobisphenol-A	43.7-57%	53.4-65.0%	89.5-90.6%
Unknown C	1.4-1.9%	5.3-7.7%	3.0-3.2%
Dimethyl and diethyl tetrabromobisphenol-A derivatives	0-0.2%	0-0.1%	0.2-1.0%
High Rf[b]	0%	0-0.1%	0-0.1%

Notes: a) A low Rf indicates products that are more polar than tetrabromobisphenol-A in TLC analysis.
b) A high Rf indicates products that are less polar than the tetrabromobisphenol-A dimethyl and diethyl derivatives in TLC analysis.
c) The amount of radioactivity recovered by Soxleht extraction (expressed as mean percentage of the radioactivity initially applied to the soil) was 87.5% for the sandy loam, 48.3% for the silty loam and 104.7% for the clay loam.

A further study investigating the degradation of tetrabromobisphenol-A in soil under anaerobic conditions is available (Wildlife International, 2006c). The test method was based on the OECD 307 test guideline. The substance tested in this study was uniformly ring labelled ^{14}C-tetrabromobisphenol-A (radiochemical purity 99.6%). The soils, test chambers and experimental method used were the same as those used under aerobic conditions (these are summarised in the aerobic degradation Section). For the anaerobic experiments the test chambers were firstly incubated for 30 days under aerobic conditions. At day 30, the test chambers for each soil type were converted to anaerobic conditions by flooding with 250 ml of water and continuously purging with nitrogen. The chambers were then maintained under these conditions for up to a further five months.

In all, eighteen aerobic test chambers were constructed for each soil, along with a further parallel set of eight test chambers (two chambers per soil) that were used to trap mineralization products. Two test chambers for each treatment were analysed for the presence of tetrabromobisphenol-A and degradation products immediately after spiking with the test substance, and two test chambers for each soil type and each incubation condition

were analysed at monthly intervals thereafter until the end of the study (the mineralization products formed under anaerobic conditions were only determined at the end of the experiments).

Various analytical methods were used to determine the degradation products formed. The parent compound and any degradation products were extracted from the soil using acidified methanol (each soil was extracted three times using around 200-250 ml of the acidified methanol with 5 minutes sonication in an ultrasonic bath for each extraction). The extracts were then concentrated and subject to analysis for total radioactivity and were also analysed for the presence of parent compound and degradation products by both HPLC analysis (where possible) and TLC analysis. In addition, the overlying water decanted from the soil and solvent extracts of the water phase was analysed for the parent compound and degradation products using similar methods. The total amount of ^{14}C present in the overlying water was also determined. The mineralization products formed ($^{14}CO_2$ and $^{14}CH_4$, along with any other volatile product) were also collected and the amounts formed determined.

The results from this study are summarised in **Table 3.16**. Similar to the case with the aerobic soil experiments, a large proportion of the radiolabel could not be extracted from the soil after one months incubation under aerobic conditions. As discussed earlier, the identity of this radioactivity is unknown, which makes interpretation of the results difficult. The amount of mineralization products increased from about 7-11% of the total radioactivity at month one, to around 12-18% of the total radioactivity by month 4. It should be noted that two parallel test systems were used to determine the mineralization products. The second series of experiments (values shown in { } in **Table 3.16**) generally showed a lower rate of mineralization (reaching around 3-9% of the total radioactivity after 6 months incubation), and a lower amount of soil-bound residues than the first series of experiments. The main difference between these two sets of experiments was that the first used 500 ml short-form, wide-mouth, amber glass bottles as the test chamber and the mineralization traps were designed to collect mainly $^{14}CO_2$, whereas the second series of experiments used 500 ml culture bottles from day 30 onwards (because of the backpressure from the mineralization traps used) and the mineralization traps were designed to trap $^{14}CO_2$, $^{14}CH_4$ and other volatile ^{14}C-containing products. The differences found in the amounts of extractable and soil-bound residues in the two test systems are indicative that the test vessel dimensions may be important in these studies, suggesting that soil-bound radioactivity could be strongly-bound but unchanged tetrabromobisphenol-A (i.e. partitioning to the soil phase could be envisaged to be dependent on the relative surface contact area between the soil and overlying water).

The extractable products found in this study are summarised in **Table 3.17**. These products were not identified unambiguously in the study as the concentrations present were low, meaning that HPLC analysis could not generally be used. Instead, the products formed were grouped in terms of their polarity in relation to either bisphenol-A and tetrabromobisphenol-A based on their behaviour during TLC analysis. The results are rather inconclusive, with indications of products of polarity intermediate between tetrabromobisphenol-A and bisphenol-A (unknown 3, unknown 4 and unknown 5) and also products less polar than tetrabromobisphenol-A (unknown 1 and unknown 2) being formed in addition to products more polar that bisphenol-A, and substances of very low polarity (effectively remaining at the origin on the TLC plates). It could be speculated that unknown 1 and unknown 2 are possibly methylether-derivatives of tetrabromobisphenol-A, and unknown 4, unknown 4 and unknown 3 are mono- to tribromobisphenol-A derivatives, but there is no firm evidence of this from this study. A further confounding aspect of this study is that no

information is available on the ^{14}C-products from a control soil (i.e. no controls using sterilised soils appear to have been run), meaning that it is difficult to put the relatively small amounts of radioactivity found as some products into context.

Table 3.16 Anaerobic degradation of tetrabromobisphenol-A in four soils(Wildlife International, 2006c)

Time (months)	Parameter	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
0 (start of test)	Soil extract[b]	104.7%	98.8%	98.2%	95.6%
	Soil bound[c]	2.6%	6.1%	6.1%	6.1%
	Total ^{14}C recovery	107.3%	104.9%	104.3%	101.7%
1	^{14}C-Mineralisation products[a]	7.4% {0.9%}[e]	7.7% {0.6%}[e]	10.7% {0.1%}[e]	9.8% {3.9%}[e]
	Water layer	2.6%	2.2%	1.3%	2.1%
	Soil extract[b]	20.7%	12.2%	10.4%	19.2%
	Soil bound[c]	69.7%	79.7%	76.0%	68.9%
	Total ^{14}C recovery	100.4%	101.8%	98.4%	100.0%
2	^{14}C-Mineralisation products[a]	10.0% {1.8%}[e]	10.7% {1.4%}[e]	12.9% {0.9%}[e]	14.6% {5.6%}[e]
	Water layer	3.3%	2.5%	1.4%	2.6%
	Soil extract[b]	18.4%	11.2%	10.6%	15.4%
	Soil bound[c]	63.4%	71.5%	74.9%	61.3%
	Total ^{14}C recovery	95.1%	95.9%	99.8%	93.9%
3	^{14}C-Mineralisation products[a]	10.8% {2.8%}[e]	10.4% {2.1%}[e]	12.6% {1.3%}[e]	16.2% {6.7%}[e]
4	^{14}C-Mineralisation products[a]	12.0% {3.5%}[e]	10.6% {2.7%}[e]	13.3% {1.9%}[e]	17.7% {7.5%}[e]
	Water layer	2.0%	1.3%	0.7%	3.5%
	Soil extract[b]	15.2%	10.1%	9.8%	12.4%
	Soil bound[c]	76.9%	74.5%	72.0%	61.7%
	Total ^{14}C recovery	106.1%	96.5%	95.8%	95.3%
5	^{14}C-Mineralisation products[a]	{2.9%}[e]	{3.1%}[e]	{2.2%}[e]	{8.0%}
6	^{14}C-Mineralisation products[a]	{4.1}[e]	{3.5%}[e]	{2.5%}[e]	{8.5%}
	Water layer	{5.5%}[e]	{2.5%}[e]	{1.1%}[e]	{2.6%}[e]
	Soil extract[b]	{30.%}[e]	{24.3%}[e]	{20.8%}[e]	{18.5%}[e]
	Soil bound[c]	{59.1%}[e]	{58.2%}[e]	{65.6%}[e]	{59.2%}[e]
	Total ^{14}C recovery	{98.7%}[e]	{88.5%}[e]	{90.0%}[e]	{88.8%}[e]

Notes: a) This represents the ^{14}C collected in the methane traps, carbon dioxide traps and volatiles traps.
b) ^{14}C-Label that was extracted from the soil using acidified methanol.
c) ^{14}C-Label that was not extracted from the soil using acidified methanol.
d) The figures in [ ] refer to the amount of radiolabel that was determined to be unchanged ^{14}C-tetrabromobisphenol-A.
e) The figures in { } refer to the ^{14}C found in the parallel series of experiments (see main text for an explanation).

Table 3.17 Products identified in the soil extracts during the anaerobic degradation of tetrabromobisphenol-A in four soils (Wildlife International, 2006c)

Time (months)	Parameter[a]	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
0 (start of test)	Polar				
	Bisphenol-A				
	Unknown 5				
	Unknown 4	1.1%	1.5%		
	Unknown 3	5.5%	4.9%	6.1%	6.2%
	Tetrabromobisphenol-A	98.2%	90.9%	92.1%	89.4%
	Unknown 2		1.3%		
	Unknown 1				
	Origin				
	Total	104.7%	98.8%	98.2%	95.6%
1	Polar	0.2%	0.3%	0.0%	0.8%
	Bisphenol-A	0.7%	1.0%	0.8%	1.6%
	Unknown 5				
	Unknown 4	0.4%	0.3%	1.3%	0.9%
	Unknown 3	1.0%	0.8%	0.6%	1.8%
	Tetrabromobisphenol-A	13.6%	7.1%	3.2%	11.6%
	Unknown 2	3.9%	1.9%	3.2%	2.1%
	Unknown 1	0.9%	0.6%	1.3%	0.3%
	Origin	0.1%	0.1%	0.0%	0.0%
	Total	20.7%	12.2%	10.4%	19.2%
2	Polar	0.0%	0.0%	0.0%	0.1%
	Bisphenol-A	0.4%	0.2%	0.3%	0.5%
	Unknown 5				
	Unknown 4	0.2%	0.1%	0.3%	0.4%
	Unknown 3	0.5%	0.4%	0.4%	0.8%
	Tetrabromobisphenol-A	9.0%	4.6%	3.6%	7.4%
	Unknown 2	4.9%	3.7%	4.0%	4.3%
	Unknown 1	3.3%	2.2%	1.9%	1.7%
	Origin	0.0%	0.0%	0.0%	0.1%
	Total	18.4%	11.2%	10.6%	15.4%

Table 3.17 continued overleaf.

Table 3.17 continued.

Time (months)	Parameter[a]	Degradation products (as a percentage of the applied radioactivity)			
		Loamy sand	Sandy clay loam	Silt loam	Silty clay loam
4	Polar	0.2%	0.2%	0.3%	0.5%
	Bisphenol-A	0.3%	0.2%	0.4%	0.5%
	Unknown 5				
	Unknown 4	0.2%	0.2%	0.3%	0.3%
	Unknown 3	0.5%	0.4%	0.6%	0.5%
	Tetrabromobisphenol-A	7.9%	5.3%	3.4%	4.7%
	Unknown 2	3.1%	1.8%	2.8%	3.4%
	Unknown 1	3.0%	1.8%	1.9%	2.4%
	Origin	0.1%	0.2%	0.1%	0.1%
	Total	15.2%	10.1%	9.8%	12.4%
6	Polar	0.2-0.6%	0.3%	0.3%	0.1-1.3%
	Bisphenol-A	0.2%	0.3%	0.7%	0.3%
	Unknown 5	0.2%	0.4%	0.6-1.3%	0.1%
	Unknown 4	0.5%	0.7%	4.0-4.2%	0.4%
	Unknown 3	1.9%	2.2-2.6%	3.2-3.3%	0.4-1.6%
	Tetrabromobisphenol-A	23.0-24.7%	17.6-20.3%	9.2-10.8%	13.0-13.9%
	Unknown 2	0.8-2.4%	0.8-1.7%	0.4-0.9%	1.9-2.5%
	Unknown 1	1.3-1.4%	0.6-1.0%	0.7%	0.3-0.8%
	Origin	0.2%	0.1%	0.3%	0.2%
	Total	30.0%	24.3%	20.8%	18.5%

Note: a) The identities of some of the degradation products were not established in this study. With the exception of time 0, all the data refer to the results of TLC analysis. The peaks found were grouped based on their retention times, and then compared with the retention times for tetrabromobisphenol-A and bisphenol-A. Thus the origin, unknown 1 and unknown 2 represents products that are less polar than tetrabromobisphenol-A, unknown 3, unknown 4 and unknown 5 represent products with a polarity intermediate between tetrabromobisphenol-A and bisphenol-A, and polar represents products that are more polar than bisphenol-A.

Analysis of the water and soil layer at month 4 and month 6 indicated that fully anaerobic conditions were not present in the test system at month 4 (dissolved oxygen content and redox potential of the water phase was 2.4 to 4.0 mg/l and 214 to 234 mV respectively and redox potential of soil layer was 182-197 mV) but anaerobic conditions had been reached by month 6 (dissolved oxygen content and redox potential of the water phase was 0.3 to 3.2 mg/l (generally $\leq$0.6 mg/l) and -59 to -109 mV respectively and redox potential of soil layer was -54 to -152 mV). Therefore, only the results from the test chambers at month 6 could be related to anaerobic degradation, but the length of time that anaerobic conditions existed is not known. Although the method used to establish anaerobic conditions follows the OECD 307 test guideline, this test design appears better suited to determining the degradation in aerobic soils following a flooding event[10] rather than to determine the actual degradation in

[10] The OECD 307 test guideline notes that aerobic conditions are dominant in surface soils and even in sub-surface soils. Anaerobic conditions may occur only occasionally during flooding of soils after heavy rainfall etc. and the test is designed to mimic this eventuality.

the deeper anaerobic layers of soils. This again adds to the difficulties in interpreting the results from this study.

Sediment systems

Ronen and Abeliovich (2000) found that tetrabromobisphenol-A was dehalogenated to bisphenol-A in an anaerobic sediment system. The sediment used in the study was from a contaminated stream in Israel. Although the sediment was nominally a freshwater sediment, the contamination in the area produced conditions more similar to a marine sediment environment. For example, the chloride, bromide and sulphate concentrations were 21,060, 5,791 and 7,127 mg/kg respectively in the sediment and 7,350, 3,372 and 1,132 mg/l in the overlying water. The sediment had a pH of 8.3 and an organic carbon content of 3.73%.

The experiment was carried out by placing 10 g wet weight (equivalent to 7 g dry weight) of drained sediment into a flask and adding 90 ml of sterile growth medium (containing 30 g/l NaCl, 1.5 g/l K_2HPO_4, 0.6 g/l $MgSO_4$, 0.5 g/l peptone, 0.5 g/l tryptone, 1 g/l glucose, and 1 g/l of yeast extract). The pH of the system was adjusted to 7.7 and tetrabromobisphenol-A (concentration 100 mg/l) was added from a stock solution prepared in 0.2N NaOH. The resulting slurry was incubated in an anaerobic chamber containing a 94% nitrogen/6% hydrogen atmosphere at 30^{o}C for up to 3 months. Autoclaved sediment was used as a control. Each treatment was carried out in triplicate and the whole experiment was carried out twice.

Tetrabromobisphenol-A was found to degrade to bisphenol-A. The presence of bisphenol-A was detected by HPLC analysis with UV detection and confirmed by GC-MS analysis of an extract from the sediment slurry. The kinetics of the degradation showed that tetrabromobisphenol-A had almost completely disappeared (~85% degraded) within the first 10 days of the experiment. Intermediate products, tentatively identified by GC-MS as tri- and dibromobisphenol-A were shown to be present at around 15 days. After 45 days, tetrabromobisphenol-A was shown to be completely dehalogenated and bisphenol-A was formed as the major product. The amount of bisphenol-A present at 45 days corresponded to a yield of ~88% based on the initial amount of tetrabromobisphenol-A added. Bisphenol-A was found to persist in the anaerobic sediment slurry with no further degradation being observed after 3 months of incubation. The study did show that bisphenol-A could be degraded rapidly under aerobic conditions using a gram-negative bacterium (tentatively identified as *Sphingomonas* sp.) isolated from soil, and it was suggested that tetrabromobisphenol-A could be completely degraded using a combination of anaerobic followed by aerobic conditions.

Further brief details of this study were reported in a poster abstract (Ronen and Abliovich, 1999). This indicated that reaction was sensitive to the salinity of the sediment, with the maximum activity being seen at 3% NaCl. The presence of electron acceptors such as nitrate, sulphate or carbonate was found to retard the dehalogenation activity, and no significant dehalogenation of tetrabromobisphenol-A was observed after 30 days incubation using a contaminated soil/sediment slurry mixture (20% w/v soil and 5% w/v sediment) when incubated under anaerobic conditions.

A follow-up study by Arbeli and Ronen (2003) investigated further the intermediate metabolites produced during the reductive debromination of Tetrabromobisphenol-A. The paper indicates that, in the original study by Ronen and Abeliovich (2000), attempts to obtain

an enrichment culture of the bacteria responsible for the degradation failed as the debrominating activity was lost after the first sub-culturing and so the follow-up study also investigated further the conditions under which the debromination occurred. The inoculum used in the study was sediment from close to an industrial complex in Israel. Experiments were carried out using a batch reactor system and also a semi-continuous batch reactor. All incubations were carried out in an anaerobic chamber with an atmosphere of 94% nitrogen and 6% hydrogen. The reactors containing mineral medium were incubated in the anaerobic chamber for 24 hours prior to inoculation (the pH was adjusted to 7.4) and after inoculation the flasks were sealed and incubated at 30°C (the flasks were only opened for sampling).

The semi-continuous batch reactor system consisted of 250 ml flasks containing 110 ml of mineral medium and 15% (on a weight basis) sediment. Tetrabromobisphenol-A (90 μM ~ 50 mg/l) and glucose (1 g/l) were added to the mineral medium. In use, around 1-23% of the liquid phase was periodically removed from the reactor and replaced with fresh anaerobic medium to give a total concentration of 90 μM tetrabromobisphenol-A and 0.5 g/l of glucose in the reactor.

The batch reactor system consisted of 120 ml flasks containing 40 ml of mineral media. Tetrabromobisphenol-A (90 μM) and ethanol (0.2% on a volume basis) were added to the mineral media just prior to inoculation. The inoculum used in these studies was 10 ml of a culture from a semi-continuous batch reactor operating on a six-day renewal basis (i.e. every six days 25% of the mixed slurry was replaced by a mineral medium containing 10% (by weight) sterile gray chalk. Tetrabromobisphenol-A and ethanol were also added to give a final concentration of 55 μM (30 mg/l) and 0.1% (on a volume basis) respectively). In order to investigate the effects on the debromination reaction, various supplements were added to the batch reactors (all were sterilized prior to use) including sediment from the site, acid-purified sand (40-100 mesh), soil from Sede-Boqer (Negev Desert), and pulverised (sieved below 0.5 mm) gray chalk and white chalk.

The experiments using the semi-continuous batch reactor showed that tetrabromobisphenol-A was being degraded. The intermediate products found to be formed in the study were tribromobisphenol-A, 2,2'-dibromobisphenol-A, monobromobisphenol-A with the final product being bisphenol-A. The debrominating ability of the system was found to decrease with time but it was found that the debrominating activity could be restored by the addition of fresh sterile sediment to the system.

A gradual loss of debrominating activity was also seen in a batch experiment containing sediment slurry (20% by weight) where tetrabromobisphenol-A (90 μM) and ethanol (0.1% by volume) were added repeatedly. After the first addition, 91.6% of the tetrabromobisphenol-A was found to be degraded to bisphenol-A within 4 days, but this fell to 71.8% in six days after the second addition and 41% in eight days after the third addition. This loss of debrominating activity was shown not to be related to any toxic effects of the bisphenol-A formed (i.e. addition of 400 μM of bisphenol-A showed no inhibition of the degradation of tetrabromobisphenol-A).

Further batch reactor studies were carried out to investigate the factors important in the debromination reaction. These showed that sterile sediment, crushed gray chalk and soil appeared to stimulate the debromination reaction, whereas crushed white chalk and acid-purified sand had no effect. The factor important for stimulating the reaction was thought to be organic in nature as heat-treated (550°C for one hour) sediment, soil and gray

chalk, and solvent-extracted gray chalk, did not stimulate the reaction. The degree of stimulation was found to depend on the concentration of sediment or gray chalk added to the system, although it was indicated that high concentrations may limit the bioavailability of tetrabromobisphenol-A in the system.

The kinetics of the debromination reaction were investigated in the batch reactor system using a range of tetrabromobisphenol-A concentrations (90, 180, 360 and 720 μM ~ 50, 100, 200 and 400 mg/l) and gray chalk concentrations (0, 2.5, 5, 10 and 20% by weight). The maximum rates of tetrabromobisphenol-A debromination and bisphenol-A formation were found to be almost identical. The initial concentration of tetrabromobisphenol-A was found to increase both the lag time (~0 days at 90 μM, <4 days at 360 μM and >4 days at 720 μM) and the maximal rate of debromination (159 μM Br^-/day at 90 μM, 221 μM Br^{-1}/day at 360 μM and 613 μM Br^-/day at 720 μM).

Overall the study concluded that the debromination of tetrabromobisphenol-A depends on the presence of solids such as sediment, soil and gray chalk and this finding was reported to be consistent with the results of other studies investigating the dehalogenation of other polyhalogenated compounds such as PCBs (e.g. Wiegel and Wu, 2000). The stimulating factor in the solids was not identified but was thought to be associated with the organic fraction of the solids and may be related to sorption of tetrabromobisphenol-A to the solids. The fact that the lag phase for the debromination increased when the initial concentration of tetrabromobisphenol-A increased was thought to suggest that tetrabromobisphenol-A may be toxic to the anaerobic bacteria present at the higher concentrations tested.

Arbeli *et al.* (2006) investigated further the factors that affected the reductive dehalogenation of tetrabromobisphenol-A in sediment from a contaminated site. The site is located above a fractured chalk aquifer and some of the fractures are exposed in an ephemeral stream bed. The degradative activity was investigated in both the surface stream sediments and deeper fracture-filling material underlying the stream (collected at a depth of 3 m during excavation work that was being carried out in the area). The fracture-filling material was of two distinct types, termed black and white in the paper.

Anaerobic microcosms were used in order to evaluate the sulphate reduction activity of the sediment and fracture-filling material (sulphate reduction activity was taken to provide an indication of total microbial activity). For these experiments, samples of sediment or fracture-filling material and water (1:10 weight: volume ratio) were augmented with acetate (concentration 3 g/l) and incubated under an atmosphere of 95% nitrogen and 6% hydrogen at 30°C, and the concentration of acetate and sulphate in the liquid phase was determined at intervals.

The reductive debromination experiments were carried out using a similar method to that used by Ronen and Abeliovich (2000) above. An enrichment culture was derived from the stream sediment and maintained in a similar semi-continuous batch reactor as used by Arbeli and Ronen (2003) above. All incubations were run in triplicate at 30°C without shaking. The incubation flasks (125 ml) containing 40 ml of mineral medium and 5 g sterile grey chalk were placed in an anaerobic chamber 24 hours prior to the start of the experiment. Tetrabromobisphenol-A (as a solution in 0.2 N NaOH) and ethanol (0.2% vol/vol) were added to give a initial nominal concentration of 90 μM (~49 mg/l). The pH was then adjusted to 7.4 and 10 ml of the enrichment culture was added as the inoculum source. The

degradation was monitored at periodic intervals by determining the concentration of bisphenol-A present in the aqueous phase.

In order to determine the optimal conditions for reductive debromination, experiments were carried out varying the incubation temperature, the sodium chloride concentration in the mineral medium and the pH. Experiments were also carried out to investigate a range of carbon sources and electron donors. These carbon source experiments were carried out in mineral medium (without chalk) inoculated with enrichment culture (10% vol/vol) augmented with one of ethanol (34.4 mM), pyruvate (17.5 mM), glucose (5.6 mM), a combination of acetate and hydrogen (17.5 mM and 25% of the atmosphere respectively), a combination of acetate and formate (17.5 mM and 43.5 mM respectively), citrate (5.2 mM) and succinate (8.5 mM). The electron donor experiments were carried out in mineral medium with chalk (1.5% wt/vol) inoculated with enrichment culture (10% vol/vol) augmented with one of Na_2SO_4 (40 mM), $NaNO_3$ (40 mM), Na_2SO_3 (40 mM) or amorphous iron (250 mM). A final experiment investigated the effect of 2,4,6-tribromophenol (concentrations of 30, 180 and 360 μM) on debromination of tetrabromobisphenol-A.

Tetrabromobisphenol-A was found to be present as a contaminant in both the sediment and fracture-filling material used in this study. The concentrations present were 17.5 mg/kg dry wt. and 120 mg/kg dry wt. respectively. The difference in concentration was thought to relate to the different microbial activities in the surface sediment compared to the fracture-filling material. For example, in the experiments designed to assess the microbial activity of the sediments, the surface sediments microcosms could reduce 43.5 nM of sulphate in nine days whereas the microcosms using black and white fracture-filling material could only reduce 51 mM and 37.1 mM respectively in 109 days. Methanogenesis in the surface sediment cultures appeared to be a minor process.

Reductive debromination of tetrabromobisphenol-A to bisphenol-A was found to occur in the experiments using surface sediments but not the experiments using fracture-filling material. The culture enrichment experiments using the surface sediments found that the optimal conditions for reductive debromination of tetrabromobisphenol-A occurred at a temperature of 30°C, a salinity of 2-3% NaCl and a pH of 7-8. Under these conditions, around 70-80 μM of bisphenol-A was formed after 10 days incubation (values read from a graph; effective conversion was therefore ~80-90%). The rate of debromination was found to be slightly (but statistically significantly) reduced at a pH of 6-6.5 but was strongly inhibited at pH 8.5 and completely inhibited at pH 9. Suitable electron donors and carbon sources for this system were found to include ethanol, pyruvate and hydrogen with acetate. The presence of electron acceptors such as iron(III) ions, sulphate, sulphite, nitrate and 2,4,6-tribromophenol was found to inhibit the debromination of tetrabromobisphenol-A. The microbial population responsible for the debromination were found to be heat sensitive (destroyed at 80°C for 10 minutes) but were not inhibited by bromoethansulphonate or molybdate.

A further anaerobic degradation study with tetrabromobisphenol-A has been carried out by Voordeckers *et al.* (2002). The study investigated the effects of different electron-accepting conditions on the degradation in estuarine sediment. The sediment was collected from the Arthur Kill tidal strait located between Staten Island and New Jersey. The test sediments were prepared by adding 3.87 ml of tetrabromobisphenol-A in hexane (2.58 mM) to 1 g of dry, sterile sediment in a 60 ml bottle and allowing the hexane to evaporate over several days. A slurry of live sediment (25% v/v) was then produced in an anaerobic methanogenic or sulphur-reducing medium and added to the tetrabromobisphenol-A-spiked dry sediment

under a N_2:CO_2 (70%:30%) atmosphere. The salinity of the medium used was not given but it contained 1.3 g/l KCl and 1.17 g/l NaCl. The bottles were then capped, shaken to mix and then incubated at 28°C in the dark without shaking. Under the conditions used the concentration of tetrabromobisphenol-A was around 200-260 µM (109-140 mg/l) and >95% of the tetrabromobisphenol-A added was partitioned to the solid phase. In addition to tetrabromobisphenol-A alone, experiments were also carried out using a mixture of tetrabromobisphenol-A and 2,6-dibromophenol. Each experiment was carried out in triplicate and sterile controls were also run. The degradation was followed by HPLC analysis. At various times during the study, each bottle was shaken and a small portion of the sediment slurry was removed and analysed for the presence of tetrabromobisphenol-A and any breakdown products formed.

The experiments carried out under methanogenic conditions showed that degradation of tetrabromobisphenol-A began within 14 days of the start of the experiment, and near complete degradation of the tetrabromobisphenol-A occurred within 55 days. The half-life for disappearance of tetrabromobisphenol-A was around 25-30 days (read from graph) in both the experiments using tetrabromobisphenol-A alone and the mixture of tetrabromobisphenol-A and 2,6-dibromophenol. The main degradation product found in the study was bisphenol-A. This product started to be formed after about 25 days in the experiments using tetrabromobisphenol-A alone, but started to be formed almost immediately in the experiments using the mixture of tetrabromobisphenol-A and 2,6-dibromophenol. The final yield of bisphenol-A was the same in both experiments with both showing almost 100% conversion.

In the experiments carried out using sulphur-reducing (sulphidogenic) conditions, almost complete conversion of the tetrabromobisphenol-A to bisphenol-A was again seen in 112 days. In this case the disappearance of tetrabromobisphenol-A showed a lag phase of around 28 days, but was virtually complete by day 112. Bisphenol-A was first shown to be formed at around day 70 of the study.

The presence of transient intermediates was detected in both the methanogenic and sulphidogenic experiments. These intermediates were not identified but were presumed to be lower halogenated bisphenol-A compounds.

A further series of experiments with tetrabromobisphenol-A using sediment that had been adapted to 2-bromophenol over a one year period gave very similar results to those found with unadapted sediment above. In studies using bisphenol-A, either on its own or as a mixture with 4-hydroxybenzoate (a known intermediate of the aerobic degradation of bisphenol-A), no degradation was seen over 162 days under methanogenic, sulphate-reducing, iron(III)-reducing or nitrate-reducing conditions (Voordeckers *et al.*, 2002).

Wildlife International (2006b) has investigated the anaerobic degradation of ^{14}C-labelled tetrabromobisphenol-A in freshwater aquatic sediment systems using the OECD 308 Test Guideline. The substance tested had a radiochemical purity of 99.6%. The sediments and water used in this study were collected from two freshwater sources, Turkey Creek (Talbot County, Maryland) and Choptank River (Caroline County, Maryland). The anaerobic water samples were collected from below the surface of the water, and the anaerobic sediment samples were collected from the top layers of sediment under approximately 1 m of water. The sediments were wet-sieved through a 2 mm sieve prior to use.

The Turkey Creek sediment was classified as loam and consisted of 43% sand, 30% silt and 27% clay, and had an organic carbon content of 7.5% (organic matter content of 12.8%). The Choptank River sediment was classified as sand and consisted of 96% sand, 3% silt and 1% clay, and had an organic carbon content of 0.7% (organic matter content of 1.1%). The sediments were analysed for the presence of tetrabromobisphenol-A prior to use. No tetrabromobisphenol-A was detected in either sediment (detection limit 15 µg/kg dry weight).

The test chambers used consisted of 500 ml glass bottles with a 2.5 cm deep layer of sediment and a 9 cm depth of overlying water. The Turkey Creek vessels contained around 100-115 g wet sediment (equivalent to 26-30 g dry weight) and 280-300 ml water, and the Choptank River vessels contained 150-170 g wet sediment (equivalent to 113-128 g dry weight) and 280-300 ml water. Similar to the case with the anaerobic sewage sludge study above, parallel sets of test chambers were used to determine the mineralization and volatile products and the initial transformation products. The mineralization and volatile products traps were analysed on days 14, 28, 42, 56, 77, 98 and 102, and the initial transformation products were determined on days 0, 14, 28, 42, 56 and 102. The experiments were carried out using biotic test systems (no sterile (abiotic) test vessels were used in this experiment) and each sediment was tested in duplicate. The test vessels for the mineralization experiments were continuously purged with nitrogen. The headspace for the experiments investigating the initial transformation products was a mixture of nitrogen (80%), carbon dioxide (10%) and methane (10%). All test chambers were incubated in the dark at 20°C for fourteen days prior to the start of the test.

The test was started by adding the test substance to the sediment as a solution in ethanol. The nominal concentration of tetrabromobisphenol-A was 50 µg/kg dry weight. The amount of ethanol added to the test chambers was between 33 and 60 µl. The incubations were carried out at 20°C for up to 102 days.

During the test the pH of the sediments was found to be in the range 6.4 to 6.8 for the Turkey Creek sediment and 6.0 and 6.9 for the Choptank River sediment. The dissolved oxygen concentration[11] of the overlying water was <2 mg/l (range was 0.5-1.8 mg/l) for the Turkey Creek sediment and <3 mg/l (range was 1.8-2.7 mg/l) for the Choptank River sediment. No decline in the microbial biomass was evident over the test duration in the Turkey Creek sediment and an increase in the microbial biomass was evident in the Choptank River sediment.

The amounts of radiolabel present in the water phase, solid phase and gaseous phase (^{14}C and other volatile mineralisation products) were determined. For the analysis, the water phase was separated from the solid phase and extracted with dichloromethane. The dichloromethane extracts were subject to analysis for total ^{14}C and further characterised by high performance liquid chromatography (HPLC). The amount of ^{14}C that was not extracted from the water phase was also determined. The solid phase was extracted using acetonitrile (extracted four times at room temperature with five minutes sonication). The acetonitrile extracts were analysed for total ^{14}C and further characterised by either HPLC or thin layer chromatography

[11] The test report indicates that there was some variability in both the dissolved oxygen concentrations and redox potentials measured during the study, and some of the measurements appear to indicate that aerobic conditions may have existed at some sampling points. Wildlife International (2006b) reports that it is not clear whether the values measured are actually representative of the test system or have been influenced by the manner in which the samples were analysed. It was also pointed out that if aerobic conditions did exist then significant mineralization of the degradation product bisphenol-A would have been expected, but this was not apparent in the results.

(TLC). The non-extracted radioactivity in the solid phase was also determined (combustion analysis).

The results of the study available so far are summarised in **Table 3.18** and shown graphically in **Figure 3.3** (Turkey Creek) and **Figure 3.4 (**Choptank River**)**. Minimal mineralization was evident in both sediments, with the mean cumulative total mineralization being 4.0% and 0.8% in the Turkey Creek and Choptank River sediments respectively over the 102 day test period. As can be seen from **Table 3.18**, at the start of the test most of the radiolabel was present in the water phase (presumably reflecting the fact that the test substance was added directly to the water phase) but at later sampling times, more of the radiolabel was found in the sediment phase.

The results shows that biodegradation of tetrabromobisphenol-A to bisphenol-A again occurred. The total yield of bisphenol-A after 102 days incubation was around 43% in Turkey Creek sediment and 31% in Choptank River, with the amount of bisphenol-A formed still showing an upward trend at the end of the study. The degradation appears to occur via three main intermediate products, but other products less polar than tetrabromobisphenol-A were also found. Overall the mass balance from this study is good.

Further work has been carried out to try to better establish the identities of the intermediate degradation products from this study (Wildlife International, 2006e). The approach taken assumed that the most likely degradation products of tetrabromobisphenol-A are tribromobisphenol-A, dibromobisphenol-A, bromobisphenol-A and bisphenol-A and so reference standards for three of these four products (reference standards were not available for bromobisphenol-A) were used in the method. In addition, analyses were also performed to evaluate the potential presence of both the mono- and dimethylethers of tetrabromobisphenol-A. The analytical method used was a screening approach utilising an HPLC/MS/MS method for selected water and sediment extracts obtained in the original degradation study. However, as this analysis was not based on determination of ^{14}C, and no clean up had been applied to the extract, (or could be used owing to the small amount of extract available), the analysis was severely compromised by the generally high background contamination in the extract when analysed by HPLC/MS/MS. Therefore it was not possible to conclude on the identities of the degradation products found. However, it was found that some extracts contained products with retention times of close similarity to one or more of the reference standards (for example dibromobisphenol-A and tribromobisphenol-A were possibly present in the water and sediment extracts, and also possibly mono- and dimethylether of tetrabromobisphenol-A were present in some of the water extracts), but other, unidentified, peaks were also present in the chromatograms (it is not entirely clear from the paper whether these are potential degradation products of tetrabromobisphenol-A or other substances that were extracted from the sludge unrelated to tetrabromobisphenol-A).

The DT_{50} for tetrabromobisphenol-A from the total test system was estimated to be around 28 days for the Turkey Creek sediment and 24 days for the Choptank River sediment. The equivalent values determined for the water layers were 16 days (Turkey Creek) and 14 days (Choptank River) and the values for the sediment layers were 42 days (Turkey Creek) and 28 days (Choptank River). It should be noted that, as the sediment and water phases did not appear to be in equilibrium at the start of the test, the half-lives for the water layers and sediment layers probably include contributions from two kinetic processes, degradation and adsorption to sediment.

Table 3.18 Summary of degradation in anaerobic freshwater sediment

Time (days)	% Radioactivity																			Total mass balance
	Non-retained		Polar[a]		Bisphenol-A		Unknown 1[a]		Unknown 2[a]		Unknown 3[a]		TBBPA[a]		Non-polar[a]		Total 14 - Not identified			
	Water	Sed.	Water	Sed.	Water	Sed.	Water	Sed.	Water	Sed.	Water	Sed.	Water	Sed.	Water	Sed.	Aqueous fraction[b]	Solids[c]	Gaseous	
Turkey Creek																				
0	0.0		0.0		4.0		0.0		0.0		2.6		83.5				1.6	0.9	0.0	96.1
14	0.0	0.0	0.2	1.2	0.6	2.3	0.0	4.8	0.0	5.7	1.7	1.9	37.4	22.7	0.8	0.1	5.5	2.8	0.3	88.0
28	0.0	0.0	0.6	2.9	1.1	6.7	0.0	10.0	1.5	10.0	2.4	3.0	20.6	22.1	1.7	0.7	4.6	6.0	0.4	94.3
42	0.0	0.0	0.0	4.8	1.1	11.8	2.0	11.0	2.4	6.5	2.9	0.7	13.2	16.6	1.5	2.3	5.5	6.2	0.4	88.9
56	0.0	0.0	1.8	7.1	3.4	21.3	4.2	13.8	3.6	5.6	2.4	0.6	5.7	8.9	1.0	1.1	3.3	5.2	0.5	89.5
102	3.4	0.0	2.8	0.0	8.8	34.2	3.4	8.4	2.0	10.8	0.9	2.5	1.1	6.0	0.0	0.0	2.0	6.9	4.0	97.2
Choptank River																				
0	0.0		0.7		1.6		0.0		0.3		3.6		90.9		2.5		0.9	0.4	0.0	104.1
14	0.0	0.0	0.2	0.0	5.1	0.0	0.2	0.0	0.5	0.6	0.8	2.0	19.6	28.7	0.9	2.7	8.4	11.0	0.1	80.8
28	0.0	0.0	0.4	0.3	0.9	0.0	0.3	1.6	1.1	3.8	2.5	4.5	18.2	26.4	1.0	3.5	14.4	6.7	0.1	85.7
42	0.0	0.0	0.0	0.5	1.7	2.5	0.0	3.7	1.2	9.6	1.4	6.7	11.6	25.2	0.9	3.3	4.9	5.2	0.1	78.5
56	0.0	0.0	1.4	0.0	2.1	6.1	1.2	5.5	1.7	10.6	1.0	4.7	4.7	11.8	0.5	1.5	11.4	11.9	0.1	76.2
102	2.5	3.8	5.0	6.2	9.7	21.5	3.5	5.6	2.1	6.7	0.3	1.9	0.5	3.9	0.0	0.0	4.9	9.8	0.8	88.7

Notes: a) The identities of some of the degradation products were not established in this study. The peaks found in HPLC analysis (using a radiochemical detector) were grouped based on their retention times, and then compared with the retention times for tetrabromobisphenol-A and bisphenol-A. Thus unknown 1, unknown 2 and unknown 3 are products with a polarity intermediate between tetrabromobisphenol-A and bisphenol-A, polar products are more polar than bisphenol-A, and non-polar products are less polar than tetrabromobisphenol-A.
b) Radiolabel that was not extracted from the water phase by dichloromethane.
c) Radiolabel that was not extracted from the solid phase by acetonitrile.

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Figure 3.3 Degradation of tetrabromobisphenol-A in Turkey Creek sediment under anaerobic conditions

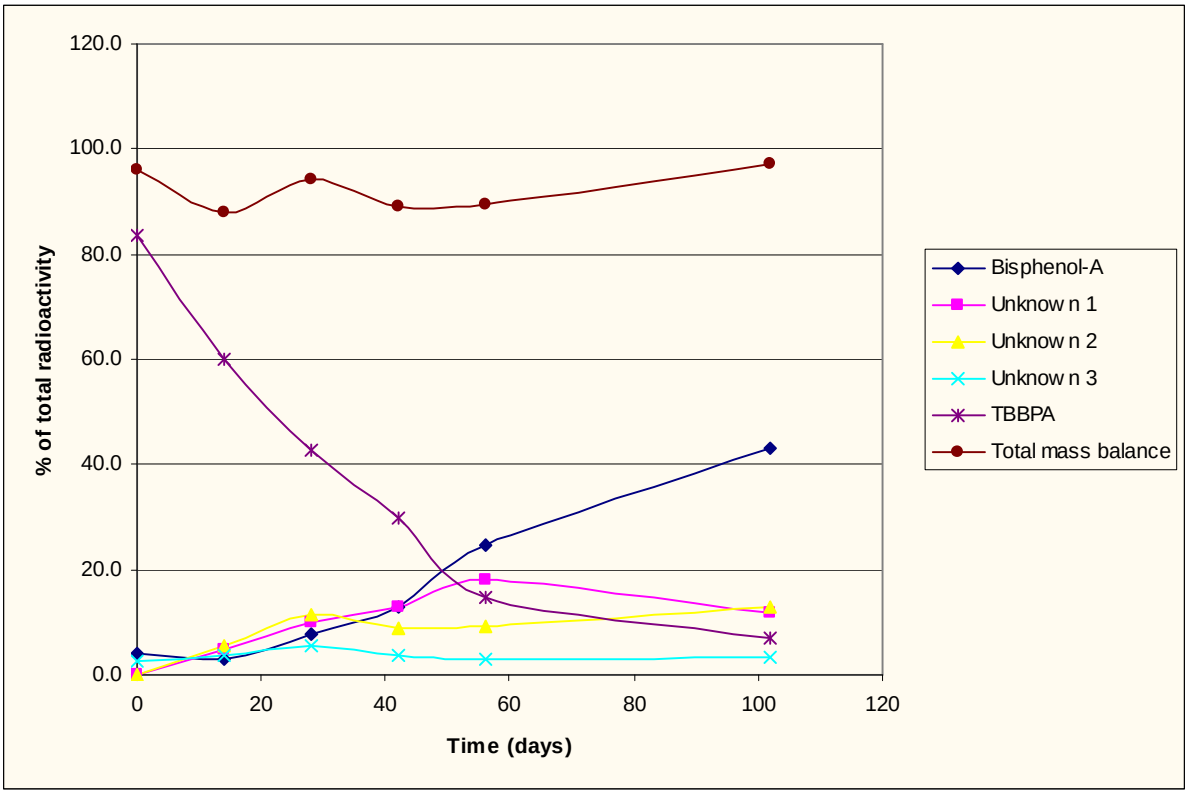
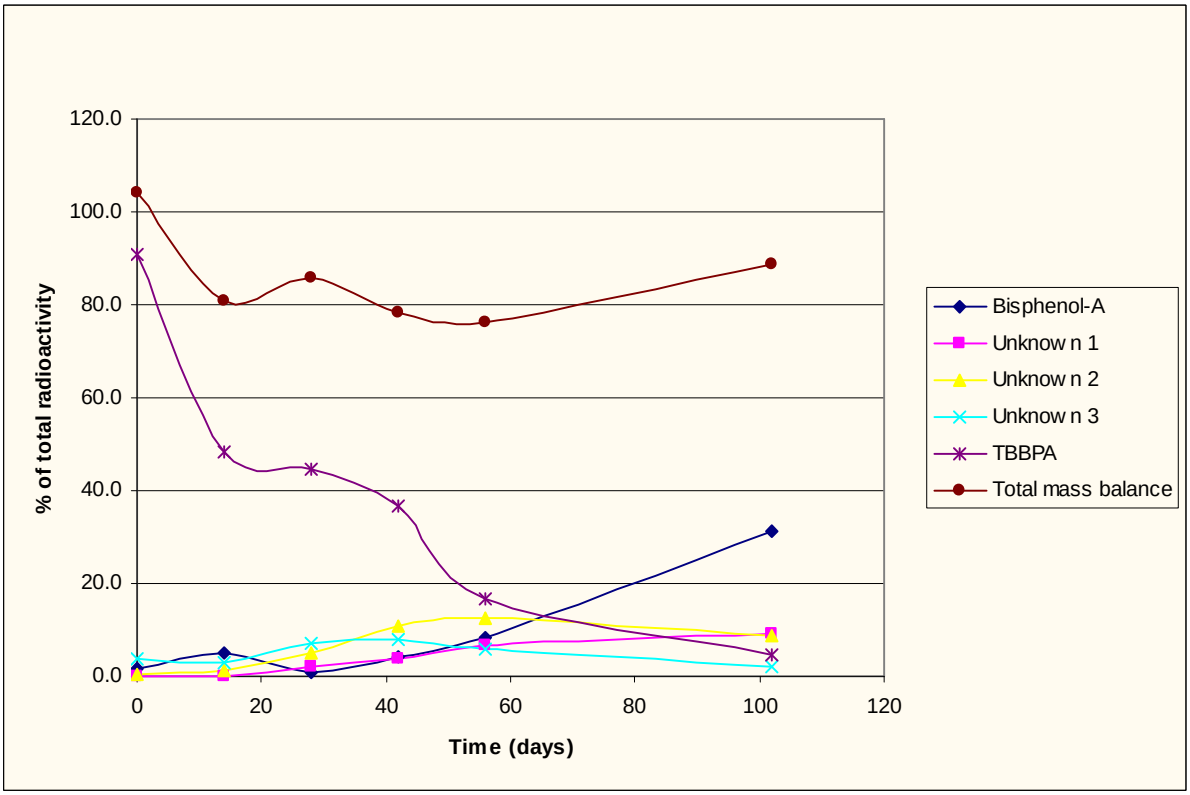


Figure 3.4 Degradation of tetrabromobisphenol-A in Choptank River sediment under anaerobic conditions



Another study has recently demonstrated that tetrabromobisphenol-A is degraded to bisphenol-A under anaerobic conditions (Ravit *et al.*, 2005). The study used sediments from contaminated and uncontaminated salt marsh field sites in New Jersey. The study was designed to investigate the effect of vegetation on the degradative ability of the sediment, and sediments were collected from areas where one of two different macrophytes were present (either *Spartina alterniflora* or *Phragmites australis*) or from unvegetated areas. The degradation of tetrabromobisphenol-A was investigated using anaerobic methanogenic sediment microcosms for up to 130 days (the test system was reported to be similar to that used by Voordeckers *et al.* (2002) and all incubations were carried out at 28°C in the dark). Tetrabromobisphenol-A was found to be degraded to bisphenol-A in the experiments, with bisphenol-A found to be more resistant to further degradation. Two transient intermediate degradation products were identified as tribromobisphenol-A and dibromobisphenol-A. The degradation of tetrabromobisphenol-A was found to occur most rapidly in contaminated (tetrabromobisphenol-A was not detectable after 61 days incubation) and uncontaminated sediments (tetrabromobisphenol-A was not detectable after 115 days incubation) from areas where *Spartina* occurred, compared with the sediments from areas where *Phragmites* occurred or unvegetated sediments.

Summary of biodegradation

The available biodegradation data show that tetrabromobisphenol-A can undergo primary biodegradation to form several products. Ultimate mineralisation to form carbon dioxide or methane appears to be low over the timeframe of the available studies (e.g. up to 6 months under aerobic conditions and >100 days under anaerobic conditions). Based on the results of standard biodegradation tests, tetrabromobisphenol-A is not readily biodegradable.

Under aerobic conditions, around 18-64% of the tetrabromobisphenol-A was degraded to unidentified products in 64 days in various soils at temperatures around 21.5°, and around 36-55% was degraded in 56 days in a sediment system at 25°C. Based on these data, the rates of primary degradation in the soil and sediment systems used appear to be similar, and approximate half-lives in the general range of 50 to 70 days at 22-25°C can be estimated from the data. These half-lives would be equivalent to half-lives of around 107-198 days[12] at 12°C (the default temperature assumed in the risk assessment). More recent studies have shown 18-22% mineralisation of tetrabromobisphenol-A over six months incubation in soil, suggesting a mineralisation half-life of >> 6 months.

One study shows that tetrabromobisphenol-A can undergo O-methylation by certain bacterial strains. This type of reaction may explain the presence of the dimethyl ether derivative of tetrabromobisphenol-A that is found in some surveys of environmental levels. However, only trace amounts of the dimethyl ether or diethyl ether derivatives were found to be formed in aerobic degradation studies using soil systems. The other products formed as a result of aerobic biodegradation of tetrabromobisphenol-A are unclear.

The identities of other intermediate degration products under aerobic conditions have also been investigated in soil simulation tests. The analytical methods used were not able to unambiguously identify the products found but there are indications that small amounts of bisphenol-A may have been formed in some test systems. Bisphenol-A has been established as a degradation product under anaerobic conditions (see below). However, as the formation

[12] Using the methods outlined in the Technical Guidance Document and incorporated into EUSES 2.0.3.

of bisphenol-A requires reductive debromination of tetrabromobisphenol-A to occur, it would be surprising if this were a significant process under strictly aerobic conditions. Although the available aerobic degradation studies were carried out using appropriate methods in order to maintain aerobic conditions during the test, it cannot be ruled out that anaerobic 'pockets' may have been present in the deeper layers of the soils used, and this may explain the presence of bisphenol-A in some of the test systems. It should also be noted that bisphenol-A is readily biodegradable (EC, 2003a) and so itself would be expected to degrade (mineralize) under the conditions of the aerobic tests. Given the relatively slow rate of degradation of tetrabromobisphenol-A under the conditions used, significant build-up of bisphenol-A would therefore not be expected in such systems even if it were formed by an aerobic process.

Tetrabromobisphenol-A has also been shown to undergo primary biodegradation under anaerobic systems. Using an anaerobic soil system, around 10-56% degradation of tetrabromobisphenol-A was seen over 64 days at 24°C. The degradation was found to be faster using a sandy loam and silty loam soil (approximate biodegradation half-life of 60-70 days), than in a clay soil (around 10% degradation in 64 days). A half-life of 60-70 days at 21.4°C would be equivalent to a half-life of 127-148 days[12] at 12°C.

Anaerobic degradation has also been demonstrated in sewage sludge, where a half-life of around 19 days was determined at 35°C. Another very recent study has shown a much shorter half-life of 0.59 days in digested sewage sludge, but this study has not yet been fully reviewed for this assessment.

Studies are also available investigating the anaerobic degradation of tetrabromobisphenol-A in sediments. Experiments with uncontaminated freshwater anaerobic sediments found a half-life of around 24-28 days at 20°C for the whole water/sediment system and a half-life of 28-42 days at 20°C when the sediment phase alone was considered. This is equivalent to a half-life of around 43-53 days (whole system) or 53-80 days (sediment phase only)[12] at 12°C. The half-life in anaerobic marine sediments was determined to be around 25-30 days at 30°C. This is equivalent to a half-life of around 72-108 days[12] at 12°C. Anaerobic degradation was found to be more rapid in a contaminated sediment system, with around 85% degradation occurring in ten days at 30°C.

Of special interest is that several of the studies have shown that the main degradation product formed under anaerobic conditions is bisphenol-A. This has been shown to be formed almost quantitatively from tetrabromobisphenol-A in some of these studies. This substance has been subject to a recent risk assessment under the Existing Substances Regulation (EC, 2003a; ECB, 2008). Although the test conditions used in the Ronen and Abliovich (2000) study, particularly the high concentrations of salts present, may not be applicable to the environment in general, the studies by Voordeckers *et al.* (2002) and Wildlife International (2006a and b) amongst others have shown that tetrabromobisphenol-A has the potential to degrade to bisphenol-A under a range of relevant anaerobic conditions (e.g. sewage sludge, freshwater sediments and marine sediments).

In terms of the environmental modelling used in this risk assessment, it is necessary to determine a biodegradation rate for use in the sewage treatment plant and the surface water, sediment and soil compartments.

For the aerobic sewage treatment plant, it will be assumed that tetrabromobisphenol-A is not readily or inherently biodegradable, and hence a rate constant of 0 h^{-1} as given in the Technical Guidance document will be used.

The situation for surface water, sediment and soil is somewhat more complicated as only primary degradation has been shown to occur in most of the available tests, with only limited mineralisation (up to 18-22% after 6 months) being seen in recent studies with soil. The rate constant used in the risk assessment should be for ultimate biodegradation (mineralisation) at 12°C, but it is not possible to currently derive a reliable rate constant for mineralisation from the available data. The default ultimate biodegradation half-lives from the Technical Guidance Document are effectively infinite for these compartments if it assumed that the substance is not biodegradable. The equivalent default biodegradation half-lives if it is assumed that tetrabromobisphenol-A is inherently biodegradable would be 150 days in water, 30,000-300,000 days for soil (the soil half-life depends on the value for the solids-water partition coefficient for soil (Kp_{soil}) , which is around 3,000 l/kg – however it is possible that under some situations the actual adsorption to soil could be higher than indicated by this value (see Section 3.1.0.7.2)), with the half-life in sediment being ten times longer than in soil (the default assumption is that the rate of anaerobic degradation in sediment is effectively zero). These predicted half-lives for ultimate biodegradation are much longer than the half-lives measured for primary biodegradation of tetrabromobisphenol-A in sediment and soil.

For tetrabromobisphenol-A it is clear that the substance has the potential to degrade in soil and sediment under both aerobic and anaerobic conditions, and so it is probably not appropriate to use a zero rate constant (or infinite half-life) for these processes. Therefore, since the available data do not allow an actual rate constant to be estimated for ultimate biodegradation, as a worst case approach it will be assumed that the default rate constants for an inherently biodegradable substance from the Technical Guidance Document are applicable in this instance. For sediment, as there is evidence that primary biodegradation under anaerobic conditions occurs at a similar rate as under aerobic conditions, and that the rate is similar in both soil and sediment, the same default biodegradation rate constant as for soil will be used in the risk assessment.

There are no biodegradation simulation studies available for water. Since degradation has been seen in soil and sediment-water systems, it is likely that tetrabromobisphenol-A will also be susceptible to biodegradation in surface water to some extent. In order to take this into account, the default half-life assuming inherent biodegradability of 150 days will be used in the risk assessment (for modelling purposes only). It should be noted that because the actual residence time of water within the model used to predict the regional and continental concentrations is much shorter than this half-life, the use of a longer half-life than this (e.g. if an infinite half-life was assumed) would have minimal effect on the concentrations predicted (for example the regional concentration goes from 5.5×10^{-4}-2.6×10^{-3} µg/l to 5.9×10^{-4}-3.1×10^{-3}µg/l when the half-life for water is changed from 150 days to infinity).

The ultimate biodegradation rate constants and half-lives that will be used in the environmental modelling are summarised in **Table 3.19**. There is some uncertainty in their applicability to tetrabromobisphenol-A, and the rate constants used, particularly for sediment and soil, may underestimate the actual biodegradation rate of tetrabromobisphenol-A in environment[13]. However, such an approach does recognise that some degradation products

[13] The degradation half-lives for tetrabromobisphenol-A were discussed at TM I'03. Here the view of some

formed from tetrabromobisphenol-A may be relatively stable and have the potential to cause effects on the environment. Appendix E considers the sensitivity of the assessment to the biodegradation rate constants chosen compared with those for primary degradation derived from the experimental data.

Table 3.19 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		4.7×10^{-3} d^{-1}	150 days
Soil	Kp_{soil} = 3,000 l/kg	2.31×10^{-5} d^{-1}	30,000 days
	Kp_{soil} >3,000 l/kg	2.31×10^{-6} d^{-1}	300,000 days
Sediment	Kp_{soil} = 3,000 l/kg	2.31×10^{-5} d^{-1}	30,000 days
	Kp_{soil} >3,000 l/kg	2.31×10^{-6} d^{-1}	300,000 days

In addition to the ultimate biodegradation rate constants summarised in **Table 3.19**, it should also be taken into account that tetrabromobisphenol-A can be degraded to bisphenol-A, particularly under certain anaerobic conditions.

Dehalogenation to bisphenol-A has so far been demonstrated under anaerobic conditions in freshwater sediments, estuarine (marine) sediments and contaminated sediments with high salt contents. It has also been shown that tetrabromobisphenol-A degrades to bisphenol-A in anaerobic sewage sludge with a disappearance half-life of 19 days at 35°C (although very recent work has found a much shorter disappearance half-life of 0.59 days in sewage sludge). There are also some indications that small amounts of bisphenol-A may be formed under aerobic conditions in for example soils (although it is not clear if this is a true aerobic process or results from 'pockets' of anaerobic conditions within the aerobic soil test system used). There are currently no simulation tests investigating the degradation of tetrabromobisphenol-A in surface water systems.

The consequences of tetrabromobisphenol-A degradation under anaerobic conditions in the environment is considered in the updated bisphenol-A risk assessment (ECB, 2008). Preliminary work (EURAS, 2006) has indicated that re-partitioning of the bisphenol-A from sediment to water may be important in the overall degradation process and this is discussed further in ECB (2008).

3.1.0.7 Distribution

3.1.0.7.1 Volatilisation

The vapour pressure of tetrabromobisphenol-A at ambient temperature is $<1.19\times10^{-5}$ Pa, most likely around 6.24×10^{-6} Pa or less. The very low vapour pressure means that, once in the environment, tetrabromobisphenol-A is likely to distribute to compartments other than the atmosphere.

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member states, notably Sweden and Denmark, was that an infinite biodegradation half-life should be used for this substance. The effect of using an infinite biodegradation rate on the predicted regional concentrations is shown in Appendix E. The use of an infinite biodegradation half-life has only a small effect on the calculated PECs and hence risk assessment.

The Henry's law constant for tetrabromobisphenol-A is <0.10 Pa m^3/mole, most likely around 0.054 Pa m^3/mole or less, which again indicates that volatilisation of tetrabromobisphenol-A from water to the atmosphere is likely to be a relatively minor environmental distribution process.

3.1.0.7.2 Adsorption

Sediment

The adsorption of tetrabromobisphenol-A to sediment has been determined during a toxicity study on sediment-dwelling midge larvae (Springborn Laboratories, 1989c). The substance used in the test was ^{14}C-labelled tetrabromobisphenol-A (possibly mixed with a composite sample of unlabelled tetrabromobisphenol-A from five different manufacturers). Three sediments of varying organic matter content were used in the test. These sediments were produced by mixing different proportions of two natural stream sediments, one rich in organic debris and one predominantly sandy in nature. The sediments had a pH value of around 5.4-5.5. The tests were carried out in centrifuge tubes containing 5 g of dry sediment and 15 ml of dilution water. The test substance was added to the dry sediment as a solution in acetone and the acetone was allowed to evaporate overnight before addition of the water. The tubes were then shaken at 84 rpm and samples of the overlying water were taken at 24 hours and 48 hours and analysed for dissolved test substance using a radiochemical method. The results of the analysis are shown in **Table 3.20** (note: the solid-phase concentrations were not measured during the study and are based on the nominal amount of substance added). The mean value for the organic carbon-water partition coefficient (Koc) that can be estimated from the data is 68,753 l/kg.

In addition, as part of the 14-day toxicity study, sediment-solids and sediment pore water concentrations were measured (full details are given in Section 3.2.1.5). These also allow estimates of the value of Koc to be made. These estimates are shown in **Table 3.21**. The mean values of Koc obtained are 1,008,730, 141,980 and 94,830 l/kg for sediments with organic carbon contents of 0.25, 2.7 and 6.8% respectively.

Table 3.20 Sediment-water adsorption data - static studies (Springborn Laboratories, 1989c)

Nominal sediment concentration (mg/kg dry wt.)	% Organic matter content	Estimated % organic carbon content	Measured water concentration (mg/l)		Estimated Koc value (l/kg)	
			24 hours	48 hours	24 hours	48 hours
500	0.44	0.22	4.5	2.1	50,505	108,225
3,000	3.0	1.5	4.5	2.1	44,444	95,238
10,000	21	10.5	not determined	2.1	-	45,351
					Mean 68,753	

Note: a) Assumes that organic matter content ~2 × organic carbon content

Table 3.21 Sediment water adsorption data - flow-through studies (Springborn Laboratories, 1989c)

% Organic carbon content	Measured sediment concentration (mg/kg dry wt.)	Measured pore-water concentration (mg/l)	Estimated Kp_{sed} (l/kg)	Estimated Koc (l/kg)
0.25	15	0.0078	1,923	769,231
	24	0.026	923	369,231
	52	0.025	2,080	832,000
	110	0.041	2,683	1,073,171
	230	0.046	5,000	2,000,000
2.7	16	0.0075	2,133	79,012
	31	0.0083	3,735	138,331
	66	0.013	5,077	188,034
	130	0.028	4,643	171,958
	240	0.045	5,333	197,531
6.8	16	0.0044	3,636	53,476
	44	0.0060	7,333	107,843
	66	0.014	4,714	69,328
	110	0.012	9,167	134,804
	340	0.046	7,391	108,696
Minimum value			923	53,476
90th percentile value			7,368	976,702
Maximum value			9,167	2,000,000

A sediment-water partition coefficient for tetrabromobisphenol-A (and its dimethyl derivative) has also been determined by Watanabe (1988). The study was carried out by adsorbing the substance onto sediment and then adding this spiked sediment to water. The remainder of the experimental details are in Japanese. For tetrabromobisphenol-A the equilibrium concentration in the sediment phase was 284 µg/kg and the concentration in the water phase was 0.0153 µg/kg, resulting in a sediment-water partition coefficient (Kp_{sed}) of 18,562 l/kg. The corresponding Kp_{sed} for the dimethyl derivative of tetrabromobisphenol-A was 70,000 l/kg (the log Kow value for the dimethyl derivative was reported to be 6.40, and so the higher value for the Kp_{sed} for this derivative than tetrabromobisphenol-A itself, is in line with the higher value for the log Kow). The organic carbon content of the sediment used in this study is not clear. If it is assumed that the sediment had an organic carbon content of around 5-10% (typical of the default sediments considered in the Technical Guidance Document), then a Koc value of around 185,600-371,240 l/kg could be derived for tetrabromobisphenol-A from this study, which is within the range of values found in the other studies reported above.

Soil systems

The mobility and adsorption of ^{14}C-labelled tetrabromobisphenol-A has been studied using a silt loam soil and sand (Larsen *et al.*, 2001). The soil was dried at 85°C for 24 hours and then 1,126 g of soil was packed into a glass column (8.4 cm×15.2 cm). The soil column was then wetted with 0.01M $CaCl_2$ solution from the bottom over a period of 24 hours, after which

time a steady state flow velocity of 4.1 mm/min was established from the top of the column. Tetrabromobisphenol-A (563 µg) was then added to the soil surface in a volume of 135 ml $CaCl_2$ solution and was eluted with 4.6 litres of $CaCl_2$ solution (equivalent to approximately 11 pore volumes) at the same steady state flow velocity as before. The effluent from the column was collected in 20 ml fractions and analysed for ^{14}C. A similar column packed with sand was also constructed as a comparison (this was eluted with 14 pore water volumes). At the end of the elution period, the soil column was removed and cut into 1 cm sections and the amount of ^{14}C present in each section was determined after drying the soil. The top (14 cm), 12cm, 10 cm, 5 cm, 3 cm and bottom (1 cm) sections were solvent extracted and analysed for tetrabromobisphenol-A by thin layer chromatographic (TLC) analysis.

No ^{14}C was eluted from the soil column after 11 pore volumes, and 16.2% of the applied radioactivity remained in the first 1 cm of the soil, with 6-7% of the total radioactivity in each of the next four sections. Generally the amount of the total radioactivity found in the lower 1 cm sections decreased from 4% to 2%, except for a slight increase to 5% of the total dose at 3-5 cm from the bottom of the column. The TLC analysis indicated that the radioactivity present was as the parent tetrabromobisphenol-A. In the sand column, a small amount (4.5%) of the total applied radioactivity was found in the column effluent, indicating that tetrabromobisphenol-A was slightly more mobile in the sand column than in the soil column.
In addition to the soil column studies, Larsen *et al.* (2001) also studied the adsorption to soil in batch equilibrium studies. In these studies the silt loam soil was shaken with a 0.01 M $CaCl_2$ solution containing ^{14}C-labelled tetrabromobisphenol-A (concentrations were 0.025, 0.25 and 2.5 mg/l). The soil to water ratio was 1.6 g soil:8 ml solution and each concentration was run in triplicate. At 48, 96 and 168 hours, bottles were centrifuged and the amount of radioactivity present in the water phase was determined. Around 93-98% of the radioactivity added to the system was found to be bound to the solid phase after 48 hours. The results at 96 and 168 hours were similar. The concentrations of radioactivity present in the solid phase were not given in the paper and no solid-water partition coefficients (Kp_{soil}) were reported. However, it is possible to estimate the Kp_{soil} as around 63-233 l/kg from the information given in the paper. The organic carbon contents of the soil used in this study were not given and so it is not possible to derive the Koc value from the paper. However, if it is assumed that the soil had an organic carbon content of 2% (Technical Guidance Document default value), then the estimated Koc value would be in the range 3,150-11,650 l/kg.

Arnon *et al.* (2006) have investigated the flushing potential of a desert loess soil that was contaminated with tetrabromobisphenol-A. The soil used in the study was taken from a site that was contaminated in the late 1980s as a result of industrial wastewater disposal in a forced evaporation facility. Along with tetrabromobisphenol-A, the other major contaminants present were inorganic chloride and bromide ions. The flushing potential of tetrabromobisphenol-A from the soil was investigated both in undisturbed soil columns in the laboratory and in small-scale experiments in the field. The soil consisted of 13% sand, 63% silt, 25% clay and had an organic carbon content of 0.14%.

Initially batch desorption studies were carried out to investigate the kinetics of desorption. In these studies, 5 g of dry, sieved (<2 mm) soil were mixed with 15 ml of distilled water and shaken at 200 rpm at 25°C for up to 100 hours. A total of 24 vials were prepared and at intervals (0.016, 0.083, 0.25, 0.5,0.75, 1, 1.5, 2, 3, 5, 13, 24, 50 and 100 hours) two vials were removed, centrifuged for 15 minutes at 3,000 rpm, and the concentration of tetrabromobisphenol-A in the water phases determined. The experiments found that the concentration in the water phase reached a maximum of 15 mg/l after 90 minutes, with the

concentration reaching ~70-80% of this value within the first five minutes. The pH of the water increased from 7.5 to 8.5 within five minutes of the start of the experiment.

The soil column experiments were carried out using three soil cores (~10 cm in diameter and ~45 cm long). Tap water (pH 7.5) was used for flushing. In these experiments, the soil columns were placed upside down and the water flow was in an upward direction (from the soil surface into the soil profile) in order to minimise air trapping. A constant flow rate (~31.8-46.9 ml/hour) was achieved by maintaining a constant head of water. Breakthrough of tetrabromobisphenol-A into the effluent form the column occurred with <1 pore volume and the maximum concentration of tetrabromobisphenol-A in the effluent (around 250 mg/l) occurred after around 1.5 pore volumes had passed through the column. After five pore volumes, the concentration of tetrabromobisphenol-A had declined to <0.2 mg/l. Initial analysis showed that most of the mass of tetrabromobisphenol-A was present in the upper part of the soil column. The flushing experiments found that tetrabromobisphenol-A was only partly flushed from the soil under these conditions, with the remaining mass being retained in the surface layers of the soil column. It was thought that this resulted from changes in the pH of the soil during the experiment, where the pH of the surface layers was found to decrease slightly whereas the pH in the deeper layers of the column was found to significantly increase, and the resulting effects on the solubility of tetrabromobisphenol-A.

The field experiments were carried out by constructing a small infiltration pond at the contaminated site. The infiltration pond consisted of an outer pond of 2 m by 2 m and an inner pond of 1.2 by 1.2 m. Both ponds were gradually filled with tap water over a four hour period, until the water level reached 45 cm above the surface. This depth of water was then kept at a constant level for a further two hours, after which the experiment was terminated. In these experiments, total organic carbon analysis was used as a marker for the organic contaminants present (these were thought to be mainly tetrabromobisphenol-A) rather than substance specific analysis. The total organic carbon analysis found that the major fraction of the organic contaminants present remained in the top soil under these conditions (the amount of water that was percolated into the soil was equal to one pore volume to a depth of 0.9 m).

Calculated values

A Koc value for tetrabromobisphenol-A can be estimated from the log Kow value of 5.90 using the methods outlined in Chapter 4 of the Technical Guidance Document. The equation recommended for phenols is $\log Koc = 0.63 \times \log Kow + 0.90$. Using this equation a Koc value of 41,400 l/kg can be estimated. This is generally lower than the values obtained from the studies with sediment above, and may indicate that the equation used is not applicable for tetrabromobisphenol-A.

The general equation from Chapter 4 of the Technical Guidance Document for estimating Koc for predominantly hydrophobic chemicals is $\log Koc = 0.81 \times \log Kow + 0.10$. Using a log Kow value, the Koc can be estimated as 47,750 l/kg, which is similar to that estimated above using the phenol equation.

A further estimate for the Koc value has been obtained using the Syracuse Research Corporation PCKOC (version 1.63) estimation software. This estimates the Koc from chemical structure using a molecular connectivity method. The Koc value was estimated to be 561,800 l/kg for tetrabromobisphenol-A, which is in general agreement with the values derived in **Table 3.21** for sediments in a flow-through system.

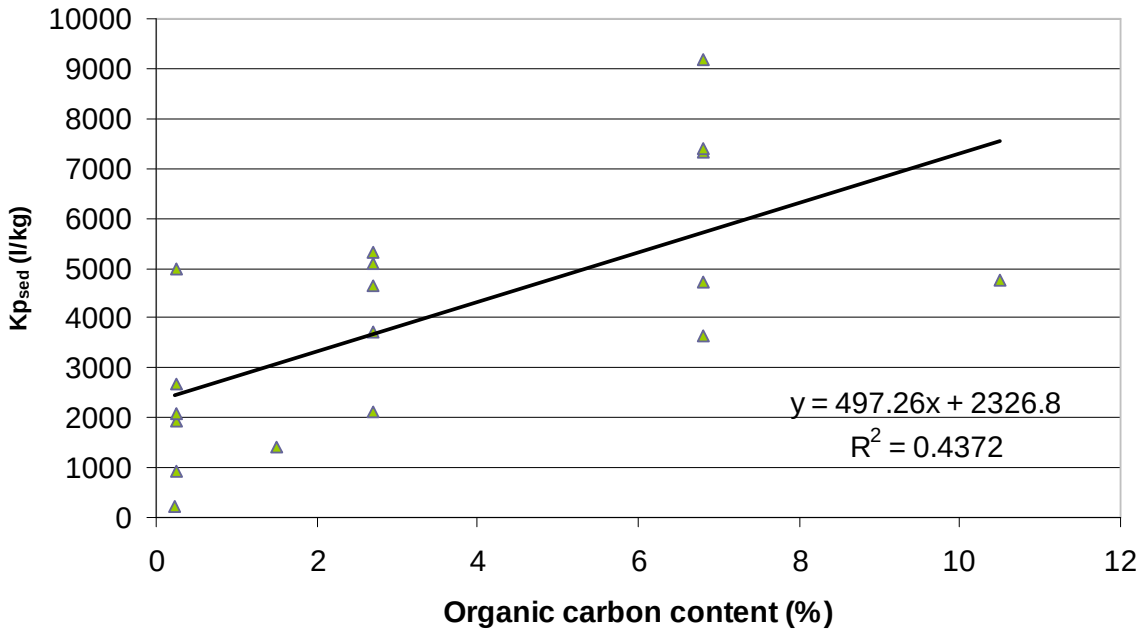
Discussion and summary

The interpretation of the adsorptive behaviour of tetrabromobisphenol-A is complicated as it could be expected to vary with pH of the soil or sediment system. As discussed in Section 1.3.14.2, at pHs below 7, tetrabromobisphenol-A is predicted to exist predominantly in the more hydrophobic undissociated form, whereas at pHs >7 the more hydrophilic dissociated forms are likely to exist. This means that it might be expected that tetrabromobisphenol-A would become more mobile in soils and sediments at higher pHs. For example, Ronen and Abeliovich (2000) report that the solubility and mobility of tetrabromobisphenol-A in calcareous soils in arid environments increased markedly as the pH of the soil increases. No other details of these experiments are available.

For some of the adsorption studies, the pH of the sediment was below 6 which indicates that the undissociated form of tetrabromobisphenol-A would predominate in these studies. However, the situation may not be as simple as this as the pH of the overlying water may be different from that of the bulk sediment (for example in the flow-through study, although the pH of the sediment was <6, the pH of the overlying water was generally in the range 6.4-7.9). This makes it difficult to estimate exactly which species are present in these studies.

In order to investigate the available adsorption data further, all the available Koc data given in Tables 3.12 and 3.13 have been converted back to the sediment – water partition coefficient (Kp_{sed}) values using the respective organic carbon contents and plotted against the organic carbon content of the sediment. The plot is shown in **Figure 3.4**. The slope of the plot corresponds to the Koc value.

Figure 3.4 Plot of Kp_{sed} against organic carbon content



When a straight line is fitted to the data in **Figure 3.4** the following poor regression equation is obtained:

Kp_{sed} = 497.26 × % organic carbon content + 2,326.8.

The slope of the plot corresponds to a Koc value of around 49,726 l/kg. However, the large intercept on the y-axis on this plot indicates that a substantial amount of the adsorption of tetrabromobisphenol-A to the sediment may not be governed by the organic carbon content. This implies that adsorption onto mineral fractions may also be important for tetrabromobisphenol-A. This finding is not altogether surprising given the weak acid nature of the substance. The plot also indicates a large variability in the available data (as seen by the poor fit (as measured by the low R^2 value)) of the plot.

Using the above regression equation, along with the default organic carbon contents for suspended sediment (10%), sediment (5%) and soil (2%), raw and settled sewage sludge (30%) and activated and effluent sewage sludge (37%), the following Kp values can be estimated for tetrabromobisphenol-A.

Kp_{susp} = 7,299 l/kg
Kp_{sed} = 4,813 l/kg
Kp_{soil} = 3,321 l/kg

$Kp_{raw\ sewage\ sludge}$ = $Kp_{settled\ sewage\ sludge}$ = 17,245 l/kg
$Kp_{activated\ sewage\ sludge}$ = $Kp_{effluent\ sewage\ sludge}$ = 20,725 l/kg

These values will be used in the risk assessment. Given the uncertainty and variation in the available data, and in order to take into account the possible natural variation of the adsorptive behaviour of the substance in the environment, the environmental assessment will also consider a set of higher adsorption coefficient values. From the data reported in Table 3.13, Koc values of up to 2,000,000 l/kg can be derived. However, it should be noted that these very high values were estimated from a sediment of low organic carbon content (0.25%) and so may be subject to large errors in cases where adsorption is not solely reliant on the organic carbon content of the sediment (as is likely to be the case for tetrabromobisphenol-A; see above analysis). A better, more reliable, way of using the data reported in Table 3.13 is to consider the variability in the estimated Kp_{sed}. As expected, this value shows a general increase with increasing organic carbon content, but the increase is not as high as would be expected based on the differences in organic carbon contents between the sediments. Again this is suggestive that a significant part of the adsorption is not governed by the organic carbon content alone. The 90th percentile value for the Kp_{sed} is 7,368 and it is proposed to use this value in the assessment, alongside the values derived directly from the above regression equation, in order to take into account some of the variability and uncertainty in the adsorptive behaviour of this substance.

Table 3.22 shows the sediment and soil adsorption coefficients derived from these values using the methods outlined in the Technical Guidance Document.

Table 3.22 Adsorption coefficients used in the environmental risk assessment

Partition coefficient	Symbol	Values used	
Organic carbon - water partition coefficient	Koc	49,726	[147,360 l/kg][a]
Solids – water partition coefficient for soil	Kp_{soil}	3,321 l/kg	[2,947 l/kg][a]
Solids – water partition coefficient for sediment	Kp_{sed}	4,813 l/kg	7,368 l/kg
Solid - water partition coefficient for suspended matter	Kp_{susp}	7,299 l/kg	[14,736 l/kg][a]
Soil - water partition coefficient	$K_{soil\text{-}water}$	4,982 m^3/m^3	[4,420 m^3/m^3][a]
Sediment - water partition coefficient	$K_{sed\text{-}water}$	2,407 m^3/m^3	3,680 m^3/m^3
Suspended matter – water partition coefficient	$K_{susp\text{-}water}$	1,826 m^3/m^3	[3,680 m^3/m^3][a]
Solids – water partition coefficient for raw and settled sewage sludge	$Kp_{raw\ sewage\ sludge}$ $Kp_{settled\ sewage\ sludge}$	17,245 l/kg	[44,200 l/kg][a]
Solids – water partition coefficient for activated and effluent sewage sludge	$Kp_{activated\ sewage\ sludge}$ $Kp_{effluent\ sewage\ sludge}$	20,725 l/kg	[54,500 l/kg][a]

Note: a) This value of Koc is used to facilitate the environmental modelling for this substance only. This value corresponds to a Kp_{sed} of 7,368 when used in the EUSES model. The other adsorption coefficients are derived from this Koc value using the methods outlined in the Technical Guidance Document. As discussed in the text, the adsorption of this substance does not appear to depend solely on the organic carbon content of the solid phase, and so there are some uncertainties associated with the partition coefficients derived using this method.

3.1.0.7.3 Modelling

The potential environmental distribution of tetrabromobisphenol-A has been studied using a generic level III fugacity model. The model used was a four compartment model (EQC version 1.01, May 1997) that has been circulated for use within the OECD HPV program. The model was run four times with a nominal release rate of 1,000 kg/hour initially entering the air, soil or water compartments in different proportions. The physico-chemical properties used and the results of the modelling exercise are shown in **Table 3.23**.

The results of the model show that only a very small amount of the tetrabromobisphenol-A released to the environment will be in the air compartment at steady state. When the substance is released to air it distributes mainly to the soil compartment, presumably by atmospheric deposition. When it is released to soil, the substance generally remains in the soil, with only a small fraction distributing to the water and sediment compartment. When released to water, the substance is likely to distribute mainly to the sediment phase at steady state, but a small but significant fraction may be expected to occur in the water (dissolved) phase and also the soil phase.

Table 3.23 Results of generic level III fugacity model for tetrabromobisphenol-A

Input data	Value				
Vapour pressure	6.24×10^{-4} Pa				
Water solubility	0.063-2.34 mg/l				
Henry's law constant	0.054 Pa m^3 $mole^{-1}$				
Log Kow	5.9				
Atmospheric half-life	130 hours				
Half-life in water	150 days				
Half-life in soil and sediment	30,000 days				
Emission rate	**Model results at steady state**				
	Amount in air	**Amount in soil**	**Amount in water**	**Amount in sediment**	**Overall residence time/persistence**
1,000 kg/hour to air 1,000 kg/hour to soil 1,000 kg/hour to water	2.7×10^{-3}%	98.1%	0.047%	1.81%	18,219 days
1,000 kg/hour to air 0 kg/hour to soil 0 kg/hour to water	9.2×10^{-3}%	99.4%	0.014%	0.54%	15,756 days
0 kg/hour to air 1,000 kg/hour to soil 0 kg/hour to water	2.2×10^{-5}%	99.7%	6.6×10^{-3}%	0.26%	38,048 days
0 kg/hour to air 0 kg/hour to soil 1,000 kg/hour to water	3.0×10^{-4}%	3.3%	2.4%	94.3%	854 days

A modelling study of the long-range atmospheric transport potential of tetrabromobisphenol-A has been carried out by Wania (2003). As part of the study, the available data on the physico-chemical properties of tetrabromobisphenol-A were reviewed and the most appropriate values were selected for each parameter (taking the mean value if more than one value was available). These values were then adjusted (using an algorithm that adjusts a set of physico-chemical properties in such a way that they conform to thermodynamic constraints but deviate only minimally from their original value) to eliminate the inconsistencies found between the various properties and to provide a set of internally consistent physico-chemical properties. The selected measured values and the final adjusted values are summarised in **Table 3.24**. The environmental half-lives used were estimated using the EPIWIN program. The study used four models that determined either the Characteristic Travel Distance (CTD; the distance in air at which the concentration has fallen to 1/e of its initial value; determined as 516-539 km in air for tetrabromobisphenol-A), the Spatial Range (SR; the distance from a point of release that contains 95% of the spatially integrated concentration functions; determined as 11% of the earth's circumference for tetrabromobisphenol-A) or the Arctic Contamination Potential (ACP_{10}; the fraction of the total global amount of a chemical that has accumulated in the Arctic Region after 10 years steady input; determined as 1.37% for tetrabromobisphenol-A). The study predicted that tetrabromobisphenol-A had a very low potential to reach remote areas compared with substances known to undergo long-range transport, and this potential depends largely on the transport behaviour of the atmospheric particulates to which it is adsorbed[14]. However, the

[14] At TMIV'03 questions were raised over the suitability of atmospheric transport models in general to predict

CTD of 500 km indicates that although the potential for long-range transport is comparatively low, it is not negligibly small.

Table 3.24 Physico-chemical parameters used in the modelling of long-range transport (Wania, 2003)

Parameter	Selected measured value	Final adjusted value
Melting point	181°C	181°C
Vapour pressure (sub-cooled liquid)	8.04×10^{-6} Pa at 25°C	1.07×10^{-5} Pa
Water solubility (sub-cooled liquid)	0.16 mg/l	3.5 mg/l
Log Kow (octanol-water partition coefficient)	5.90	5.67
Log K_{OA} (octanol-air partition coefficient)	12.17	12.29
Log K_{AW} (air-water partition coefficient)		-6.18
Estimated half-life in air	86.8 hours	
Estimated half-life in water	3,600 hours	
Estimated half-life in soil	3,600 hours	
Estimated half-life in sediment	14,400 hours	

3.1.0.7.4 Accumulation

Fish

The uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A (radiopurity 96.0%) has been studied with fathead minnows (*Pimephales promelas*) in a flow-through system (Springborn Life Sciences, 1989a). The fish used in the study had a mean (± standard deviation) total length and weight of 39±4 mm and 0.57±0.20 g respectively. The fish were continuously exposed to a nominal concentration of 5 µg/l of the test substance for 24 days, followed by a 6-day depuration period in uncontaminated flowing water. The concentrations of the radiolabel in water and in the exposed organisms were determined after 0 (water only), 5 and 10 hours, 1, 2, 4, 9, 14, 22 and 24 days of the exposure period, and on days 1, 4, 5 and 6 of the depuration period. Since the stock solution of the test substance was made up in acetone, there was a small amount (4.5 µl/l) of acetone co-solvent present in the exposure vessels. A solvent control was run at this level. In total, 91 fish were used in each of the treatment and solvent control tanks, with four fish from each group being analysed at each sampling time.

The well water used in the test had a total hardness of 26-30 mg/l as $CaCO_3$, a pH of 7.0-7.6 and a dissolved oxygen concentration of 8.6-9.6 mg/l. The water flow rate used gave 6.9 aquaria volume replacements per day (90% replacement time of 8 hours) and the temperature of the water was maintained at 20°C.

The measured concentration of radiolabel in the water phase was relatively constant during the exposure period of the experiment and the mean (± standard deviation) measured

the long-range transport properties of particle-bound substances. For example, rain-out is an important removal mechanisms for atmospheric particulates and so transport over longer distances could be expected during periods of dry weather (the models generally assume constant wash out of particulates, and the models generally assume a single particle size (KEMI, personal communication)). Therefore the results from such model predictions should be considered with caution.

concentration of tetrabromobisphenol-A was 4.7±0.3 µg/l based on the radiochemical analyses. The concentration of radiolabel in the water during the depuration period was below the limit of detection of the method (<0.29 µg/l). The concentration of radiolabel in fish appeared to reach steady-state after two to four days of exposure and the mean (± standard deviation) steady-state tissue concentration calculated by the authors was 5,800±1,300 µg/kg at steady state. This gives a fish bioconcentration factor (BCF) of 1,234 l/kg based on the concentration of radiolabel. The uptake data are summarised in **Table 3.25**.

Table 3.25 Uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A in *Pimephales promelas*

Exposure/ depuration period	Mean water concentration (µg/l)	Mean tissue concentration (µg/kg wet wt.)
Exposure period		
0 hours	4.8	-
5 hours	4.5	2,400
10 hours	4.5	2,800
1 day	5.0	5,000
2 days	4.5	7,500
4 days	4.4	6,000
9 days	4.8	5,200
14 days	5.3	4,300
22 days	4.8	5,000
24 days	4.3	6,500
Depuration period		
1 day	<0.29	1,200
4 days	<0.29	170
5 days	<0.29	120
6 days	<0.29	120

During the depuration period there was a rapid elimination of ^{14}C-residues from the fish and the half-life for elimination was estimated to be <1 day. After 6 days depuration, 98% of the accumulated radiolabel had been eliminated from the fish. The depuration data are summarised in **Table 3.25**.

Based on the uptake and depuration kinetics (estimated uptake rate constant = 2,400 d^{-1} and estimated depuration rate constant = 1.8 d^{-1}) a BCF of ~1,300 was estimated, again based on the radiolabel measurements. This is very similar to the measured steady-state value.

Further analysis was carried out on a sample of fish edible tissue and viscera from day 24 of exposure using thin-layer chromatography (after Soxhlet extraction with acetone for 16 hours) in order to try to identify any radiolabelled metabolites present. The results of this analysis indicated that a significant portion of the extracted ^{14}C-residues was present as metabolites more polar than tetrabromobisphenol-A itself. For the sample at day 24, only around 15.2% of the total radioactivity recovered from carcass tissue and 9.7% of the total radioactivity recovered from viscera was found to be parent tetrabromobisphenol-A. The sizes of the samples used in this analysis were around 0.92 g for carcass tissue and around

0.50 g for viscera, and so it can roughly be estimated that the amount of parent tetrabromobisphenol-A present as a proportion of the total body burden of radioactivity was around 13%. Using these data, the BCFs expressed in terms of the amount of parent tetrabromobisphenol-A present in the organism would be around 160 l/kg based on the measured concentration in fish at equilibrium or 177 l/kg based on the kinetic data. This indicates that the BCFs derived from the ^{14}C-measurements will overestimate the actual BCF for tetrabromobisphenol-A itself.

A second uptake and elimination study has been carried out using bluegill sunfish (*Lepomis macrochirus*) with ^{14}C-labelled tetrabromobisphenol-A (Stoner Laboratories, 1978).

The test was carried out using a flow-through system with a 28-day uptake period followed by a 14-day depuration period. Aerated tap water was used as dilution water. The concentration of tetrabromobisphenol-A used was 10 µg/l.

A treatment and control tank were run. At the start of the test each tank contained 275 fish (weight 0.5-2 g) in a working volume of 90 litres. Water samples were collected from the tank on a daily basis and fish samples (~10 g) were collected on days 1, 3, 7,10, 14, 21 and 28 of the uptake phase and days 1, 3, 7, 10 and 14 of the depuration phase. The fish were separated into edible tissues and visceral tissues before analysis. All concentrations in water and fish were determined by radiochemical analysis. The detection limit of the method was 2 µg/l in water and 10 µg/kg in fish samples.

The substance was delivered into the aquaria in an aqueous ethanol solution (the concentration of ethanol in the test vessel was around 0.2 ml/l, although acetone appears to have been used in the solvent control). As a result of the presence of ethanol, a slime bacteria (*Sphaerotilus* sp.) grew in both the treatment and control test system on days 3-5. As a result a filter was installed in each tank to remove the bulk of the bacteria. Analysis of the bacteria showed that no radiolabel was present in the bacteria, indicating the tetrabromobisphenol-A had not been taken up. Fish mortality was also seen to occur early in the study in both the treatment (7 deaths) and control (25 deaths) groups. This was thought to be due to the large range of size of the fish used in the study and competition for food between fish as mortality occurred in smaller fish between 0.5 and 1 g in weight.

The mean (± standard deviation) concentration of the test substance in the water phase was 9.8±1.4 µg/l. The mean steady-state concentration of radiolabel in edible tissues and visceral tissues of the fish was 196 µg/kg and 1,690 µg/kg respectively. Based on these data, the BCF for edible tissues is 20 and the BCF for viscera is 172 (both based in radiolabel measurements). The uptake data are shown in **Table 3.26**.

During the depuration phase, the level of radiolabel in the water phase rapidly fell to be below detectable levels. Elimination from the fish was also rapid, with the estimated half-life for both edible tissue and viscera being <1 day. By days 3-7 of depuration the level of radioactivity in the fish was below detectable levels. The depuration data are shown in **Table 3.26**.

The mortality seen in this study, although less than 10% of the total population, indicates that there may have been some deficiencies in the test system used. This, coupled to the problems with bacterial growth seen in the study, means that the results should be used with caution.

Table 3.26 Uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A in *Lepomis macrochirus*

Exposure/ depuration period	Mean water concentration (µg/l)	Mean tissue concentration (µg/kg wet wt.)	
		Edible tissue	Viscera
Exposure period			
1 day	5	43	1,252
3 days	7	157	1,718
7 days	9	160	808
10 days	10	168	1,480
14 days	11	260	2,840
21 days	10	260	1,870
28 days	10	170	1,421
Depuration period			
1 day	2	40	990
43days	<2	35	91
7 days	<2	<10	10
10 days	<2	<10	<10
14 days	<2	<10	<10

A further fish BCF test has been carried out by CITI (1992). The results of this test are available in summary form only, although some details of the test guideline used are available. The fish used in the test were carp (*Cyprinus carpio*) and they were exposed to tetrabromobisphenol-A at two different concentrations (80 µg/l and 8 µg/l) for 8 weeks in a continuous-flow system. A cosolvent/dispersant (HCO-40) was used in the test, but the concentration used was not given. No further details of how this specific test was carried out are given but according to the test guideline around 15-20 fish are used for each treatment level in 100 litres of water. The fish are about 30 g in weight and 10 cm in length and typically have a lipid content of 2-6%. The water flow-rate used in the method is around 200-800 ml/minute and the test is carried out at around 25^{o}C. The fish are fed throughout the test with pelleted feed at a rate of around 2% of the total body weight per day.

In the test, the concentrations of tetrabromobisphenol-A itself were analysed by a gas chromatographic method. The fish BCF values were reported to be 30-341 l/kg in the 80 µg/l experiment exposure and 52-485 l/kg in the 8 µg/l exposure experiment. Although the study appears to have been carried out using an acceptable method, the lack of experimental detail means that the test cannot be fully validated. In particular, it should be noted that the fact that an unknown concentration of dispersant was used in the test introduces some uncertainty into the results obtained.

Chapter 4 of the Technical Guidance gives an equation for estimation of fish BCF from log Kow (log BCF = 0.85×log Kow - 0.70). Using this method and a log Kow of 5.9, a BCF of 20,654 l/kg can be estimated for tetrabromobisphenol-A. This is higher than the experimental data.

As well as BCF data, the uptake of tetrabromobisphenol-A by fish from diet has been investigated (Rattfelt *et al.,* 2006). Only brief details of the study are currently available.

Male zebrafish (*Danio rerio*) were fed a diet of freeze-dried chironomids spiked with a mixture of brominated flame retardants for 42 days, followed by a 14 day depuration period. The brominated flame retardants included were decabromodiphenyl ether, 2,4,4-tribromodiphenyl ether, 2,4,6-tribromophenol, 2-bromostyrene, 1,2-dibromo-4-(1,2-dibromoethyl)cyclohexane, hexabromocyclododecane, hexabromobenzene, 2,2',3,4,4',5',6-heptabromodiphenyl ether, tetrabromobisphenol-A, tetrabromobisphenol-A 2-hydroxyethyl ether and tetrabromobisphenol-A 2,3-dibromopropyl ether (all added to the food at approximately 100 nmol/g dry food, which is equivalent to ~54 mg/kg dry food for tetrabromobisphenol-A). The feeding rate was approximately 2% of the fish body weight per day. The concentrations of the brominated flame retardants present in the fish were determined on days 0, 3, 7, 14, 28, 35 and 42 of the uptake phase, and days 7 and 14 of the depuration phase. Tetrabromobisphenol-A was not detectable in any of the fish samples (the detection limit of the analytical method used was not stated) and the biomagnification factor for tetrabromobisphenol-A was thought to be <<1.

It might be expected that the BCF value for tetrabromobisphenol-A would vary with pH. Of the three fish BCF tests carried out, only one reports the actual pH of the test water. Therefore, it is not possible to investigate this possibility with the available data. From theoretical considerations, the BCF may be expected to be higher for the undissociated acid form of tetrabromobisphenol-A than the dissociated ionic forms, reflecting the possible decreased solubility and increased lipophilicity of the undissociated form.

For tetrabromobisphenol-A, BCF values have been determined from methods using either radiolabel analysis or parent compound analysis. Although there are uncertainties with some of the tests, it is clear that the available BCF data obtained using analysis based on the parent compound (tetrabromobisphenol-A itself) are relatively consistent (BCF in the range ~170-485 l/kg) but lower than those obtained using radiolabel methods (BCF ~1,234-1,300). The reason for this difference is that tetrabromobisphenol-A has been shown to be extensively metabolised in fish and so the BCF based on radiolabel analysis includes the contribution from these metabolites.

In terms of the risk assessment, it is pertinent to consider if any of these metabolites in fish are themselves accumulative and/or have to potential to elicit toxic effects similar to tetrabromobisphenol-A itself. The identity of the metabolites of tetrabromobisphenol-A is unclear in this case, but formation of other brominated (possibly phenolic) compounds is a possibility. Therefore in order to be conservative, a fish BCF of 1,234 l/kg will be used in the environmental risk assessment as a worst case in order to reflect that at least some of these metabolites may potentially be toxic. This value was obtained at pH 7.0-7.6.). Of the other data, BCF values of up to 485 l/kg have been reported based on parent compound analysis, and this value will also be considered in the environmental risk assessment as being a realistic worst case value for tetrabromobisphenol-A itself.

Aquatic invertebrates

Freshwater

The uptake of tetrabromobisphenol-A by midge (*Chironomus tentans*) larvae has been determined as part of a 14-day toxicity study (Springborn Laboratories, 1989c). Full details of the toxicity study are given in Section 3.2.1.5. The substance tested was a composite sample of tetrabromobisphenol-A from five suppliers, along with ^{14}C-labelled

tetrabromobisphenol-A. The water used in the test was well water and had a pH of 6.9-7.8. The exposure of the organism was in a flow-though system containing sediment for 14-days at 22^{o}C and the concentrations in midge were determined at the end of the exposure period. A radiochemical method was used to determine the concentrations. These concentrations allow midge-sediment bioaccumulation factors (BAFs) and midge-pore water bioconcentration factors (BCFs) to be estimated based on radiolabel measurements. The results of this analysis are shown in **Table 3.27**.

Table 3.27 Uptake of ^{14}C-labelled tetrabromobisphenol-A by *Chironomus tentans* larvae from sediment

% Organic carbon content of sediment	Measured sediment concentration (mg/kg dry wt.)	Measured pore-water concentration (mg/l)	Measure concentration in midge (mg/kg wet wt.)	BAF[a] based on sediment concentration	BCF[b] based on pore water concentration (l/kg)
0.25	15	0.0078	10	0.67	1,282
	24	0.026	15	0.63	577
	52	0.025	35	0.67	1,400
	110	0.041	57	0.52	1,390
	230	0.046	150	0.65	3,261
2.7	16	0.0075	3.2	0.2	427
	31	0.0083	4.8	0.15	578
	66	0.013	8.8	0.13	677
	130	0.028	19	0.15	679
	240	0.045	42	0.18	933
6.8	16	0.0044	1.0	0.063	227
	44	0.0060	2.2	0.050	367
	66	0.014	4.3	0.065	307
	110	0.012	6.3	0.057	525
	340	0.046	17	0.050	370

Note: a) BAF = Bioaccumulation factor - defined as concentration in midge (mg/kg wet wt.)/concentration in sediment (mg/kg dry wt.) - concentrations based on radiolabel measurements.
b) BCF = Bioconcentration factor - defined as concentration in midge (mg/kg wet wt.)/concentration in pore water (mg/l) - concentrations based on radiolabel measurements.

The BAF clearly is dependent on the sediment organic carbon content, and decreases with increasing organic carbon content. This indicates that the majority of the uptake is likely to be via the sediment pore water, with an insignificant contribution from the direct intake of the sediment-bound substance. The mean BAFs calculated based on radiolabel measurements are 0.63 for the 0.25% organic carbon sediment, 0.16 for the 2.7% organic carbon sediment and 0.057 for the 6.8% organic carbon sediment.

When the BCFs based on the sediment pore water are considered, there is reasonable agreement between the values obtained in the 3 sediments, again indicating that uptake from porewater is the main route of accumulation in the organism. The mean value for the BCF is 1,582 l/kg for the 0.25% organic carbon sediment, 659 l/kg for the 2.7% organic carbon sediment and 359 l/kg for the 6.8% organic carbon sediment, again based on radiolabel measurements.

Saltwater

Springborn Life Sciences (1989c) carried out a flow-through uptake and elimination study with eastern oysters (*Crassostrea virginica*) using ^{14}C-labelled tetrabromobisphenol-A mixed with a composite sample of unlabelled tetrabromobisphenol-A from five different producers. Stock solutions of the test substance were made up in acetone and so a small amount of acetone (7.2 µl/l) was also present in the exposure vessels. A solvent control was run using the same acetone concentration.

In the test the oysters (initial number was 60/treatment) were continuously exposed to 1 µg/l of tetrabromobisphenol-A in unfiltered natural seawater (salinity 32-34‰, pH 7.6-8.1, temperature 19^{o}C and dissolved oxygen concentration 4.9-8.7 mg/l) for 20 days, followed by a 14-day depuration period. The dilution water flow rate provided 10 aquarium volumes every 24 hours. Tissue (four oysters/sampling) and water samples were collected at 0, 6, and 12 hours, and days 1, 2, 5, 9, 14 and 20 of the exposure period and days 1, 3, 5, 8,10, 14 of the depuration period. All samples were analysed for the presence of tetrabromobisphenol-A by a radiochemical method.

The mean (± standard deviation) measured water concentration of tetrabromobisphenol-A during the exposure phase of the experiment was 1±0.07 µg/l. The level of ^{14}C present in the tissues of exposed oysters reached steady-state by day 5 of the experiment and the mean (± standard deviation) steady-state concentration measured was 720±160 µg/kg wet wt. The steady-state BCF is therefore 720 l/kg based on radiolabel measurements. The uptake data are shown in **Table 3.28**.

During the depuration phase, the water concentration rapidly fell to concentrations below the limit of detection (<0.34 µg/l). The tissue concentration of ^{14}C-residues also decreased during the depuration phase, with about half of the radiolabel being eliminated by day 3-5 of depuration. The depuration data are shown in **Table 3.28**.

Based on the uptake and depuration kinetics (uptake rate constant = 260 d^{-1} and depuration rate constant = 0.34 d^{-1}) data, a BCF of 780 l/kg was estimated, again based on radiolabel measurements. This is very similar to the measured steady-state value above.

Further analysis was carried out on a sample of oysters at day 20 of exposure using thin-layer chromatography (after Soxhlet extraction with acetone for 16 hours) in order to try to identify any radiolabelled metabolites present. The results of this analysis indicated that a significant portion of the extracted ^{14}C-residues was present as metabolites more polar than tetrabromobisphenol-A itself (although some metabolites less polar than tetrabromobisphenol-A were also indicated). Only around 20.6% of the total radiolabel recovered was found to be parent tetrabromobisphenol-A. Using this value, the above BCFs expressed in terms of the amount of parent tetrabromobisphenol-A present in the organisms would be around 148 l/kg based on the measured concentration in the organism at equilibrium and 160 l/kg based on the kinetic data.

Table 3.28 Uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A in *Crassostrea virginica*

Exposure/ depuration period	Mean water concentration (µg/l)	Mean tissue concentration (µg/kg wet wt.)
Exposure period		
0 hours	0.93	-
6 hours	1.0	170
12 hours	0.95	260
1 day	1.0	420
2 days	1.0	460
5 days	0.97	700
9 days	0.93	800
14 days	1.1	730
16 days	1.1	-
20 days	0.94	640
Depuration period		
1 day	<0.34	420
3 days	<0.34	380
5 days	<0.34	280
7 days	<0.34	-
8 days	<0.34	300
10 days	<0.34	260
14 days	<0.34	260

Earthworms

Wildlife International (2003c) determined the uptake of tetrabromobisphenol-A by earthworms (*Eisenia fetida*) from soil as part of an earthworm toxicity study. The substance had a purity of 98.91% and was mixed with sand and added to soil to give nominal test concentrations of 0.63, 1.3, 2.5, 5.0, 10, 20 and 40 mg/kg dry weight in the test soil. The soil used was an artificial soil consisting of 10% sphagnum moss peat, 70% quartz sand, 20% kaolinite clay and a small amount of calcium carbonate. The soil had an organic carbon content of 4.5%, a pH of 5.83-6.15 at the start of the test and the moisture content was around 20.9-22.6% at the start of the test and around 33.6-39.6% by day 56 (the uptake was investigated over the first 28 days only).

At the start of the test, 4 replicates of 10 adult worms each were exposed to the test substance in 500 g dry weight of soil. After 28 days, the remaining adult worms were removed and any cocoons present were allowed to hatch over the following 28 days. The concentration of the test substance present in the soil phase (on days 0 and 28), and the adult worms (on day 28) was determined. The results are shown in **Table 3.29**.

Table 3.29 Uptake of tetrabromobisphenol-A by earthworms

Exposure concentrations		Measured concentrations in earthworms at day 28	$BAF_{earthworm}$[a]
Nominal	Mean measured over day 0-56		
Control	<0.10 mg/kg dry weight	<0.25 mg/kg	-
0.63 mg/kg dry weight	0.563 mg/kg dry weight	2.86 mg/kg	5.1
1.3 mg/kg dry weight	1.16 mg/kg dry weight	0.279 mg/kg	0.24
2.5 mg/kg dry weight	2.11 mg/kg dry weight	0.394 mg/kg	0.19
5.0 mg/kg dry weight	4.50 mg/kg dry weight	0.456 mg/kg	0.10
10 mg/kg dry weight	9.01 mg/kg dry weight	0.453 mg/kg	0.050
20 mg/kg dry weight	16.7 mg/kg dry weight	0.611 mg/kg	0.037
40 mg/kg dry weight	35.4 mg/kg dry weight	0.677 mg/kg	0.019

Note: a) Earthworm BCF calculated as concentration in earthworm (mg/kg wet wt.)/concentration in soil (mg/kg dry weight).
b) No offspring were produced at this concentration.

As can be seen from **Table 3.29**, the earthworm bioaccumulation factor ($BAF_{earthworm}$) as calculated directly from the ratio of concentration in earthworm/concentration in soil decreases with increasing soil concentration. The reason for this decrease is not apparent from the study.

A possible explanation of this finding is that the uptake by the earthworm may be solely via the pore water, and at the soil concentrations used in this study, the pore water becomes saturated with the test substance. For example, assuming a Koc value of 49,726 l/kg or 147,360 l/kg for tetrabromobisphenol-A (see Section 3.1.0.7.2) a Kp value of either 4,564 l/kg or 6,631 l/kg can be estimated for a soil of 4.5% organic carbon content. Using this value to estimate the equilibrium concentration of the substance present in soil pore water indicates that the pore water would contain 0.20-0.28 µg/l, 0.38-0.54 µg/l, 0.75-1.1µg/l, 1.5-2.2 µg/l, 3.0-4.4 µg/l and 6.0-8.8 µg/l of the test substance at soil concentrations of 1.3, 2.5, 5.0, 10, 20 and 40 mg/kg dry weight respectively. These are well below the water solubility of tetrabromobisphenol-A and so it is unlikely that that saturation of the pore-water would have occurred in this study.

The other possible mode of uptake of the substance by earthworms from soil is direct ingestion of soil-bound substance. If direct ingestion of soil-bound substance was a major uptake route, then the concentration of substance present in the earthworm would be expected to be directly related to the soil concentration and so the $BAF_{earthworm}$ would be expected to be independent of the exposure concentration.

The following equation from the Technical Guidance Document can be used to estimate a $BCF_{earthworm}$ (note this factor relates the concentration in earthworms to the concentration in pore water rather than the whole concentration is soil, and so is not directly comparable with the values reported in **Table 3.29**).

$$BCF_{earthworm} = 0.84 + \frac{0.012 \times Kow}{RHO_{earthworm}}$$

where $RHO_{earthworm}$ = density of earthworm = 1 kg wet wt./l.
Kow = octanol-water partition coefficient = 794,328 (log value = 5.9) for tetrabromobisphenol-A.

Using this equation the $BCF_{earthworm}$ is estimated at 9,533 l/kg.

Birds

Halldin *et al.* (2001) examined the uptake and distribution of ^{14}C-labelled tetrabromobisphenol-A in quail embryos following injection into the yolk. The substance used in the test had a radiochemical purity of >99% and was mixed with non-labelled tetrabromobisphenol-A (purity >99%, recrystallised before use) prior to administration. In the studies with embryos, the test substance was dissolved in an emulsion of peanut oil, lecithin and water and was injected into 3-day-old fertilised eggs at a concentration of 1.9 µg/g egg. The embryos were removed from the eggs on day 6 or day 9 of incubation (4 embryos at each sampling time) and subjected to radiochemical analysis to determine the amount of radioactivity present. A further series of experiments using the same administration method investigated the distribution of the radioactivity within the embryos at day 6, day 10 and day 15 of incubation.

The uptake of radioactivity by the embryos was found to be low, with 0.14-0.39% and 0.16-0.37% of the administered dose being present in the embryo at day 6 and day 9 respectively. Analysis of the embryos at day 10 and day 15 indicated that the radiolabel was present in liver, bile and allantoic fluid, with smaller amounts present in albumen, the contents of the gastro-intestinal tract and kidneys. The presence of radiolabel in bile and allantoic fluid was taken as an indication that the substance was being metabolised and excreted by the embryos.

In addition to the studies with embryos, Halldin *et al.* (2001) also investigated the distribution of the same test substance in laying females following oral (two birds) or intravenous (one bird) administration. The birds used in the test were 200-250 g and the injected dose (given as a solution in 50 µl of dimethyl sulphoxide) was 250 µg/bird (details of the oral dose were not given). The radioactivity present in the birds was analysed 24 hours or nine days after the oral dose and one hour after the intravenous dose.

The results for the orally dosed birds showed that at 24 hours there was a high level of radiolabel present in the gastro-intestinal tract and in a thin layer of yolks in the ovary and oviduct. Some radioactivity was also found in the liver, kidney and lung. Nine days after dosing, only small amounts of radiolabel were still present in the bird. Some radiolabel was still present in the gastro-intestinal tract and radiolabel was also present in a central layer of large yolks. The results for the intravenously dosed bird one hour after dosing showed a high level of radiolabel in the gall bladder and gastro-intestinal tract, with some radiolabel also being present in liver, kidney and lung. Overall, these results were taken to indicate that a large proportion of the administered dose was excreted via the bile within nine days.

Mammals

Brady (1979) investigated the uptake, distribution and elimination of a single oral dose of ^{14}C-labelled tetrabromobisphenol-A. Four groups of female rats (10 rats in total with weights between 151 and 176 g) were dosed with around 6.5-7.6 mg/kg body weight of the test

substance in corn oil. Blood and urine samples were collected at 4, 8, 16, 24, 48 and 72 hours after dosing, and tissue samples were collected at 8, 24 and 72 hours after dosing. The total radioactivity in blood, tissues and excreta were determined. The results are shown in **Table 3.30**.

Table 3.30 Uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A in female rats

Time after dosing	Distribution of radioactivity (% of administered dose)										
	Urine	Feces	Blood	Fat	Kidney	Liver	Brain	Spleen	Muscle	Gonads	Skin
4 hours	0.03-0.05%	0.0015-0.002%	0.03%								
8 hours	0.02-0.09%	0.0015-0.15%	0.03%	0.068%	0.005%	0.41%	0.03%	0.001%	0.12%	0.002%	0.12%
16 hours	0.12%	7.5-25.8%	0.02%								
24 hours	0.15%	7.4-49.6%	0.01%	0.16%	0.009%	0.33%	0.002%	0.016%	0.16%	0.002%	0.18%
48 hours	0.30%	36.3%	0.01%								
72 hours	0.32%	1.5%		0.083%	0.002%	0.013%	0.002%	0.001%	0.093%	0.002%	2.42%[a]
Total excreted	1.01%	95.0%									

Note: a) The skin of one of the two rats analysed was contaminated. The individual values were 4.7% and 0.13%.

The authors indicated that the test substance was poorly absorbed by the rats (although this finding can be questioned as the amount of radioactivity in the bile was not determined, and the studies below have shown the substance is well absorbed), with around 95% of the administered dose being excreted in the feces within 72 hours. Less than 1.1% of the administered dose was found in urine. The radioactivity in blood was observed to be at a maximum at between 4 and 8 hours after dosing, and decreased to be below 0.01% of the administered dose within 24 hours. The half-life in blood was estimated to be 19.9 hours. The total amount of radioactivity found in tissues at 72 hours accounted for 0.33% of the administered dose and the elimination half-life was determined to be 70.8 hours in fat, 17.1 hours in kidney, 10.8 hours in liver, 39.3 hours in spleen, 48.0 hours in muscle and 60.5 hours in gonads. Based on these data, the authors calculated the theoretical body burden after repeated dosing at 24-hour intervals to be around 2.5 mg/kg body weight (0.48 mg/kg in fat, 0.30 mg/kg in kidney, 0.31 mg/kg in spleen and 0.10 mg/kg in muscle). The time required to reach this theoretical equilibrium level was estimated to be between 3 and 17 days, depending on the tissue (mean value 10.3 days).

A similar pattern of excretion was found by Hakk *et al.* (2000) using both conventional and bile-duct cannulated rats. In this study tetrabromobisphenol-A (a mixture of ^{14}C-labelled and unlabelled in peanut oil) was administered to male rats (weight 310-354 g) as a single oral dose of 2.0 mg/kg body weight by stomach tube. The results of the experiment are shown in **Table 3.31**.

Table 3.31 Uptake and elimination of ^{14}C-labelled tetrabromobisphenol-A in conventional and bile-duct cannulated male rats (Hakk *et al.*, 2000)

Distribution of radioactivity (% of administered dose)	Time after dosing							
	Conventional rats				Bile-duct cannulated rats			
	0-24 hours	24-48 hours	48-72 hours	Total excreted	0-24 hours	24-48 hours	48-72 hours	Total excreted
Urine	0.1%	0.2%	0.02%	0.3%	0.4%	0.3%	0.03%	0.7%
Bile					48.4%	21.0%	1.9%	71.3%
Feces	6.6%	65.6%	19.5%	91.7%	6.0%	15.3%	5.0%	26.3%
Adipose			ND				ND	
Blood			ND				ND	
Carcass			0.2%				0.3%	
Large intestine			1.0%				0.4%	
Small intestine			0.7%				0.2%	
Heart			ND				ND	
Kidney			0.003%				0.001%	
Liver			0.06%				0.05%	
Lung			0.2%				0.07%	
Spleen			ND				ND	
Testis			ND				ND	
Thymus			ND				ND	

Note: ND - Not detected. Limit of quantification was 0.0005% of administered dose.

In the conventional rats, >91% of the administered dose was excreted in feces by 72 hours, with only 2% of the radioactivity being found in tissues. In the bile-duct cannulated rats, >71% of the substance was excreted via the bile in 72 hours and <1% of the dose was present in tissues. Excretion of radioactivity via the urine was low in both types of rats (<1%). Metabolites identified in bile at 0-24 hours included a diglucuronide ether conjugate of tetrabromobisphenol-A, a glucuronic acid/sulphate ester diconjugate of tetrabromobisphenol-A and a monoglucuronic acid conjugate of tetrabromobisphenol-A. The feces samples collected were analysed for metabolites. In these samples, around 28-54% of the radioactivity present was not extracted by the method used and the extractable fraction was found to be almost entirely parent tetrabromobisphenol-A.

As discussed in the human health risk assessment (see Section 4), there is some uncertainty over the extent of adsorption of tetrabromobisphenol-A when administered to mammals at high doses[15]. In this study using relatively low doses, it can be seen that >71% of the

[15] One or two Member States expressed concern over the oral absorption of undissolved particles of tetrabromobisphenol-A, particularly when administered as a suspension at high dose levels. In the opinion of these Member States, there was some uncertainty as to whether 100% of the administered dose would be absorbed at these higher dose levels and consequently whether the dosing of particles in suspension will underestimate the toxicity. However, the majority of Member States agreed with the position of the UK rapporteur that, although this concept is important, the data do not allow a quantitative estimate of oral absorption at such high dose levels to be determined. Therefore, it was agreed to assume that 100% of an orally administered dose of tetrabromobisphenol-A is absorbed.

administered dose was absorbed in bile-duct cannulated rats, with around 26% of the dose identified in the feces. Circumstantial evidence of a high intestinal absorption is also evident from the experiments with conventional rats. Here the data show a delay in fecal excretion, with only 6.6% being excreted within the first 24 hours compared with 66% excretion between 24 and 48 hours after exposure. Hakk *et al.* (2000) concluded that this delay in excretion most probably resulted from intestinal absorption followed by enterohepatic circulation, involving hepatic conjugation of absorbed tetrabromobisphenol-A, excretion via bile, deconjugation by bacterial microflora, and reabsorption in the lower gut. Overall, Hakk *et al.* (2000) concluded that the data indicated that tetrabromobisphenol-A was readily absorbed from the gut, metabolized and excreted within 72 hours in this experiment.

A further study has looked at the metabolism and disposition of ^{14}C-labelled tetrabromobisphenol-A in both conventional and bile duct cannulated male rats (Larsen et al, 1998). The rats were given a single oral dose of 2 mg/kg body weight of the test substance and bile, urine and feces were collected every 24 hours and after 3 days the amount of radioactivity in various organs and tissues was determined. The results from the experiment are shown in **Table 3.32**. Most of the radioactivity was excreted in the bile (71%) or feces (92%) within 72 hours of dosing, with around 2.1% of the dose remaining in tissues. Metabolites found in bile included the diglucuronide conjugate of tetrabromobisphenol-A, the sulphate ester glucuronide diconjugate of tetrabromobisphenol-A, and the monoglucuronide of tetrabromobisphenol-A. In the feces, most of the ^{14}C-label was present as parent tetrabromobisphenol-A, indicating that the gut flora deconjugated the glucuronide and sulphate conjugates excreted in the bile.

Table 3.32 Distribution of ^{14}C-tetrabromobisphenol-A in conventional and bile duct cannulated male rats (Larsen *et al.*, 1998)

Sample	^{14}C distribution (% of applied dose) at 72 hours	
	Conventional rats	Bile duct cannulated rats
Urine	0.32%	0.73%
Bile	-	71.3%
Feces	91.7%	26.3%
Spleen	0%	0%
Heart	0%	0%
Liver	0.06%	0.05%
Thymus	0%	0%
Lung	0.23%	0.07%
Fat	0%	0%
Kidney	0.003%	0.001%
Carcass	0.15%	0.33%
Small intestine	0.68%	0.16%
Large intestine	0.98%	0.37%
Testes	0%	0%
Total recovery	94.1%	99.3%

Szymańska *et al.* (2001) investigated the uptake and distribution of ^{14}C-labelled tetrabromobisphenol-A in female rats over 72 hours following a single intraperitoneal dose of 250 or 1,000 mg/kg body weight. The test substance was administered as a solution in olive oil. The amounts of radioactivity excreted in urine and feces and distributed to various tissues during the course of the experiment are shown in **Table 3.33**. Fecal excretion was found to be the main route of ^{14}C elimination during the course of the study, with only 0.27-0.31% of the radioactivity being found in the urine. Overall, around 51-66% of the administered dose was excreted within 72 hours. The radioactivity present in the feces was found to be mainly unchanged tetrabromobisphenol-A (around 90%) and tribromobisphenol-A (around 10%).

Table 3.33 Tissue distribution and elimination of ^{14}C-labelled tetrabromobisphenol-A in female rats

Dose	Time	Amount of ^{14}C present							
		Urine	Feces	Blood	Fat	Muscle	Liver	Other organs	Total
250 mg/kg bw	24 hr	0.11%	37.4%	1.78%	3.72%	4.27%	0.38%	0.05%	47.35%
	48 hr	0.18%	61.48%	4.01%	3.34%	7.17%	0.09%	0.03%	77.30%
	72 hr	0.27%	65.48%	3.83%	2.78%	3.81%	0.06%	0.04%	77.27%
1,000 mg/kg bw	24 hr	0.13%	25.26%	not determined	3.26%	8.19%	0.11%	0.03%	35.98%
	48 hr	0.22%	42.81%	not determined	3.05%	3.83%	0.07%	0.03%	50.01%
	72 hr	0.31%	50.90%	not determined	6.06%	14.26%	0.09%	0.04%	71.65%

The distribution of tetrabromobisphenol-A in pregnant and fetal rats has been investigated by Meerts *et al.* (1999). Pregnant rats were given oral doses of 5 mg/kg body weight of ^{14}C-labelled tetrabromobisphenol-A in corn oil from day 10 to day 16 of gestation. The exposed rats were sacrificed on gestation day 20 and the radioactivity present in tissues and organs from the dams and fetuses was determined. In addition, the cumulative amount of radioactivity in faeces was measured. The results of the experiment are shown in **Table 3.34**. Most of the radioactivity (79.8% of the total) was excreted in the feces within 48 hours of the last dose.

Taken together, the excretion data from the conventional and cannulated rats are consistent with the substance being readily adsorbed from the gut (as indicated by the presence in bile) followed by excretion via the bile within 72 hours. The net result is that tetrabromobisphenol-A is excreted largely as the parent compound via the feces.

Table 3.34 ^{14}C tissue distribution in pregnant and fetal rats on gestation day 20

Tissue	Radioactivity (% of total dose)	
	Dams	Fetuses
Carcass	0.368%	0.068%
Liver	0.256%	0.062%
Skeletal muscle	0.059%	not detected
Abdominal fat	0.016%	not detected
Placenta	0.014%	not detected
Total plasma	0.008%	9.7×10^{-5}%
Forebrain	0.002%	0.0013%
Kidney	0.001%	2.2×10^{-4}%
Lungs	5.0×10^{-4}%	9.9×10^{-4}%
Spleen	4.4×10^{-4}%	not detected
Heart	3.9×10^{-4}%	1.2×10^{-4}%
Cerebellum	3.0×10^{-4}%	6.3×10^{-4}%
Pancreas	2.0×10^{-4}%	not detected
Thymus	8.0×10^{-5}%	not detected
Total	0.83%	0.34%
Feces	80.6%	

A further toxico-kinetic study of the behaviour of tetrabromobisphenol-A in rats following oral administration has been published by Schauer *et al.* (2006). In his study, rats were administered a single oral dose of tetrabromobisphenol-A of 300 mg/kg body weight. The concentration of tetrabromobisphenol-A (and metabolites) in blood and urine were then monitored. The levels of tetrabromobisphenol-A in the plasma peaked at 103 µmol/l three hours after administration and then declined with a half-life of around 13 hours. Tetrabromobisphenol-A-glucuronide (peak level 25 µmol/l at three hours after administration) and tetrabromobisphenol-A–sulphate (peak level 694 µmol/l at six hours after administration) were identified as the main metabolites in both blood and urine, but low levels of other metabolites (a diglucuronide and a mixed glucuronide-sulphate conjugate of tetrabromobisphenol-A and the glucuronide of tribromobisphenol-A) were also found. It was concluded that tetrabromobisphenol-A was absorbed from the gastrointestinal tract and was then rapidly metabolised by conjugation. This study is still to be evaluated by the Rapporteur and is not currently included in Section 4.

The uptake, distribution and metabolism of tetrabromobisphenol-A in mammalian systems is considered further in Section 4 of this report. It is concluded that tetrabromobisphenol-A has a low potential for bioaccumulation in mammalian systems.

Summary of accumulation data

Bioconcentration data are available for freshwater fish and freshwater and marine invertebrates. The highest bioconcentration factor, based on radiolabel measurements, in fish is 1,234 l/kg with *Pimephales promelas*. The bioconcentration factors determined based on

radiolabel measurements for freshwater and marine invertebrates are of a similar order of magnitude to this value (around 867 and 780 l/kg respectively). When the data based on analysis of tetrabromobisphenol-A itself are considered, the bioconcentration factors are in the range 160-485 l/kg and around 148-160 for marine invertebrates. The reason for the difference between the data based on radiolabel measurements and those based on measurements of tetrabromobisphenol-A itself is that tetrabromobisphenol-A has been shown to be extensively metabolised in the studies with freshwater fish (*Pimephales promelas*) and marine invertebrates (*Crassostrea virginica*) and so the BCF based on radiolabel analysis includes the contribution from these metabolites.

Excretion of tetrabromobisphenol-A from aquatic organisms appears to be rapid, with a half-life generally of the order of <1 day in fish to 3-5 days in marine oysters. The rapid excretion may explain why the measured BCF values are generally lower than would be predicted for a substance with a log Kow of 5.9.

A fish BCF of 1,234 l/kg will be used in the environmental risk assessment as a worst case. This value was obtained at pH 7.0-7.6 and is based on analysis of ^{14}C-residues in the fish and so also includes contributions from metabolites as well as the parent compound. Although it is recognised that this value will overestimate the accumulation of tetrabromobisphenol-A itself, it is used in the assessment in order to take into account the possibility that at least some of the metabolites of tetrabromobisphenol-A may themselves be potentially toxic and accumulative. In addition a BCF of 485 l/kg for fish will be considered in the assessment as being a realistic worst case value for tetrabromobisphenol-A itself.

As discussed earlier, it is possible that the BCF value for tetrabromobisphenol-A may vary with pH, but the available data do not allow this possibility to be explored.

In addition to a fish BCF, the risk assessment methodology outlined in the Technical Guidance document requires a biomagnification (BMF) value. No measured value is available for tetrabromobisphenol-A. However, according to the Technical Guidance Document, the BMF for tetrabromobisphenol-A would be set to 1 (since the fish BCF is <2,000 l/kg) and so this value will be used in the risk assessment.

The available avian and mammalian data show that the substance is absorbed through the gut, but its rapid excretion via feces means that it is thought to have a low potential for bioaccumulation on repeated exposure.

3.1.1 Aquatic compartment

As tetrabromobisphenol-A is a weak acid that may be dissociated at environmentally relevant pHs, this has to be taken into account in the PEC calculations. Therefore, calculations are performed wherever possible to take into account the probable different environmental behaviour of the undissociated acid form and the dissociated anionic forms. In practice, this is currently limited to possible differences in adsorptive behaviour of the two forms.

3.1.1.1 Calculation of PECs

The PECs for tetrabromobisphenol-A are calculated using the methods given in the Technical Guidance Document and the release figures given in **Table 3.4**. The Technical Guidance Document suggests that the size of the waste water treatment plant at a site should be around

2,000 m^3/day, and the effluent from the plant will be diluted by a factor of 10 in the receiving water. It is assumed that no biodegradation occurs during waste water treatment.

Based on the physico-chemical properties of tetrabromobisphenol-A (vapour pressure = 6.24×10^{-6} Pa, water solubility = 0.063-2.34 mg/l, Henry's law constant = 0.014-0.054 Pa m^3/mole and Koc = 49,726 l/kg or 147,360 l/kg) the predicted behaviour of the substance during waste water treatment (as estimated by EUSES 2.0.3 (see Appendix B)) is:

	Koc = 49,726 l/kg	Koc = 147,360 l/kg
% to air	3.2×10^{-3}%	1.3×10^{-3}%
% to sludge	81.5%	87.7%
% degraded	0%	0%
% to surface water	18.5%	12.3%

A recent study by Kuch *et al.* (2004) and Schneider *et al.* (2004) has investigated the behaviour of tetrabromobisphenol-A during wastewater treatment in various types of treatment plant. The total removal seen in the plants (based on the amounts of tetrabromobisphenol-A in the water phase and particulate phase) were around 84% for a plant using an activated sludge process, around 91% for a plant using an oxidation ditch, around 82% for a plant using a rotating disk filter and 75% for a plant using a trickling filter. It was concluded that adsorption onto sludge was an important elimination mechanism in the treatment plants studied. These removal rates are generally in very good agreement with the estimates obtained above.

On release to surface water, the substance will adsorb onto suspended sediment. The following equation from the Technical Guidance Document has been used in all calculations to take this into account.

$$Clocal_{water} = \frac{Clocal_{eff}}{(1 + Kp_{susp} \times SUSP_{water} \times 10^{-6}) \times DILUTION}$$

where $Clocal_{water}$ = local concentration in surface water during an emission episode.
$Clocal_{eff}$ = concentration in effluent from waste water treatment plant.
Kp_{susp} = solids-water partition coefficient for suspended matter = 7,299 l/kg or 14,736 l/kg for tetrabromobisphenol-A.
$SUSP_{water}$ = concentration of suspended matter in surface water = 15 mg/l.
DILUTION = dilution factor for effluent in receiving water = 10 for generic scenarios.

The final $PEC_{local(water)}$ is estimated from the following equation.

$$PEC_{local(water)} = Clocal_{water} + PEC_{regional(water)}$$

where $PEC_{regional(water)}$ = 1.3×10^{-3} µg/l (using Koc = 147,360 l/kg) and 1.3×10^{-3} µg/l (using Koc = 49,726 l/kg), based on the EUSES 2.0.3 calculation (see Appendix B)

Finally the PEC for sediment is estimated from the following equation.

$$PEC_{local(sed)} = \frac{K_{susp\text{-}water} \times PEC_{local(water)} \times 1000}{RHO_{susp}}$$

where $K_{susp\text{-}water}$ = suspended matter – water partition coefficient = 1,826 m^3/m^3 or 3,680 m^3/m^3
RHO_{susp} = bulk density of suspended matter = 1,150 kg/m^3

3.1.1.1.1 Production

There is currently thought to be no production of tetrabromobisphenol-A in the EU. The information given here in **Table 3.35** is for reference only and allows the potential risks associated with production to be evaluated.

Table 3.35 PEC calculation for a generic production site

	Generic production site	
	Koc = 49,726 l/kg	**Koc = 147,360 l/kg**
Local release to waste water (kg/day)	13.6	13.6
No of days of release/year	300	300
Size of WWTP (m^3/day)	2,000	2,000
Influent concentration (µg/l)	6,800	6,800
% to water during WWTP	18.5	12.3
$C local_{eff}$ (µg/l)	1,260	836
Dilution factor	10	10
$C local_{water}$ (µg/l)	113	68.6
$PEC_{local(water)}$ (µg/l)	113	68.6
$PEC_{local(sediment)}$ (mg/kg wet wt.)	180	220

3.1.1.1.2 Use as intermediate in production of tetrabromobisphenol-A derivatives

The Industry Consortium for tetrabromobisphenol-A have indicated that none of its members currently manufacture derivatives of tetrabromobisphenol-A in the EU (Industry Consortium, 2003). World-wide, the use of these derivatives appears to be increasing, and given that brominated flame retardants are produced (or have been produced in the recent past) at some sites in the EU, it cannot be ruled out that production of these derivatives will not occur in the future. The calculation given here in **Table 3.36** is therefore currently for reference only and allows the potential risks associated with the use of tetrabromobisphenol-A to make flame retardant derivatives to be evaluated.

Table 3.36 PEC calculation for a generic site producing derivatives of tetrabromobisphenol-A

	Generic production site	
	Koc = 49,726 l/kg	**Koc = 147,360 l/kg**
Local release to waste water (kg/day)	17.5	17.5
No of days of release/year	200	200
Size of WWTP (m^3/day)	2,000	2,000
Influent concentration (µg/l)	8,750	8,750
% to water during WWTP	18.5	12.3
$Clocal_{eff}$ (µg/l)	1,620	1,076
Dilution factor	10	10
$Clocal_{water}$ (µg/l)	146	88.3
$PEC_{local(water)}$ (µg/l)	146	88.3
$PEC_{local(sediment)}$ (mg/kg wet wt.)	232	283

3.1.1.1.3 Use of tetrabromobisphenol-A as a reactive flame retardant

In Section 3.1.0.2.2, emissions of tetrabromobisphenol-A to waste water were estimated from the manufacture and further processing of epoxy and polycarbonate resins. These release estimates have been used here, along with the predicted behaviour of tetrabromobisphenol-A in the generic waste water treatment plant, to estimate the PEC_{local} for these lifecycle stages. The calculations are summarised in **Table 3.37** and **Table 3.38**.

Table 3.37 Generic PEC calculation for epoxy and/or polycarbonate resin production

	Epoxy and/or polycarbonate production	
	Koc = 49,726 l/kg	**Koc = 147,360 l/kg**
Local release to waste water (kg/day)	0.027	0.027
No of days of release/year	300	300
Size of WWTP (m^3/day)	2,000	2,000
Influent concentration (µg/l)	13.5	13.5
% to water during WWTP	18.5	12.3
$Clocal_{eff}$ (µg/l)	2.50	1.66
Dilution factor	10	10
$Clocal_{water}$ (µg/l)	0.23	0.14
$PEC_{local(water)}$ (µg/l)	0.23	0.14
$PEC_{local(sediment)}$ (mg/kg wet wt.)	0.36	0.44

Table 3.38 Generic PEC calculation for epoxy and polycarbonate resin processing

	Epoxy resin processing		Polycarbonate processing	
	Koc = 49,726 l/kg	**Koc = 147,360 l/kg**	**Koc = 49,726 l/kg**	**Koc = 147,360 l/kg**
Local release to waste water (kg/day)	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
No of days of release/year	32	32	28	28
Size of WWTP (m^3/day)	2,000	2,000	2,000	2,000
Influent concentration (μg/l)	0.025	0.025	0.025	0.025
% to water during WWTP	18.5	12.3	18.5	12.3
$C_{local_{eff}}$ (μg/l)	4.6×10^{-3}	3.1×10^{-3}	4.6×10^{-3}	3.1×10^{-3}
Dilution factor	10	10	10	10
$C_{local_{water}}$ (μg/l)	4.2×10^{-4}	2.5×10^{-4}	4.2×10^{-4}	2.5×10^{-4}
$PEC_{local(water)}$ (μg/l)	1.7×10^{-3}	1.5×10^{-3}	1.7×10^{-3}	1.5×10^{-3}
$PEC_{local(sediment)}$ (mg/kg wet wt.)	2.7×10^{-3}	4.9×10^{-3}	2.7×10^{-3}	4.9×10^{-3}

In addition to the PECs given in **Table 3.37** for a generic epoxy resin production site confidential information (including amounts of tetrabromobisphenol-A used and in some cases number of days of operation, size of sewage treatment works and dilution information and actual monitoring data) has been provided for eight major companies in the EU using tetrabromobisphenol-A as a reactive flame retardant intermediate. Using these data, along with the generic emission factor of 0.001% to waste water where appropriate (see Section 3.1.0.2.2) leads to $PEC_{local(water)}$ of between 1.3×10^{-3} μg/l (i.e. the regional background level) and 0.21 μg/l using a Koc of 49,726 l/kg and between 1.3×10^{-3} μg/l (regional background) and 0.13 μg/l respectively using a Koc of 147,360 l/kg (see Appendix F). The corresponding concentrations in sediment are between 2.0×10^{-3} and 0.34 mg/kg wet weight using a Koc of 49,726 l/kg and 4.1×10^{-3} and 0.41 mg/kg wet weight using a Koc of 147,360 l/kg. The upper limits of these PECs are similar to those calculated for the generic site.

3.1.1.1.4 Use of tetrabromobisphenol-A as an additive flame retardant

The emissions of tetrabromobisphenol-A to waste water have been estimated from several stages of processing of ABS (see Section 3.1.0.2.3). These emission estimates are used here, along with the predicted behaviour of tetrabromobisphenol-A in the generic waste water treatment plant to estimate the PEC_{local} for these lifecycle stages. The calculations for ABS are summarised in **Tables 3.39**.

Table 3.39 Generic PEC calculation for additive flame retardant use in ABS

	Compounding site		Conversion site	
	Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Local release to waste water (kg/day)	1.1	1.1	0.050	0.050
No of days of release/year	171	171	171	171
Size of WWTP (m^3/day)	2,000	2,000	2,000	2,000
Influent concentration (µg/l)	550	550	25	25
% to water during WWTP	18.5	12.3	18.5	12.3
$Clocal_{eff}$ (µg/l)	102	67.7	4.6	3.1
Dilution factor	10	10	10	10
$Clocal_{water}$ (µg/l)	9.2	5.6	0.42	0.25
$PEC_{local(water)}$ (µg/l)	9.2	5.6	0.42	0.25
$PEC_{local(sediment)}$ (mg/kg wet wt.)	14.6	17.8	0.66	0.81

In addition to these estimates, confidential site specific information has been received from a site using tetrabromobisphenol-A as an additive flame retardant in the EU. Using these data the PEC_{local} for water and sediment can be estimated as 9.3 µg/l and 14.8 mg/kg wet weight respectively using a Koc of 49,726 l/kg and 8.5 µg/l and 27.1 mg/kg wet weight respectively using a Koc of 147,360 l/kg. These values are of a similar magnitude to those obtained in **Table 3.39** for the generic scenarios.

3.1.1.1.5 Calculation of $PEC_{regional}$ and $PEC_{continental}$

The predicted concentrations of tetrabromobisphenol-A in the regional and continental scenarios have been estimated by EUSES 2.0.3, using the release data outlined in **Table 3.4**. A printout of the EUSES model is given in Appendix B. The estimated $PEC_{regional}$ and $PEC_{continental}$ are shown in **Table 3.40**.

Table 3.40 Estimate $PEC_{regional}$ and $PEC_{continental}$ for the aquatic compartment

Compartment	PEC	Value estimated using Koc = 49,726 l/kg	Value estimated using Koc = 147,360 l/kg
Surface water	$PEC_{regional(water)}$	1.3×10^{-3} µg/l	1.3×10^{-3} µg/l
	$PEC_{continental(water)}$	2.3×10^{-4} µg/l	2.1×10^{-4} µg/l
Sediment	$PEC_{regional(sediment)}$	4.0×10^{-3} mg/kg wet wt.	8.1×10^{-3} mg/kg wet wt.
	$PEC_{continental(sediment)}$	7.2×10^{-4} mg/kg wet wt.	1.3×10^{-3} mg/kg wet wt.

3.1.1.2 Measured levels in water and sediment

3.1.1.2.1 Water

Peltola (2002) has determined the concentration of tetrabromobisphenol-A in water from a creek in Finland that is fed by stormwater from a large urban area in Helsinki. The concentration of tetrabromobisphenol-A was below the limit of detection of the method used (0.2 µg/l). In addition, the concentration of tetrabromobisphenol-A was investigated in two samples of leachate from landfills. The concentration present was below the limit of detection in the sample from a landfill in Espoo but was 0.9 µg/l in leachate from a landfill at a metal dismantling plant.

de Boer *et al.* (2002) and Morris *et al.* (2004) have determined the levels of tetrabromobisphenol-A (and the dimethylated derivative) in influents and effluents from sewage treatment plants from the United Kingdom and the Netherlands. The samples from the United Kingdom showed that tetrabromobisphenol-A was present in the dissolved phase in influent from four out of the five plants sampled. The levels found were 2.6-85.2 ng/l. However, tetrabromobisphenol-A was found in the particulate phase in only one out of the five samples at a concentration of 21.7 µg/kg dry weight, and no tetrabromobisphenol-A was found in the effluent samples (either in the dissolved phase or particulate phase) from the five sites. In addition, the dimethylated tetrabromobisphenol-A derivative was not found in any influent or effluent sample. The detection limit was around 15 ng/l for the water phase and 3.9 µg/kg dry weight for the particulate phase for both substances.

Only the particulate fraction was analysed for the samples collected in the Netherlands (de Boer *et al.*, 2002). These samples showed tetrabromobisphenol-A was not found in the influent from five sewage treatment plants (detection limit was between 1 and 3.8 µg/kg dry weight), but it was present in all five effluent samples at a concentration of 3.1-63 µg/kg dry weight (mean 42 µg/kg dry weight). In addition, the dimethylated tetrabromobisphenol-A derivative was found in three out of five effluent samples at 0.4-0.6 µg/kg dry weight, but was not present in any of the five influent samples (detection limit of the method was 0.1-5.6 µg/kg dry weight).

A similar study of influent concentrations for waste water treatment plants has been carried out for five plants in Baden-Württemberg in Germany (Kuch *et al.*, 2001). The dissolved concentrations of tetrabromobisphenol-A in the influent were between 0.86 and 17.4 ng/l (detected in all five samples), but tetrabromobisphenol-A was not found in the particulate phase (detection limit 0.2 µg/kg dry weight). In addition no dimethylated tetrabromobisphenol-A was detected in the influent samples (detection limit was 0.2 µg/kg dry weight for particulates and 0.2 ng/l for the dissolved phase).

Kuch *et al.* (2001) also investigated the concentrations of tetrabromobisphenol-A in waste water treatment plant effluent and the receiving water upstream and downstream of the waste water treatment plant. Tetrabromobisphenol-A was detected in ten out of 19 effluent samples at a concentration of 0.62-25.0 ng/l. The concentration in the receiving waters was in the range 0.81 to 20.4 ng/l in the upstream samples (detected in four out of 15 samples analysed) and in the range to 1.1 to 18.8 ng/l in the downstream samples (detected in three out of 15 samples analysed). The detection limit of the method used was 0.2 ng/l. The dimethylated derivative of tetrabromobisphenol-A was also found to be present in some samples (detected

in five effluent samples at 0.33-1.45 ng/l; detected in two upstream samples at 0.42-0.86 ng/l; detected in one downstream sample at 1.06 ng/l; detection limit was again 0.2 ng/l).

The levels of tetrabromobisphenol-A in river, lake and marine surface waters from Japan have been reported by Watanabe and Tatsukawa (1989). The samples were collected from industrialised and non-industrialised areas from all over Japan in 1987. Tetrabromobisphenol-A was detected in 1 out of 75 samples collected at a concentration of 0.05 µg/l.

Further surveys of the levels of tetrabromobisphenol-A in surface waters from all over Japan have been carried out by Environment Agency Japan (1996). In 1977, tetrabromobisphenol-A was not detected in 15 samples analysed (detection limit in the range 0.02-0.04 µg/l). In 1987, tetrabromobisphenol-A was detected in 1 out of 75 samples at a concentration of 0.05 µg/l (detection limit was 0.03 µg/l). The 1987 results are probably the same results as reported by Watanabe and Tasukawa (1989) above. In 1988 tetrabromobisphenol-A was not detected in 150 samples analysed (detection limit was 0.04 µg/l).

A study of the levels of tetrabromobisphenol-A in precipitation has recently been commissioned by Greenpeace (Peters, 2003). In this study, samples of precipitation were collected from 47 locations throughout the Netherlands, two locations in Germany and one location in Belgium over a four-weekly period during February/March. The samples were collected using open sample collectors (which were unable to distinguish between wet- and dry deposition) and so the findings represent the total deposition rather than from precipitation alone. Tetrabromobisphenol-A was found in 16% of the samples analysed at a maximum concentration of 2.6 ng/l. The mean and median concentrations detected were 1.1 and 0.9 ng/l respectively. The detection limit of the method used was 0.5 ng/l.

Peters (2003) also reports the results of a study by Duyzer and Vonk (2002) that investigated the levels of tetrabromobisphenol-A in precipitation in the Netherlands. In this study, tetrabromobisphenol-A was reported to be found in 50% of the air and precipitation samples analysed. The highest concentration found in precipitation was 4.1 ng/l. The samples in this study were four-weekly samples collected over a period of two years. Tetrabromobisphenol-A was detected more frequently, and at higher concentrations, in the samples collected during summer months.

de Boer *et al.* (2002) and Morris *et al.* (2004) investigated the levels of tetrabromobisphenol-A (and its dimethylated derivative) in landfill leachates from the United Kingdom, Ireland and the Netherlands. Tetrabromobisphenol-A and its dimethylated derivative were not found in the leachate samples (either dissolved or associated with the particulates) from three landfills in the United Kingdom. The detection limit for these samples was around 15 ng/l for the dissolved phase and 3.9 µg/kg dry weight for the particulate phase. Similarly neither tetrabromobisphenol-A nor its dimethylated derivative were found in six samples of landfill leachate from three sites in Ireland (the detection limit for these samples was again 15 ng/l for the dissolved phase and 3.9 µg/kg dry weight for the particulate phase). In contrast to this, tetrabromobisphenol-A was detected in the particulate phase in leachates from three out of nine landfill sites in the Netherlands. The concentration found was 43-320 µg/kg dry weight (the detection limit was 5.5-37 µg/kg dry weight). However, tetrabromobisphenol-A was not found in two sewage sludge samples collected from landfill sites in the Netherlands (the detection limit for these samples was 0.3-0.4 µg/kg dry weight). The dimethylated tetrabromobisphenol-A derivative was not found in any of

these samples from the Netherlands (detection limit for this substance was 0.1 µg/kg dry weight).

A recent study on the levels of tetrabromobisphenol-A in leachate from landfill sites in Japan has been published (Osako *et al.*, 2004). The samples were collected from the leachate treatment plants present at the landfill sites (samples were taken before treatment, and in some cases also after treatment). The landfill sites sampled included five municipal solid waste landfills (in Japan around 80% of municipal solid waste is incinerated prior to landfill disposal and so the landfills were almost completely composed of incineration ash, incombustibles and crushed fragments from bulk wastes (including waste electrical and electronic equipment)), one landfill that received sewage treatment sludge as well as municipal solid waste and an industrial waste landfill (the actual industries served by this landfill were not stated but the landfill contained organic and inorganic sludge, incineration residues and waste plastics). Tetrabromobisphenol-A was detected in raw leachate samples from three of the five municipal solid waste landfills at a total (dissolved plus particulate phase) concentration of 9-620 ng/l (the detection limit of the analytical method used was 1 ng/l). The total level of tetrabromobisphenol-A in the treated effluent from these sites was <1-11 ng/l. For the site receiving sewage sludge, the total concentration in the raw leachate was found to be 49-150 ng/l (no treated effluent samples were taken from this site). For the industrial waste landfill samples, the concentration of tetrabromobisphenol-A in the dissolved and particulate phase of the leachate samples was determined separately. These raw leachate samples from this site contained 4.3 ng/l in the dissolved phase and <1 ng/l in the particulate phase. This was reduced to <0.5 ng/l in both phases in the treated leachate sample.

Almqvist and Hanæs (2006) analysed samples of graywater from households in Sweden for the presence of tetrabromobisphenol-A. Graywater was defined as household waste water without any input from toilets. The samples were taken from a housing estate of 32 apartments with around 80 residents. The samples were collected over three one-week periods in October 2001 and were pooled into weekly samples. Tetrabromobisphenol-A was not detected in any of the three pooled samples (detection limit was 0.005 µg/l).

Suzuki and Hasegawa (2006) determined tetrabromobisphenol-A to be present at concentrations of 0.3-540 ng/l in leachate from five industrial waste landfill sites in Japan, and a concentration of 7.7 ng/l in a sample of treated landfill leachate water (the concentration prior to treatment was 130 ng/l). The samples were collected during April 2004. Sediments from the landfill sites were also analysed (see Section 3.1.1.2.2) and the concentrations refer to the total concentration (i.e. dissolved and particulate).

3.1.1.2.2 Sediment

The levels of tetrabromobisphenol-A in surficial (top 1 cm) sediments have been determined near to a plastics factory in Sweden that was known to be using tetrabromobisphenol-A (Sellström and Jansson, 1995). The sediments were taken from two locations, one 2 km upstream from the factory and the other 5 km downstream from the factory. The downstream sediment analysed had a high organic carbon content and was reported to be black with a strong smell of hydrogen sulphide. As well as tetrabromobisphenol-A, the sediment samples were also analysed for the presence of the dimethylated derivative (a possible metabolite of tetrabromobisphenol-A; see Section 3.1.0.6.2). The concentration of tetrabromobisphenol-A was determined to be 34 µg/kg dry weight in the upstream sediment and 270 µg/kg dry weight in the downstream sediment (the same results were reported by Sellström *et al.* (1989

and 1990) on a dry weight ignition loss (ig) basis as 50 µg/kg ig upstream and 430 µg/kg ig downstream). The concentration of the dimethylated derivative was 24 µg/kg dry weight in the upstream sediment and 1,500 µg/kg dry weight in the downstream sediment samples. The concentrations reported were not corrected for recovery of the method. The recovery of tetrabromobisphenol-A using the method was adequate at 79-86%, but the recovery of the dimethylated derivative was variable between 18 and 72%, with a lower recovery generally being found at lower concentrations. The results for the dimethylated derivative should therefore be treated with caution.

The levels of tetrabromobisphenol-A in sediment samples from the River Elbe have been determined (Heemken *et al.*, 2001). The samples represented "freshly deposited" sediment and were collected during January and February 2001. Tetrabromobisphenol-A was detected in 7 out of 20 samples analysed at a concentration of 0.5-4.6 µg/kg dry weight. The mean level found was 2.5 µg/kg dry weight.

Verslycke *et al.* (2005) found that tetrabromobisphenol-A was not detectable (<0.1 µg/kg dry weight) in sediment samples from three locations in the Scheldt estuary. The samples were collected in November 2001 and were sieved (<63 µm) prior to analysis. Tetrabromobisphenol-A was however found to be present at trace amounts in some samples of mysid shrimp from the same area (see Section 3.1.4.2).

The levels of tetrabromobisphenol-A in sediments from the United Kingdom have been measured. The samples were collected during 1998 near to sites that were thought to be using chlorinated paraffins (for various applications) at the time, and represent industrial areas of the United Kingdom. Samples were collected both upstream and downstream of the source of release (usually a waste water treatment plant or outfall). These samples were reanalysed in 2002 for the presence of tetrabromobisphenol-A. Out of the 50 samples analysed, tetrabromobisphenol-A was detected in only one sample at a level of 2.3 mg/kg wet weight. The limit of quantification for the method used was 1.07 µg/kg wet weight (CEFAS, 2002).

Kuch *et al.* (2001) investigated the concentrations of tetrabromobisphenol-A (and dimethylated derivative) in sediment samples from the Rivers Eyach, Körsch, Necktar, Donau and Lauter. Samples were taken both upstream and downstream of waste water treatment plants. and tetrabromobisphenol-A was found to be present in eight out of the 19 samples analysed at a concentration of 0.17-1.83 µg/kg dry weight. The dimethylated derivative was not detected in any sample The detection limit of the method used was 0.2 µg/kg dry weight.

Kemmlein (2000) investigated the concentrations of tetrabromobisphenol-A in sediment samples from the Berlin area of Germany. For some sites, sediments from different depths within the core were analysed in order to obtain information on the time trends in the concentrations found. The results of the analysis are shown in **Table 3.41**.

Table 3.41 Concentrations of tetrabromobisphenol-A in sediments from the Berlin area (Kemmlein, 2000)

Location	Depth of sample	Approximate year of sample	Total organic carbon content	Concentration of tetrabromobisphenol-A (µg/kg dry weight)
Weissensee	40-50 cm	pre 1960	11.8%	0.02
	1-16 cm	1970's		1.95
	0-4 cm	1980's onwards		2.41
Havelkasino	110-150 cm	1950's		not detected
	55-80 cm	1960's	15.74	not detected
	35-45 cm	1970's	15.63	2.71
	0-15 cm	1985 onwards	8.31	18.68
Tegeler See	surface sample	1999		0.13
Oder-Spree Kanal	surface sample	1998	5.4	0.46
Nordhafen Spandau	surface sample	1998	6.2	not detected
Scharfe Lanke	surface sample	1997	10.4	5.62
Maselake	surface sample	1996	11.9	0.22
Mariner Lanke	surface sample	1996	15.1	3.56
Teltowkanal	100-138 cm	1970's	12.0	0.29
	10-45 cm	1990's	12.0	1.05
Bugsinsee	26-40 cm	pre 1960's	35	not detected
	0-6 cm	1990's	36.4	0.49
Osthafen	surface sample	1998	6.3	1.29
Rummelsburger See	surface sample	1998	17.2	0.16
Kleine Malche	surface sample	1996	3.7	0.52

de Boer *et al.* (2002) and Morris *et al.* (2004) determined the levels of tetrabromobisphenol-A in sediments from the Scheldt Estuary, the Netherlands, United Kingdom and Ireland. Tetrabromobisphenol-A was found to be present in 13 out of 19 samples from the Scheldt basin at a concentration of <0.1-32 µg/kg wet weight (<0.1-67 µg/kg dry weight; mean 5.4 µg/kg dry weight), 14 out of 19 samples from the Western Scheldt at a concentration of 0.1-1.3 µg/kg wet weight (<0.1-3.2 µg/kg dry weight; mean 1 µg/kg dry weight), not detected in eight samples from Dublin Bay (but was present at 1 µg/kg wet weight in one sample from the River Liffey at Dublin), in three out of four river sediment samples from Ireland at a concentration of <2.4-3.7 µg/kg dry weight, in 10 out of 22 sediment samples from United Kingdom rivers and estuaries at a concentration of 4.53-57.07 µg/kg dry weight (River Tees), 2-5.1 µg/kg dry weight (River Tyne), up to 9,753 µg/kg dry weight (River Skerne) and not detected in River Humber, Mersey and Clyde, and in 8 out of 9 river sediment samples from the Netherlands at a concentration of 0.4-4.2 µg/kg wet weight (<0.1-6.9 µg/kg dry weight; mean 2.2 µg/kg dry weight). The detection limit of the method used was generally around 0.1 µg/kg wet weight or 2.4 µg/kg dry weight. The highest levels from the United Kingdom were from the River Skerne which is close to a brominated flame retardant production site.

The same study (de Boer *et al.*, 2002) also investigated the levels of dimethylated tetrabromobisphenol-A. The concentrations found were 0.2-0.3 µg/kg wet weight in

sediments from the Scheldt basin (detected in two out of 19 samples), and 0.1-0.4 µg/kg wet weight in river sediments from the Netherlands (detected in four out of nine samples), but was not detected in 19 samples from the Western Scheldt, nine samples from Dublin Bay/Liffey, four river sediment samples from Ireland and 22 samples from United Kingdom rivers and estuaries. The detection limit was again generally around 0.1 µg/kg wet weight or 2.4 µg/kg dry weight.

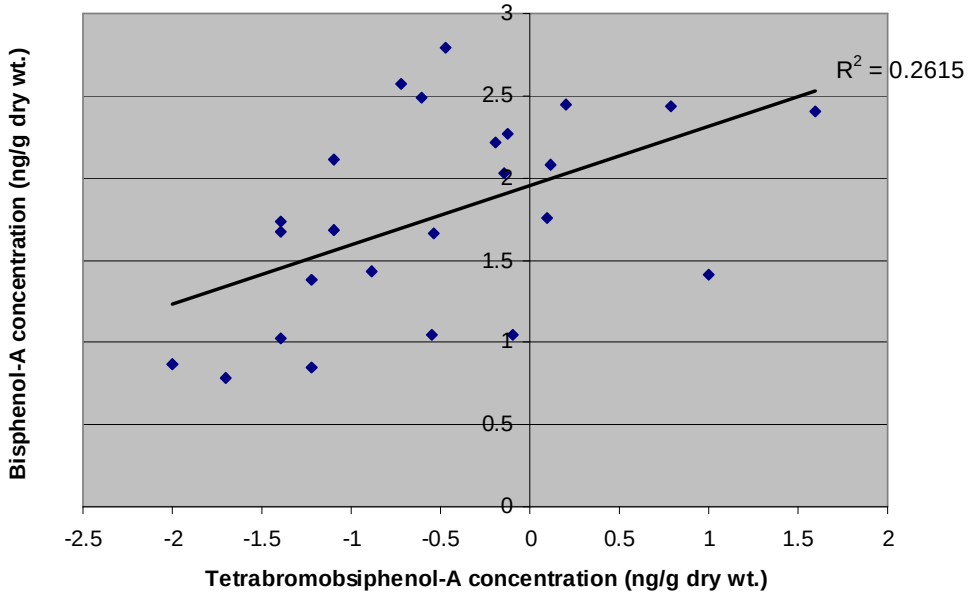
Peltola (2002) has recently determined the levels of tetrabromobisphenol-A in sediment samples from Finland. The samples were collected in the summer/autumn of 2000 and were taken from the aerobic surface layer of the sediments. The detection limit for the method was 0.2 µg/kg dry weight. Tetrabromobisphenol-A was not detected in three coastal samples taken around the Finnish Gulf, but was present at a concentration of 0.4 µg/kg dry weight in sediment from an urban creek that collects stormwater from Helsinki. The highest level found in the study was 21 µg/kg dry weight in a sediment sample from a stormwater trench of a metal dismantling plant.

A recent study by Sternbeck *et al.* (2003) investigated the levels of Tetrabromobisphenol-A in sediments from eastern Sweden. A total of 34 sites were surveyed. Fourteen of these sites were located in the coastal region of Svealand and the remaining twenty sites were located in the Stockholm municipality (the sediments from the Stockholm municipality were further sub-divided into suburban lakes samples and samples from central Stockholm). The samples consisted of the top two cm of sediment at each location (four subsamples of coastal sediments or at least eight subsamples of sediments from the Stockholm municipality were collected at each sampling station and pooled prior to analysis). Using the known sedimentation rates in the area, it was estimated that the top 2 cm corresponded to a time interval of around 1-5 years in the coastal sediments, 1-2 years in the sediments from central Stockholm and 2.5-5 years in the lake sediments. Effluents from the three waste water treatment plants were thought to directly influence two of the sampling locations in central Stockholm. Tetrabromobisphenol-A was not detected in any of the samples analysed. The detection limit of the method used was 5 µg/kg dry weight.

The levels of tetrabromobisphenol-A in various sediment samples from Norway have been determined by Fjeld *et al.* (2004) (some of these data are also reported in Schlabach *et al.*, 2004). The sites sampled included sediment samples from landfill leachate ponds and soil samples or pond/river bed sediment samples from industrially contaminated sites (the combined total of landfill and industrial sites sampled was eight), freshwater surface sediment samples (the top 0-2 cm) from Lake Mjøsa (from fourteen sites) and Lake Losna (one site), freshwater surface sediment samples from the Drammens River (seven sites in an industrialised area) and Drammensfjord (three sites close to industrial sites and one site in the main basin) and marine sediment samples from along the Norwegian coast (two sites in harbours, one site in a fjord with industrial contamination and three sites in open coastal waters). Tetrabromobisphenol-A was found to be present in all of the soil and sediment samples from landfills and industrial sites at a concentration of 0.06-6.2 µg/kg dry weight. The concentration was found to be lower in the sediments from Lake Mjøsa and Lake Losna (0.04-0.13 µg/kg dry weight). The levels of tetrabromobisphenol-A in the sediment samples from Drammens River were in the range 0.2-10 µg/kg dry weight, with the highest concentration being found at the site close to an industrial area, and the levels found in Drammensfjord were 0.3-39 µg/kg dry weight with the highest level again being found close to an industrial area. In the marine samples, the levels of tetrabromobisphenol-A were in the range 0.01-2.4 µg/kg dry weight, with the highest levels being found in harbours.

The study by Fjeld *et al.* (2004) is interesting in that the levels of bisphenol-A were also determined in the samples. In most cases the level of bisphenol-A found was higher than that of tetrabromobisphenol-A. **Figure 3.5** shows a plot of the concentration of bisphenol-A versus the concentration of tetrabromobisphenol-A found in each of the samples. As can be seen from the plot there appears to be some (albeit very poor) correlation between the levels of bisphenol-A and tetrabromobisphenol-A. Such a correlation would only be expected if both substances were being released from the same industrial processes in the areas sampled. This is a possible explanation as both tetrabromobisphenol-A and bisphenol-A are used in the production of epoxy resins. Further information on the actual industries present/sampled in the area has been obtained (SFT, 2004a). The sediment samples were taken near to some production sites/industrial areas, waste disposal sites and sewage treatment plants but, as the screening program was not directly designed to identify the industrial sources, the actual industries sampled are not known in many cases. However it was known that one sample was taken from close to a site that was known to use tetrabromobisphenol-A in the production of printed circuit boards (and so probably used also bisphenol-A), and so it is possible that the weak correlation seen is a result of similar sources of emission for tetrabromobisphenol-A and bisphenol-A. Another possible explanation of these findings is if tetrabromobisphenol-A is degrading in the sediments to form bisphenol-A. This has been shown to occur in anaerobic marine sediments in the laboratory, and such a degradation mechanisms could explain the findings here. However the uncertainty associated with this analysis is too large to be able to draw any firm conclusions on this issue.

Figure 3.5 Comparison of concentrations (on a log - log scale) of bisphenol-A and tetrabromobisphenol-A concentrations in sediment samples from Norway



Chu *et al.* (2005) has analysed surface sediment samples from Lake Erie for the presence of both tetrabromobisphenol-A and possible degradation products including tribromobisphenol-A, dibromobisphenol-A, monobromobisphenol-A and bisphenol-A. A total of fifty five samples were collected from forty eight locations during May-June 2004, forty six of the samples were collected from a depth of 0-10 cm and the remaining nine samples were collected from a depth of 10-20 cm. Tetrabromobisphenol-A was detected in

only three of the samples, and could be quantified in only one of the samples (level present was 0.51 µg/kg dry weight). Tribromobisphenol-A was also found in the same sample at a concentration of 0.34 ug/kg dry weight. No dibromobisphenol-A or monobromobisphenol-A were detected in any of the samples (the detection limit was in the sub-µg/kg dry weight region). In contrast to this, 65% of the samples were found to contain bisphenol-A, at concentrations up to 6.1 µg/kg dry weight.

Watanabe *et al.* (1983a) determined the levels of tetrabromobisphenol-A in a river sediment sample from Osaka, Japan. The sample was collected in September 1981 and the concentration of tetrabromobisphenol-A present was around 20 µg/kg dry weight.

A further study of the levels of tetrabromobisphenol-A in sediments from Japan have been reported by Watanabe and Tatsukawa (1989). In the first part of this study, sediments were collected from the Osaka area in 1981-1983. Tetrabromobisphenol-A was detected in 14 out of 19 samples at a concentration of 0.5-140 µg/kg dry weight. The samples included both river and marine sediments. Dimethylated tetrabromobisphenol-A (a possible metabolite of tetrabromobisphenol-A) was found in 5 out of 19 samples at a concentration of 0.6-1.8 µg/kg dry weight). In the second part of the study, river and marine sediments were collected from industrialised and non-industrialised areas from all over Japan in 1987. Tetrabromobisphenol-A was detected in 14 out of 66 samples at a concentration of 20-150 µg/kg dry weight, with the substance present mainly in river sediments from industrial areas. The dimethylated derivative was not investigated in the second part of the study. The data for 1981-1983 are also reported in Watanabe *et al.* (1983b).

Another survey of the levels of tetrabromobisphenol-A in sediments from all over Japan was carried out by Environment Agency Japan (1996). In 1977, tetrabromobisphenol-A was not detected in 15 samples analysed (detection limit in the range 1.3-7 µg/kg dry weight). In 1987, tetrabromobisphenol-A was detected in 14 out of 66 samples at a concentration of 2-150 µg/kg dry weight (detection limit was 2 µg/kg dry weight). The 1987 results are probably the same results as reported by Watanabe and Tasukawa (1989) above. In 1988 tetrabromobisphenol-A was detected in 20 out of 130 samples analysed at a concentration of 2-108 µg/kg dry weight (detection limit was 2 µg/kg dry weight).

Ohta *et al.* (2002) has recently determined the concentration of tetrabromobisphenol-A in sediment samples collected from six locations in the coastal area around Osaka Bay, Japan. The samples were collected in 1999 and tetrabromobisphenol-A was found to be present in all six samples at a concentration in the range 0.68-12 µg/kg dry weight. The highest level was found in a sample from Rokkou Island collected in an area with many harbour facilities.

The levels of tetrabromobisphenol-A in surface sediments collected in 2003 from seventeen locations around the coastal area of the Setouchi Sea, Japan, were determined to be in the range 0.08 to 5 µg/kg dry weight (Ohta *et al.*, 2004b). The highest levels found were from an area containing many chemical factories.

DeCarlo (1979) found that tetrabromobisphenol-A was present in sediment taken from near to tetrabromobisphenol-A manufacturing facilities in Arkansas, United States. The concentration present was not given.

Zweidinger *et al.* (1979) determined the levels of tetrabromobisphenol-A in sediment samples taken from near to two brominated organic chemical production sites in the United States.

One of these sites (site A) was known to produce tetrabromobisphenol-A. The sediment samples were collected in 1977 and the sample represented the top 2.5 cm of the sediment core. The levels of tetrabromobisphenol-A determined at site A were in the range 0.30 to 330 mg/kg. At site B the levels found were in the range not detected to 0.030 mg/kg. The detection limit of the method used was stated to be around 0.1 mg/kg.

Quade *et al.* (2003) determined the levels of tetrabromobisphenol-A in suspended sediments from eight locations in the Detroit River and Trenton Canal, Canada. The samples were collected during July 2000. The analytical method used involved derivatisation of the tetrabromobisphenol-A to form dimethylated bisphenol-A and so the concentrations reported represent the sum of the tetrabromobisphenol-A and any dimethylated bisphenol-A present in the sample. Tetrabromobisphenol-A (and/or the dimethylated derivative) was detected in all eight samples collected. The levels determined ranged from 0.60 µg/kg dry weight in a sample from southern Lake St. Clair to 1.84 µg/kg dry weight from a site downstream from a waste water treatment plant.

SFT (2002) carried out a screening study for the concentrations of tetrabromobisphenol-A in sediments associated with the effluents from waste dumps in Norway. In all, samples from twelve locations were analysed and tetrabromobisphenol-A was found to be present in all twelve samples at a concentration of 1.92-44.4 µg/kg wet weight. Dimethylated tetrabromobisphenol-A was also found in eleven out of twelve of the samples at a concentration of 0.11-1.23 µg/kg wet weight.

Suzuki and Hasegawa (2006) determined tetrabromobisphenol-A to be present at concentrations of <0.2-1.6 µg/kg in sediments from five industrial waste landfill sites in Japan and a concentration of 5.5 µg/kg in a marine sediment sample from an urban bay. The samples were collected during 2004. Leachate samples from the landfill sites were also analysed (see Section 3.1.1.2.1). {Note: the units for these data are unclear from the paper. They are reported in some places as ng/l and in others as ng/g (µg/kg) – this latter unit has been assumed to be correct here.}

3.1.1.2.3 Comparison of measured level with predicted levels

Tetrabromobisphenol-A has been measured in surface water from Europe and Japan, although the actual amount of monitoring data available is limited. In addition it has also been found in influents and effluents of waste water treatment plants in Europe. When present in surface water, the concentrations found in Europe are in the region of 1×10^{-3}-0.020 µg/l, which is similar to the regional concentration predicted here of 1.3×10^{-3} µg/l, however, it should also be noted that a large proportion of the surface water samples analysed so far do not contain detectable amounts of tetrabromobisphenol-A. No measured data are available with which to compare the predicted local concentrations.

For sediment, recent measurements from Germany found tetrabromobisphenol-A present in sediments at up to around 19 µg/kg dry weight, and measurements from Sweden found a concentration of around 270 µg/kg dry weight downstream of a plastics factory. Elevated levels (up to 9,752 µg/kg dry weight) have been found in industrial areas of the United Kingdom. Using the dry weight to wet weight conversion factors given in the Technical Guidance Document, these concentrations are equivalent to around 7, 104 and 3,750 µg/kg wet weight respectively. When these are compared with the predicted concentrations, it can be seen that the measured concentrations from Sweden and the United Kingdom are of a

similar order to the predicted local concentration for some scenarios. The predicted regional concentration (4.0-8.1 μg/kg wet weight) is generally consistent with the available monitoring data.

In the absence of sufficient monitoring data covering all scenarios considered in the assessment, the predicted concentrations for surface water and sediment will be considered in the Risk Characterisation.

3.1.2 Terrestrial compartment

3.1.2.1 Calculation of PECs

3.1.2.1.1 Production and use of tetrabromobisphenol-A

The estimated concentrations of tetrabromobisphenol-A in soil are shown in **Table 3.42** for the regional and continental scenarios and **Table 3.43** for the local scenarios. These concentrations have been estimated using the EUSES 2.0.3 program (see Appendix B). The vast majority of tetrabromobisphenol-A is likely to enter soil via adsorption onto and subsequent spreading of sewage sludge, but for uses where atmospheric emissions occur, then these releases can also contribute to the concentrations found in soil over time. In addition, particulate waste containing tetrabromobisphenol-A is predicted to be a direct source of emission to industrial/urban soil.

Table 3.42 Estimated regional and continental soil concentrations for tetrabromobisphenol-A

Soil type	Regional concentration (mg/kg wet wt.)		Continental concentration (mg/kg wet wt.)	
	Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Natural soil	2.6×10^{-4}	1.0×10^{-3}	3.2×10^{-5}	1.3×10^{-4}
Agricultural soil	1.5×10^{-3}	9.9×10^{-3}	1.6×10^{-4}	1.0×10^{-3}
Industrial/urban soil	1.9×10^{-3}	6.1×10^{-3}	2.0×10^{-4}	6.5×10^{-4}

In addition to the PECs calculated in **Table 3.43**, some confidential site specific information has been provided for eight of the eleven companies in the EU using tetrabromobisphenol-A as a reactive flame retardant in manufacture of epoxy/polycarbonate resins. The information provided includes details of the amounts of tetrabromobisphenol-A used at the sites and in some cases the number of days of use, information on the emissions to air and the size of the waste water treatment plant. The available information indicates that no sewage sludge from these sites is applied to agricultural land, and so this route to soil has not been included in the calculations (the calculations effectively only assumed atmospheric deposition from the local source but do include the regional background contribution from other sources). Using these data, along with the generic emission factors of 0.001% to air (see Section 3.1.0.2.2) where no site-specific emission factors or data were available, the local concentrations in agricultural soil (averaged over 30 days) for these sites can be estimated to be in the range 3.4×10^{-4}-2.3×10^{-3} mg/kg wet weight using a Koc of 49,726 l/kg and 1.0×10^{-3} to 3.1×10^{-3} mg/kg wet weight respectively using a Koc of 147,360 l/kg (see Appendix F).

Table 3.43 Estimated local concentrations in soil for tetrabromobisphenol-A

Scenario			Koc = 49,726 l/kg			Koc = 147,360 l/kg		
			Agric. soil 30 day average (mg/kg wet w t.)[b]	Agric. soil 180 day average (mg/kg wet wt.)[b]	Grassland 180 days average (mg/kg wet wt.)[b]	Agric soil 30 day average (mg/kg wet wt.)[b]	Agric. soil 180 day average (mg/kg wet wt.)[b]	Grassland 180 day average (mg/kg wet wt.)[b]
Production of tetrabromobisphenol-A	Example calculation		198 [2.6×10^{-4}]	198 [2.6×10^{-4}]	79.2 [2.8×10^{-4}]	221 [1.0×10^{-3}]	221 [1.0×10^{-3}]	88.2 [1.0×10^{-3}]
Use as an intermediate in the production of derivatives	Example calculation		255 [6.3×10^{-4}]	255 [6.4×10^{-4}]	102 [1.0×10^{-3}]	284 [1.4×10^{-3}]	284 [1.4×10^{-3}]	114 [1.8×10^{-3}]
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[a]		0.40 [8.5×10^{-4}]	0.40 [8.6×10^{-4}]	0.16 [1.5×10^{-3}]	0.44 [1.6×10^{-3}]	0.44 [1.6×10^{-3}]	0.18 [2.3×10^{-3}]
	Processing of epoxy resins		9.9×10^{-4} [2.6×10^{-4}]	9.8×10^{-4} [2.6×10^{-4}]	5.5×10^{-4} [2.6×10^{-4}]	1.8×10^{-3} [1.0×10^{-3}]	1.8×10^{-3} [1.0×10^{-3}]	1.3×10^{-3} [1.0×10^{-3}]
	Processing of polycarbonate resins		9.9×10^{-4} [2.6×10^{-4}]	9.8×10^{-4} [2.6×10^{-4}]	5.5×10^{-4} [2.6×10^{-4}]	1.8×10^{-3} [1.0×10^{-3}]	1.8×10^{-3} [1.0×10^{-3}]	1.3×10^{-3} [1.0×10^{-3}]
Additive flame retardant use	ABS	Compounding[a]	16.1 [3.8×10^{-4}]	16.0 [3.8×10^{-4}]	6.4 [5.1×10^{-4}]	17.9 [1.2×10^{-3}]	17.9 [1.2×10^{-3}]	7.1 [1.3×10^{-3}]
		Conversion	0.73 [$8.8\text{x}10^{-4}$]	0.73 [8.9×10^{-4}]	0.29 [1.5×10^{-3}]	0.81 [1.7×10^{-3}]	0.81 [1.7×10^{-3}]	0.33 [2.3×10^{-3}]
Electronic equipment collection/recycling site			2.6×10^{-4}	2.6×10^{-4}	2.6×10^{-4}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}

Note: a) Industry have indicated that the main sites using tetrabromobisphenol-A in these operations do not apply sewage sludge to agricultural land.
b) The default calculations assumed sewage sludge is applied to agricultural land. The resulting concentrations in soil assuming no sludge is applied to land are shown in [ ].

Confidential site specific information has been also received from a site using tetrabromobisphenol-A as an additive flame retardant in the EU. Using these data the PEC_{local} for soil can be estimated as 0.036 mg/kg wet weight using a Koc of 49,726 l/kg and 0.039 mg/kg wet weight using a Koc of 147,360 l/kg. It should be noted that the concentrations in soil for this site result mainly from atmospheric deposition as sludge from the site is not applied to agricultural land.

It should be noted that the generic calculations in **Table 3.43** assume that sludge from the site is applied to agricultural land. Information from Industry indicates that sludge from the known sites in the EU that carry out manufacture of epoxy/polycarbonate resins (and other reactive uses of tetrabromobisphenol-A) and compounding of ABS using tetrabromobisphenol-A as an additive is not applied to agricultural land (BSEF, 2006b). Therefore, the calculations have also been carried out assuming that no sludge is applied to land. The resulting concentrations are shown in [ ] in **Table 3.43**. The fate of sludge at all processing sites using the flame-retarded epoxy/polycarbonate resins and all sites carrying out conversion of ABS is not currently clear. Therefore it is still relevant to consider a generic scenario for these scenarios whereby sewage sludge is applied to agricultural land to cover these instances.

3.1.2.2 Measured levels

Ronen and Abeliovich (2000) report the results of analysis by Arnon (1999) for tetrabromobisphenol-A in soil samples at a contaminated site in Israel. The concentration found in the upper 15 cm of the soil profile was 450 mg/kg.

DeCarlo (1979) found that tetrabromobisphenol-A was present in soil taken from near to tetrabromobisphenol-A manufacturing facilities in Arkansas, United States. The concentration present was not given.

Tetrabromobisphenol-A has been reported to be present at a concentration of 0.12 µg/kg wet weight in soil collected from outside of a tetrabromobisphenol-A production plant in China (Jin *et al.*, 2006). The study is currently available only as an extended abstract and few other details of the sample are available.

Tetrabromobisphenol-A has been found to be present in compost derived from kitchen and green waste (extended abstract by Brändli *et al.*, 2006). The study investigated the concentrations of various pollutants in over 80 samples of composts and digestates derived from source-separated green and kitchen wastes from 39 commercial composting and digestion plants in Switzerland. The median concentration of tetrabromobisphenol-A found was 0.51 µg/kg dry weight (range of concentrations was around 0.1-2.3 µg/kg dry weight; all values read from a chart).

No further information on the levels of tetrabromobisphenol-A in soils is available.

As an important route for the substance to soil is through the application of sewage sludge, it is relevant to also consider here the available data on the levels of tetrabromobisphenol-A in sewage sludge.

Sellström and Jansson (1995) determined the levels of tetrabromobisphenol-A, and its dimethylated derivative (a possible metabolite of tetrabromobisphenol-A; see Section 3.1.0.6.2) in sewage sludge from a treatment plant that received leachate water from a landfill that was known to contain waste from a plastics factory using tetrabromobisphenol-A. In addition, a sewage sludge sample was also analysed from a treatment plant with no known sources of tetrabromobisphenol-A. Tetrabromobisphenol-A was tentatively identified in both samples of sewage sludge. The concentration found in the sludge sample from the treatment plant receiving the leachate was 56 µg/kg dry weight and the concentration found in the sludge sample from the other treatment plant was similar at 31 µg/kg dry weight. The dimethylated derivative was not found (detection limit 1.9 µg/kg dry weight) in either sample. The concentrations reported were not corrected for recovery of the method. The recovery of tetrabromobisphenol-A using the method was adequate at 79-86%, but the recovery of the dimethylated derivative was variable between 18 and 72%, with the recovery generally being lower at lower concentrations. The results for the dimethylatedr derivative should therefore be treated with caution.

Sellström *et al.* (1999) reported levels of tetrabromobisphenol-A of around 5, 10 and 45 µg/kg dry weight (values read from a graph) in sewage sludge samples from three municipal sewage treatment plants in Stockholm, Sweden. These levels are reported elsewhere as 2.9-76 µg/kg dry weight (de Wit, 1999).

Peltola (2002) has recently determined the concentrations of tetrabromobisphenol-A in municipal sewage sludge samples from two sewage treatment plants in Finland. The samples were pooled samples of dried sludge collected over 15 days at each plant. The concentration of tetrabromobisphenol-A was below the detecting limit of the method used (0.2 µg/kg dry weight) in both samples.

The levels of tetrabromobisphenol-A in 57 sewage sludge samples taken from 22 municipal wastewater treatment plants in Sweden have been reported by Öberg *et al.* (2002). The levels found were in the range not detected (<0.3 µg/kg wet weight) to 220 µg/kg wet weight, with the median level being 2.0 µg/kg wet weight. The samples were collected between October 1999 and September 2000. The samples with the highest concentration of tetrabromobisphenol-A were collected from a waste water treatment plant that had possible contributions from the electronics industry.

Metzger and Kuch (2003) determined the levels of tetrabromobisphenol-A in sludge samples collected from 32 municipal waste water treatment plants in Baden-Württemberg, Southwestern Germany. Tetrabromobisphenol-A was found to be present at a concentration of 0.6-62 µg/kg dry weight, with a mean level of 16 µg/kg dry weight. It was also reported that tetrabromobisphenol-A was found to be present in the aqueous phase in the samples, but no levels were given.

Kuch *et al.* (2001) also gives details of the levels of tetrabromobisphenol-A (and the dimethylated derivative) in sludge samples collected from waste water treatment plants in Baden-Württemberg (these may be the same samples reported by Metzger and Kuch). Tetrabromobisphenol-A was found to be present in eleven out of twelve sludge samples (consisting of activated sludge, primary sludge or clarified/settled sludge) from 8 treatment plants at a concentration of 5.2-34.5 µg/kg dry weight. The dimethylated derivative was found to be present in seven out of the twelve samples analysed at a concentration of

0.39-11.0 µg/kg dry weight. The detection limit for both substances was 0.2 µg/kg dry weight.

de Boer *et al.* (2002) and Morris *et al.* (2004) determined the levels of tetrabromobisphenol-A (and the dimethylated derivative) in samples of sewage sludge from treatment plants in the United Kingdom, Ireland and the Netherlands. Tetrabromobisphenol-A was found to be present in five out of six sewage sludge samples from three treatment plants in Ireland at a concentration of 7.33-192 µg/kg dry weight (mean 95 µg/kg dry weight). Similarly, tetrabromobisphenol-A was found to be present in sewage sludge samples from all five treatment plants sampled in the United Kingdom at a concentration of 15.9-112 µg/kg dry weight (mean 59 µg/kg dry weight). The samples from the Netherlands showed tetrabromobisphenol-A to be present in sludge samples from all eight waste water treatment plants analysed at a concentration of 2.1-600 µg/kg dry weight (mean 79 µg/kg dry weight). The detection limit of the method used was around 0.1-2.4 µg/kg dry weight). The dimethylated derivative was generally not found (it was present in three of the samples from the Netherlands at 0.2-5.5 µg/kg dry weight) in the samples analysed (detection limit 0.-2.4 µg/kg dry weight).

Tetrabromobisphenol-A has also been found to be present in municipal sewage sludge in Canada (Lee and Peart, 2002). Samples of both raw sludge (collected from the primary sedimentation tanks) and digested sludge (collected from the secondary clarifiers) were included in the study. In all, 35 sludge samples taken from 21 municipal sewage treatment plants between 1994 and 2000 were analysed. Tetrabromobisphenol-A was found to be present in 34 of the samples (the detection limit was 1 µg/kg) at a concentration ranging between 2.9 to 46.2 µg/kg dry weight. The median level found was 12.4 µg/kg dry weight.

Quade *et al.* (2003) determined the levels of tetrabromobisphenol-A in sewage sludge from waste water treatment plants in the Great Lakes area. The analytical method used involved derivatisation of the tetrabromobisphenol-A to form dimethylated bisphenol-A and so the concentrations reported represent the sum of the tetrabromobisphenol-A and any dimethylated bisphenol-A present in the sample. Tetrabromobisphenol-A (plus the dimethylated derivative) was detected in all seven sludge samples collected from southern Ontario communities at concentrations in the range 14.3 to 43.8 µg/kg dry weight. The samples included both raw and digested sludges.

Tetrabromobisphenol-A was found to be present at a concentration of around 330 µg/kg dry weight (samples collected in 2003) and 310 µg/kg dry weight (samples collected in 2004) in samples of sewage sludge from the Montreal area, Canada (Saint-Louis and Pelletier, 2004).

Chu *et al.* (2005) has analysed sewage sludge samples from Canada for the presence of both tetrabromobisphenol-A and possible degradation products including tribromobisphenol-A, dibromobisphenol-A, monobromobisphenol-A and bisphenol-A. The samples were collected form the Little River wastewater treatment plant and West Windsor pollution control plant in Windsor, Ontario. The results of the analysis are summarised in **Table 3.44**. All samples of sludge contained tetrabromobisphenol-A, and the possible degradation products tribromobisphenol-A, dibromobisphenol-A and in some cases monobromobisphenol-A were also present. Bisphenol-A was also present in all samples. These results provide indirect supporting evidence that tetrabromobisphenol-A can undergo debromination reactions in the environment to eventually form bisphenol-A.

Table 3.44 Concentrations of tetrabromobisphenol-A and debrominated bisphenol-A in sewage sludge samples from Canada

Substance	Concentration (µg/kg dry weight)			
	Little River – sample 1	Little River – sample 2	Little River – sample 3	West Windsor
Tetrabromobisphenol-A	5.75	2.09	5.34	28.3
Tribromobisphenol-A	0.26	0.11	0.23	0.55
Dibromobisphenol-A	0.29	0.18	0.22	0.52
Monobromobisphenol-A	1.00	0.10	not detected	0.25
Bisphenol-A	7.01	3.78	74.4	37.5

Other data relevant for the terrestrial compartment are summarised below.

SFT (2002) determined the concentrations of tetrabromobisphenol-A in eleven out of eleven samples of moss from Norway. The concentration found was in the range 0.019-0.89 µg/kg wet weight. The report suggested that the presence in moss was indicative of transport of tetrabromobisphenol-A via the atmosphere. No dimethylated tetrabromobisphenol-A was detected in any sample (the detection limit for this substance was 0.005 µg/kg wet weight).

Further details of the sampling locations used in the moss study have been provided (SFT, 2004b). The samples (approximate size 1 litre) were collected in forest areas not closer than 300 m to the nearest road or building/house. The distance of each sampling site from the nearest village/town was at least 10 km and the population of these villages/towns ranged from around 1,500 (Limingen) to 24,000 (Molde).

3.1.2.3 Comparison of measured levels with predicted levels

There are no measured levels for tetrabromobisphenol-A in soil in the EU. There is evidence that tetrabromobisphenol-A is present in sewage sludge in the EU and so is likely to enter into the soil compartment when this sludge is applied to soil, but it is not possible to relate these values directly to the scenarios considered in this assessment. The predicted concentrations in soil will therefore be used in the Risk Characterisation.

As a comparison, the highest level of tetrabromobisphenol-A measured in sewage sludge on a dry weight basis is around 600 µg/kg, with values more commonly being between a few µg/kg dry weight and 192 µg/kg dry weight. The approximate 90th percentile value of the sludge concentrations is around 94 µg/kg dry weight (this value is based on the data reported for Europe in Section 3.1.2.2; it is only an approximate value as in some studies only the range (upper and lower limit and sometimes mean value) were reported, whereas in other studies individual values for each sample were reported). The actual source of tetrabromobisphenol-A in the sewage sludge samples is not known.

Using the estimated 90th percentile value of 94 µg/kg dry weight as a worst case (but not extreme) approach, the predicted concentrations in agricultural soil after 10 years application (using the methods given in the Technical Guidance Document) would be around 1.3×10^{-3} mg/kg wet weight using a Koc of 49,726 l/kg and 1.4×10^{-3} mg/kg wet weight using a Koc of 147,360 l/kg. These values are similar to the estimates obtained for some local scenarios (e.g. reactive flame retardant use and electronic equipment collection/recycling) and the regional scenario using the lower Koc value (although it should be noted that a direct

comparison is problematic as the actual source of the tetrabromobisphenol-A in the sewage sludge samples is not known and the regional concentrations are estimated at steady state, whereas these concentrations have been estimated over a relatively short time frame (10 years)).

One possible explanation for the occurrence of tetrabromobisphenol-A in municipal sewage sludge could be from emissions from articles in use (e.g. volatilisation loss with subsequent condensation on surfaces, particulate loss, etc.). However other possibilities also exist (for example as indicated in Section 3.1.0.4.2, tetrabromobisphenol-A has been reported to be found in toilet paper). The significance of these sources in relation to the levels found in municipal sewage sludge is not clear.

3.1.3 Air compartment

3.1.3.1 Calculation of PECs

The concentrations of tetrabromobisphenol-A in the atmosphere have been estimated using EUSES 2.0.3. The predicted atmospheric concentrations are shown in **Table 3.45**.

Table 3.45 Estimated air concentrations of tetrabromobisphenol-A

Scenario			Air concentrations (C_{local}) (mg/m^3)		$PEC_{local(air),\ ann}$ (mg/m^3)
			Emission episode	Annual average	
Production of tetrabromobisphenol-A	Example calculation		5.0×10^{-8}-1.2×10^{-7}	4.1×10^{-8}-1.0×10^{-7}	4.2×10^{-8}-1.0×10^{-7}
Use as an intermediate in the production of derivatives	Example calculation		7.0×10^{-6}	3.8×10^{-6}	3.8×10^{-6}
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		7.5×10^{-6}	6.2×10^{-6}	6.2×10^{-6}
	Processing of epoxy resins		1.4×10^{-8}	1.2×10^{-9}	2.5×10^{-9}
	Processing of polycarbonate resins		1.4×10^{-8}	1.1×10^{-9}	2.4×10^{-9}
Additive flame retardant use	ABS	Compounding	2.8×10^{-6}	1.3×10^{-6}	1.3×10^{-6}
		Conversion	1.4×10^{-5}	6.5×10^{-6}	6.5×10^{-6}
Electronic equipment collection/recycling site			5.1×10^{-8}	4.2×10^{-8}	4.3×10^{-8}

The local concentrations arise from direct emission of tetrabromobisphenol-A from the various industrial processes involved. Emissions to air from waste water treatment plants are very small but are included in the estimates obtained by EUSES. At the regional and continental level, diffuse source releases of tetrabromobisphenol-A have also been considered in the estimations. These releases were identified in Section 3.1.0. The full output of the EUSES model is given as Appendix B. The regional air concentration is estimated at around 1.0×10^{-9}-1.3×10^{-9} mg/m^3.

In addition to the PECs given in **Table 3.45**, some confidential site specific information has been provided for the eight major brominated epoxy resin manufacturing companies in the EU. The information provided includes details of the amounts of tetrabromobisphenol-A used

at the sites and in some cases, the number of days of use and in some cases information on the emissions of tetrabromobisphenol-A to air from the process. Using these data, along with the generic emission factor to air of 0.001% (see Section 3.1.0.2.2) for the sites where no specific release information was provided, results in predicted concentrations in air during an emission episode of between 7.3×10^{-9} and 2.6×10^{-5} mg/m^3. The upper limit of these values is of a similar order of magnitude to the value given in **Table 3.45** for a generic epoxy resin manufacturing site.

In addition, confidential information is available on the emissions to air from a site using tetrabromobisphenol-A as an additive flame retardant in the EU. Using this information, the predicted concentration in air from this site is around 7.5×10^{-4} mg/m^3, which is considerably higher than estimated for the generic sites in **Table 3.45**.

3.1.3.2 Measured levels

The levels of tetrabromobisphenol-A in airborne particulates have been determined in outdoor air sampled at two facilities in the United States that manufactured organobromine chemicals (Zweidinger *et al.*, 1977 and 1979). The samples were composite samples collected over 24 hour periods during 1977. The detection limit for tetrabromobisphenol-A was 10 ng/m^3. The level found in airborne particulates at one facility was not detected-28 ng/m^3 and the level found at the other company was not detected to 1,800 ng/m^3.

DeCarlo (1979) found that tetrabromobisphenol-A was present in air particulates taken from near to tetrabromobisphenol-A manufacturing facilities in Arkansas, United States. The concentration present was not given.

A number of studies have recently determined the concentration of tetrabromobisphenol-A in indoor air at various facilities, such as those handling electronic equipment, and offices containing computer equipment. The results of these studies are given below and summarised in **Table 3.46**. These data are more relevant to occupational exposure than environmental exposure.

Bergman *et al.* (1999) determined the level of tetrabromobisphenol-A in indoor air at a facility for dismantling electronic equipment and in offices equipped with computers in Sweden. The concentration found in air at the dismantling facility was 7.0-58.8 ng/m^3 (mean 29.4 ng/m^3) and the concentration found in the office was 9.6×10^{-3}-0.070 ng/m^3 (mean 0.035 ng/m^3). The levels reported refer to the total concentration (i.e. particle bound plus vapour phase) in air.

The levels of tetrabromobisphenol-A in indoor air have been determined at a plant for recycling electronic equipment, a factory for assembling circuit boards, a facility for repairing computers, a computer teaching hall and offices containing computers in Sweden (Sjödin *et al.*, 2001). At the electronic equipment recycling plant samples were taken from two locations, the dismantling hall and the shredder room. The concentration found in the dismantling hall was in the range 6.9 to 61 ng/m^3. The concentration in the shredder room was found to be around 130-150 ng/m^3 when plastic containing brominated flame retardants was being shredded and around 34-41 ng/m^3 when plastic that didn't contain brominated flame retardants was being shredded. Tetrabromobisphenol-A was also found in air at the other locations investigated. The concentrations found were 0.11-0.37 ng/m^3 at the circuit board factory, 0.010-0.070 ng/m^3 in offices with computers, 0.031-0.038 ng/m^3 at the

computer repair facility and 0.035-0.15 ng/m^3 at the computer teaching hall. Tetrabromobisphenol-A was not detected in two samples of outdoor air from a suburban area of Stockholm. The levels reported refer to the total concentration (i.e. particle bound plus vapour phase) in air.

Table 3.46 Concentrations of tetrabromobisphenol-A in indoor air

Location	Country	Concentration (ng/m^3)		Reference
		Range	Mean	
Electronic equipment dismantling facility	Sweden	7.0-58.8	29.4	Bergman *et al.*, 1999
Electronic equipment dismantling facility - dismantling hall	Sweden	6.9-61	30	Sjödin *et al.*, 2001
Electronic equipment dismantling facility - dismantling hall	Sweden		37	Pettersson *et al.*, 2001
Electronic equipment dismantling facility - dust removal area	Sweden		12	Pettersson *et al.*, 2001
Electronic equipment dismantling facility – shredder	Sweden	34-150		Sjödin *et al.*, 2001
Electronic equipment dismantling facility – dismantling hall	Sweden		13.8	Tollbäck *et al.*, 2006
Office with computers	Sweden	9.6×10^{-3}-0.070	0.035	Bergman *et al.*, 1999
Office with computers	Sweden	0.010-0.070	0.036	Sjödin *et al.*, 2001
Office with computers	Germany		0.029	Kemmlein, 2000
Office with computers	Germany		0.008	Kemmlein, 2000
Circuit board manufacturing facility	Sweden	0.11-0.37	0.20	Sjödin *et al.*, 2001
Computer repair facility	Sweden	0.031-0.038		Sjödin *et al.*, 2001
Computer teaching hall	Sweden	0.035-0.15		Sjödin *et al.*, 2001
Houses	Japan	~0.1-1		Inoue *et al.*, 2003

Pettersson *et al.* (2001) reported levels of tetrabromobisphenol-A in indoor air samples and sedimentary dust samples from an electronic equipment dismantling plant in Örebro, Sweden. The samples were collected from two locations within the plant during a two week period in August 2000. In the dust removal area the level found in air was 12 ng/m^3 and the level found in sedimentary dust was 31 mg/kg. The levels found in the dismantling hall were 37 ng/m^3 and 4.1 mg/kg in the air and sedimentary dust respectively. It is not totally clear from the paper whether the air levels refer to the vapour phase concentration or the total concentration (particulates plus vapour phase) although the total concentration is most likely.

Tollbäck *et al.* (2006) found that tetrabromobisphenol-A was present at a mean concentration of 13.8 ng/m^3 in air samples from the dismantling hall at an electronic equipment recycling plant in Sweden. The samples were collected during a single day from approximately the same location within the plant. The level refers to the total concentration in air (i.e. particulate plus vapour phase).

Kemmlein (2000) determined the concentration of tetrabromobisphenol-A in indoor air samples in two rooms containing computers in Germany. The samples were collected over a three week period and the level of tetrabromobisphenol-A found was 0.029 ng/m^3 in a 30 m^2

room containing eight computers and 0.008 ng/m^3 in a 100 m^2 room containing six computers. Tetrabromobisphenol-A was not found in samples of outdoor air. It is not clear if these levels refer to the vapour phase or total (i.e. vapour phase plus particulate phase) concentration.

The levels of tetrabromobisphenol-A in indoor air from Japan have been reported (Inoue *et al.*, 2003). The samples were taken from an apartment and a house in Tokyo and a total of 48 samples were collected over 24-hour periods from March to May 2003. The concentration of tetrabromobisphenol-A determined was in the range 0.1-1 ng/m^3 (values read from graph). The levels appear to refer to the total (i.e. vapour phase plus particulate phase) concentration.

The results of a survey of the levels of tetrabromobisphenol-A in dusts collected from Parliament from eight EU countries, and also from the offices of a computer/internet provider in the Netherlands, have been reported (Santillo *et al.*, 2001). The dust samples were collected from the bags of vacuum cleaners and so the levels found cannot be directly related to the concentration present in air. In all, 10 dust samples were analysed for the presence of tetrabromobisphenol-A, and also its dimethylated derivative. The concentration of tetrabromobisphenol-A found was generally below the detection limit of the method (the detection limit varied between 0.5 and 3 µg/kg), but was found in 1 sample at 5 µg/kg. The dimethylated derivative of tetrabromobisphenol-A was not found in any sample (the detection limit for this substance varied between 0.1 and 0.5 µg/kg).

de Wit and Muir (2004) and de Wit *et al.* (2006) reported that tetrabromobisphenol-A had been detected at a concentration of 70 pg/m^3 in one air filter sample from Dunai (Russian Arctic). The samples analysed were part of a study investigating the levels of brominated flame retardants in archived air samples (from 1994-1995) from Alert and Tagish (Canadian Arctic) and Dunai. The main focus of the study was the analysis of brominated diphenyl ethers but some of the samples were screened for tetrabromobisphenol-A.

3.1.3.3 Comparison of measured levels with predicted levels

Most of the available monitoring data for air in the EU relate to indoor or occupational exposure and so are not directly comparable with the scenarios considered in the environmental risk assessment. The levels predicted in the environment are generally low (around 1×10^{-5} mg/m^3 (10 ng/m^3) and below) and will be considered in the risk characterisation.

The levels calculated at an electronics equipment recycling plant are around 5×10^{-8} mg/m^3 (~0.05 ng/m^3), which is lower than measured in air at such facilities (ca. 12-37 ng/m^3). This is not necessarily inconsistent as the indoor air may be filtered or otherwise treated prior to being emitted from the facility, and will in addition be diluted on leaving the facility.

3.1.4 Non-compartment specific exposure relevant for the food chain

3.1.4.1 Predicted concentrations in biota

The levels of tetrabromobisphenol A in fish for the secondary poisoning assessment have been calculated using EUSES 2.0.3 which implements the methods given in the Technical Guidance Document. For fish, a measured BCF of 485 l/kg (representing the accumulation of tetrabromobisphenol-A alone) and 1,234 l/kg (representing the accumulation of tetrabromobisphenol-A plus metabolites; see Section 3.1.0.7.4 for a discussion of the data), and a BMF of 1 was used in the calculations. The resulting concentrations are shown in **Table 3.47**. The full output of the EUSES model (using the BCF of 1,234 l/kg) is given in Appendix B.

For earthworms, the $BCF_{earthworm}$ is estimated at 9,533 l/kg using the methods outlined in the Technical Guidance Document. In addition, a $BAF_{earthworm}$ (relating the concentration in worms to the concentration in soil) of up to 5.1 (on a wet weight worms/dry weight soil basis) has been measured for tetrabromobisphenol-A (see Section 3.1.0.7.4). This value is equivalent to a $BAF_{earthworm}$ of 5.8 on a wet weight worms/wet weight soil basis using the default water content of soil from the Technical Guidance Document). The resulting predicted concentrations in earthworms are shown in **Table 3.48**. There is generally good agreement between the two calculation methods.

Table 3.47 Estimated concentrations of tetrabromobisphenol-A in fish for the secondary poisoning assessment

Scenario			Predicted concentration in fish (mg/kg)	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg
Production of tetrabromobisphenol-A	Example calculation		22.6[a] or 57.5[b]	13.7[a] or 34.8[b]
Use as an intermediate in the production of derivatives	Example calculation		19.4[a] or 49.3[b]	11.7[a] or 29.8[b]
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.046[a] or 0.12[b]	0.028[a] or 0.071[b]
	Processing of epoxy resins		6.3×10^{-4} [a] or 1.6×10^{-3} [b]	6.2×10^{-4} [a] or 1.6×10^{-3} [b]
	Processing of polycarbonate resins		6.3×10^{-4} [a] or 1.6×10^{-3} [b]	6.2×10^{-4} [a] or 1.6×10^{-3} [b]
Additive flame retardant use	ABS	Compounding	1.0[a] or 2.7[b]	0.63[a] or 1.6[b]
		Conversion	0.048[a] or 0.12[b]	0.029[a] or 0.075[b]

Note: a) Estimate for tetrabromobisphenol-A alone using a BCF of 485 l/kg.
b) Estimate for tetrabromobisphenol-A plus metabolites using a BCF of 1,234 l/kg.

Table 3.48 Estimated concentrations of tetrabromobisphenol-A in earthworms for the secondary poisoning assessment

Scenario			Predicted concentration in earthworms (mg/kg)[b]			
			Using $BCF_{earthworm}$ = 9,533 l/kg		Using $BAF_{earthworm}$ = 5.8	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Production of tetrabromobisphenol-A	Example calculation		300 [2.7×10^{-3}]	375 [0.019]	574 [5.1×10^{-3}]	641 [0.032]
Use as an intermediate in the production of derivatives	Example calculation		385 [3.2×10^{-3}]	482 [0.019]	740 [6.2×10^{-3}]	824 [0.033]
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[a]		0.60 [3.6×10^{-3}]	0.76 [0.020]	1.2 [6.8×10^{-3}]	1.3 [0.033]
	Processing of epoxy resins		3.8×10^{-3} [2.7×10^{-3}]	0.020 [0.019]	7.2×10^{-3} [5.1×10^{-3}]	0.034 [0.032]
	Processing of polycarbonate resins		3.8×10^{-3} [2.7×10^{-3}]	0.020 [0.019]	7.2×10^{-3} [5.1×10^{-3}]	0.034 0.032]
Additive flame retardant use	ABS	Compounding[a]	24.2 [2.9×10^{-3}]	30.3 [0.019]	46.7 [5.5×10^{-3}]	51.9 [0.032]
		Conversion	1.1 [3.6×10^{-3}]	1.4 [0.020]	2.1 [6.9×10^{-3}]	2.4 [0.034]
Electronic equipment collection/recycling site			2.7×10^{-3}	0.019	5.1×10^{-3}	0.032

Note: a) Industry have indicated that the main sites using tetrabromobisphenol-A in these operations do not apply sewage sludge to agricultural land.
b) The default calculations assumed sewage sludge is applied to agricultural land. The resulting concentrations in soil assuming no sludge is applied to land are shown in [ ].

In addition to the PECs calculated in **Table 3.47** and **Table 3.48**, some confidential site specific information has been provided for eight of the major brominated epoxy resin manufacturing companies in the EU. The information provided includes details of the amounts of tetrabromobisphenol-A used at the sites and, in some cases, the number of days of use, information on the emissions to air and water and the size of the waste water treatment plant. Using these data, along with the generic emission factors of 0.001% to air and waste water (see Section 3.1.0.2.2) where no site-specific emission factor was available, the local concentrations in fish (using a BCF_{fish} of 1,234 l/kg) at the these sites can be estimated as between 1.6×10^{-3} and 0.065 mg/kg wet weight using a Koc of 49,726 l/kg and 1.6×10^{-3} and 0.040 mg/kg wet weight using a Koc of 147,360 l/kg. Similarly the predicted concentrations in earthworms are between 2.7×10^{-3} and 5.8×10^{-3} mg/kg wet weight using a Koc of 49,726 l/kg and between 0.019 and 0.022 mg/kg wet weight using a Koc of 147,360 l/kg (all data estimated using the earthworm BCF of 9,533 l/kg wet weight).

The values for fish are similar to those given in **Table 3.47** for a generic epoxy resin manufacturing site, however the values for earthworms are generally lower than given in **Table 3.48** as sewage sludge from the known manufacturing sites is not applied to agricultural land (the generic calculations in **Table 3.48** assume that sludge from the site is applied to agricultural land). Information from Industry indicates that sludge from the known sites in the EU that carry out manufacture of epoxy/polycarbonate resins (and other reactive

uses of tetrabromobisphenol-A) and compounding of ABS using tetrabromobisphenol-A as an additive is not applied to agricultural land (BSEF, 2006b). Therefore, the generic calculations have also been carried out assuming that no sludge is applied to land. The resulting concentrations are shown in [ ] in **Table 3.48**. The fate of sludge at all processing sites using the flame-retarded epoxy/polycarbonate resins and all sites carrying out conversion of ABS is not currently clear. Therefore it is still relevant to consider a generic scenario whereby sewage sludge is applied to agricultural land to cover these instances.

In addition, confidential information is available on the emissions to water and air from an site using tetrabromobisphenol-A as an additive flame retardant. Using this information, the predicted concentration in fish from this site is around 2.9 mg/kg wet weight (using a Koc of 49,726 l/kg) or 2.6 mg/kg wet weight (using a Koc of 147,360 l/kg), which is similar to that estimated for the generic site. The predicted concentrations in earthworms for this site are 0.058 mg/kg wet weight (using a Koc of 49,726) or 0.084 (using a Koc of 147,360). These are lower than for the generic site, reflecting the fact that sewage sludge from this site is not applied to agricultural land.

The concentrations of tetrabromobisphenol-A in food and other media for human consumption have also been estimated using EUSES 2.0.3 and are shown in **Table 4.1** in Section 4.

3.1.4.2 Measured levels in biota

The available data for levels of tetrabromobisphenol-A in biota are summarised in **Table 3.49**.

Tetrabromobisphenol-A has been detected in blood from Baltic Salmon (*Salmo salar*) collected in 1995. The concentration present was not determined (Asplund *et al.*, 1999).

Kemmlein (2000) determined the concentration of tetrabromobisphenol-A in fish from the Berlin area of Germany. The samples analysed included two eels (approximately 10-12 years old) from the Tegeler See/Oberhavel, and a sample of perch and pike from the Weissensee. The samples were collected in 1998/1999. The levels found were 0.47 and 0.78 µg/kg lipid in the two eel samples, 0.91 µg/kg lipid in the perch and 1.12 µg/kg lipid in the pike. The fat content of the samples was 9.5% and 13.2% respectively in the eel samples, 3.6% in the perch sample and 1.9% in the pike sample. The concentrations expressed on a whole body weight basis are therefore 0.045 and 0.10 µg/kg fresh weight in the eel, 0.033 µg/kg fresh weight in the perch and 0.021 µg/kg fresh weight in the pike.

Table 3.49 Summary of levels of tetrabromobisphenol-A in biota

Sample	Comment	Concentration	Reference
Baltic salmon	Blood sample from 1995.	Detected but not quantified	Asplund *et al.*, 1999
	Ten muscle samples from the River Kymijoki and River Simojoki, Finland, 1993-1999.	Detected in 2 samples at 2.0 and 5.0 µg/kg fresh weight	Peltola, 2002
Eel	Two samples from Berlin area from 1998/1999.	0.045 and 0.10 µg/kg fresh weight	Kemmlein, 2000
	Samples from Scheldt basin, 2000. Detected in 6 out of 18 samples (detection limit 0.1 µg/kg wet weight).	<0.1-2.6 µg/kg wet weight (<0.1-13 µg/kg lipid; mean 1.6 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
	Samples from rivers in the Netherlands. Detected in 3 out of 11 samples (detection limit 0.1 µg/kg wet weight).	<0.1-0.2 µg/kg wet weight (<0.1-1.3 µg/kg lipid; mean 0.3 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
Fish	Pooled samples from Lake Mjøsa, Norway. Detected in 6 out of 8 samples.	0.01-0.18 µg/kg wet weight	Fjeld *et al.*, 2004
	Pooled samples from River Vorma Norway. Detected in 1 out of 2 samples.	0.01 µg/kg wet weight	Fjeld *et al.*, 2004
	Pooled samples from Lake Øyeren Norway. Detected in 2 out of 2 samples.	0.03 µg/kg wet weight	Fjeld *et al.*, 2004
	Pooled samples from Drammensfjord. Detected in 1 out of 6 samples.	0.05 µg/kg wet weight (~0.3 µg/kg lipid)	Fjeld *et al.*, 2004 Schlabach *et al.*, 2004
Perch	Sample from Berlin area from 1998/1999.	0.033 µg/kg fresh weight	Kemmlein, 2000
Pike	Sample from Berlin area from 1998/1999.	0.021 µg/kg fresh weight	Kemmlein, 2000
	Three muscle samples from Finland, 1997.	Not detected	Peltola, 2002
Cod liver	Samples from North Sea. Detected in 1 out of 2 samples. Detection limit 0.1 µg/kg wet weight.	<0.1-0.8 µg/kg wet weight (<0.3-1.8 µg/kg lipd)	de Boer *et al.*, 2003; Morris *et al.*, 2004
Hake liver	Not detected in 1 sample. Detection limit 0.1 µg/kg wet weight or 0.2 µg/kg lipid.	Not detected	de Boer *et al.*, 2003; Morris *et al.*, 2004
Mussel (*Mytilus edulis*)	Sample from Osaka Bay, Japan, 1981. Detection limit not stated.	Not detected	Watanabe *et al.*, 1983a
Whiting (fillet)	North Sea, 1999. Detected in 2 out of 3 samples. Detection limit 97 µgkg lipid.	<97-245 µg/kg lipid (mean 136 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
Whiting muscle	UK Sea Estuaries. Detected in 1 out of 2 samples. Detection limit ~ 4.8 µg/kg wet weight.	<4.8-3.3 µg/kg wet weight	de Boer *et al.*, 2002

Table 3.49 continued overleaf.

Table 3.49 continued.

Sample	Comment	Concentration	Reference
Cod liver	Samples from around Norway. Detected in 6 out of 6 samples.	0.08-0.16 µg/kg wet weight	SFT, 2002
Cod liver	Samples from around Norway. Detected in 5 out of 6 samples.	0.35-1.73 µg/kg wet weight	Fjeld et al., 2004
Gudgeon	Western Scheldt. Not detected in 1 sample. Detection limit 0.1 µg/kg wet weight.	Not detected	de Boer et al., 2002
Fish	75 Samples from industrial and non-industrial areas of Japan. in 1987. Detection limit 1 µg/kg fresh weight.	Not detected	Watanabe and Tatsukawa, 1989; Environment Agency Japan, 1996
	135 Samples from industrial and non-industrial areas of Japan. in 1988. Detection limit 1 µg/kg fresh weight.	Not detected	Environment Agency Japan, 1996
	25 samples from Inland Sea of Japan, 1998, including horse mackerel, conger eel, sea bass, yellowtail, flounder, gray mullet and red sea bream. Detection limit 0.05 µg/kg wet weight.	Not detected	Hori *et al.*, 2000
Grey mullet	Samples of stock-fish from the years 1986 to 1999 from the Osaka Bay area of Japan.	3.4-23 µg/kg lipid	Ohta *et al.*, 2004b
Fish	Samples of edible fish collected from three markets in Japan. Detection limit 0.01 µg/kg wet weight. Detected in 29 out of 45 samples.	Mean 0.02 µg/kg wet weight Range not detected – 0.11 µg/kg wet weight	Nakagawa *et al.*, 2006
Blue mussel	Samples from around Norway. Detected in 6 out of 6 samples.	0.01-0.03 µg/kg wet weight	SFT (2002)
Mussel	Samples from four sites around Norway.	Not detected	Fjeld et al, 2004
Hermit crab (abdomen)	North Sea, 1999. Detected in 5 out of 9 samples. Detection limit 1 µgkg lipid.	<1-35 µg/kg lipid (mean 11 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
Mysid shrimp	Western Scheldt. Not detected in 1 sample. Detection limit 0.1 µg/kg wet weight.	Not detected	de Boer *et al.*, 2002
	Scheldt estuary. Samples from three locations, detected in 2 samples.	<7.7, 0.8 and 0.9 µg/kg lipid	Verslycke *et al.*, 2005
Sea star (pyloric caeca)	North Sea, 1999. Detected in 2 out of 3 samples. Detection limit 1 µgkg lipid.	<1-10 µg/kg lipid (mean 4 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
Star fish	UK Estuaries. Detected in 1 out of 1 sample.	4.5 µg/kg wet weight	de Boer *et al.*, 2002
Whelk (whole body)	North Sea, 1999. Detected in 3 out of 3 samples.	5-96 µg/kg lipid (mean 45 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004

Table 3.49 continued overleaf.

Table 3.49 continued.

Sample	Comment	Concentration	Reference
Harbour porpoise (blubber)	North Sea. Not detected in 5 samples (detection limit 11-18 µg/kg lipid).	Not detected	de Boer et al., 2002; Morris et al., 2004
	North Sea estuaries. Detected in 5 out of 5 samples. (CEFAS (2002) reports the results as detected in 8 out of 25 samples; and Law et al. (2003) report the results as detected in 4 out of 25 samples).	0.05-376 µg/kg wet weight (0.1-418 µg/kg lipid; mean 83 µg/kg lipid)	de Boer et al., 2002; CEFAS, 2002; Law et al., 2003; Morris et al., 2004
	Stranded or bycaught in the United Kingdom. A total of 68 samples from the period 1994-2003 analysed. Detected in 18 samples (detection limit was around 5 µg/kg wet weight).	6-35 µg/kg wet weight (up to 38 µg/kg lipid)	Law *et al.* (2006)
Harbour seal (blubber)	North Sea. Not detected in 5 samples (detection limit 14 µg/kg lipid).	Not detected	de Boer et al., 2002; Morris et al., 2004
Harbour seal (liver)	North Sea. Not detected in 5 samples (detection limit 231 µg/kg lipid).	Not detected	de Boer et al., 2002
Common Tern eggs	Western Scheldt. Not detected in 10 samples (detection limit <0.1-<0.3 µg/kg wet weight or 2.9 µg/kg lipid).	Not detected	de Boer *et al.*, 2002; Morris *et al.*, 2004
Cormorant liver	Archived samples from around the United Kingdom.	Detected in 7/28 samples at 0.07-10.9 µg/kg fresh weight	CEFAS, 2002
	United Kingdom. Detected in 5 out of 5 samples.	0.07-0.28 µg/kg wet weight (2.5-14 µg/kg lipid; mean 7.1 µg/kg lipid)	de Boer *et al.*, 2002; Morris *et al.*, 2004
Predatory birds' eggs	Samples from Norway including 2 White-tailed Eagle, 2 Peregrine Falcon, 2 Golden Eagle and 2 Osprey.	<0.004-0.013 µg/kg wet weight	Herzke *et al.*, 2003 and 2005; WWF, 2005; Berger *et al.*, 2004.
Peregrine falcon eggs	Samples from South Greenland from between 1986 and 2003 (total of 37 samples).	Tetrabromobisphenol-A not detected in any sample. Dimethyl derivative of tetrabromobisphenol-A detected in 28/32 samples at 0.1-940 µg/kg lipid (median 230 µg/kg lipid).	Sørensen *et al.,* 2004; Vorkamp *et al.*, 2005
Human blood serum	Samples from computer technicians in Sweden.	Detected in 4/19 samples at <0.5-1.8 µg/kg lipid	Hagmar *et al.*, 2000a
	Samples from computer technicians in Sweden, 1999.	Detected in 8/10 samples at <0.54-1.8 µg/kg lipid	Jakobsson *et al.*, 2002
	Samples from four workers at an electronics equipment dismantling plant in Sweden.	1.1-3.8 µg/kg lipid	Hagmar *et al.*, 2000b
	Samples from workers at an electronics equipment dismantling plant in Norway	0.64-1.8 µg/kg lipid Mean 1.3 µg/kg lipid	Thomsen *et al.* 2001a and 2001c
	Smelter workers in Sweden.	Detected in 1/9 samples at 0.76 µg/kg lipid	Hagmar and Bergman, 2001

Table 3.49 continued overleaf.

Table 3.49 continued.

Sample	Comment	Concentration	Reference
Human blood serum (continued)	Samples from printed circuit board producers in Norway. Detection limit 0.4 ng/kg plasma.	Not detected-0.80 μg/kg lipid Mean 0.54 μg/kg lipid	Thomsen *et al.*, 2001a and 2001c
	Samples from laboratory personnel in Norway. Detection limit 0.4 ng/kg plasma.	Not detected-0.52 μg/kg lipid Mean 0.34 μg/kg lipid	Thomsen *et al.*, 2001a and 2001c
	Samples from an hospital in Norway.	Around 0.4 ng/kg plasma	Thomsen *et al.*, 2001b
	Archived samples from Norway covering 1977-1999. Detection limit was 0.4-1.6 ng/kg serum.	1977 - Not detected 1981 - Not detected 1986 - 0.44 μg/kg lipid 1998 - 0.34-0.71 μg/kg lipid 1999 - 0.65 μg/kg lipid	Thomsen *et al.*, 2002a
	Pooled samples from Norway	<0.1-1.0 μg/kg lipid	CREDO, 2006c
	Samples from 54 volunteers from Japan, 1998.	Median - 2.4 μg/kg lipid Maximum - 12.0 μg/kg lipid	Nagayama *et al.*, 2001
	Samples from 40 individuals from 17 countries. Detected in 68% of the samples.	2 – 330 ng/kg whole blood	WWF, 2004a
	26 Samples of maternal serum from France.	Median - 7 μg/kg lipid	Antignac *et al.* (2006)
	26 Samples of umbilical serum from France.	Median - 10 μg/kg lipid	Antignac *et al.* (2006)
Human hair	Composite sample from near a tetrabromobisphenol-A manufacturing plant in the United States.	2 μg/kg	DeCarlo, 1979
Human breast milk	Four samples from Berlin, 1998/1999.	Detected in 2/4 samples at 0.29-0.94 μg/kg lipid	Kemmlein, 2000
	Sample from Faroe Islands.	11.0 μg/kg lipid	Kemmlein, 2000
	Pooled sample from Norway, 2001	0.067 μg/kg lipid	Thomsen *et al.*, 2002b
	Three pooled samples from Norway, 2001; levels refer to dimethyl tetrabromobisphenol-A.	0.01-0.10 μg/kg lipid	Thomsen *et al.*, 2003
	Nine pooled samples from Japan, 2002 (5 multiparae and 4 primiparae samples). Detected in all samples.	0.18-0.45 μg/kg lipid (multiparae) 0.27-0.94 μg/kg lipid (primiparae)	Ohta *et al.*, 2004a
	Pooled, freeze-dried sample from sixteen women from France.	1.4 μg/kg dry weight 7.0 μg/kg lipid weight	Cariou *et al.*, 2005
	23 Samples from France.	Range 0.034-9.4 μg/kg lipid Median – 0.17 μg/kg lipid	Antignac *et al.* (2006)
Human adipose	26 Maternal samples from France.	Not detected	Antignac *et al.* (2006)
Cows' milk	Sample from Norway, 2001	0.013 μg/kg lipid	Thomsen *et al.*, 2002b

CEFAS (2002) analysed archived samples of harbour porpoise blubber and cormorant liver for the presence of tetrabromobisphenol-A. The samples were taken from various locations in

and around the United Kingdom. Tetrabromobisphenol-A was detected in eight out of 25 porpoise blubber samples at a concentration of 0.05-376 µg/kg fresh weight, with a mean concentration of 52 µg/kg fresh weight. In the cormorant liver samples, tetrabromobisphenol-A was detected in seven out of 28 samples at a concentration of 0.07-10.9 µg/kg fresh weight, with a mean concentration of 2.6 µg/kg fresh weight. The limit of quantitation of the method was given as 1.07 µg/kg fresh weight and some of the levels reported appear to be below this limit.

The levels of tetrabromobisphenol-A and methylated tetrabromobisphenol-A have recently been determined in samples of biota from the Scheldt basin, UK Estuaries and the North Sea (de Boer et al, 2002; Morris *et al.*, 2004). The study found tetrabromobisphenol-A to be present at concentrations of <0.1-2.6 µg/kg wet weight in eel, 5-96 µg/kg lipid in whelk, <1-10 µg/kg lipid in sea star, <1-35 µg/kg lipid in hermit crab, <97-245 µg/kg lipid in whiting, 0.07-0.28 µg/kg wet weight in cormorant liver, 0.05-376 µg/kg wet weight in porpoise, 4.5 µg/kg wet weight in whole starfish and <0.1-0.8 µg/kg wet weight in cold liver, but was not detected in seal blubber or liver, tern eggs, mysid shrimp, gudgeon or hake liver. The levels of tetrabromobisphenol-A found are summarised in **Table 3.49**. Dimethylated tetrabromobisphenol-A was not detected in cormorant livers (detection limit 5 µg/kg wet weight), porpoise blubber (detection limit 5 µg/kg wet weight), whiting muscle (detection limit 4.8 µg/kg wet weight), whole star fish (detection limit 4.8 µg/kg wet weight), mysid shrimp (detection limit 0.1 µg/kg wet weight), gudgeon (detection limit 0.1 µg/kg wet weight), cod liver and hake liver (detection limit 0.1 µg/kg wet weight), but was detected in 7 out of 18 eel samples from the Scheldt basin at a concentration of 0.2-2.5 µg/kg wet weight (detection limit 0.1 µg/kg wet weight), 10 out of 11 eel samples from rivers in the Netherlands at a concentration of 0.2-1.3 µg/kg wet weight, 4 out of 10 Common Tern (*Sterna hirundo*) eggs from the Western Scheldt at a concentration of 0.4-0.8 µg/kg wet weight.

The levels of tetrabromobisphenol-A (determined as its dimethylated transformation product) have been determined in fish samples from Finland (Peltola, 2002). The samples analysed included Baltic salmon (*Salmo salar*) muscle from populations from the River Kymijoki and River Simojoki) and pike (*Esox lucius*) muscle samples. In all, three pike muscle samples from 1997 and 10 salmon muscle samples covering the years 1993 to 1999 were analysed. The detection limit of the method was around 10 µg/kg lipid and tetrabromobisphenol-A was found to be present in two salmon samples at a concentration of 88 and 500 µg/kg lipid. These levels were equivalent to 2.0 and 5.0 µg/kg on a fresh weight basis (the salmon samples were collected immediately before spawning and so had a relatively low lipid concentration). No tetrabromobisphenol-A was found in the pike muscle samples.

Verslycke *et al.* (2005) found that tetrabromobisphenol-A was present in mysid shrimp (*Neomysis integer*) from two out of three sites in the Scheldt estuary. The samples were collected in November 2001. The levels found were <7.7, 0.8 and 0.9 µg/kg lipid in the three samples. Tetrabromobisphenol-A was not detectable in sediment samples from the same area (see Section 3.1.1.2.2). The Mysids were not depurated prior to analysis.

SFT (2002) have recently determined the concentrations of tetrabromobisphenol-A present in blue mussel and cod livers from Norway. Tetrabromobisphenol-A was found to be present in all samples analysed (six blue mussel and six cod liver) and the concentrations found were 0.01-0.03 µg/kg wet weight in blue mussel and 0.08-0.16 µg/kg wet weight in cod liver. No

dimethylated tetrabromobisphenol-A was detected in any sample (the detection limit for this substance was 0.1 µg/kg wet weight in blue mussel and 0.5 µg/kg wet weight in cod liver).

Nakagawa *et al.* (2006) reported tetrabromobisphenol-A levels in samples of marine fish from three regions of Japan. These were purchased in markets in Nagoya, Seto Inland Sea and Kyushu (a total of 15 samples for each market were analysed). The detection limit for tetrabromobisphenol-A for the analytical method used was 0.01 µg/kg wet weight and the substance was found to be present in eight out of the fifteen samples from Nagoya, eight out of the fifteen samples from Seto Inland Sea and thirteen out of the fifteen samples from Kyushu. The mean concentration of tetrabromobisphenol-A found in the samples was reported as 0.01 µg/kg wet weight (range not detected – 0.04 µg/kg wet weight) in samples from Nagoya, 0.02 µg/kg wet weight (range not detected – 0.10 µg/kg wet weight) in samples from Seto Inland Sea and 0.02 µg/kg wet weight (range not detected – 0.11 µg/kg wet weight) in samples from Kyushu. The overall mean level found was 0.02 µg/kg wet weight. The samples analysed included wild and cultivated sea bream and wild conger eel. The results are available in the form of an extended abstract only at present.

Tetrabromobisphenol-A has been found to be present in marine mammals from around the United Kingdom (Law *et al.,* 2003). The samples were collected from porpoises stranded or bycaught between 1996 and 2000 and, in all, blubber samples from 25 individuals were screened for the presence of tetrabromobisphenol A. The substance was found to be present in four samples at a concentration of 3.9-376 µg/kg wet weight. These may be the same results reported by CEFAS (2002), de Boer (2002) and Morris *et al.* (2004).

A further study by Law *et al.* (2006) report levels of tetrabromobisphenol-A in sixty eight harbour porpoises stranded or bycaught in the United Kingdom over the period 1994-2003. Tetrabromobisphenol-A was detected in eighteen samples at concentrations between 6 and 35 µg/kg wet weight (or up to 38 µg/kg lipid).

Fjeld *et al.* (2004) determined the levels of tetrabromobisphenol-A in biota samples from several locations in Norway (some of these data are also reported in Schlabach *et al.* (2004)). The samples analysed included fish from Lake Mjøsa, River Vorma and Lake Øyeren (pooled fish muscle or whole body samples (typically 7-20 individuals per sample) including brown trout (*Salmo trutta*), perch (*Perca fluviatilis*), pike (*Esox lucius*), burbot (*Lota lota*), vendace (*Coregonus albula*) and smelt (*Osmerus eperlanus*) – archived samples of vendace collected in 1993-2002 were also included), fish from Drammensfjord (industrial area; pooled fish muscle samples (typically 5-20 individuals per sample) including brown trout, perch, orfe (*Leuciscus idus*), cod (*Gadus morhua*), flounder (*Platichthys flesus*) and eel (*Anguilla anguilla*)) and blue mussel (50 individuals per sample) and cod liver samples (seven individuals per sample, three samples per site) from sites along the Norwegian coast. The levels of tetrabromobisphenol-A found in the freshwater fish samples were 0.01-0.18 µg/kg wet weight in samples from Lake Mjøsa (detected in six out of eight samples), 0.01 µg/kg wet weight in samples from the River Vorma (detected in one out of two samples), 0.03 µg/kg wet weight in samples from Lake Øyeren (detected in two out of two samples) and 0.05 µg/kg wet weight in samples from Drammensfjord (detected in one out of six samples). For the marine fish samples, tetrabromobisphenol-A was found to be present at a concentration of 0.35-1.73 µg/kg wet weight in the cod liver samples (detected in five out of six samples) but does not appear to have been detectable in the mussel samples (four samples in total).

Watanabe *et al.* (1983a) determined the levels of tetrabromobisphenol-A and its dimethylated derivative (a possible metabolite of tetrabromobisphenol-A) in mussels (*Mytilus edulis*) from Osaka Bay, Japan. The mussels were collected in September 1981 and the concentration of tetrabromobisphenol-A present was below the analytical detection limit of the method used (detection limit not given). The dimethylated derivative of tetrabromobisphenol-A was found to be present at around 5 µg/kg fresh weight.

Further studies of the levels of tetrabromobisphenol-A and its dimethylated derivative in biota from Japan have been reported by Watanabe and Tatsukawa (1989). In the first part of this study, fish and shell fish (including mussels, mullet and Japanese sea bass) were collected from the Osaka area in 1983. Dimethylated tetrabromobisphenol- was found in two out of 19 samples at a concentration of 0.8-4.6 µg/kg wet weight. The levels of tetrabromobisphenol-A present were not reported. In the second part of the study, fish (including mullet, Japanese sea bass, crucian carp) were collected from industrialised and non-industrialised areas from all over Japan. Tetrabromobisphenol-A was not detected in any of the 75 samples analysed (detection limit was 1.0 µg/kg fresh weight). The dimethylated derivative was not investigated in the second part of the study.

Further surveys of the levels of tetrabromobisphenol-A in fish from all over Japan have been carried out by Environment Agency Japan (1996). In 1987, tetrabromobisphenol-A was not detected in any of the 75 samples analysed (detection limit was 1 µg/kg wet weight). The 1987 results are probably the same results as reported by Watanabe and Tasukawa (1989) above. In 1988 tetrabromobisphenol-A was not detected in any of the 135 samples analysed (detection limit was 1 µg/kg fresh weight).

Hori *et al.* (2000) analysed samples of horse mackerel, conger eel, sea bass, yellowtail, flounder, gray mullet and red sea bream for the presence of tetrabromobisphenol-A. The samples were collected from the Inland Sea of Japan during October-December 1998 and in all 25 samples were analysed. Tetrabromobisphenol-A was not detected in any of the samples analysed (the detection limit of the method used was 0.05 µg/kg wet weight).

Ohta *et al*. (2004b) carried out a time-trend analysis of the levels of polybrominated flame retardants (including tetrabromobisphenol-A) in stock-fish samples of Japanese sea bass and grey mullet from 1986 to 1999. The fish were sampled from Osaka Bay, Japan, and the mouth of the Yamato River (which flows into Osaka Bay). Tetrabromobisphenol-A was found to be present in the sea bass samples at a concentration of between 3.4 µg/kg lipid and 23 µg/kg lipid. The highest levels were found in samples for 1986 (23 µg/kg lipid) and 1990 (17 µg/kg lipid), but were between 3.4 and 9.9 µg/kg lipid in the other years investigated. The results for grey mullet were not presented in the paper. The demand for tetrabromobisphenol-A in Japan was reported to be 31,000 tonnes in 2002, but data for other years were not given and so it is not possible to see how the concentrations found relate to the amounts being used over the period of the study.

Herzke *et al.* (2003 and 2005) reported that tetrabromobisphenol-A was present in eggs of certain predatory birds from Norway. The species sampled included white-tailed eagle (*Haliaeetus albicilla*; 2 samples from 1992-2000), peregrine falcon (*Falco peregrinus*; 2 samples from 1993-2000), golden eagle (*Aquila chrysaetos*; 2 samples from 1992-2002) and osprey (*Pandion haliaetus*; 2 samples from 1993-2000). The white-tailed eagle eggs were taken from the Norwegian coast (between 61°N and 68°N), the peregrine falcon eggs were taken from the southern and western coast (59°N to 70°N), the golden eagle eggs were taken

from Norway's mountain range (59°N to 71°N) and the central part of Norway (62°N to 65°N) and the osprey eggs were taken from the Oslo fjord area (59°N) and an inland area (62°N) (note the eggs analysed for tetrabromobisphenol-A were a subset of the total eggs collected from the above locations; the actual locations of the specific eggs analysed for tetrabromobisphenol-A were not given). It was reported that tetrabromobisphenol-A was present in all samples analysed at a concentration of <0.004 µg/kg wet wt. to 0.013 µg/kg wet wt. Generally, the highest levels found were in the Osprey egg samples. The same data (referenced to Berger *et al.* (2004)) appear in WWF (2005). This report gives the levels as up to 0.013 µg/kg wet weight in golden eagle eggs, up to 0.010 µg/kg wet weight in osprey eggs, up to 0.0042 µg/kg wet weight in peregrine falcon eggs and up to 0.0072 µg/kg wet weight in white-tailed eagle eggs.

The levels of tetrabromobisphenol-A in peregrine falcon (*Falco peregrinus*) eggs from South Greenland have been determined (Sørensen *et al.*, 2004; Vorkamp *et al.*, 2005). The samples analysed were collected between 1986 and 2003 and consisted of 37 samples (addled eggs) from 28 different clutches.

Tetrabromobisphenol-A was not found to be present in any of the samples analysed. However, the dimethylated derivative of tetrabromobisphenol-A was found to be present in 28 out of the total of 32 samples that were analysed for this substance at a concentration of 0.1-940 µg/kg lipid (median level 230 µg/kg lipid; the detection limit of the method used was 0.1 µg/kg lipid for dimethylated tetrabromobisphenol-A).

The Greenland peregrine falcon populations are thought to migrate from Central (females) and South America (males) and so the levels found are likely to be related to the emission situation in those areas rather than emissions in Europe.

The concentration of tetrabromobisphenol-A in blood serum from computer technicians in Sweden has been determined to be in the range <1-3.4 pmol/g lipid (<0.5-1.8 µg/kg lipid). Tetrabromobisphenol-A was detected in four out of the 19 samples analysed (Hagmar *et al.*, 2000a).

Hagmar *et al.* (2000b) determined the concentration of tetrabromobisphenol-A in blood serum in four workers from an electronics equipment dismantling plant in Sweden. Samples were collected just before the summer vacation and at various times during the summer vacation. The concentration found was 2-7 pmol/g lipid (1.1-3.8 µg/kg lipid) in the samples taken prior to the vacation. The concentration was found to decrease during the vacation period and a half-life of 2.2 days was estimated for tetrabromobisphenol-A in blood serum.

Hagmar and Bergman (2001) reported that tetrabromobisphenol-A was found in the blood plasma in one out of nine samples from smelter workers in Sweden. The concentration found was 0.76 µg/kg lipid.

A further study of the levels of tetrabromobisphenol-A in computer technicians from Sweden has been carried out by Jakobsson *et al.* (2002). In this study, volunteers from an information technology unit of a hospital, who worked full time with computer systems, were studied. The blood sampling was carried out during 1999 and, in all, samples from ten individuals were analysed for tetrabromobisphenol-A. Tetrabromobisphenol-A was detected in eight out of the ten samples analysed, but was present above the limit of quantification (1 pmol/g lipid or 0.54 µg/kg lipid) in only four of these. The median level of tetrabromobisphenol-A found

was <1 pmol/g lipid (<0.54 µg/kg lipid) and the range was <1-3.4 pmol/g lipid (<0.54-1.8 µg/kg lipid).

Thomsen *et al.* (2001a and 2001c) determined the concentration of tetrabromobisphenol-A in blood plasma from humans in three occupational groups in Norway: electronic equipment dismantlers, circuit board producers and laboratory personnel. The levels found in the various populations were 0.64-1.8 µg/kg lipid (mean 1.3 µg/kg lipid) in the electronic equipment dismantlers, not detected-0.80 µg/kg lipid (mean 0.54 µg/kg lipid) in the circuit board producers and not detected-0.52 µg/kg lipid (mean 0.34 µg/kg lipid) in the laboratory personnel. The limit of quantification of the method used was 0.4 ng/kg plasma. In another study, Thomsen *et al.* (2001b) found that tetrabromobisphenol-A was present at a concentration around 0.4 ng/kg plasma in plasma samples taken from an hospital in Norway.

A further study of blood serum levels in populations from Norway has been carried out by Thomsen *et al.* (2002a). The study used archived samples from six time periods between 1977 and 1999. For each time point a pooled sample from five males aged 40-50 years old was analysed for the presence of tetrabromobisphenol-A. The substance was not found to be present in the samples from 1977 and 1981 (limit of quantification of the method used was around 0.4-1.6 ng/kg serum), but showed a slight increase in concentration over the period 1986 to 1999 (the concentration was 0.44 µg/kg lipid in 1986 rising to 0.65 µg/kg lipid in 1999). The study also looked at pooled samples from eight groups of individuals of differing age and gender collected in 1998. Each groups consisted of 10-14 individuals, and the level of tetrabromobisphenol-A found in these samples was in the range 0.34 to 0.71 µg/kg lipid, with the highest levels being found in the 0-4 year old group.

CREDO (2006c) briefly reports the results of a survey of the levels of tetrabromobisphenol-A in serum samples from the general population of Norway. Tetrabromobisphenol-A was reported to be present at a concentration of <0.1-1.0 µg/kg lipid. No details are currently available about the total number of samples analysed or the number of samples in which tetrabromobisphenol-A was detected.

A survey of the levels of tetrabromobisphenol-A in whole blood samples from Members of the European Parliament (MEPs) has recent been completed (WWF, 2004a). In all, blood samples from 47 individuals (including 39 MEPs) from 17 countries were collected. Tetrabromobisphenol-A was analysed for in 40 of the samples and was found to be present in 27 (68%) of these at a level of 2-330 ng/kg whole blood (the detection limit of the method was variable but was generally around 20-70 ng/kg whole blood in the samples where tetrabromobisphenol-A was not detected). The median of the detected levels was 36 ng/kg whole blood.

In a follow-up study, WWF (2004b) analysed blood samples from seven families (a total of 33 individuals, consisting of six grandparents, thirteen parents and fourteen children) in the United Kingdom for the presence of various brominated flame retardants (including tetrabromobisphenol-A). However, the report indicates that the analysis method used for tetrabromobisphenol-A was not sufficiently sensitive to allow the results to be reported with a satisfactory degree of confidence and no further information on the levels or occurrence of tetrabromobisphenol-A was given.

WWF (2004c) carried out a further survey of the levels in blood samples, this time from fourteen Ministers from thirteen European countries. The samples were collected in June

2004 and were screened for the presence of a total of 103 chemicals, including tetrabromobisphenol-A. However, owing to analytical difficulties it was not possible to determine whether or not tetrabromobisphenol-A was present in any of the samples.

The level of tetrabromobisphenol-A in blood of Japanese people has been determined by Nagayama *et al.* (2001). The blood samples were from 54 volunteers (27 males and 27 females) in the age range 37 to 49 years old in 1998. The median and maximum levels found were reported as 2.4 µg/kg lipid and 12.0 µg/kg lipid respectively in the Nagayama *et al.* (2001) paper. Earlier results from this study indicate a mean level of 1.35 µg/kg from the 14 samples analysed at that time (Nagayama *et al.* 2000).

DeCarlo (1979) found that tetrabromobisphenol-A was present in a sample of human hair taken from near to tetrabromobisphenol-A manufacturing facilities in Arkansas, United States. The concentration present in one composite sample was 2 µg/kg.

Watanabe and Tatsukawa (1989) investigated the levels of dimethylated tetrabromobisphenol-A (a possible metabolite of tetrabromobisphenol-A (see Section 3.1.0.6.2)) in human fat from Japan. The substance was not found in any of the five samples analysed. The detection limit for the method used was 20 µg/kg fat.

The concentration of tetrabromobisphenol-A in mothers' milk has been determined by Kemmlein (2000). In the study, samples of milk from four individuals (age range 25-37 years old) from the west Berlin area were analysed. The samples were collected in 1998/1999. Tetrabromobisphenol-A was not found in two of the samples but was present at 0.29 µg/kg lipid and 0.94 µg/kg lipid in the other two samples. In addition, a sample of mothers milk from the Faroe Islands was also analysed. The concentration found in this sample was 11.0 µg/kg lipid.

Thomsen *et al.* (2002b) have also indicated that tetrabromobisphenol-A was present in breast milk. The sample analysed appears to have been a pooled sample from Norwegian mothers collected in 2001. The concentration of tetrabromobisphenol-A found was 0.067 µg/kg lipid (67 pg/g lipid). The lipid content of the sample was 2.6% and so this concentration is equivalent to a whole milk concentration of 0.0017 µg/kg. In addition, the level of tetrabromobisphenol-A in cows milk (collected directly from a milk transport vehicle) was 0.013 µg/kg lipid (13 pg/g lipid). The lipid content of this sample was 3.9% and so this concentration is equivalent to a whole milk concentration of 5.1×10^{-4} µg/kg.

The levels of dimethylated tetrabromobisphenol-A in mothers' milk from Norway has been reported to be in the range ~0.010-0.10 µg/kg lipid (~10-100 pg/g lipid) (Thomsen *et al.*, 2003). The samples were collected from a coastal area (Tromsø), a rural inland area (Hamar), and an industrialised area with a known dioxin source (Skien/Porsgrunn) and in 2001. Each sample consisted of a pooled sample of milk from ten to twelve mothers. In addition, individual samples were analysed from mothers from Oslo living near to a municipal waste incinerator (again the samples were collected in 2001). The origin of the substance was unknown although it was thought that it may have originated from biological methylation of tetrabromobisphenol-A or from a minor/infrequent use of the substance itself as a flame retardant.

Ohta *et al.* (2004a) determined the levels of tetrabromobisphenol-A in samples of mothers' milk from Japan. The samples were collected from sixteen primiparae and twenty multiparae

mothers at one month after delivery in 2002. Samples were pooled in groups of four (giving a total of five multiparae samples and four primiparae samples) prior to analysis. Tetrabromobisphenol-A was detected in all nine pooled samples. The levels found were in the range 0.18-0.45 μg/kg lipid in the multiparae samples and 0.27 to 0.94 μg/kg in the primiparae samples. The lipid contents of the samples were between 2.96 and 4.21% (mean 3.39%).

Cariou *et al.* (2005) determined tetrabromobisphenol-A to be present at a concentration of 7.0 μg/kg lipid (1.4 μg/kg dry weight) in a pooled, freeze-dried sample of breast milk from sixteen women from France.

A survey of the levels of tetrabromobisphenol-A in over 100 human biological samples from mothers and fetus in France has been undertaken (Antignac *et al.*, 2006, available as an extended abstract only at present). In all, 26 maternal serum samples, 26 umbilical serum samples, 26 maternal adipose tissue samples and 23 breast milk samples were collected from March to September 2005 during caesarean deliveries. Tetrabromobisphenol-A was not detected in any of the samples of adipose tissue (the detection limit was not stated). In breast milk, tetrabromobisphenol-A was found to be present at concentrations ranging from 0.034 μg/kg lipid to 9.4 μg/kg lipid (median value 0.17 μg/kg lipid), and the median value measured in serum was 7 μg/kg lipid in maternal serum and 10 μg/kg lipid in umbilical serum.

3.1.4.3 Comparison of measured levels with predicted levels

The available monitoring data for biota in the EU indicate that the level of tetrabromobisphenol-A present in aquatic organisms is generally low (up to around a few 100s of μg/kg lipid). These data are generally similar to or lower than the levels predicted in the various scenarios considered. However, the database of measured levels in biota from the EU is relatively small and so it is not possible to relate the measured levels in aquatic organisms to the scenarios considered in this assessment. Therefore, the predicted levels in fish and earthworms will be considered in the risk characterisation. A number of studies have found tetrabromobisphenol-A to be present in the tissues of predatory organisms (e.g. birds and their eggs, and marine mammals), although the levels are generally very low and tetrabromobisphenol-A was not detectable in many of the samples. However it should be noted that some of the samples where tetrabromobisphenol-A was detectable were taken from relatively remote regions (for example birds eggs from coastal and inland areas of Norway up to 71°N).

The available data for humans indicates that tetrabromobisphenol-A is present in some samples of blood plasma, especially those related to occupational exposure, but tetrabromobisphenol-A has also been found occasionally in samples taken from the general population. It should also be noted that tetrabromobisphenol-A has been found to be present at low levels in human breast milk, including a single sample from a relatively remote area (Faroe Islands). The available database of the measured levels in human breast milk is relatively small however and so it is not possible to identify geographical trends in the levels found. When considering these data, it should be born in mind that although there are a number of positive occurrences of tetrabromobisphenol-A in human samples, tetrabromobisphenol-A was not detectable in many of the samples.

3.1.5 Marine risk assessment

This Section considers the risks to the marine environment from the production, use and disposal of tetrabromobisphenol-A. The methodology used is based on the marine risk assessment chapter of the Technical Guidance Document.

3.1.5.1 Marine exposure assessment

The methodology outlined in the marine risk assessment guidance essentially assumes that the adsorption/desorption, degradation and accumulation behaviour in the marine environment can, in the absence of specific information for the marine environment, be adequately described by the properties of the substance relevant for the freshwater environment. The relevant properties for tetrabromobisphenol-A are summarised in **Table 3.50**.

Table 3.50 Adsorption and accumulation properties for tetrabromobisphenol-A used in the marine assessment

Property	Value
Log Kow	5.90
Water solubility	1.26-2.34 mg/l
Organic carbon - water partition coefficient (Koc)	49,726 l/kg
Solid-water partition coefficient in suspended matter (Kp_{susp})	7,299 l/kg
Suspended matter - water partition coefficient ($K_{susp\text{-}water}$)	1,826 m^3/m^3
Fish bioconcentration factor (BCF_{fish})	485 l/kg (tetrabromobisphenol-A alone) 1,234 l/kg (tetrabromobisphenol-A plus metabolites)
Biomagnification factor in fish (BMF_1)[a]	1
Biomagnification factor in predators (BMF_2)[a]	1

Note: a) Taken from the marine risk assessment guidance using the BCF_{fish} as the trigger value. Actual biomagnification factors for tetrabromobisphenol-A appear to be <1 based on feeding studies.

As the pH of seawater is around 8, tetrabromobisphenol-A is expected to be present in an ionised form in the marine environment. The effect of pH on the partition coefficients and water solubility of the substance is considered in Section 1 and Section 3.1.0 and the values reported in **Table 3.50** are considered to be those most appropriate for the pH conditions likely to be found in the marine environment. The one possible exception to this is the log Kow, where the pH of the water used in the determination was not given. However, as suitable values for Koc and BCF_{fish} are available from elsewhere, the log Kow is not vital to the assessment.

The starting point for the local marine assessment is the concentration of tetrabromobisphenol-A in effluent from the site of discharge. This effluent from industrial sites is assumed to enter into the marine environment without further waste water treatment.

As all the emissions are estimated on a mass/day basis, in order to estimate these concentrations, knowledge of the total aqueous effluent volume discharge from generic sites is needed. These data are not available. In this situation the Technical Guidance indicates that it can be assumed that the amount emitted per day is diluted into a volume of 200,000 m^3, with adsorption onto suspended matter also being taken into account.

The emissions used as the starting point for the marine risk assessment are shown in **Table 3.51**. **Table 3.51** also shows the resulting concentrations in seawater, marine sediment and marine biota. These have been estimated using the methods outlined in the Technical Guidance Document and the properties shown in **Table 3.50** for the adsorption and accumulation behaviour of tetrabromobisphenol-A (EUSES 2.0.3 was used for the calculation).

For secondary poisoning, the concentrations in predators and top predators have been estimated using the following equations.

$PEC_{oral,\ predator} = 0.5 \times (PEC_{local,\ seawater,\ ann} + PEC_{regional,\ seawater,\ ann}) \times BCF_{fish} \times BMF_1$

$PEC_{oral,\ top\ predator} = (0.1 \times PEC_{local,seawater,\ ann} + 0.9 \times PEC_{regional,\ seawater\ ann}) \times BCF_{fish} \times BMF_1 \times BMF_2$

The regional concentration in seawater and marine sediment have been estimated using EUSES 2.0.3 (assuming a Koc value of 49,726 l/kg). The EUSES printout is given in Appendix B. The values obtained are $PEC_{regional,\ sea\ water} = 1.3 \times 10^{-4}$ µg/l and $PEC_{regional,\ marine\ sediment} = 4.0 \times 10^{-4}$ mg/kg wet weight.

For sites manufacturing epoxy and/or polycarbonate resins, and the major compounding sites for additive use of tetrabromobisphenol-A, information has been received from Industry indicating that none of the sites within the EU discharge directly into the marine environment. One site was identified around 50 km from the coast that discharged their effluent via a waste water treatment plant into a water course. The generic calculations in **Table 3.51** have therefore assumed that the effluent is treated in a waste water treatment plant.

Table 3.51 Estimated PECs for tetrabromobisphenol-A for the local marine risk assessment

Scenario	Comment	Daily emission to water (kg/day)	No. of days of release	$C_{local, seawater}$ (µg/l)[c]	$C_{local, seawater, ann}$ (µg/l)	$PEC_{local, seawater}$ (µg/l)[d]	$PEC_{local, seawater, ann}$ (µg/l)[d]	$PEC_{local, sed}$ (mg/kg wet wt.)	$PEC_{oral predator}$ (mg/kg)[d]		$PEC_{oral, top predator}$ (mg/kg)[d]	
									a	b	a	b
Production of tetrabromobisphenol-A	Example calculation	13.6	300	61.3	50.4	61.3	50.4	97.3	31.1	12.2	6.2	2.4
Use as an intermediate in the production of derivatives	Example calculation	17.5	200	78.9	43.2	78.9	43.2	125	26.7	10.5	5.3	2.1
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[e]	0.027	300	0.023	0.019	0.023	0.019	0.036	0.012	4.6×10^{-3}	2.4×10^{-3}	9.6×10^{-4}
	Processing of epoxy resins	5.0×10^{-5}	32	2.3×10^{-4}	2.0×10^{-5}	3.6×10^{-4}	1.5×10^{-4}	5.6×10^{-4}	1.7×10^{-4}	6.8×10^{-5}	1.6×10^{-4}	6.4×10^{-5}
	Processing of polycarbonate resins[e]	5.0×10^{-5}	28	2.3×10^{-4}	1.7×10^{-5}	3.6×10^{-4}	1.5×10^{-4}	5.6×10^{-4}	1.7×10^{-4}	6.7×10^{-5}	1.6×10^{-4}	6.4×10^{-5}
Additive flame retardant use - ABS	Compounding[e]	1.1	171	0.92	0.43	0.92	0.43	1.5	0.27	0.10	0.053	0.021
	Conversion	0.05	171	0.23	0.11	0.23	0.11	0.36	0.065	0.026	0.013	5.2×10^{-3}

Notes: a) Calculations assuming BCF_{fish} = 1,234 l/kg.
b) Calculations assuming BCF_{fish} = 485 l/kg.
c) Assumes the daily emission is diluted into 200,000 m^3 of water and the concentration of suspended matter in the seawater is 15 mg/l.
d) Calculations assume that the $PEC_{regional, seawater}$ is 1.3×10^{-4} µg/l as estimated using EUSES 2.0.3 with a Koc value of 49,726 l/kg.
e) The calculations for these scenarios assume that the effluent is treated in a waste water treatment plant prior to discharge to the marine environment.

3.2 EFFECTS ASSESSMENT: HAZARD IDENTIFICATION AND DOSE (CONCENTRATION - RESPONSE (EFFECT) ASSESSMENT

3.2.1 Aquatic compartment

The following Sections review the available toxicity data for tetrabromobisphenol-A with aquatic organisms. Where possible, a validity marking is given for each study (this appears in the summary Tables within each Section). The following validity markings have been used:

1 **Valid without restriction**. The test is carried out to internationally recognised protocols (or equivalent protocols) and all or most of the important experimental details are available.

2 **Use with care**. The test is carried out to internationally recognised protocols (or equivalent protocols) but some important experimental details are missing, or the method used, or endpoint studied, in the test means that interpretation of the results is not straight forward.

3 **Not valid**. There is a clear deficiency in the test that means that the results cannot be considered as valid.

4 **Not assignable.** Insufficient detail is available on the method used to allow a decision to be made on the validity of the study.

In terms of the risk assessment, toxicity data assigned a validity marking of 1 or 2 will be considered in preference to the other toxicity data when deriving the PNEC.

One important criterion that has to be considered in relation to the aquatic toxicity of tetrabromobisphenol-A is the water solubility, and the fact that it varies with pH. The available data indicate that the solubility of tetrabromobisphenol-A at room temperature is around 0.063-0.24 mg/l in pure water, 0.15 mg/l at pH 5, 1.26 mg/l at pH 7 and 2.34 mg/l at pH 9.

In most of the toxicity tests for which data are available, the pH of the test water is above 7, where tetrabromobisphenol-A may exist, at least in part, as an ionised form and has a water solubility >1 mg/l. Several studies have demonstrated, based on analytical measurements, that dissolved concentrations of around at least 0.5-1 mg/l appear to be adequately maintained during the test, which is consistent with the available solubility data. Based on these data, the toxicity tests where concentrations of up to around 1 mg/l have been used are in general unlikely to have been affected unduly by solubility problems. It is also possible that higher concentrations than this could be tested successfully in some test systems, but these tests should only be considered as fully valid if adequate analysis was undertaken to confirm that the dissolved test concentration was maintained throughout the test.

The main analytical method used in several of the aquatic toxicity tests is based on a radiochemical technique using ^{14}C-labelled tetrabromobisphenol-A (e.g. Springborn laboratories, 1989a and 1989b; Springborn Life Sciences, 1988a, 1988b and 1989b). No details of the purity of the ^{14}C-labelled tetrabromobisphenol-A used in these experiments are given and so it is possible that this method could lead to an overestimate of the actual dissolved concentration of tetrabromobisphenol-A if a more soluble impurity was present. However, in this case it is considered that this is unlikely since, for several of the studies, the concentration of the substance present in solution was confirmed for the highest

concentration tested using an HPLC technique that would not be subject to such problems. Further, the aquatic toxicity solutions were generally filtered (0.45 μm) before analysis, which should mean that the concentrations obtained represent the substance present in the dissolved phase only. The details of the concentrations measured by the various methods are given in the following sections.

Another aspect that needs to be taken into account when considering the toxicity data is the fact that different species may be present in tests carried out at different pHs, and these species may have different toxicities to aquatic organisms. Figure 1.2 in Section 1.3.14.2 shows the relative amounts of the different species that are theoretically present at any given pH.

3.2.1.1 Toxicity to fish

3.2.1.1.1 Short-term studies

Freshwater

The short-term toxicity of tetrabromobisphenol-A to freshwater fish is summarised in **Table 3.52**.

The acute toxicity of a commercial tetrabromobisphenol-A product (FMBP 4A) to bluegill sunfish (*Lepomis macrochirus*) and rainbow trout (*Oncorhynchus mykiss*) has been determined using the test method recommended by the Committee on Methods for Toxicity Tests with Aquatic Organisms (1975). The 96-hour LC_{50} values determined were 0.51 mg/l for bluegill sunfish and 0.40 mg/l for rainbow trout (Union Carbide Corporation, 1978b and 1978c). However, the validity of these studies is questionable as the dissolved oxygen concentration in the test solutions was found to be reduced at 96 hours, and this reduction appeared to be greatest at the higher concentrations tested. For example, with bluegill sunfish, the dissolved oxygen concentration at 96 hours was 6.7 mg/l in the control, 5.5 mg/l in the solvent control, 3.4 mg/l in the 0.18 mg/l treatment group and 2.2 mg/l in the 0.56 mg/l treatment group. Similarly for rainbow trout the dissolved oxygen concentration at 96 hours was 8.7 mg/l in the control group, 5.7 mg/l in the solvent control group, 6.2 mg/l in the 0.10 mg/l treatment group and 4.1 mg/l in the 0.32 mg/l treatment group. Thus it is possible that the toxicity seen in these tests was due to a reduction in the dissolved oxygen concentration rather than a direct effect of the test substance.

A flow-through toxicity study has been carried out with fathead minnow (*Pimephales promelas*) using a mixture of tetrabromobisphenol-A from 5 different producers along with ^{14}C-labelled tetrabromobisphenol-A (Springborn Life Sciences, 1988b). The test method was based on the USEPA 40 CFR 797.1400 test guideline. The test water used in the study was well water with a hardness of 30 mg/l as $CaCO_3$, a pH of 7.0-7.3 and a dissolved oxygen concentration of 6.6-8.7 mg/l. The flow-rate used in the study provided around 9.8 test volume replacements in 24 hours.

Table 3.52 Short-term toxicity of tetrabromobisphenol-A to freshwater fish

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Brachydanio rerio		12 (2 replicates of 6 each) loading was 6 fish in 2 l	2-3 cm	Dimethyl sulphoxide and hydrogenated caster oil HCO-40 (concentration unclear)	Concentrations not given – tested without added humic acids	N	Tap water	21°C					Mortality		96h-LC_{50} = ~3.0 mg/l (value read from graph)	Lee *et al.*, 1993	2
					Tested with humic acid at 0.5 mg TOC/l	N	Tap water	21°C					Mortality		96h-LC_{50} = ~3.3 mg/l (value read from graph)	Lee *et al.*, 1993	2
					Tested with humic acid at 5.0 mg TOC/l	N	Tap water	21°C					Mortality		96h-LC_{50} = ~3.1 mg/l (value read from graph)	Lee *et al.*, 1993	2
					Tested with humic acid at 50 mg TOC/l	N	Tap water	21°C					Mortality		96h-LC_{50} = ~3.4 mg/l (value read from graph)	Lee *et al.*, 1993	2
Lepomis macrochirus	Committee on Methods for Toxicity Tests with Aquatic Organisms, 1975	10, loading was 0.39 g/l	0.59 g	Acetone (concentration not clear)	0.18, 0.32, 0.56, 1.00 and 1.80 mg/l plus control and acetone control	N	Artificial soft water	21.7°C	44 mg/l	6.9-7.9	Static	2.2-8.6	Mortality	0% mortality	48h-LC_{50} = 0.51 mg/l 96h-LC_{50} = 0.51 mg/l [95% conf. interval 0.43-0.61 mg/l]	Union Carbide Corporation, 1978c	3

Table 3.52 continued overleaf.

Table 3.52 continued.

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Oncorhynchus mykiss	Committee on Methods for Toxicity Tests with Aquatic Organisms, 1975	10, loading was 0.34 g/l	0.51 g	Acetone (concentration not clear)	0.1, 0.18, 0.32, 0.56 and 1.00 mg/l plus control and acetone control	N	Artificial soft water	12.3°C	40 mg/l	6.9-7.5	Static	4.1-9.5	Mortality	0% mortality	48h-LC_{50} = 0.67 mg/l 96h-LC_{50} = 0.40 mg/l [95% conf. interval 0.36-0.45 mg/l]	Union Carbide Corporation, 1978b.	3
	OECD 203 – limit test	10 per replicate, 2 replicates/treatment, loading was 0.36 g/l	0.54 g	Dimethyl formamide at 0.1 ml/l	1.1 and 1.7 mg/l plus control and solvent control. Concentrations measured by HPLC.	M_u	Well water	12°C	131 mg/l	8.0-8.2	Flow	8.8-9.3	Mortality	0% mortality	45% mortality at 1.1 mg/l (remaining fish were lethargic or lying on bottom) 100% mortality at 1.7 mg/l	Wildlife International, 2003a	2
Oryzias latipes	Japanese Industry Standard (JIS K 0102-1986-71)	10, loading was 10 fish in 4 litres					Well water	25°C			Semi-static		Mortality		48h-LC_{50} = 8.2 mg/l	CITI, 1992	2

Table 3.52 continued overleaf.

Table 3.52 continued.

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Pimephales promelas	Based on USEPA Method 40 CFR 797.1400	20 (2 replicates of 10 each), loading was 0.046 g/l	0.5 g	Acetone at up to 0.098 ml/l	0.19, 0.26, 0.32, 0.45 and 0.63 mg/l plus control and acetone control. Concentrations determined by ^{14}C analysis.	M_f	Well water	22°C	30 mg/l	7.0-7.3	Flow	6.6-8.7	Mortality	0% mortality	48h-LC_{50} >0.63 mg/l 96h-LC_{50} = 0.54 mg/l [95% conf. interval 0.45-0.63 mg/l] 120h-LC_{50} = 0.50 mg/l [95% conf. interval 0.45-0.63 mg/l] 144h-LC_{50} = 0.49 mg/l [95% conf. interval 0.45-0.63 mg/l]	Springborn Life Sciences, 1988b	1
											Flow				96h-LC_{50} = 1.04 mg/l	Brooke (1991)	4
											Static				96h-LC_{50} = 0.71 mg/l	Brooke (1991)	4
											Static				96h-LC_{50} = 0.89 mg/l	Brooke (1991)	4
											Static				96h-LC_{50} = 0.060 mg/l	Brooke (1991)	4

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 μm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Hard. = Water hardness.
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

Stock solutions of tetrabromobisphenol-A were prepared in acetone and added to the water inflow to give nominal concentrations of 0.18, 0.27, 0.42, 0.65 and 1.0 mg/l. A radiochemical method was used to measure the actual dissolved exposure concentrations (after filtering (0.45 µm)) on days 0, 4 and 6 of the experiment. These indicated that the actual concentrations averaged around 82% of the nominal values. The mean measured concentrations in the five exposure groups were 0.19, 0.26, 0.32, 0.45 and 0.63 mg/l. Further analyses for the highest concentration carried out by a high performance liquid chromatography (HPLC) gave similar results to the radiochemical method (mean concentration was 0.68 mg/l).

The 96-hour LC_{50} determined in this study was 0.54 mg/l, based on the mean measured concentrations. The study was extended to 144-hours to see if the toxicity increased with longer exposure periods. The 144-hour LC_{50} of 0.49 mg/l was similar to the 96-hour value.

Lee *et al.* (1993) studied the effect of dissolved humic acids on the acute toxicity of tetrabromobisphenol-A (purity 98%) to zebra fish *Brachydanio rerio.* The fish were tested in tap water with various concentrations of humic acids added (humic acid concentration = 0, 0.5, 5.0 and 50 mg/l as total organic carbon (TOC)). The 96-hour LC_{50} values were displayed graphically in the paper and so the approximate values only can be obtained. The 96-hour LC_{50} values were in the range 3.0-3.4 mg/l, with only a very slight decrease in toxicity being seen with increasing humic acid concentration. The results appear to be based on nominal concentrations. A cosolvent (dimethyl sulphoxide and hydrated caster oil) was used in the study but there is no indication if the solubility of the test substance in the system was exceeded.

A 48-hour LC_{50} value of 8.2 mg/l has been determined by CITI (1992) for tetrabromobisphenol-A with medaka (*Oryzias latipes*). The test was carried out in a semi-static system (renewal of test solution every 24 hours). Few other details of the specific study, in particular if the solubility of the substance was exceeded in the test, are available (some details of the method as outlined in the test guideline are reported in **Table 3.52**).

A recent limit test for the toxicity of tetrabromobisphenol-A to *Oncorhynchus mykiss* has been carried out (Wildlife International, 2003b). The tetrabromobisphenol-A used in the test was a composite sample from three manufacturers and had a purity of 99.17%. Only two, closely spaced concentrations were tested (measured concentrations of 1.1 and 1.7 mg/l) and a flow-through system was used. The test report indicates that although the test solutions appeared clear and colourless, a slight white precipitate was seen in the mixing chamber of the diluter/flow-through system used. As the analytical method used did not appear to involve filtering the samples prior to analysis it would not distinguish between dissolved and undissolved test material in the exposure tanks, thus it is also possible that the actual dissolved exposure concentration could be lower than indicated by the measurements. No effects were seen in the control group but 45% of the fish in the 1.1 mg/l group and 100% of the fish in the 1.7 mg/l group had died after 96 hours exposure. The limited number of data points available in this study precluded estimation of a reliable LC_{50} from the study. It was also reported that the surviving fish in the 1.1 mg/l group were all either lethargic or lying on the bottom of the tank.

Further toxicity values for tetrabromobisphenol-A with fish have been reported in the AQUIRE database. The 96-hour LC_{50} values given were 1.04, 0.71, 0.89 and 0.06 mg/l, all with fathead minnow (*Pimephales promelas*). The citation in the database is to Brooke (1991)

but it has not been possible, so far, to obtain the original manuscript and so the studies cannot be validated.

Chapter 4 of the Technical Guidance document gives an equation for estimating the 96-hour LC_{50} for fish from log Kow values ($\log LC_{50} = -0.73 \times \log Kow - 2.16$; where LC_{50} is in mole/l). The equation is applicable to more polar substances such as phenols. Using a log Kow value of 5.90, the 96-hour LC_{50} for fish can be estimated as 0.19 mg/l for tetrabromobisphenol-A. The estimated value is slightly lower than, but comparable with, the experimental data.

Saltwater

No short-term toxicity data for tetrabromobisphenol-A with saltwater fish have been located in the literature.

3.2.1.1.2 Long-term studies

Freshwater

The long-term toxicity data from tetrabromobisphenol-A with fresh water fish are summarised in **Table 3.53**.

A 35-day embryo-larval study has been carried out with fathead minnow (*Pimephales promelas*) using a flow-through system (Springborn Laboratories, 1989b). The method used was based on the USEPA 40 CFR 797.1600 test guideline. The test was started with fertilised eggs (<18 hours after fertilisation) and continued through to 30 days posthatch (total duration of exposure was 35 days). The substance tested was a composite sample from five producers of tetrabromobisphenol-A, along with ^{14}C-labelled tetrabromobisphenol-A. Stock solutions of the test substance were prepared in acetone and the maximum acetone concentration in the test vessels was 0.018 ml/l. An acetone control was run at this concentration.

The dilution water used in the test was well water (pH 7.0-8.2, hardness 28-29 mg/l as $CaCO_3$) and the test was carried out at 24°C. The flow rate of dilution water was such as to provide around 6.3 aquarium volume replacements every 24 hours (giving a 90% replacement time of 9 hours). The nominal test concentrations used were 0.025, 0.050, 0.10, 0.20 and 0.40 mg/l. The mean measured levels, as determined by radiochemical analysis of filtered (0.45 µm) solutions, were 0.024, 0.040, 0.084, 0.16 and 0.31 mg/l (~78-96% of nominal). Analysis of the highest test concentration by a HPLC method generally confirmed the presence of tetrabromobisphenol-A in the test media (the concentrations found on five sampling days (days 14, 15, 18, 29 and 35) were 0.17-0.27 mg/l, but on three sampling days (days 11, 25 and 32) the concentration was <0.071 to <0.10 mg/l. The low levels found on days 11, 25 and 32 were thought to be due to the level of suspended solids present in solution on these days). Throughout the experiment a small amount of precipitate was observed in the mixing chamber of the diluter system, but no visible signs of insoluble material were seen in any of the test vessels.

The exposure was started with fertilised embryos (<18 hours after fertilisation) and two groups of 60 embryos were used per concentration and control. Hatching was considered complete by day 5 (<10% unhatched viable embryos remained in any incubation chamber).

Table 3.53 Long-term toxicity of tetrabromobisphenol-A to freshwater fish

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Brachydanio rerio		Three males and three females followed by 50 eggs (or less if insufficient eggs were available)	Partial lifecycle test	Dimethyl sulphoxide at 0.01%	0.013, 0.026, 0.051, 0.102, 0.204, 0.408, 0.816, 1.63 and 3.26 mg/l plus solvent control – the exposure concentrations were not maintained	N		27°C		7.2-8.4	Sem-static (96h re-newal)	>5 mg/l	Egg production and juvenile develop-ment	Average clutch size ~370-480	Effects seen at body burden of 5-7 mg/kg lipid	Kuiper *et al.* (2007)	3
Pimephales promelas	Based on USEPA 40 CFR 797.1600	120 embryos (2 replicates of 60 each)	embryo-larval	Acetone at up to 0.018 ml/l.	0.024, 0.040, 0.084, 0.16 and 0.31 mg/l plus control and solvent control. Concentrations determined by ^{14}C analysis.	M_f	Well water	24°C	28-29 mg/l	7.0-8.2	Flow	8.1-8.3 mg/l	Hatching	84% Hatch	NOEC = 0.16 mg/l LOEC = 0.31 mg/l	Springborn Laboratories, 1989b	1
													Larval survival	93% survival	35d-NOEC = 0.16 mg/l 35d-LOEC = 0.31 mg/l	Springborn Laboratories, 1989b	1
													Growth (length and weight)	Mean length 25 mm, mean weight 111 mg	35d-NOEC ≥0.16 mg/l	Springborn Laboratories, 1989b	1

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 μm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Hard. = Water hardness.
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

At this time, 30 live larvae per replicate (i.e. 60 per concentration) were selected from the surviving larvae and these were used in the 30-day post hatch exposures.

The endpoints investigated were embryo survival at time of hatch (day 5) and larval survival and growth (length and weight) at the end of the study. All statistical comparisons were carried out at the 95% confidence level (p=0.05). No significant differences were seen between the response of the control group and the solvent control group and so these two groups were pooled for comparison with the exposed populations.

At the time of hatch, survival in the highest exposure group (0.31 mg/l) was significantly reduced compared with the pooled control population (28% against 84% in the control).

Survival at all other treatment levels ranged from 74 to 94% and was not statistically significantly different from the control population. The NOEC for survival at time of hatch is therefore 0.16 mg/l.

Since survival was significantly reduced at the time of hatch in the highest exposure group, fewer larvae than planned were available for this concentration for the 30-days post hatch part of the study. At 2-days post hatch, all larvae in this 0.31 mg/l treatment group had died. The survival at day 30 post hatch in all the other treatment groups was similar to the controls (survival was 87-93% in the exposed populations compared with 93% in the pooled controls). Therefore the NOEC for larval survival at 30-days post hatch is 0.16 mg/l.

No statistically significant effects were seen on fish wet weights or total lengths at day 30 post hatch in the surviving exposed animals compared with the pooled control populations (exposed animals were 24-25 mm and 112-126 mg compared to 25 mm and 111 mg in the pooled controls). As all fish died at the highest concentration, it was not possible to determine effects on growth at 0.31 mg/l. Thus the NOEC for growth is ≥0.16 mg/l.

A long-term toxicity test with zebrafish (*Brachydanio rerio*) has recently been carried out as part of the EU FIRE project (Kuiper *et al.*, 2007). The test was a partial life-cycle test consisting of a thirty day adult exposure followed by exposure of the offspring until the juvenile stage (47 days posthatch). The endpoints measured in the study included egg production and fertilization, development and mortality. As the study also considered possible effects on the endocrine system, it is summarised in detail in Section 3.2.1.6.1 and only a brief summary of the results is given here. Overall it was concluded that effects on population-relevant parameters (e.g. egg production, juvenile development of offspring) occurred at body burdens of around 5-7 mg/kg lipid. However, it should be noted that the results of this test are difficult to interpret as, for example the exposure concentrations in water fell markedly during the 96 hour renewal period used and no replicates appear to have been used. The problems in interpreting this study are discussed in detail in Section 3.2.1.6.1 and it is considered that the study is not robust enough to be considered in the PNEC derivation.

Saltwater

No long-term toxicity data for tetrabromobisphenol-A with salt water fish have been located in the literature.

3.2.1.2 Toxicity to aquatic invertebrates

3.2.1.2.1 Short-term studies

Freshwater

The short-term toxicity data for tetrabromobisphenol-A with fresh water aquatic invertebrates are summarised in **Table 3.54**.

A standard static 48-hour toxicity test with *Daphnia magna* has been carried out with a commercial tetrabromobisphenol-A product (FMBP 4A) using the test method recommended by the Committee on Methods for Toxicity Tests with Aquatic Organisms (1975). The 48-hour LC_{50} was determined to be 0.96 mg/l based on nominal concentrations (Union Carbide Corporation, 1978a). No information is given as to whether the solubility of the substance was exceeded in the test system used.

Lee *et al.* (1993) studied the effect of dissolved humic acids on the acute toxicity of tetrabromobisphenol-A to *Daphnia magna.* The *Daphnia* were tested in artificial dilution water with various concentrations of humic acids added (humic acid concentration = 0, 0.5, 5.0 and 50 mg/l as total organic carbon (TOC)). The 48-hour EC_{50} values were displayed graphically in the paper and so the approximate values only can be obtained. The 48-hour LC_{50} values were in the range 0.94-1 µg/l and the humic acid concentration appeared to have little or no effect on the observed toxicity.

The paper indicates that the results for tetrabromobisphenol-A were not uniform, with variations being seen between replicates. No further details of this are given. The results appear to be based on nominal concentrations. A cosolvent (dimethyl sulphoxide and hydrated caster oil) was used in the study but there is no indication if the solubility of the test substance in the system was exceeded. The results are indicated to be in units of µg/l. However, given the results of the experiment by Union Carbide Corporation (1978a) above and the results of the 21-day *Daphnia magna* reproduction study given in Section 3.2.1.2.2, it is possible that this could be a typing error in the original paper, and that the actual LC_{50} values were in the range 0.94 and 1 mg/l. No details of the actual concentrations tested in the study are given and so it is not possible to verify if this is the case. Thus, the results of this test should be treated with caution. A summary of the findings of the test is also reported by Steinberg *et al.* (1992).

A further 48h-EC_{50} value for *Daphnia magna* of 7.9 mg/l has been reported for tetrabromobisphenol-A in the AQUIRE database. The citation in the database is to Brooke (1991) but it has not been possible, so far, to obtain the original manuscript and so the study cannot be validated. The EC_{50} value obtained is well above the water solubility of the substance and so it is possible that the substance was not in true solution in this test.

Table 3.54 Short-term toxicity of tetrabromobisphenol-A to freshwater invertebrates

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Daphnia magna	Committee on Methods for Toxicity Testing with Aquatic Organisms, 1975	20	<20 hour	Acetone up to 0.64 ml/l	0.32, 0.56, 1.00, 1.80 and 3.20 mg/l plus control and solvent control	N	Lake water	17.5°C	64 mg/l	7.32	Static	7.8-8.2 mg/l	Mortality	0% mortality	48h-LC_{50} = 0.96 mg/l [95% conf. interval 0.81-1.13 mg/l]	Union Carbide Corporation, 1978a	2
		40 or 50 (4 or 5 replicates of 10 each)	<24 hour	Dimethyl sulphoxide and hydrogenated caster oil HCO-40 (concentration unclear)	Concentrations not given - tested without added humic acids	N	Artificial water (DIN 38412 Teil 30)	20°C					Immob.		48h-EC_{50} = ~1.0 µg/l (value read from graph)	Lee *et al.*, 1993	3
					Tested with humic acid at 0.5 mg TOC/l	N	Artificial water (DIN 38412 Teil 30)	20°C					Immob.		48h-EC_{50} = ~0.94 µg/l (value read from graph)	Lee *et al.*, 1993	3
					Tested with humic acid at 5.0 mg TOC/l	N	Artificial water (DIN 38412 Teil 30)	20°C					Immob.		48h-EC_{50} = ~0.94 µg/l (value read from graph)	Lee *et al.*, 1993	3
					Tested with humic acid at 50 mg TOC/l	N	Artificial water (DIN 38412 Teil 30)	20°C					Immob.		48h-EC_{50} = ~0.95 µg/l (value read from graph)	Lee *et al.*, 1993	3

Table 3.54 continued overleaf.

Table 3.54 continued.

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Daphnia magna											Semi-static		Immob.		48h-EC_{50} = 7.9	Brooke, 1991	4
	OECD 202 – limit test	10 per replicate, 2 replicates per treatment	<24h	Dimethyl formamide at 0.1 ml/l	1.2 and 1.8 mg/l plus control and solvent control. Concentrations measured by HPLC.	M_u	Well water	20°C	131 mg/l	8.1-8.2	Flow	≥8.6 mg/l	Immob.	10% immobil. in control group. 0% immobil. in solvent control group.	48h-NOEC ≥1.8 mg/l	Wildlife International, 2003b	1

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 μm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Hard. = Water hardness.
Temp. = Temperature.
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

A recent limit test for the toxicity of tetrabromobisphenol-A to *Daphnia magna* has been carried out (Wildlife International, 2003b). The tetrabromobisphenol-A used in the test was a composite sample from three manufacturers and had a purity of 99.17%. Only two, closely spaced concentrations were tested (measured concentrations of 1.2 and 1.8 mg/l) and a flow-through system was used, in which the *Daphnia* were maintained in glass compartments (with a nylon screen at the top) within the exposure vessel. No effects were seen at either concentration tested and so it was concluded that the 48h-EC_{50} for *Daphnia* was >1.8 mg/l. This value is consistent with that reported by Brooke (1991) above, but is slightly higher than the EC_{50} value of 0.96 mg/l reported by Union Carbide Corporation (1978a). Some of this difference may be due to differences in water hardness and pH in the test systems used (e.g. the Union Carbide Corporation (1978a) study was carried out at a hardness of 64 mg/l as $CaCO_3$ and a pH of 7.8-8.2, compared with a hardness of 131 mg/l and a pH of 8.1-8.2 in the Wildlife International (2003b) study) which may be important to the ionisation behaviour of tetrabromobisphenol-A in the test system.

Hutchinson *et al.* (1998) carried out an analysis of the aquatic toxicity data held by ECETOC and found that invertebrate larvae and juveniles were equally sensitive to tetrabromobisphenol-A. The ratio of EC_{50} for larvae compared to juveniles was 0.85 and this was not considered to show a significant difference in response between the two lifestages. The actual data used in this comparison were not given.

Chapter 4 of the Technical Guidance document gives an equation for estimating the 48-hour EC_{50} for *Daphnia magna* from log Kow values ($\log EC_{50} = -0.56 \times \log Kow - 2.79$; where EC_{50} is in mole/l). The equation is applicable to more polar substances such as phenols. Using a log Kow value of 5.90, the 48-hour EC_{50} can be estimated as 0.43 mg/l for tetrabromobisphenol-A. The estimated value is slightly lower than, but comparable to, the experimental data given in Union Carbide Corporation (1978a).

Saltwater

The short-term toxicity data of tetrabromobisphenol-A to saltwater invertebrates are summarised in **Table 3.55**.

Goodman *et al.* (1988) investigated the effects of organism age on the acute toxicity of tetrabromobisphenol-A to the estuarine mysid shrimp (*Mysidopsis bahia*). Three series of 96-hour tests were carried out in a flow-through system using animals that were ≤1 day, 4-5 days or 9-10 days old at the start of the test. Groups of 20 animals were exposed per treatment. The water used was filtered seawater diluted with tapwater to give a salinity of 20.6‰ and was delivered to the test system at a rate of 13 l/hour. All tests were carried out at 25^{o}C. A carrier solvent (90% triethylene glycol and 10% acetone) was present in the test system at a concentration of 0.096 ml/l, and a solvent control was run using the same concentration. During the test the pH was in the range 7.96-8.16 and the dissolved oxygen concentration was in the range 6.2-7.3 mg/l. The test concentrations were verified by analytical measurement using a gas chromatographic technique with electron capture detector on two occasions during the test. The samples were not filtered prior to these analyses and so the results would represent total, rather than dissolved, tetrabromobisphenol-A present.

Table 3.55 Short-term toxicity of tetrabromobisphenol-A to marine invertebrates

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Sal.	pH	Static/ flow	D.O.					
Acartia tonsa	Draft ISO/DIS 14669	Four replicates, 5 animals per replicate	12-14 day old	Acetone at 100 µl/l.	Six concentrations between 0.1 and 0.5 mg/l plus control and solvent control	N	Artificial sea water	20°C	18‰		Static	Maint-ained adequ-ately	Mortality	Not given	48h-LC_{50} = 0.40 mg/l [95% conf. interval 0.37-0.43 mg/l] 48h-LC_{10} = 0.30 mg/l [95% conf. interval 0.23-0.33 mg/l]	Breitholtz *et al.* (2001); Wollen-berger *et al.*, (2002 and 2005)	2
Crassostrea virginica	Based on USEPA 40 CFR 797.1800	40 (2 replicates of 20 each)	41 mm	Acetone at up to 0.040 ml/l	0.075, 0.100, 0.160, 0.260 and 0.310 mg/l plus control and acetone control. Analysis by a ^{14}C method.	M_u	Natural seawater	20°C	33-34 ‰	7.9-8.1	Flow		Shell deposition	Not given	96h-EC_{50} = 0.12 mg/l [95% conf. interval 0.086-0.26 mg/l]	Springborn Life Sciences (1989b)	2
		40 (2 replicates of 20 each)	41 mm	Acetone	0.018, 0.032, 0.051, 0.087 and 0.15 mg/l plus control and acetone control. Analysis by a ^{14}C method.	M_u	Natural seawater	19°C	33-34	7.9-8.1	Flow	6.3-7.9	Shell deposition	1.5 mm shell regrowth	96h-EC_{50} = 0.098 mg/l [95% conf. interval 0.020-0.21 mg/l] 96h-EC_{10} = 0.0026-0.0062 mg/l	Springborn Life Sciences (1989b)	2

Table 3.55 continued overleaf.

Table 3.55 continued.

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Sal.	pH	Static/ flow	D.O.					
Mysidopsis bahia		20	<1 day	Triethylene glycol/ acetone at 0.096 ml/l	Not given - control and solvent control were run. Analysis by GC method.	M	Natural seawater	25°C	20.6‰	8.0-8.2	Flow	6.2-7.3 mg/l	Mortality	≥94% survival	96h-LC_{50} = 0.86 mg/ [95% conf. interval 0.67-1.2 mg/l]l	Goodman *et al.* (1988)	1
		20	4-5 day	Triethylene glycol/ acetone at 0.096 ml/l	Not given - control and solvent control were run. Analysis by GC method.	M	Natural seawater	25°C	20.6‰	8.0-8.2	Flow	6.2-7.3 mg/l	Mortality	≥94% survival	96h-LC_{50} = 1.1 mg/l (estimated)	Goodman *et al.* (1988)	2
		20	9-10 day	Triethylene glycol/ acetone at 0.096 ml/l	Not given - control and solvent control were run. Analysis by GC method.	M	Natural seawater	25°C	20.6‰	8.0-8.2	Flow	6.2-7.3 mg/l	Mortality	≥94% survival	96h-LC_{50} = 1.2 mg/l (estimated)	Goodman *et al.* (1988)	2
Nitocra spinipes	Swedish Standard SS 02 81 06						Brackish water				Static		Mortality	Not given	96h-LC_{50} = 0.35 mg/l [95% conf. interval 0.30-0.41 mg/l]	Breitholtz *et al.* (2001); Wollenberger *et al.* (2002)	2

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 μm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Sal. = Water salinity (given as parts per thousand (‰)).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

Survival in all control treatments was ≥94%. The 96-hour LC_{50}, based on the mean measured concentration, was determined to be 0.86 mg/l for the <1-day old group. For the 5-day old and 10-day old groups, the mortality seen at the highest concentration tested (measured concentration 1.15 mg/l) was 55% and 45% respectively, and the 96-hour LC_{50} for these two groups was estimated graphically as 1.1 and 1.2 mg/l respectively.

A 96-hour LC_{50} of 0.35 mg/l has been determined for tetrabromobisphenol-A with the brackish water copepod *Nitocra spinipes* (Breitholtz *et al.*, 2001) and Wollenberger *et al.*, (2002). The test was performed according to Swedish Standard Procedures using a static method (Swedish Standard SS 02 81 06). Few other experimental details of the study are reported.

Breitholtz *et al.* (2001) and Wollenberger *et al.* (2002 and 2005) report a 48-hour LC_{50} of 0.40 mg/l for tetrabromobisphenol-A with the marine copepod *Acartia tonsa*. The test was carried out in water of salinity 18‰ according to the draft International Standard ISO/DIS 14669 method. The method used was a static test using nominal concentrations.

The effect of tetrabromobisphenol-A on shell regrowth in eastern oysters (*Crassostrea virginica*) has been determined in a short-term flow-through study (Springborn Life Sciences, 1989b). The method used was based on the USEPA 40 CFR 797.1800 test guideline. The substance used in the test was a composite sample from five tetrabromobisphenol-A producers, along with ^{14}C-labelled tetrabromobisphenol-A. Stock solutions of the test substance were prepared in acetone and the maximum concentration of acetone in the test solution was 0.04 ml/l. An acetone control was also run at this concentration. The water used in the test was natural seawater that had a pH of 7.9-8.1 and a salinity of 33-34‰. The flow rate used gave around 6 aquaria volume replacements every 24 hours.

At the start of the test, 3-5 mm of new shell growth was removed from the oysters by grinding and the oysters were then held overnight prior to use in the test. The endpoint used in the test was new shell growth, which was expressed as a percentage of the shell regrowth seen in the control populations. The test was carried out twice.

In the first test, nominal concentrations of 0.052, 0.086, 0.140, 0.240 and 0.40 mg/l were used. Radiochemical analysis of the unfiltered test solutions indicated that the actual exposure concentrations were 0.075, 0.10, 0.16, 0.26 and 0.31 mg/l in these exposures. The second test used slightly lower concentrations in order to better identify the NOEC. The nominal concentrations used in the second test were 0.019, 0.032, 0.054, 0.090 and 0.15 mg/l and radiochemical analysis indicated that the actual exposure concentrations were 0.018 mg/l, 0.032 mg/l, 0.051 mg/l, 0.087 mg/l and 0.15 mg/l. Analysis of the nominal 0.15 mg/l concentration at the start and end of the test was also carried out using a HPLC method. The concentrations measured using this technique were 0.13 and 0.097 mg/l (mean 0.11 mg/l) and were consistent with the radiochemical measurements. The samples for HPLC analysis were filtered (0.45 µm) prior to analysis and so represent the dissolved concentration of tetrabromobisphenol-A. At the end of the study, some undissolved test substance was observed in the mixing chamber of the diluter system, but no undissolved test substance was seen in test aquaria.

During the study, all exposed and control organisms appeared to be feeding and siphoning normally and no mortality occurred, and no significant difference (p=0.05) was seen in the shell regrowth of control and solvent control organisms. The mean (± standard deviation)

shell regrowth seen in control and solvent control populations was 1.3±0.8 mm and 1.6±1.1 mm respectively (the shell regrowth in the pooled control was 1.5±0.3 mm). The USEPA test guideline OPPTS 850.1025 (USEPA, 1996), which supersedes the guideline used in this test, indicates that a minimum of 2 mm new shell growth should be seen in the control populations in such a test. Therefore the shell regrowth seen in the control population in this test was slightly lower than recommended in the current guidelines for such a test and so introduces some uncertainty into the results. However, given the response seen in the exposed populations (see below) it is clear that significant treatment-related effects were seen in this study.

In the exposed populations a statistically significant (p=0.05) dose-related reduction in shell regrowth relative to pooled control organisms was seen at all concentrations tested. In the first study, shell regrowth was reduced by 82% at the highest concentration tested (0.31 mg/l) and by 41% at the lowest concentration tested (0.075 mg/l). The 96-hour EC_{50} was determined to be 0.12 mg/l. In the second study, shell regrowth was reduced by 60% at the highest concentration tested (0.15 mg/l) and was reduced by 33% at the lowest concentration tested (0.018 mg/l). The 96-hour EC_{50} was determined to be 0.098 mg/l.

Using the data from both experiments, the authors constructed an equation relating shell regrowth inhibition to exposure concentration. Using this equation, the 96-hour EC_{10} was estimated to be around 0.0062 mg/l when all the data are considered, and around 0.0026 mg/l when the data from the second experiment only are considered. These EC_{10} values should be treated with caution as they are extrapolated below the lowest concentration tested and the control response was slightly lower than is recommended in the current guidelines for such a test. Further discussion of the results of this test is given in Section 3.2.1.7.1

3.2.1.2.2 Long-term studies

Freshwater

The long-term toxicity data for tetrabromobisphenol-A on freshwater invertebrates are summarised in **Table 3.56**.

A 21-day reproduction study with *Daphnia magna* has been carried out with tetrabromobisphenol-A using a flow-through system based on the USEPA 40 CFR 797.1330 test guideline (Springborn Laboratories, 1989a). The test substance was a mixture of tetrabromobisphenol-A from five different manufacturers, along with ^{14}C-labelled tetrabromobisphenol-A.

The water used in the test was well water that was fortified to give a hardness of 170 mg/l as $CaCO_3$. The flow rate used in the test gave a 90% test solution replacement time of around 9 hours. The pH and dissolved oxygen concentration of the test solution was 8.1-8.2 and 8.0-8.7 mg/l respectively throughout the test. The test was carried out at 20^{o}C.

Table 3.56 Long-term toxicity of tetrabromobisphenol-A to freshwater invertebrates

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Chironomus tentans	Based on ASTM, 1987 and Adams *et al.*, 1985	50 (2 replicates of 25 each)	2nd instar	Acetone up to 0.074 ml/l.	0.066, 0.12, 0.20, 0.41 and 0.85 mg/l plus control and solvent control. Analysis by a ^{14}C method.	M_f	Well water	22°C	29-30 mg/l	6.9-7.8	Flow	7.9-8.6 mg/l	Mortality	84-100% survival	14d-NOEC = 0.12 mg/l 14d-LC_{50} = 0.13 mg/l [95% conf. interval 0.11-0.15 mg/l]	Springborn Laboratories, 1989c	2
													Growth	Mean weight 12-19 mg	Effects on growth over 14 days at 0.066 mg/l	Springborn Laboratories, 1989c	2
Daphnia magna	Based on USEPA 40 CFR 797.1330	40 (2 replicates of 20 each)	<24 hour	Acetone at up to 0.017 ml/l.	0.056, 0.10, 0.19, 0.30 and 0.98 mg/l plus control and solvent control. Analysis by a ^{14}C method.	M_f	Well water	20°C	170	8.1-8.2	Flow	8.0-8.7 mg/l	Mortality	98% survival	21d-NOEC ≥0.98 mg/l	Springborn Laboratories, 1989a	1
													Growth	Average length 4.1 mm	21d-NOEC ≥0.98 mg/l		
													Repro.	60 offspring/ female	21d-NOEC = 0.30 mg/l		

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 µm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Hard. = Water hardness.
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

Stock solutions of the test substance were made up in acetone and varying amounts of this stock solution were mixed with the inflowing water to give nominal concentrations of 0.13, 0.25, 0.5,1.0 and 2.0 mg/l. The highest amount of acetone present in the test solution was 0.017 ml/l, and a solvent control was run at this concentration. Analysis for the tetrabromobisphenol-A concentration in all treatments was carried out on days 0, 7, 14 and 21 of the test using a radiochemical method. In addition, the concentration of tetrabromobisphenol-A in the highest treatment group was also determined by a high pressure liquid chromatography (HPLC) method at each sampling time. The radiochemical measurements indicated that the mean measured concentrations were around 40% of the nominal values, and were constant at this level throughout the test (the samples for the radiochemical method were filtered (0.45 µm) prior to analysis and so represent dissolved concentrations). The mean measured concentrations were 0.056 mg/l, 0.10 mg/l, 0.19 mg/l, 0.30 mg/l and 0.98 mg/l. Analysis of the highest test concentration by the HPLC method gave mean measured concentrations of 0.65 mg/l for filtered samples and 0.94 mg/l for unfiltered samples. Throughout the exposure period a small amount of precipitate was seen in the diluter mixing chamber but no undissolved tetrabromobisphenol-A was seen in any of the test solutions.

No statistically significant differences (p=0.05) were seen between the response of the control group and the solvent control group and so the two control groups were pooled for statistical comparison (p=0.05) with the treatment groups.

At the end of the test, the survival in all treatment groups was in the range 95% to 100% and this was not significantly different from the pooled control group (survival 98%). Therefore the NOEC for survival was ≥0.98 mg/l.

Reproduction, in terms of the number of offspring per female, was significantly reduced at the highest concentration tested (0.98 mg/l) when compared with the pooled control group (21 offspring/female compared with 60 offspring/female in pooled controls). The number of offspring/female was not significantly different from the pooled control group at any other treatment level. The NOEC for reproduction is therefore 0.30 mg/l.

The growth of the organisms (as determined by final mean body length) was 4.0 to 4.4 mm in the treatment groups which was not significantly different from the pooled control group (mean body length was 4.1 mm). Thus the NOEC for growth is ≥0.98 mg/l.

The toxicity of tetrabromobisphenol-A to sediment-dwelling midge (*Chironomus tentans*) larvae has been studied in a 14-day partial life-cycle test using a continuous-flow exposure via the water phase (Springborn Laboratories, 1989c). The method used was based on the ASTM (1987) proposed guideline for conducting sediment bioassays with midge larvae and Adams *et al.* (1985). The toxicity of tetrabromobisphenol-A to the same species exposed via the sediment phase is described in Section 3.2.1.5. The substance tested was a composite sample of tetrabromobisphenol-A from five producers, along with ^{14}C-labelled tetrabromobisphenol-A. The substance was stated to have a purity of 99.15% (related to active ingredient) and the ^{14}C-labelled tetrabromobisphenol-A had a radiopurity of 96.0%. Stock solutions of the test substance were made up in acetone. The maximum concentration of acetone in the test vessels was 0.074 ml/l, and a solvent control was also run at this level. The nominal tetrabromobisphenol-A concentrations used were 0.31, 0.63, 1.3, 2.5 and 5.0 mg/l. The mean measured concentrations over the exposure period, determined by a radiochemical method after filtering (0.45 µm) the solution, were 0.066, 0.12, 0.20, 0.41 and

0.85 mg/l respectively. The mean measured concentrations were 15-23% of the nominal values throughout the test which indicates that a significant proportion of the test substance may not have been in solution. A precipitate was seen in the mixing cell of the diluter system in the test and this was thought to be the cause of the high coefficients of variation (30-55%) found in the mean measured concentrations.

The dilution water used in the test was well water (pH 6.9-7.8, hardness 29-30 mg/l as $CaCO_3$, temperature 22^oC) and the flow rate was such as to provide 5 test volume replacements every 24 hours (90% solution replacement time was 10 hours). The organisms used in the test were 2nd instar larvae (~9-11 day old). Each exposure concentration and control was carried out in duplicate, with 25 larvae/replicate.

The endpoints investigated in the study were survival and growth (wet weights). The survival of the control and solvent control organisms was 84-100%. Survival of the exposed populations was statistically significantly (p=0.05) reduced at concentrations of 0.2 mg/l and above compared with controls (survival of exposed populations was 0%-28%). The 14-day NOEC for survival was therefore 0.12 mg/l and the 14-day LC_{50} was calculated to be 0.13 mg/l. The growth (wet weight) of the organisms was significantly reduced at all exposure concentrations compared with control organisms. The mean wet weight per organism in the two replicates at the lowest concentration tested (0.066 mg/l) were 5 and 3 mg. These compare with the mean weight per organism of 17 and 19 mg in the two solvent control groups and 12 and 13 mg in the two control groups. From these data it is not possible to derive a NOEC for growth. The validity of these findings could be questioned as there appear to have been problems adequately maintaining the concentration of tetrabromobisphenol-A during the test, and undissolved test substance may have been present in the test media. However, the effects on growth appear to have been severe at all concentrations tested and it cannot be ruled out that the effects seen were due to dissolved tetrabromobisphenol-A alone.

Saltwater

The long-term toxicity of tetrabromobisphenol-A to saltwater invertebrates is summarised in **Table 3.57**.

The effects of tetrabromobisphenol-A exposure on development and reproduction of two copepod species, *Nitocra spinipes* and *Acartia tonsa* have been reported by Breitholtz *et al.* (2001) and Wollenberger *et al.* (2002).

In the test with *N. spinipes* groups of 10-15 nauplii (<36 hour old) were placed in glass vials with 10 ml of brackish water containing the test substance and fed with 30 µl of a feed suspension prepared from commercial salmon feed. Nominal concentrations up to 0.035 mg/l were tested, which corresponds to up to 1 tenth of the 96-hour LC_{50} value for this species. Eight replicate vessels were used for each treatment group. The test solutions were renewed (70% of the solution replaced) every second day, and further feeding with 15 µl of suspension was carried out at the time of renewal.

Table 3.57 Long-term toxicity to saltwater aquatic invertebrates

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Sal.	pH	Static/ flow	D.O.					
Acartia tonsa		30-40	eggs			N		20°C	18‰		Semi-static		Larval development rate	~50% copepodites in 5 days	5 day EC_{50} = 0.125 mg/l [95% conf. interval 0.065-0.238 mg/l]	Breitholtz *et al.* (2001); Wollen-berger *et al.* (2002)	2
		30-40 per replicate, four replicate per treatment	eggs (<24 h)	Acetone at up to 79 mg/l (100 µl/l)	2, 5, 13, 32, 80 and 200 µg/l plus control and solvent control	N	Artificial sea water	20°C	18‰		Semi-static		Larval development rate	~50% copepodites in 5 days	5 day EC_{10} = 12.7 µg/l [95% conf. interval 2.5-63.6 µg/l] 5 day EC_{50} = 125 µg/l [95% conf. interval 65.1-238 µg/l]	Wollen-berger *et al.* (2005).	

Table 3.57 continued overleaf.

Table 3.57 continued.

Species	Test guideline	Number of animals/ treatment	Age/ size	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions						Endpoint	Control response	Effect concentration	Reference	Val.
							Media	Temp.	Sal.	pH	Static/ flow	D.O.					
Mytilus edulis		10 per replicate, 3 replicates per treatment	8-12 mm	Dimethyl formamide at 3.3 µl/l	17, 32, 62, 126 and 226 µg/l plus control and solvent control	M	Natural sea water	15±1° C	35‰ ±1‰	7.9-8.1	Flow	>60 %	Specific growth rate – shell length	Mean growth rates 0.64±0.18 (control) and 0.58±0.16 (solvent control)	70 day NOEC = 17 µg/l	Brown *et al.* (2005)	1
													Specific growth rate – wet tissue weight	Mean growth rates 1.85±0.55 (control) and 1.71±0.48 (solvent control)	70 day NOEC = 62 µg/l		
													Specific growth rate – dry tissue weight	Mean growth rates 2.42±0.58 (control) and 2.24±0.55 (solvent control)	70 day NOEC = 17 µg/l		
													Mortality	0% Mortality	70 day NOEC ≥226 µg/l		
Nitocra spinipes		10-15 per replicate, 8 replicates per treatment	nauplii <36 h		Up to 0.035 mg/l	N	Brackish water				Semi-static		Larval development rate, fecundity and sex ratio	Not given	18 day NOEC ≥0.035 mg/l	Breitholtz *et al.* (2001); Wollen-berger *et al.* (2002)	2

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 µm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Sal. = Water salinity (given as parts per thousand (‰)).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

On day 7-8 of the study (by this time normally about 50% of the offspring would have reached the copepodite stage) the larval development ratio was determined as the percentage of copepodites among all offspring divided by the total number of juveniles at the beginning of the experiment. On day 15-18 of the study gravid females were individually transferred to vials containing the test substance. Exposure was terminated on day 18 of the study but the individually isolated gravid females were left to hatch until day 22. The nauplii were then counted and the remaining copepods were examined for morphological malformations. No effects were seen in the exposed populations when compared with controls in the larval development rate, fecundity or sex ratio. Thus the NOEC for this study is ≥0.035 mg/l.

The larval development test with *A. tonsa* was carried out using 30-40 eggs in 80 ml of test solution containing tetrabromobisphenol-A in saltwater (18‰) at 20°C. The test solutions were renewed on day 3 of the experiment (50% of the solution was replaced). The organisms were fed microalgae (5×10^4 cells/ml) on day 0 and 3 of the experiment. On day 5 of the experiment ~50% of the copepodites had hatched in the control population and the larval development ratio (defined as the ratio of copepodites to the sum of nauplii and copepodites) in the exposed and control populations were determined. The 5-day EC_{50} for effect on the larval development rate was determined as 0.125 mg/l.

The results of a (sub)chronic toxicity test with *Acartia tonsa* have recently become available (Wollenberger *et al.*, 2005; it is possible that this study is the same as the one reported above by Breitholz *et al.*, 2001 and Wollenberger *et al.*, 2002 given above). The study investigated the effects on larval development in a five day study, which covered the period of development from egg hatching to the first copepodite stages. The endpoint used in the study was the larval development rate (the percentage of test organisms that had turned into copepodites) at the time when about 50% of the control organisms have reached a copepodite stage (which at 20°C takes five days). The larval development rate of 50% in the control value was used as it allows detection of possible stimulatory effects, as well as inhibitory effects, as a result of the treatment to be determined.

Stock solutions of tetrabromobisphenol-A were prepared in acetone and stored in the dark. The test solutions were prepared by diluting the acetone solution in synthetic seawater (salinity 18‰). The experiments were started by adding around 30-40 eggs (<24 hour old) to 80 ml of the test solution. The test solutions were partially renewed (50% of the solution was replaced) on day 3 of the test. A total of six tetrabromobisphenol-A concentrations were run (nominal concentrations of 2, 5, 13, 32, 80 and 200 µg/l). Eight replicates were used for the controls (both controls and solvent controls were run) and four replicates for each test concentration. The organisms were fed at the start of the test, and on day three of the test, with algal cells (5×10^4 cells/ml).

Egg hatching was not found to be affected by any treatment level compared with the control population. The hatching rate was generally in the range 80-90%. Similarly larval survival was >80% in all treatment and control groups at day 5. Exposure to tetrabromobisphenol-A was, however, found to cause a dose dependent inhibition of the larval development rate compared with the control population. The percentage inhibition was determined as 10%, -7%, 19%, 27%, 31% and 66% at the nominal treatment levels of 2, 5, 13, 80 and 200 µg/l respectively. The 66% inhibition seen at 200 µg/l was statistically significant (p=0.05) compared with the control population. Based on these data, the 5 day-EC_{10} was calculated to be 12.7 µg/l and the 5 day-EC_{50} was calculated to be 125 µg/l.

The larval development of this species is controlled hormonally by ecdysteroids and so, in order to distinguish between general toxicological effects and endocrine-mediated effects, tetrabromobisphenol-A was also tested *in vitro* for potential ecdysteroid agonistic/antagonistic effects using the ecdysteroid-responsive *Drosophila melanogaster* B_{II}-cell line. The results of this test are summarised in Section 3.2.1.6.2.

The effects on mortality and growth of common mussels (*Mytilus edulis*) from long-term exposure to tetrabromobisphenol-A have been recently studied (Brown *et al.*, 2005). The substance tested was a composite sample from three manufacturers and had a purity of 99.2%.

The water used in the test was natural seawater that was filtered (1 μm) prior to use. At the start of the test the mussels had a shell length of 8-12 mm (mean and standard deviation were 10.8±0.7 mm). The test was carried out using a continuous-flow system. Triplicate vessels were used with each vessel containing around three litres of water and ten mussels. The flow rate was 200 ml/minute (giving a water refreshment rate of >25 litres/mussel/day). A glass petri dish was placed within each vessel to allow the mussels to attach.

Stock solutions of the test substance were prepared in dimethylformamide solvent and the dilution system used had a nominal dilution of 1:300,000. The concentration of solvent in the test chambers was 3.3 μl/l and a solvent control was run as well as a control. The flow-through system was operated for twelve days prior to the start of the test to ensure that the expected concentrations could be achieved and maintained. The tanks were not aerated during the test. The nominal concentrations tested were 19, 38, 75, 150 and 300 μg/l. The mean measured concentrations found during the test were 17, 32, 62, 126 and 226 μg/l (based on measurements on day 0, 4, 7, 11, 15, 22, 29, 36, 43, 50, 57 and 64 of the study). The results are expressed in terms of the mean measured concentrations.

The test was started placing batches of ten mussels in each replicate tank. The individual shell lengths were measured using digital callipers prior to adding to the tank. Individuals were not marked within the tanks. In addition a group of thirty mussels were also measured, sacrificed and the flesh weights (on both a wet and dry weight basis) determined. Subsequently the mussels were re-measured every fourteen days. The experiment was stopped on day 70, by which time the control mussels had achieved an increase in shell length of >50% compared with their day 0 values. After shell measurement, the wet and dry mussel flesh weights of all mussels were determined at the end of the test. The growth data were used to calculate the specific growth rates (over day 0-14, 0-20, 0-42, 0-56 and 0-70 for shell length and over day 0-70 for wet and dry flesh weights).

The mussels were fed throughout the test with an algal (*Tetraselmis* sp.) suspension. The alga was introduced into the water inflow. The test systems (including the tanks) were cleaned approximately once per week to remove feces and detritus and to maintain the effective running of the flow-through system.

The endpoints determined in the study were mortality and the specific growth rates calculated both on shell length and body weight (both wet weight and dry weigh). The specific growth rate was analysed using the procedures outlined in the OECD 215 test method for juvenile fish growth.

The results of the test are summarised in **Table 3.58**. No statistically significant (p=0.05 level) differences were seen between the control population and the solvent control population and so the two controls were pooled. No treatment mortalities were observed during the test (i.e. NOEC for mortality is ≥226 µg/l). In the 226 µg/l treatment, an excessive length of fecal material compared with other treatment groups was noted on days 2 and 4 of the experiment, but this was not evident after day 4. The overall NOEC was 17 µg/l based on specific growth rate for length of shell and the dry flesh weight. The NOEC based on the specific growth rate for wet flesh weight was 62 µg/l. It was considered that measurement of the wet and dry flesh weights of small mussels was less reliable than measurement of mussel shell length (it was stated that it can be difficult to remove all the flesh from the shells) and this may explain some of the apparent variability in the results based on mussel weights (for example the relatively poor dose-response seen in the specific growth rates based on dry weight). Therefore the most relevant NOEC from this study for use in the risk assessment is the value of 17 µg/l based on the specific growth rate for shell length.

Table 3.58 Summary of growth data in the toxicity test with *Mytilus edulis*

Concentration	Mean specific growth rate (day^{-1})						
	Based on length (mm)					Based on wet weight (mg) (day 0-70)	Based on dry weight (mg) (day 0-70)
	Day 0-14	Day 0-28	Day 0-42	Day 0-56	Day 0-70		
Control	0.981±0.459	0.770±0.275	0.673±0.237	0.656±0.204	0.642±0.182	1.85±0.55	2.42±0.58
Solvent control	1.00±0.457	0.882±0.281	0.750±0.223	0.647±0.187	0.576±0.159	1.71±0.48	2.24±0.55
17 µg/l	0.848±0.472	0.773±0.279	0.670±0.224	0.602±0.190	0.532±0.171	1.83±0.50	2.18±0.68
32 µg/l	0.801±0.517	0.736±0.281	0.639±0.202	0.565±0.164	0.498*±0.137	1.71±0.36	1.45*#±1.14
62 µg/l	0.814±0.518	0.709#±0.255	0.590*#±0.178	0.497*#±0.141	0.432*#±0.121	1.61±0.34	2.61±0.29
126 µg/l	0.538*#±0.466	0.464*#±0.246	0.388*#±0.177	0.336*#±0.149	0.302*#±0.138	1.22*±0.46	1.99*±0.49
226 µg/l	0.507*#±0.637	0.447*#±0.355	0.342*#±0.235	0.282*#±0.180	0.234*#±0.147	1.14*±0.51	1.50*#±0.70

Note: ± = Standard deviation.
* = Statistically significant difference (p=0.05) between treatment group and pooled control group.
# = Statistically significant difference (p=0.05) between treatment group and solvent control group.

Canesi *et al.* (2005) have investigated the mechanism of action of tetrabromobisphenol-A on the immune cells (hemocytes) of the marine mussel *Mytilus galloprovincialis* in *in vitro* studies. In mussel, the hemocytes are responsible for cell-mediated immunity through phagocytosis and various cytotoxic reactions (for example the release of lysomal enzymes and antimicrobial peptides, and the respiratory burst which involves production of oxygen metabolites).

The study found that at low micromolar concentrations (around 5 µM which is equivalent to a concentration of 2.7 mg/l) tetrabromobisphenol-A induces hemocyte lysomal membrane destabilization. This effect was reduced or prevented by hemocyte pre-treatment with specific inhibitors or mitogen activated protein kinases (MAPKs) and of protein kinase C (PKC). Tetrabromobisphenol-A was found to stimulate phosphorylation of MAPK members and PKC, and stimulated the hemocyte microbicidal activity towards *E coli*, lysomal enzyme release, phagocytic activity and extracellular superoxide production. It was concluded that *in*

vitro tetrabromobisphenol-A activates the immune function of mussel hemocytes through kinase-mediated cell signalling.

3.2.1.3 Toxicity to algae

Woin *et al.* (2001) carried out studies to investigate the partitioning of tetrabromobisphenol-A between plankton, water and glass in a system designed for toxicity testing. The effects of phytoplankton concentration, glass surface area and chemical concentration on the phytoplankton-water partition coefficient were investigated in the test. The results showed that these variables had no affect on the partitioning behaviour seen, with the log phytoplankton-water partition coefficient being determined at around 6.5 in all experiments.

This indicates that in algal tests, tetrabromobisphenol-A would be expected to adsorb to the algal cells. According to the current OECD test guidelines, adsorption of the substance onto algal cells, with subsequent disappearance of the test substance from water, does not necessarily invalidate the test.

3.2.1.3.1 Freshwater

The toxicity of tetrabromobisphenol-A to freshwater alga is summarised in **Table 3.59**.

The toxicity of tetrabromobisphenol-A to the green alga (*Pseudokirchneriella subcapitata*[16]) has been determined over 96 hours (Springborn Life Sciences, 1988a). The method used was based on the USEPA 40 CFR 797.1050 test guideline. The substance tested was a composite sample from five producers along with ^{14}C-labelled tetrabromobisphenol-A. Stock solutions of the test substance were prepared in acetone and varying amounts of this stock solution were added to the test media to give nominal concentrations of 0.60, 1.2, 2.4, 4.8 and 9.6 mg/l. The highest amount of acetone present in the test solutions was 0.1 ml/l, and a solvent control was run at this concentration. The initial inoculum concentration was 1×10^4 cells/ml. The temperature of the test was 20-24^{o}C and the pH of the test medium was around 7.0 at the start of the test, rising to 8.6-9.6 at the end of the test. The current OECD test guideline indicates that the pH of the solution should not normally deviate by more than one pH unit during the test. The significance for the result of the increase in pH seen in this test is unclear.

The test concentrations were verified by radiochemical analysis. These showed that the mean measured concentrations were around 57-63% of the nominal values (mean measured concentrations were 0.34-5.6 mg/l) and the measured concentrations at 96-hours were very close to the measured concentrations at the start of the test. The highest test concentration was also determined by an HPLC method at 96-hours. Here the measured concentration was 2.7 mg/l which was in reasonable agreement with the results from the radiochemical method. The analytical methods involved filtering through a 0.45 µm filter and a significant amount of the ^{14}C-labelled tetrabromobisphenol-A was found on the filter papers (23-28% of the nominal concentration). This indicated that the solubility of the test substance had been exceeded in all of the test solutions. The authors estimated the solubility to be around 0.5 mg/l in the test system based on these results.

[16] Formerly *Selenastrum capricornutum.*

Table 3.59 Toxicity of tetrabromobisphenol-A to freshwater algae

Species	Test guideline	Initial inoculum concentration	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions				Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH					
Pseudokirchneriella subcapitata (formerly *Selenastrum capricornutum*)	Based on USEPA 40 CFR 797.1050	1×10^4 cells/ml. 3 replicates/ concentration.	Acetone up to 0.1 ml/l	0.34, 0.76, 1.5, 3.0 and 5.6 mg/l plus control and solvent control. Analysis by ^{14}C method.	M_f	Artificial growth medium	20-24°C		7.0-9.6	Cell density (biomass)	Cell density ~1.1-1.4$\times10^6$ cells/ml at 96-hours	72h-NOEC ≥5.6 mg/l 72h-EC_{50} >5.6 mg/l 96h-NOEC ≥5.6 mg/l 96h-EC_{50} >5.6 mg/l	Springborn Life Sciences, 1988a	2

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 μm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Hard. = Water hardness (given as mg $CaCO_3$/l).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

No effects on total cell numbers (biomass) were seen at any concentration when compared with the control solutions at 24-, 48-, 72- or 96-hours (although the test duration of 96 hours is longer than the 72 hours currently recommended in the OECD Test Guidelines, the alga appeared to still be undergoing exponential growth at the end of the study). Thus the NOEC from this study is ≥5.6 mg/l. However, given the uncertainties with the analytical results from this study, the results are best regarded as showing no effects of tetrabromobisphenol-A at its limit of solubility in the test system.

3.2.1.3.2 Saltwater

The toxicity of tetrabromobisphenol-A to marine algae is summarised in **Table 3.60**.

The toxicity of tetrabromobisphenol-A to three species of marine algae (*Skeletonema costatum*, *Thalassiosira pseudonana* and *Chlorella* sp.) has been determined using six different growth media (Walsh *et al.*, 1987). The six growth media used were natural seawater and five artificial seawater formulations. All tests were carried out at a salinity of 30‰. Stock solutions of tetrabromobisphenol-A were prepared in acetone and 0.05 ml of these solutions were added to 51 ml of algal growth media (the final concentration of acetone was 0.98 ml/l). A solvent control was also run. The concentrations of the test substance in the stock solutions and in the test media were verified by analytical measurements using a gas-liquid chromatographic technique (it is not clear if these measurements were on filtered or unfiltered solutions).

Each experiment was carried out twice. Growth was determined by cell count (number of cells at beginning of the test was 4.7×10^4 cells/ml) and the average growth rate over the 3-day (*S. costatum* and *T. pseudonana*) or 4-day (*Chlorella* sp.) period was determined. The average growth rates in the controls for the three algal species were similar in all growth media used (0.58-0.68 d^{-1} for *S. costatum*, 0.60-0.75 d^{-1} for *T. pseudonana* and 0.49-0.57 d^{-1} for *Chlorella* sp.).

The 96-hour EC_{50} for *Chlorella* sp. was >1.5 mg/l (the highest concentration tested) in all test media (the raw data for this experiment is not available and so it is not possible to verify that the alga were still undergoing exponential growth at 96 hours). The mean 72-hour EC_{50} for *S. costatum* was 0.55 mg/l in natural sea water, and 0.09, 0.14, 0.49 and 0.89 mg/l in four artificial seawaters. For *T. pseudonana*, the mean 72-hour EC_{50} was 0.83 mg/l in natural seawater, and 0.13, 0.17, 0.21, 0.31 and 1.0 in five artificial seawaters. Tetrabromobisphenol-A was found to be more toxic in the test media with lower pH values (the pH was 8.1 in natural seawater and ranged between 7.6 and 8.2 in the artificial seawaters), and may indicate that the undissociated form of tetrabromobisphenol-A may be more toxic than the dissociated form.

Table 3.60 Toxicity of tetrabromobisphenol-A to marine algae

Species	Test guideline	Initial inoculum concentration	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions				Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Sal.	pH					
Chlorella sp.		4.7×10^4 cells/ml	Acetone at 0.98 ml/l	Not given - control and solvent controls were run. Analysis by GC method.	M	Natural seawater		30‰	8.1	Average growth rate	Average growth rate = 0.65 d^{-1}	96h-EC_{50} >1.5 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.70 d^{-1}	96h-EC_{50} >1.5 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.67 d^{-1}	96h-EC_{50} >1.5 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.60 d^{-1}	96h-EC_{50} >1.5 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.70 d^{-1}	96h-EC_{50} >1.5 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.74- 0.75 d^{-1}	96h-EC_{50} = >1.5 mg/l	Walsh *et al.*, 1987	2
Skeletonema costatum		4.7×10^4 cells/ml	0.98 ml/l	Not given - control and solvent controls were run. Analysis by a GC method.	M	Natural seawater		30‰	8.1	Average growth rate	Average growth rate = 0.65 d^{-1}	72h-EC_{50} = 0.55 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.64 d^{-1}	72h-EC_{50} = 0.09 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.61- 0.62 d^{-1}	72h-EC_{50} = 0.49 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.67- 0.68 d^{-1}	72h-EC_{50} = 0.14 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.58- 0.61 d^{-1}	72h-EC_{50} = 0.89 mg/l	Walsh *et al.*, 1987	2

Table 3.60 continued overleaf.

Table 3.60 continued.

Species	Test guideline	Initial inoculum concentration	Cosolvent	Concentrations tested/analytical method	N or M	Test conditions				Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Sal.	pH					
Thalassiosira pseudonana		4.7×10^4 cells/ml	0.98 ml/l	Not given - control and solvent controls were run. Analysis by a GC method.	M	Natural seawater		30‰	8.1	Average growth rate	Average growth rate = 0.65 d^{-1}	72h-EC_{50} = 0.83 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.70 d^{-1}	72h-EC_{50} = 0.17 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.67 d^{-1}	72h-EC_{50} = 0.21 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.60 d^{-1}	72h-EC_{50} = 0.31 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	7.6	Average growth rate	Average growth rate = 0.70 d^{-1}	72h-EC_{50} = 0.13 mg/l	Walsh *et al.*, 1987	2
					M	Artificial seawater		30‰	8.2	Average growth rate	Average growth rate = 0.74- 0.75 d^{-1}	72h-EC_{50} = 1.00 mg/l	Walsh *et al.*, 1987	2

Notes: N = Nominal concentration.
M_f = Measured concentration in filtered (0.45 µm) solution. M_u = Measured concentration in unfiltered solution. M = Measured concentration (not clear if solution was filtered or unfiltered).
Temp. = Temperature.
Sal. = Water salinity (given as parts per thousand (‰)).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

3.2.1.4 Toxicity to micro-organisms

Kawamura *et al.* (1986) investigated the effect of tetrabromobisphenol-A on the respiratory activity of the parasitic protozoan *Giardia lamblia*. Trophozoites of the organism were cultivated for 72 hours at 35.5°C in a growth medium. The harvested organisms were washed and suspended in a buffered sucrose solution (pH 7.4, containing 0.25 M sucrose and a protein content of 5 to 8 mg/ml). The large granule fraction was also collected (by centrifuge at 15,000 g for 20 minutes) and this was suspended in buffered sucrose solution (protein content of 1.1 to 2.3 mg/ml.

The effects of tetrabromobisphenol-A exposure on endogenous respiration of the suspended trophozoites or NADH oxidase and NADPH oxidase activities in the suspended large granule fraction was determined polarographically at 30°C over 0.5 to 1 minutes. The EC_{50} values for tetrabromobisphenol-A (the concentration required to inhibit respiratory activity by 50%) were determined to be 163 mg/l (0.30 mM) for endogeneous respiration, and 82 mg/l (0.15 mM) for both NADH oxidise activity and NADPH oxidase activity.

An activated sludge respiration inhibition test (OECD Guideline 209) has been carried out with tetrabromobisphenol-A (Wildlife International, 2002b). The substance tested was a composite sample from three tetrabromobisphenol-A suppliers and had a purity of 98.91%. The activated sludge used in the test was from a waste water treatment plant that receives mainly domestic sewage. The test was carried out at 20-22°C and the sludge used had a total suspended solids content of 3.640 mg/l and a pH of 7.8. The test was carried out as a limit test, with a single Tetrabromobisphenol-A concentration of 15 mg/l being tested in triplicate. Two controls were run and a reference substance (3,5-dichlorophenol) was also tested at concentrations of 3, 15 and 50 mg/l. The respiration rates of the two controls after 3 hours were 15.3 and 17.1 mg O_2/l/hour and the variability between the two controls (10.5%) was within the 15% limit specified in the test guidelines. The respiration rate after 3 hours in the three replicate tetrabromobisphenol-A treatments were all 15.9 mg O_2/l/hour, which was equivalent to approximately 1.9% inhibition when compared to the controls. An EC_{50} of 9.6 mg/l was determined for the 3,5-dichlorophenol reference substance which was within the normal range (5 to 30 mg/l). Overall, exposure to 15 mg/l of tetrabromobisphenol-A caused little or no effect on activated sludge respiration. As this is a reliable study, the NOEC for tetrabromobisphenol-A is therefore taken to be ≥15 mg/l.

3.2.1.5 Toxicity to sediment organisms

The available toxicity data for organisms exposed via sediment are summarised in **Table 3.61**.

3.2.1.5.1 Midge

The survival and growth of midge (*Chironomus tentans*) larvae has been studied in sediment spiked with tetrabromobisphenol-A (Springborn Laboratories, 1989c). The toxicity of tetrabromobisphenol-A to the same species was also tested via the water phase alone; these results are discussed in Section 3.2.1.2.2. For sediment, a 14-day partial life-cycle test was carried out using a flow-through system. The method used was based on the ASTM (1987) proposed guideline for conducting sediment bioassays with midge larvae and Adams *et al.* (1985).

Table 3.61 Toxicity of tetrabromobisphenol-A to freshwater sediment organisms

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested/analytical method	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Chironomus riparius	Based on OECD 218	80 (4 replicates of 20 each)	0.01% humic acid, 0.5% dolomite, 13% alpha cellulose, 10% kaolin clay and 77% quartz sand. The organic carbon content was not given but is expected to be around 5%.	63, 125, 250, 500 and 1,000 mg/kg dry weight plus control and solvent (acetone) control. The results are based on nominal concentrations but the actual concentrations at the lowest and highest exposures were determined during the study and found to be adequately maintained. The concentrations in the overlying water of the lowest and highest exposure groups were 0.203-1.92 mg/l and 0.940-9.34 mg/l respectively, and the corresponding concentrations in the interstitial (pore) water were 0.575-6.34 mg/l and 1.16-3.92 mg/l for the two treatments respectively. Analysis was by a HPLC method and the water samples were not filtered prior to analysis.	N	Well water	20°C	132	7.7-8.6	Semi-static	>5.9 mg/l	% Emerged	99% (control) and 98% (solvent control)	28d-EC_{50} = 235 mg/kg dry wt.	Wildlife International, 2005a	1
												Abnormal behav-iour	Normal	28d-NOEC = 125 mg/kg dry wt.	Wildlife International, 2005a	1
												Mean develop-ment time	13.7 days (control) and 13.3 days (solvent control)	28d-NOEC = 125 mg/kg dry wt.	Wildlife International, 2005a	1
												Mean emerg-ence ratios	0.99 (control) and 0.98 (solvent control)	28d-NOEC = 125 mg/kg dry wt.	Wildlife International, 2005a	1
												Mean develop-ment rate	0.0765 d^{-1} (control) and 0.0788 d^{-1} (solvent control)	28d-NOEC = 125 mg/kg dry wt.	Wildlife International, 2005a	1

Table 3.61 continued overleaf.

Table 3.61 continued.

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested/analytical method	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Chironomus tentans	Based on ASTM, 1987 and Adams *et al.*, 1985	50 (2 replicates of 25 each)	Mixture of natural sandy sediments - organic carbon content 0.25% and pH 5.5	15, 24, 52, 110 and 230 mg/kg dry wt. plus control and solvent (acetone) control - the corresponding interstitial water concentrations in the 5 treatments were 7.8, 26, 25, 41 and 46 µg/l and the corresponding overlying water concentrations were 8.3, 22, 23, 34 and 27 µg/. Analysis was by a ^{14}C method. The water samples were filtered (0.45 µm) before analysis.	M	Well water	22°C	27-29 mg/l	6.9-7.8	Flow	7.0-8.0	Mortality	76-92% survival in solvent control and 4-24% survival in control	14d-NOEC ≥230 mg/kg dry wt.	Springborn Laboratories, 1989c	3
												Growth (weight)	Mean wet weight was 6.7-15.6 mg in solvent control and 2.1-7.1 mg in control	14d-NOEC ≥230 mg/kg dry wt.	Springborn Laboratories, 1989c	3
		50 (2 replicates of 25 each)	Mixture of natural sandy sediments - organic carbon content 2.7% and pH 5.5	16, 31, 66, 130 and 240 mg/kg dry wt. plus control and solvent (acetone) control - the corresponding interstitial water concentrations in the 5 treatments were 7.5, 8.3, 13, 28 and 45 µg/l and the corresponding overlying water concentrations were <7.4, <7.4, 7.7, 14 and 23 µg/l. Analysis was by a ^{14}C method. The water samples were filtered (0.45 µm) before analysis.	M	Well water	22°C	27-29 mg/l	6.4-7.9	Flow	6.2-7.3 mg/l	Mortality	72-76% survival in solvent control and 8-24% survival in control[a]	14d-NOEC ≥240 mg/kg dry wt.	Springborn Laboratories, 1989c	3
												Growth (weight)	Mean wet weight was 14.7-17.0 mg in solvent control and 6.0-13.3 mg in control	14d-NOEC ≥240 mg/kg dry wt.	Springborn Laboratories, 1989c	3

Table 3.61 continued overleaf.

Table 3.61 continued.

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Chironomus tentans	Based on ASTM, 1987 and Adams *et al.*, 1985	50 (2 replicates of 25 each)	Mixture of natural sandy sediments - organic carbon content 6.8% and pH 5.4	16, 44, 66, 110 and 340 mg/kg dry wt. plus control and solvent (acetone) control - the corresponding interstitial water concentrations in the 5 treatments were 4.4, 6.0, 14, 12 and 46 µg/l and the corresponding overlying water concentrations were 0.05, 1, 2.7, 4 and 14 µg/l. Analysis was by a ^{14}C method. The water samples were filtered (0.45 µm) before analysis.	M	Well water	22°C	27-28 mg/l	6.7-8.3	Flow	5.2-6.7 mg/l	Mortality	60-76% survival in solvent control and 44-64% survival in control	14d-NOEC ≥340 mg/kg dry wt.	Springborn Laboratories, 1989c	3
												Growth (weight)	Mean wet weight was 17.6-19.5 mg in solvent control and 14.7-16.1 mg in control	14d-NOEC ≥340 mg/kg dry wt.	Springborn Laboratories, 1989c	3

Table 3.61 continued overleaf.

Table 3.61 continued.

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Hyalella azteca	Based on USEPA (2000) ASTM Standard E 1706-00 and USEPA OPPTS 850.1735	80 (8 replicates of 10 each)	Artificial sediment – organic carbon content 5.7%. Sufficient food for the entire test was added to the sediment at the start of the test.	Nominal concentrations of 63, 125, 250, 500 and 1,000 mg/kg dry weight plus control and solvent (acetone) control. The actual concentrations were verified analytically and found to be close to nominal throughout. The concentration in overlying water was <0.2 mg/l. The pore water concentrations were in the range 0.32-4.88 mg/l. The water samples were not filtered prior to analysis.	N	Well water	23°C	116-132 mg/l	7.7-8.2	Flow	≥67%	Survival	Mean survival per replicate was 8.8 (88%) in the control and 8.4 (84%) in the solvent control	28d-NOEC = 250 mg/kg dry weight	Wildlife International, 2006d	1
												Growth (weight)	Mean individual dry weight was 0.1997 mg and 0.1897 mg in the control and solvent control respectively	28d-NOEC ≥1,000 mg/kg dry weight	Wildlife International, 2006d	1

Table 3.61 continued overleaf.

Table 3.61 continued.

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Lumbriculus variegatus	ASTM E 1706-95b and USEPA OPPTS No. 850.1735	80 (8 replicates with 10 worms per replicate)	Artificial sediment - 2.5% organic carbon content and pH 8.1	90, 151, 254, 426, 715 and 1,200 mg/kg dry weight plus control - the corresponding interstitial water levels in the 90, 715 and 1,200 mg/kg treatments were 0.23-0.84 mg/l, 1.35-6.01 mg/l and 1.83-8.64 mg/l respectively - the overlying water levels in these treatments were 2.6-188 µg/l, 13.5-229 µg/l and 33.3-292 µg/l respectively. The water samples were not filtered before analysis.	M*	Well water	23°C	127-128 mg/l	6.3-8.3	Flow	>45%	Mortality/ repro.	Mean number of organisms/ replicate in control was 17.4	28d-NOEC = 90 mg/kg dry wt. 28d-EC_{50} = 294 mg/kg dry wt. (95% conf. interval 140-391 mg/kg dry wt.)	Wildlife International, 2002d	1
												Growth (dry weight)	Mean dry weight of individual worms in control was 2.48 mg	28d-NOEC ~ 254-715 mg/kg wt.	Wildlife International, 2002d	1

Table 3.61 continued overleaf.

Table 3.61 continued.

Species	Test guideline	Number of animals/ treatment	Sediment properties	Concentrations tested	N or M	Dilution water properties						Endpoint	Control response	Effect concentration	Reference	Val.
						Media	Temp.	Hard.	pH	Static/ flow	D.O.					
Lumbriculus variegatus	ASTM E 1706-95b and USEPA OPPTS No. 850.1735	80 (8 replicates with 10 worms per replicate)	Artificial sediment - 5.9% organic carbon content and pH 8.0	90, 151, 254, 426, 715 and 1,200 mg/kg dry weight plus control - the corresponding interstitial water concentrations in the 90, 715 and 1,200 mg/kg treatments were 0.46-2.93 mg/l, 1.94-7.93 mg/l and 3.09-8.85 mg/l respectively and the overlying water concentrations in these treatments were 6.7-171 µg/l, 32.6-159 µg/l and 35.0-189 µg/l respectively. The water samples were not filtered before analysis.	M*	Well water	23°C	127-128 mg/l	7.5-8.3	Flow	>49%	Mortality/ repro.	Mean number of organisms/ replicate in control was 16.8	28d-NOEC = 254 mg/kg dry wt. 28d-EC_{50} = 405 mg/kg dry weight (95% conf. interval 314-869 mg/kg dry wt.)	Wildlife International, 2002e	1
												Growth (dry weight)	Mean dry weight of individual worms in control was 2.48 mg	28d-NOEC = 254 mg/kg dry weight	Wildlife International, 2002e	1

Notes: a) A contaminant worm species was found in the control sediment at termination of the test.
N = Nominal concentration.
M = Measured concentration.
M* = The sediment concentrations given are nominal values but analytical measurements showed that the actual concentration was >80% of the nominal value.
Temp. = Temperature.
Hard. = Water hardness (given as mg $CaCO_3$/l).
D.O. = Dissolved oxygen (given as mg O_2/l or % saturation).
Val. = Validity rating (see Section 3.2.1): 1) Valid without restriction; 2) Use with care; 3) Not valid 4); Not assignable.

The substance tested was a composite sample of tetrabromobisphenol-A from five producers, along with ^{14}C-labelled tetrabromobisphenol-A. The substance was stated to have a purity of 99.15% (related to active ingredient) and the ^{14}C-labelled tetrabromobisphenol-A had a radiopurity of 96.0%. Stock solutions of the test substance were made up in acetone. The substance was then spiked onto the sediment by adding 20 ml of the acetone solution to 0.38 kg of wet sediment and then mixing the sediment for 10-15 minutes. After mixing, the sediment was divided in to two replicate vessels and dilution water (well water) was passed through the vessels at a rate of seven volume additions/day (90% replacement time was seven hours) for 4-5 days prior to addition of the test organisms. Replicate acetone control sediments were prepared in the same way. The sediment depth in the exposure vessel was approximately 5 cm, with around 1 litre of overlying water and the temperature was maintained at 22^{o}C.

Three sediments were used in the test. These were produced by mixing two different natural stream sediments (one was rich in organic debris and the other was predominantly sandy in nature) to give sediments with the desired organic carbon contents. The three test sediments had total organic carbon contents of 0.25% (low organic sediment), 2.7% (middle organic sediment) and 6.8% (high organic sediment) respectively and were all slightly acidic (pH 5.4-5.5) and sandy (92-94% sand, 1-6% silt and 2-6% clay) in nature.

The organisms used in the test were 2nd instar larvae (approximately 9-11 day old) and two replicates of 25 organisms each were used for each treatment and control group. During the test the organisms were fed once-daily with a suspension of dry fish food. Gentle aeration was used in each test vessel in order to maintain the dissolved oxygen level at >60% of saturation. Water column and interstitial water samples were collected on days 0, 3, 7, 10 and 14 of the test, and sediment samples were taken on days 0 and 14 of the test. The concentration of tetrabromobisphenol-A in these samples was determined by a radiochemical method (the water samples were filtered (0.45 µm) prior to analysis). The nominal sediment concentrations used were 13, 25, 50, 100 and 200 mg/kg dry weight. The mean sediment concentrations measured during the test were 15, 24, 53, 110 and 230 mg/kg dry weight in the low organic sediment, 16, 31, 66, 130 and 240 mg/kg dry weight in the middle organic sediment and 16, 44, 66, 110 and 340 mg/kg dry weight in the high organic sediment. The concentrations in interstitial pore water and overlying water were found to increase with increasing sediment concentration and were 7.8 to 46 µg/l and 8.3 to 27 µg/l respectively in the low organic sediment, 7.5 to 45 µg/l and <7.4 to 23 µg/l respectively in the middle organic sediment and 4.4 to 46 µg/l and 0.05 to 14 µg/l in the high organic sediment. The measured exposure concentrations were found to be relatively constant throughout the exposure period indicating that equilibrium between the sediment and water was maintained, and that the flow-through system resulted in a negligible loss of test substance from the system.

The survival of the control organisms in the study was variable. In the low organic sediment, the solvent control survival was 76% and 92% in the two replicates but survival of the control (no acetone) population was only 4% and 24% in the two replicates. Similarly in the middle organic sediment survival was 72 and 76% in the solvent control replicates and 8 and 24% in the control replicates (the study indicates that an oligochaete worm species was present in the control sediments in this case). Finally survival was 60% and 76% in the solvent control replicates and 44% and 64% in the control replicates in the high organic sediment. Although the actual reason for the poor and variable control response in the study is unknown, one possible explanation given in the paper is that the midges may have been more stressed in the

sediments with the lower organic carbon contents as it was observed during the test that the daily food ration added was partially washed out of the system due to the flow-through water supply, and that the high organic carbon sediment may have acted as a better food source than the lower organic carbon sediments. As a result of the control response, all treatment populations were statistically compared (at the 95% confidence level) with the solvent control populations.

The survival of the exposed populations was 64-96% in the low organic sediment, 44-88% in the middle organic sediment and 56-76% in the high organic sediment. These survival rates were not significantly different from the solvent control populations and so the NOEC for survival was determined to be the highest concentration tested. Similarly, the mean wet weights of the exposed organisms (10.7-20.4 mg in the low organic sediment, 11.7-20.0 mg in the medium organic sediment and 18.6-22.1 mg in the high organic sediment) were not significantly different from the solvent control populations (6.7-15.6 mg in the low organic sediment, 14.7-17.0 mg in the middle organic sediment and 17.6-19.5 mg in the high organic sediment). Thus the NOEC for growth was determined to be the highest concentration tested.

In this study, the poor survival in the control population, and in some of the solvent control populations, means that the significance of the survival data is uncertain. Also, given that there may have been problems with the feeding in the study, the growth data are also likely to be uncertain. When this species was tested in water alone (see Section 3.2.1.2.2) effects on growth were seen at all concentrations tested. However, the lowest concentration tested in water-phase study (66 µg/l) is higher than the pore water and overlying water concentrations found in this sediment study, which may explain the lack of effects seen. A further complication is that the food used in this study did not contain tetrabromobisphenol-A. Uptake from food may be an important route of exposure for tetrabromobisphenol-A that may not have been adequately addressed in this study.

A further sediment toxicity test with midge (*Chironomus riparius*) has recently been completed (Wildlife International, 2005a). In this test the substance tested was a composite sample of tetrabromobisphenol-A from three producers that had a purity of 99.2%. Stock solutions of the test substance were made up in acetone and the substance was spiked onto the sediment by initially adding 15 ml of the appropriate stock solution to 150 g of dry sediment, mixing and allowing the solvent to evaporate. This spiked portion of the sediment was then mixed with 700 g of dry sediment for ¾ hour and then finally with a further 650 g of dry sediment for 64 hours.

The sediment used in the study was an artificial sediment consisting of 0.01% humic acid, 0.5% dolomite, 13% alpha cellulose (used as a standardised source of organic carbon), 10% kaolin clay and 77% industrial quartz sand. The actual organic carbon content of the final sediment was not given in the test report but, by comparison with the sediments used for the tests with *Lumbriculus variegatus* (see Section 3.2.1.5.2), the organic carbon content would have been around 5%.

Four replicate test chambers were prepared for each treatment level and the control and solvent (acetone) control (additional replicate test chambers were prepared for analytical determination and water quality monitoring). Each test chamber consisted of a 2,000 ml glass beaker containing sediment to a depth of 2 cm and water to a depth of 8 cm above the sediment level. Sufficient food for the entire test duration (280 mg of fish flake food) was mixed into the dry sediment prior to adding the overlying water. Once the overlying water

was added, the system was allowed to equilibrate for 49 hours prior to addition of the test organisms. No further feeding was carried out during the course of the test. A pre-study had found that this amount of food was adequate for the survival of the control population without further supplementary feeding during the test, or complications resulting from ammonia formation during the test (Wildlife International, 2005b).

The organisms used in the test were first instar (1-4 day old) and a total of 80 organisms per treatment (four replicates of 20 organisms each) was used. The test was carried out using a semi-static method whereby the overlying water was partially renewed three times per week. Gentle aeration was used in each test vessel in order to maintain the dissolved oxygen level at >60% of saturation. The nominal tetrabromobisphenol-A sediment concentrations tested were 63, 125, 250, 500 and 1,000 mg/kg dry weight. Sediment, water column and interstitial water samples were collected on days 0, 7 and 28 of the test from the highest and lowest treatment levels, the controls and the solvent controls for determination of the actual concentration of tetrabromobisphenol-A present. The water samples do not appear to have been filtered prior to analysis and so probably represent total (i.e. dissolved phase plus particulate phase) concentrations. For the highest concentration tested (1,000 mg/kg dry weight nominal) the measured concentration in the sediment was around 91.5% of nominal at day 0, 75.6% of nominal at day 7 and 69.8% of nominal at day 28. For the lowest concentration tested (63 mg/kg dry weight nominal) the measured concentration in the sediment was 75.7% of nominal at day 0, 106% of nominal at day 7 and 117% of nominal at day 28. Based on these results it appears that the actual concentration present in the sediment was reasonably close to the nominal value throughout the test (particularly at the lower concentrations). The concentration of tetrabromobisphenol-A in the overlying water tended to show a decreasing trend over the course of the study (1.92, 1.05 and 0.2 mg/l at days 0, 7 and 28 in the 63 mg/kg dry weight treatment and 9.34, 5.01 and 0.94 mg/l at days 0, 7 and 28 in the 1,000 mg/kg treatment) whereas the interstitial pore water concentrations paralleled the sediment concentrations and remained reasonably constant throughout the test (pore water concentrations were 6.34, 0.575 and 0.704 mg/l at days 0, 7 and 28 in the 63 mg/kg dry weight treatment and 3.92, 1.16 and 2.61 mg/l in the 1,000 mg/kg dry weight treatment). As noted above the water samples do not appear to have been filtered prior to analysis and so a small amount of contamination by the particulate phase may have occurred during sampling which may explain some of the erratic results obtained. Overall it can be concluded that the concentration of tetrabromobisphenol-A was adequately maintained throughout the test.

As well as the levels of tetrabromobisphenol-A, the levels of ammonia were also monitored throughout the test as ammonia production is known to be a potential problem in sediment tests carried out without supplementary feeding. These results generally showed the level of ammonia to be below the detection limit (<0.017 mg/l). Higher levels were present in some replicates on day 7 (i.e. 0.290, 0.0591 and 0.0433 mg/l in the solvent control, the 63 mg/kg dry weight and the 125 mg/kg dry weight treatments respectively) but these were back to below the detection limit on day 28 (and the solvent control response was similar to the control response). Therefore it can be concluded that no adverse effects from the formation of ammonia are likely to have occurred in this study.

The endpoints determined in the study included a visual inspection of abnormal behaviour (e.g. leaving the sediment, unusual swimming), mean development time, percentage emergence, emergence ratio and development rates. No statistically significant difference ($p=0.05$) was seen between the control and solvent control population for any endpoint and so the pooled control population was used for the comparison with the treatment groups. The

performance of the control groups met the criteria for a valid study (the percentage emergence of the control and solvent control was 99% and 98% respectively and the mean development time was 13.7 days and 13.3 days respectively).

Treatment related effects were noted for a number of endpoints. Abnormal behaviour (leaving the sediment and climbing on the walls of the test chamber) was apparent in the 250, 500 and 1,000 mg/kg dry weight treatment groups compared with the control groups. The NOEC for this endpoint was taken as 125 mg/kg dry weight.

The mean development time was 14.0, 14.6, 18.3, 20.6 and 21.0 days in the 63, 125, 250, 500 and 1,000 mg/kg treatment groups respectively and these were statistically significantly (p=0.05) different from the control group at 250 mg/kg dry weight and above. The NOEC for mean development time was therefore 125 mg/kg dry weight.

The mean emergence ratios (ratio of number of emerged to the number of larvae introduced) were 0.99 and 0.98 in the control and solvent control and 0.90, 0.89, 0.56, 0.08 and 0.01 in the 63, 125, 250, 500 and 1,000 mg/kg dry weight treatment groups respectively. The emergence rates were statistically significantly different (p=0.05) from the control group at a concentration of 250 mg/kg dry weight and above. The NOEC of emergence ratio was therefore 125 mg/kg dry weight. An EC_{50} of 235 mg/kg dry weight was also derived based on the emergence of midges

The mean development rate (the portion of larval development that took place per day) was 0.0765 and 0.0788 d^{-1} in the control and solvent control and 0.0756, 0.0715, 0.0577, 0.0501 and 0.0488 d^{-1} in the 63, 125, 250, 500 and 1,000 mg/kg treatment groups respectively. The mean development rates were statistically significantly different (p=0.05) from the control group at a concentration of 250 mg/kg dry weight and above. The NOEC of mean development rate was therefore 125 mg/kg dry weight.

Overall the NOEC from this study was 125 mg/kg dry weight. The study is considered to be of good quality.

3.2.1.5.2 Oligochaete

Prolonged sediment toxicity tests with tetrabromobisphenol-A have been carried out with the oligochaete *Lumbriculus variegatus* using a flow-through test system with sediments of 2.5% organic carbon content (Wildlife International, 2002d) and 5.9% organic carbon content (Wildlife International, 2002e). The test protocol was based on the ASTM E 1706-95b Guideline and USEPA Series 850 Ecological Effects Test Guidelines OPPTS No. 850.1735.

The sediment used in the test was an artificial sediment consisting of 0.01% humic acid, 0.5% dolomite and either 5% alpha-cellulose, 14% kaolin clay and 80% industrial quartz sand (for the 2.5% organic carbon content sediment) or 16% alpha-cellulose, 10% kaolin clay and 74% industrial quartz sand (for the 5.9% organic carbon content sediment). The alpha-cellulose acted as the source of organic matter in the sediment. The sediments had a pH of 8.0-8.1.

The test substance was a composite sample from three manufacturers and had a purity of 98.91%. The test substance was added directly to a suitable amount of dry sediment and then mixed until the sample was homogeneous (approximately 65 hours for the 5.9% organic carbon sediment). After mixing, 100 ml of the spiked sediment was placed in 300 ml glass

beakers and placed into diluter tanks and overlying water (approximately 100-150 ml of moderately hard (127-128 mg/l as $CaCO_3$) well water that was filtered to 0.45 µm to remove microorganisms and particles) was allowed to flow through the test system. The flow-rate through the system provided approximately 12 volume additions of water per day and the representative depth of water in the test beakers was 3.9-4.2 cm (each test beaker contained approximately 100-150 ml of overlying water). The system was allowed to equilibrate for approximately 48 hours prior to addition of the test organisms. The total exposure period was 28 days.

The nominal concentrations tested in the studies were 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight, plus a control group. Each treatment and control group was replicated eight times with ten oligochaetes per replicate. Additional replicates were also run in each treatment and control group for analytical sampling of water and sediment.

The temperature was maintained at 23±2^{o}C during the tests. In both tests, the dissolved oxygen levels fell below 60% of saturation in some treatment groups. This occurred on days 4 and 6 in the 2.5% organic carbon content sediment (minimum dissolved oxygen concentration reached was 3.8 mg/l or 45% of saturation) and on day 7 of the test in the 5.9% organic carbon content sediment (minimum dissolved oxygen concentration reached was 4.2 mg/l or 49% of saturation). Gentle aeration of the overlying water was then introduced into both tests for the remainder of the duration of the study and the dissolved oxygen concentrations remained >60% of saturation for the remainder of the study. The overlying water was clear and colourless at the start of the tests but at test termination appeared slightly cloudy and colourless in all test treatments. The pH of the overlying water was in the range 6.8-8.3 in the test with the 2.5% organic carbon content sediment and 7.5-8.3 in the test with the 5.9% organic carbon content sediment.

The organisms were fed salmon starter during the tests. A 20 mg aliquot of food was added to each test compartment every three days during the tests. The food was not spiked with tetrabromobisphenol-A. The Technical Guidance Document indicates that for highly adsorptive substances such as tetrabromobisphenol-A (log Kow 5.9), food could be an important exposure pathway in this type of sediment toxicity test, and recommends that the test method used should try to ensure that exposure via this route cannot be avoided in the test. In this case, tetrabromobisphenol-A would only be present in food if sufficient time for uptake into the food from the test medium occurred before the food was eaten, and so it is possible that this route of exposure (and hence toxicity) was not fully covered in the test. However, given that the results obtained can be best explained by equilibrium partitioning (see later), the actual significance of this route of exposure for tetrabromobisphenol-A is unclear.

The endpoints investigated in the studies were survival/reproduction (as measured by the total number of organisms present, which is a combination of parent survival and reproduction) and growth (as determined by dry weight of organisms). In addition, the test chambers were observed at least three times per week to determine the number of individuals exhibiting signs of toxicity or abnormal behaviour (qualitative observations).

In the experiment with the 2.5% organic carbon content sediment, mortality was noted during the test in the 245, 426, 715 and 1,200 mg/kg treatment groups. There was a general trend for greater numbers of oligochaetes to be found out of the sediments in the treatment groups compared with control. Based on the cumulative total of qualitative observations during the

14 observation periods in the test, a total of 193, 618, 447, 448, 657, 419 and 517 oligochaetes were found out of the sediments in the control, 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight treatment groups respectively. The interpretation of these findings is difficult owing to the qualitative nature of the observations and also to the fact that the total number of organisms in each treatment group varies during the test as a result of both reproduction and mortality.

The mean number of worms present at test termination in the 2.5% organic carbon content sediment was 17.4 in the control group (indicating the reproduction had occurred) and 12.3, 10.5, 9.9, 3.6, 5.9 and 1.3 in the 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight treatment groups respectively. These reductions in numbers were statistically significant (p=0.05) compared with the control group at concentrations of 151 mg/kg dry weight and above. The NOEC for mean numbers of worms was therefore 90 mg/kg dry weight. The EC_{50} was determined to be 294 mg/kg dry weight.

The average individual dry weight of surviving worms in the 2.5% organic carbon content sediment was 2.48 mg in the control group and 2.22, 2.10, 2.01, 1.34, 1.90 and 1.04 in the 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight treatment groups respectively. The reduction in mean dry weight was statistically significant compared with the control group at concentrations of 426 and 1,200 mg/kg dry weight only. Thus no clear NOEC/LOEC could be determined for this endpoint owing to the poor dose-response seen. It should be noted that the mean weights depend on the relative proportion of young/adults in each treatment group, and could also be influenced by the total number of worms present (e.g. the more worms present in a replicate the less food is potentially available for each worm), and so it does not necessarily follow that a simple dose-response will always be obtained for this endpoint.

In the test with the 5.9% organic carbon content sediment, mortality was seen in the 254, 426, 715 and 1,200 mg/kg dry weight treatment groups, and some oligochaetes were again observed leaving the sediment. The cumulative numbers of oligochaetes seen out of the sediment over the 14 observation periods during the test were 145 in the control group, and 204, 47, 231, 96, 158 and 168 in the 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight treatment groups. In this case no clear trend was seen in the number of oligochaetes leaving the sediment and the effects do not appear to be treatment-related.

The mean number of worms present at test termination in the 5.9% organic carbon content sediment was 16.8 in the control group (indicating the reproduction had occurred) and 13.3, 17.5, 12.0, 7.9, 7.4 and 5.5 in the 90, 151, 254, 426, 715 and 1,200 mg/kg dry weight treatment groups respectively. These reductions in numbers were statistically significant (p=0.05) compared with the control group in the 426, 715 and 1,200 mg/kg treatment groups. The NOEC for mean numbers of worms was therefore 254 mg/kg dry weight. The EC_{50} was determined to be 405 mg/kg dry weight.

The average individual dry weight of surviving worms in the 5.9% organic carbon content sediment was 1.76 mg in the control group and 1.66, 1.55, 2.18, 1.14, 1.14 and 1.03 in the 90, 151, 254, 426, 715 and 1,200 mg/kg treatment groups respectively. The reduction in mean dry weight was statistically significant compared with the control group at concentrations of 426, 715 and 1,200 mg/kg dry and the NOEC for this endpoint was determined as 254 mg/kg dry weight.

The overall NOECs from the two studies are therefore 90 mg/kg dry weight in the 2.5% organic carbon content sediment and 254 mg/kg dry weight in the 5.9% organic carbon content sediment, both based on the nominal exposure concentration. In addition, oligochaetes were observed leaving the sediment during the test. These observations, although qualitative in nature, appeared to be treatment-related in the 2.5% organic carbon content sediment but were not treatment-related in the 5.9% organic carbon content sediment. The effect of organisms leaving the sediment could be considered to be an ecologically relevant endpoint as it could theoretically lead to increased predation of the oligochaetes. However, the nature of the observations means that it is not possible to determine if this effect was statistically significant in the 2.5% organic carbon content sediment.

During the studies with *Lumbriculus variegatus*, the concentrations of tetrabromobisphenol-A present in the sediment, overlying water and pore water phases of the test medium were determined analytically. These results are shown in **Table 3.62** and show that the concentrations of tetrabromobisphenol-A present in the sediment remained relatively constant throughout the test and were generally very close to the nominal concentrations. The concentrations measured in the overlying water and pore water of the sediment are somewhat variable.

Table 3.62 Measured concentration of tetrabromobisphenol-A during the toxicity test with *Lumbriculus variegatus*

Treatment - nominal sediment concentration (mg/kg dry wt.)	Sampling time	2.5% organic carbon sediment			5.9% organic carbon sediment		
		Dry sediment (mg/kg)	Overlying water (µg/l)	Pore water (mg/l)	Dry sediment (mg/kg)	Overlying water (µg/l)	Pore water (mg/l)
Control	Day 0	<16.7	<5	<0.005	<20.2	<5	<0.005
	Day 7	<16.7	<5	<0.005	<20.2	<5	<0.005
	Day 28	<16.7	<5	<0.005	<20.2	<5	<0.005
90	Day 0	92.7-99.9	148-188	0.71-0.84	77.7-86.9	139-171	2.39-2.93
	Day 7	94.9-110	2.6-37.7	0.41-0.62	86.0-93.1	29.3-35.6	0.90-0.95
	Day 28	75.7-82.4	18.5-62.8	0.23-0.24	79.1-80.1	6.7-9.4	0.46-0.61
	Mean[a]	92.6±12.3	80±70	0.51±0.25	83.8±5.9	65±71	1.37±1.03
715	Day 0	674-725	101-146	3.90-6.01	676-687	131-159	5.99-7.47
	Day 7	650-658	13.5-22.9	3.19-3.91	708-848	33.8-40.6	1.94-1.97
	Day 28	605-633	116-229	1.35-1.89	671-804	32.6-39.7	3.76-7.93
	Mean[a]	658±41	105±80	3.38±1.66	732±75	73±57	4.84±2.67
1,200	Day 0	1,138-1,200	71.0-113	6.73-8.64	1,240-1,409	186-189	6.76-8.82
	Day 7	1,102-1,239	33.3-292	3.10-3.14	1,144-1,186	35.0-39.9	3.09-3.35
	Day 28	1,051-1,105	96.0-124	1.83-3.56	1,111-1,204	47.4-50.7	4.25-8.85
	Mean[a]	1,139±69	122±90	4.50±2.61	1,216±105	91±75	5.85±2.65

Note: a) Mean value ± standard deviation.

The samples were not filtered prior to analysis (although the pore water was separated from the bulk sediment by centrifugation for five minutes at 2,000 rpm) and so the results may be affected by the presence of particulate-bound substance in the water samples. The results of

the water samples also appear to be slightly contradictory as the highest concentrations in the overlying water samples appear to be present in the test with the 2.5% organic carbon sediment (as would be expected), but the highest pore water concentrations appear to be present in the test with the 5.9% organic carbon sediment. This latter finding would suggest that the pore water data may be influenced by the presence of particulate-bound substance in the sample.

3.2.1.5.3 *Hyalella azteca*

A toxicity test using the amphipod *Hyalella azteca* has been carried out using tetrabromobisphenol-A (Wildlife International, 2006d). The substance tested was a composite sample from three suppliers of tetrabromobisphenol-A, and had a purity of 99.2%. The sediment used in the test was an artificial sediment consisting of approximately 0.01% humic acid, 0.5% dolomite, 13% alpha cellulose (used as the source of organic carbon), 10% kaolin clay and 77% industrial quartz sand (all percentages are based on the dry sediment weight). The organic carbon content of the sediment was 5.7%.

The test substance was added to the sediment as a solution in acetone. Firstly, 15 ml of a stock solution of tetrabromobisphenol-A solution was added to 150 g of dry sediment, mixed, and the acetone allowed to evaporate. This spiked sediment was mixed into a further 700 g of dry sediment for one hour, and this was mixed with a further 650 g of dry sediment for approximately 70 hours. A solvent control sediment was prepared in the same manner using pure acetone, and a negative control was prepared by mixing unspiked sediment for around 70 hours.

The test system used was a flow-through system where supplementary feeding was avoided. Each test chamber consisted of 100 ml of dry sediment in a 300 ml beaker. The food used in the test was 28 ml of yeast, cereal grass media and trout chow and this was mixed into the dry sediment prior to the start of the test (this ration was sufficient for the entire 28-day test period). Water was then allowed to flow through the test chamber (each chamber contained around 150 ml of overlying water and the flow-through rate was approximately two volume additions per day). The system was allowed to equilibrate for 50 hours prior to introduction of the organisms (start of the test). Under these conditions the depth of sediment and overlying water in the test chambers was approximately 3.4 cm and 5.8 cm respectively. Five nominal test concentrations were used (63, 125, 250, 500 and 1,000 mg/kg dry weight) along with a solvent control and negative control group, and a total of eight replicates of ten amphipods each were used (giving the total number of organisms used as 80 per treatment group). Additional replicates were used for measurement of the actual exposure concentrations (sediment, pore water and overlying water) at day 0, day 7 and day 28.

The water used in the test was well water with a hardness of 116-132 mg/l as $CaCO_2$. Throughout the test the temperature was maintained at 23°C, the pH range between 7.7 and 8.2 and the dissolved oxygen concentration was ≥67% of saturation. The ammonia concentration in the water was also monitored during the test and was always <0.17 mg/l (the lowest concentration that could be detected with the analytical method used).

The measured concentrations in sediment were found to be both stable and close to the nominal values throughout the test (for example the measured concentrations at day 28 were 65.7, 133, 218, 539 and 1,183 mg/kg dry weight in the nominal 63, 125, 250, 500 and 1,000 mg/kg dry weight treatments respectively, and the measured concentrations were between

82.8 and 118% of nominal at all sampling times) and so the nominal concentrations were used to determine the NOEC. The concentration in overlying water was below the quantitation limit of the analytical method used (0.2 mg/l) in all treatment groups and all sampling times. The concentrations found in the pore water showed a decreasing trend with time (4.88, 2.97, 2.67, 3.02 and 2.96 mg/l at day 0, 2.03, 0.91, 0.73, 0.85 and 0.86 mg/l at day 7 and 0.67, 0.33, 0.32, 0.38 and 0.46 mg/l at day 28 for the five nominal treatment groups respectively).

The endpoints monitored in the study were survival and growth (dry weight of organisms). The mean number of amphipods per replicate in the negative control and the solvent control groups were 8.8 and 8.4 respectively (i.e. 88% and 84% survival). The mean number of survivors in the tetrabromobisphenol-A treatments were 8.9, 8.6, 8.0, 5.9 and 5.9 for the 63, 125, 250, 500 and 1,000 mg/kg dry weight groups respectively. The survival at 500 and 1,000 mg/kg dry weight was found to be statistically significantly (p=0.05) reduced compared to the pooled control population. For the growth endpoint, the mean individual dry weight at the start of the test was 0.075 mg. The average individual dry weight at the end of the test was 0.1997 and 0.1891 mg in the negative control and solvent control respectively, and 0.2641, 0.1629, 0.1950, 0.2011 and 0.1937 mg in the 63, 125, 250, 500 and 1,000 mg/kg dry weight treatment groups respectively. No statistically significant differences (p=0.05) were found in the individual dry weights between any treatment group and the pooled control group.

Overall the NOEC and LOEC from this study were determined as 250 and 500 mg/kg dry weight respectively based on the survival endpoint.

3.2.1.6 Endocrine activity

In addition to the growth and reproduction studies discussed earlier, some studies have specifically investigated the possible effects of tetrabromobisphenol-A on the endocrine system in aquatic organisms. These studies are reported in the following Sections.

3.2.1.6.1 Fish

Christiansen *et al.* (2000) investigated the *in vivo* vitellogenin induction in rainbow trout (*Oncorhynchus mykiss*) following intraperitoneal injection of several bisphenol-A derivatives, including tetrabromobisphenol-A. Immature rainbow trout (80-120 g) were used in the test and were held in running fresh-water at 11-14^{o}C for 1 week prior to the start of the test. The compounds tested included bisphenol-A, bisphenol-A dimethacrylate and tetrabromobisphenol-A and each chemical was dissolved in dimethyl sulphoxide and administered at concentrations of 50 mg/kg body weight to groups of 10 fish/treatment. A positive control group was administered 17ß-estradiol (1 mg/kg body weight) dissolved in corn oil. In addition vehicle control groups were also run for the two solvents used. The total exposure period was 18 days, and the test substances were administered on days 0, 6 and 12 of the experiment. Blood was sampled prior to each injection of the test substance and on day 18 of the test, and was analysed for the level of vitellogenin using a direct sandwich enzyme-linked immunosorbant assay (ELISA). The experimental detection limit of the method used was 100 ng vitellogenin/ml blood plasma.

Neither of the solvent vehicles used produced a significant response (p=0.05) when comparing the pre-exposure level of vitellogenin with the level found at the end of the exposure. The positive control caused an increase in the mean (± standard deviation) plasma

vitellogenin from 109±12.9 ng/ml at the start of the test to $2.03\times10^{7}\pm2.6\times10^{6}$ ng/ml at day 18. Both bisphenol-A and bisphenol-A methacrylate were found to cause a significant (p=0.001) increase in plasma vitellogenin concentrations, reaching mean (± standard deviation) levels of 66,000±59,000 ng/ml (range ~70-482,000 ng/ml) with bisphenol-A and 14,000±7,000 ng/ml (range 900-53,000 ng/ml) for bisphenol-A methacrylate. In contrast to these results, no statistically significant (p=0.05) induction of plasma vitellogenin was seen with tetrabromobisphenol-A. A repeat experiment using tetrabromobisphenol-A dissolved in peanut oil lead to the same conclusions.

The authors indicated that the results for tetrabromobisphenol-A fitted in with a general pattern that is emerging amongst phenolic compounds (such as alkyl phenols and hydroxylated congeners of polychlorinated biphenyls) in that a sterically unhindered hydroxyl group is required for the substance to show estrogenic activity. This requirement may not be fulfilled for tetrabromobisphenol-A as it has two bromine groups *ortho* to the phenolic hydroxyl group.

The results of a screening study of the effects of tetrabromobisphenol-A on selected biomarkers in juvenile rainbow trout (*Oncorhynchus mykiss*) have been reported (Ronisz *et al.*, 2001; Ronisz *et al.*, 2004). The fish were injected with tetrabromobisphenol-A dissolved in peanut oil at a concentration of 0.1, 1, 10, 50, 100 or 500 mg/kg and the effects on several biomarkers were determined after 1, 4, 14 and 28 days. The biomarkers investigated included ethoxyresorufin-*O*-deethylase (EROD) activity of the enzyme CYPIA, glutathione-S-transferase activity, glutathione reductase and catalase activity, liver somatic index, formation of DNA adducts and the induction of vitellogenin in blood plasma of male fish.

The EROD activity was found to be significantly inhibited after 4 days at doses of 100 and 500 mg/kg (the fish exposed to 500 mg/kg had trouble keeping their balance and so 100 mg/kg was used as the highest dose in the longer experiments), but no effects on EROD activity were found at 14 and 28 days. Ronisz *et al.* (2004) also showed that tetrabromobisphenol-A could inhibit EROD activity in the liver microsomal fraction *in vitro*, although the exact mechanism was unclear (it was thought that this was possibly through competition with ethoxyresorufin). The glutathione reductase activity was found to decrease after 1 day at 100 mg/kg but it was significantly increased after 4, 14 and 28 days at the same dose level. There was no evidence of elevated levels of vitellogenin in the blood from exposed fish, and no effects were seen on the other biomarker endpoints considered.

Ronisz *et al.* (2004) indicated that induction of glutathione reductase activity is a sensitive biomarker for oxidative stress in fish in laboratory studies, and the results obtained for tetrabromobisphenol-A could indicate a possible oxidative stress-inducing activity of tetrabromobisphenol-A, but that more studies would be needed in order to investigate this possible activity further.

A similar series of experiments were carried out with the marine fish eelpout (*Zoarces viviparous*) (Ronisz *et al.* (2004). The biomarkers investigated were the same as for rainbow trout above with the exception of the levels of vitellogenin in blood plasma. The fish were given a single dose of tetrabromobisphenol-A (100 mg/kg) and the effects on the various biomarkers were examined after five days. No effects were seen on any of the endpoints investigated in this study.

Shi *et al.* (2005) has recently carried out further experiments investigating the role of tetrabromobisphenol-A exposure in inducing oxidative stress in fish. In this study, goldfish (*Carassius auratus*) of weight 25-35 g were injected intraperitoneally with 0.4-0.6 ml of a solution of tetrabromobisphenol-A dissolved in oil. Two series of experiments were carried out. In the first experiment, fish received a single dose of tetrabromobisphenol-A of 100 mg/kg and the effects on the fish were determined between 3 hours and 28 days. In the second series, a single dose of between 0 and 300 mg/kg was used and the effects on the fish were investigated after 24 hours. At each sampling point, six fish per treatment group were analysed. Reactive oxidative substances (ROS) present in the liver and bile of fish were trapped by phenyl-tert-butyl nitrone and then analysed by electron paramagnetic resonance. Two indicators of oxidative damage of macromolecules induced by ROS were also determined. These were the protein carbon (PCO) and lipid peroxidation product (LPO) contents of the liver.

Tetrabromobisphenol-A exposure was found to significantly induce ROS production starting 12 hours after administering a single dose. The maximum ROS production occurred around 24 hours after dosing and thereafter decreased. The ROS levels in liver were generally slightly higher than in bile. The increase in ROS production was also found to be dose-dependent. The main ROS induced by exposure to tetrabromobisphenol-A was identified as the hydroxyl radical. Exposure to tetrabromobisphenol-A was also found to result in increased PCO content (starting 24 hours after dosing) and LPO content (starting 3 days after dosing). The PCO and LPO contents reached a maximum around 3 days and 5 days respectively after dosing, whereafter the levels showed a decreasing trend. **The study concluded that exposure to tetrabromobisphenol-A can induce hydroxyl radical production and this may lead to oxidative damage in liver.**

Tetrabromobisphenol-A is currently being studied further for possible *in vitro* and *in vivo* endocrine disrupting effects in the EU FIRE project being carried out by the Cluster of Research into Endocrine Disruption in Europe (CREDO, 2005). Full details of some of these studies are not yet available but it is known that partial life cycle reproduction studies with zebrafish (*Brachydanio rerio*) and flounder (*Platichthys flesus*) have been carried out. A progress report on the studies is given in a newsletter outlining the Fire project progress for the period up to November 2004 (Fire, 2004). Below is a brief summary of the findings so far from the *in vitro* studies taken from this newsletter, papers in press and the available extended abstracts of the work (some of the studies with mammalian systems are described in Section 3.2.4.3). The *in vitro* assays were carried out using human, rat and fish cell lines and included endpoints such as (ant)agonism of estrogen-receptor, (ant)agonism of androgen receptor, (ant)agonism of progesterone receptor, (ant)agonsim of dioxin-receptor, capacity to displace thyroxine (T4) from its plasma carrier protein transthyretin (TTR), triiodothyronine (T3) mimicking and inhibiting capacity, vitellogenin induction, androgen synthesis, aromatase activity, estrogen sulfotransferase (E2-SULT) activity, CYP1A1 activity, CYP3A4 activity and cytotoxicity (MTT and LDH assays) (Fire, 2004 and Hamers, 2006a and 2006b). Based on the results of these screening tests tetrabromobisphenol-A was determined to have a high TTR-binding affinity and a high E2-SULT inhibiting potency and it was decided to investigate the endocrine disrupting effects further in *in vivo* tests.

The results of the *in vivo* tests with zebrafish have recently become available (Kuiper *et al.*, 2007; a summary of the results is also reported in Wester *et al.*, 2006). The test was a partial life-cycle test consisting of a thirty day adult exposure followed by exposure of the offspring until the juvenile stage (47 days posthatch). The endpoints measured in the study included

egg production and fertilization (reproductive endpoints), development and mortality. In addition, whole body sections of both adults and offspring were examined histologically for effects on reproductive and endocrine target organs.

The substance used in the test had a purity of 99.17% and was a composite mixture of technical products from several EU suppliers of the substance. The test system used was a semi-static system (water renewal every 3-4 days) with continuous aeration. The water used was standard formulated water and had a pH of 7.2-8.4. The temperature was maintained at 27±2°C during the test and the dissolved oxygen concentration was > 5 mg/l.

The test substance was added to the water as a solution in dimethyl sulphoxide (DMSO). The concentration of DMSO present in the exposure solutions was 0.01% and a solvent control was also run at this level. A total of nine exposure concentrations were used. The nominal concentrations were 0.023, 0.047, 0.094, 0.188 0.375, 0.750, 1.50, 3.00 and 6.00 μM (equivalent to 0.013, 0.026, 0.051, 0.102, 0.204, 0.408, 0.816, 1.63 and 3.26 mg/l). A single group of three males and three females were exposed at each treatment level. The solvent control group consisted of duplicate groups of three males and three females. Males were kept separate from females inside a nylon mesh net. Both sexes were placed inside the net for 24 hours and reproduction was monitored one day after each water renewal.

Water samples were collected for analysis of the exposure concentrations at the end of week four of the experiment (immediately after renewal) and at the end of week 5 (immediately before renewal). Water samples were also collected from two aquaria under identical conditions but without fish, at 0, 72 hours and 96 hours after renewal.

During weeks 4 and 5 of the adult exposure, replicate groups of 50 fertilized eggs per treatment (or less in cases where insufficient eggs were available) were placed in 10-cm glass Petri dishes containing 60 ml of the test solution. Renewal of the test solution was carried out twice weekly. From day 1 to day 14 post-hatch, the larvae were fed with fresh rotifer suspension daily. Starting at day 7 post-hatch the larvae were also fed with newly hatched *Artemia* nauplii twice daily. At day 15 post-hatch, the larvae were transferred to glass aquaria similar to those used for the adult exposure (containing 1.5 l of water per 50 animals, this was increased to 3 l of water at day 21 post-hatch). Water samples for analysis were collected during week 5 of the post-hatch exposure from one control group and the 0.094, 0.375 and 1.5 μM treatment groups.

In addition to this, eggs from control parents were exposed to tetrabromobisphenol-A for three days. The nominal concentration used were 0.094, 0.188, 0.375, 0.75, 1.5, 3.9 and 6.0 μM (equivalent to 0.051, 0.102, 0.204, 0.408, 0.816, 1.63 and 3.26 mg/l) plus a control; around 12 eggs per treatment were used and the experiment was carried out in duplicate.

The chemical analysis revealed that the concentrations in water in the adult fish treatments immediately after renewal were 96% (standard deviation 11%) of the nominal value, but this had fallen to 5.2% (standard deviation 2.7%) by 96 hours (the mean measured concentration over the 96 hour period would therefore be around 50% of the nominal value). In aquaria without fish, the tetrabromobisphenol-A levels also decreased with exposure time, but here the decrease was not as marked as in the aquaria with fish (i.e. the measured levels were 71% and 61% of nominal values after 72 hours and 96 hours respectively). The decrease seen in the exposures with fish was thought to be due, at least in part, to metabolism by the fish.

For the juvenile fish, the analysis of water samples indicated that the actual tetrabromobisphenol-A concentration was around 80% (standard deviation 16%) of nominal immediately after renewal, falling to 22% (standard deviation 6%) of nominal by 72 hours (the mean concentration over the 72-hour exposure period would again be around 50% of the nominal value).

The results are summarised in Table 3.63. Abnormal behaviour was apparent in adult fish exposed to 3.0 and 6.0 μM tetrabromobisphenol-A within 1 hour of the start of the experiment and within a few hours the fish were recumbent on the bottom of the tank. These exposures were therefore stopped at this stage for ethical reasons. No other exposure-related morbidity, mortality, or differences in weight, length or condition factor (defined as the ratio of weight/length^3) were noted.

For the reproduction endpoints, the number of eggs produced per group on days when reproduction was monitored (the number of eggs was monitored one day after each water renewal period) was variable in both the control and treatment groups, but the total number of eggs produced by all exposure groups was lower than the number of eggs produced by each control group. There was also a large variation in the number of clutches produced. A more consistent dose-response was found for the average clutch size and a 50% reduction in clutch size was found to occur at an internal body concentration of 7.2 mg/kg lipid tetrabromobisphenol-A. No treatment-related effects were seen on the egg-fertilization ratio. Hatching of embryos was decreased at all treatment levels compared with controls, except for the 0.375 μM treatment.

For the juvenile exposures, insufficient eggs were produced during the last week of adult exposure in the 0.047, 0.188 and 0.75 μM treatment group and so data were only generated for the 0.023, 0.094, 0.375 and 1.5 μM treatment groups. Hatching ratios were statistically significantly reduced compared with the control group in all treatments except for the 0.375 μM treatment group. Further, no clear dose-response was evident in the hatching ratios. No effects were seen on post hatch survival compared with the control population at exposure concentrations up to 0.375 μM, but survival was only 19% in the 1.5 μM treatment group (the deaths occurred during the first week of exposure; this is statistically significantly different from the control group). The mortality was preceded by retardation of development (for example smaller animals and no swim-up even after 72 hours posthatching) and malformations including abnormally curved spines and accumulation of clear fluid in the pericardial region and body cavity. No malformations and no effects on length, weight of condition factor were seen in any of the treatment groups exposed to 0.375 μM or lower.

Histological examination of the surviving juveniles at 47 days posthatch showed some dose-related changes in sex differentiation. For the control group, and the groups exposed to 0.375 μM or lower of tetrabromobisphenol-A, male differentiation was observed in 50-55% of the animals. For the 1.5 μM treatment group, a statistically significant lower number was found, and more female gonads were observed (79%).

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Table 3.63 Results of *in vivo* tests with zebrafish (Kuiper *et al.*, 2007)

Nominal exposure concentration	Internal body concentration in adults after 30 days exposure				Endpoint				
	Male		Female		Number of clutches per three females	Total egg production[a] [egg production per clutch[a]]	Fertilization ratio[a]	Percentage hatching (during week 4 of exposure)	Posthatch survival
	µg/kg wet weight	µg/kg lipid	µg/kg wet weight	µg/kg lipid					
Solvent control – A	<11	<262	<6.3	<166	4	~1,900 [~480]	~53%	79.7%	97%
Solvent control – B	<11	<262	<7.1	<175	9	~3,300 {~370}	~83%		
0.023 µM (13 µg/l)	120	3,871	190	6,129	5	~1,200 [~240]	~80%	43.0%*	98%
0.047 µM (26 µg/l)	590	16,857	1,500	30,612	1	~100 [~100]	~70%	33.3%*	no data
0.094 µM (51 µg/l)	2,300	71,875	na	na	4	~450 [~100]	~93%	20.1%*	100%
0.188 M (102 µg/l)	1,800	36,735	9,800	376,923	5	~600 [~120]	~67%	13.0%*	no data
0.375 µM (204 µg/l)	4,000	114,286	3,900	59,091	4	~600 [~150]	~93%	80.0%	96%
0.75 µM (408 µg/l)	9,100	178,431	6,200	193,750	1	~150 [~150]	~100%	no data	
1.5 µM (816 µg/l)	12,000	285,714	23,000	489,362	8	~1,000 [~125]	~77%	58.1%*	19%*

Note: a) The actual values for the total number of eggs were displayed graphically only in the paper. The data here have been estimated from the graphs presented. The number of eggs per clutch are estimated here from the total number of eggs and the number of clutches. In the paper, the geometric mean number of eggs per clutch is used (again displayed graphically only) – these data appear to be slightly different from the values presented here.
na = Not analysed.
* Statistically significantly different from the solvent control groups (p=0.01)
The actual values were displayed graphically only in the paper. The data here have been estimated from the graphs presented.

In the experiments where fertilized eggs from the solvent control population were exposed to tetrabromobisphenol-A for 96 hours, severe retardation of development (delayed closure of hindgut), caudal and cranial malformation and edema in the pericardial and yolk sac region were seen at exposures of 3.0 and 6.0 μM, along with failure to hatch. This retardation was statistically significantly different from controls (p=0.01) at both 3.0 and 6.0 μM from 23 hours postfertilization, and by 47 hours all embryos exposed to 6.0 μM had died. No significant effects on hatching was seen at any other concentration

Histological examination of the exposed adults showed an increased estimated area occupied by previtellogenic oocytes in both females that were analysed from the 1.5 μM treatment group. This condition was seen in one out of four control females, and did not occur in any of the other treatment groups. Indications of early atresia of oocytes (hypertrophy and vacuolization of surrounding granulosa cells, hyalinization and fragmentation of the zona radiate, and disruption of yolk vesicles) were observed in females from all treatment groups (occurred in around 35% of females overall) and in one out of four females from the control population (the difference between the controls and exposed population was not statistically significant). No dose-related changes were found in male gonads. Thyroid tissue appeared to be similar in both the control and treatment groups and no dose-related effects were found in livers of males and females.

Overall, it was concluded that effects on population-relevant parameters (e.g. egg production, juvenile development of offspring) occurred at body burdens of around 5-7 mg/kg lipid. It was also concluded that , although the results could be consistent with estrogenic activity of tetrabromobisphenol-A, it was not clear as to the extent such a mechanism played a role in the toxicity seen. There were no indications of anti-thyroid activity.

In terms of defining a clear NOEC, the results from this study are difficult to interpret for a number of reasons. For example, the exposure concentrations in water fell markedly during the 96-hour renewal period, no replicates appear to have been used (with the exception of the hatchability and larval development studies), the number of animals used was relatively low, and there appears to be a high variability in some of the reproduction endpoints in the two control populations (e.g. in the number of clutches per three females, the total egg production and the fertilization ratio). In addition, a clear dose-response was not always evident in these endpoints when considering the water concentration. In order to get around some of the problems with the lack of constant exposure concentrations, Kuiper *et al.* (2007) expressed some of the results in terms of an internal body concentration in the adult fish after 30 days exposure and based on this concluded that population-relevant effects may occur at body burdens of around 5-7 mg/kg lipid. It should be noted that the internal body concentration in the fish did not always increase linearly with increasing exposure concentration.

It is difficult to use an internal body burden in the risk assessment. One possible approach would be to convert this to an estimated water concentration using the fish BCF. Comparison of the wet weight concentration data with the lipid weight concentration data presented in **Table 3.63** allows the mean lipid concentration of the fish to be estimated to be around 3.9% for males and 4.2% for females. Further, using the assumption that the mean water concentration over the test period was around 50% of the nominal, the mean BCF (mean ± standard deviation, expressed on a fish wet weight basis) for the fish in this study can be

estimated at around 43±23 l/kg for males and 77±65 l/kg for females. Therefore, backcalculating from an internal body burden of 5-7 mg/kg lipid gives an equivalent water concentration of around 3-4 µg/l based on the female BCF or 5-6 µg/l based on the male BCF. These values are below the lowest concentration tested. Owing to the observed concentration losses and the variability and lack of dose response seen in some of the reproductive endpoints studied, the study is not deemed to be robust enough for PNEC derivation.

A chronic *in vivo* test with flounder has also been carried out as part of the FIRE project. A summary of the results of this study has recently become available (CREDO, 2005 and 2006a), along with an extended abstract (Wester *et al.*, 2006) (although the full details of the study are not yet available). In the study, groups of ten fish (mean weight of individuals was 92 g) were exposed to tetrabromobisphenol-A (purity 99.17%) nominal concentrations of 0.001, 0.01, 0.1, 0.2, 0.4 and 0.8 µM (~5.4×10^{-4}, 5.4×10^{-3}, 0.054, 0.11, 0.22 and 0.44 mg/l) for three months (105 days). The test system consisted of glass aquaria containing 10 kg of sediment and 160 litres of water (the area of the glass aquaria was 70×100 cm) using a continuous-flow system (flow-rate 160 l per day). The water had a salinity of 3.2‰, a pH of 7.19-7.65, a mean oxygen content of 73% of saturation and a temperature of 21°C during the test. The tetrabromobisphenol-A was administered dissolved in dimethysulphoxide to the inflowing water. The final dimethylsulphoxide concentration was 0.1‰ in all tanks, including the control. The exposure concentrations were verified analytically and were found to be stable throughout the test (the actual measured concentrations were not given). The concentrations in fish muscle were also determined at the end of the study. This concentration at the end of the study (based on a wet weight basis) was around 5-10 times higher than the corresponding concentration in water (the concentration in muscle was reported to be 545 ng/g wet weight in muscle at the highest exposure concentration – this concentration is equivalent to 0.545 mg/kg wet weight; as the highest concentration in water tested was 0.44 mg/l the concentration in fish appears to be actually similar to the concentration in water in this case rather than 5-10 times higher as reported in CREDO, 2006a)).

The study was designed to look at effects of exposure on CYP1A (measured by EROD) and CYP 19 aromatase (responsible for estrogen synthesis) activities, and levels of thyroid hormones and the estrogen responsive yolk precursor protein vitellogenin in plasma. In addition all fish were examined histologically with emphasis on tissue of major endocrine importance (e.g. liver, kidney, gonads and thyroid).

It was found that there was no treatment-related effect on general health and toxicity parameters such as behaviour, survival, growth rate and relative liver and gonad weight, and no treatment related effects on EROD activity in liver were evident. However gonadal CYP 19 aromatase activity was found to show a mild treatment-related increase in males (the maximum value was reported to be around nine times the median), but no treatment-related effects on the vitellogenin concentrations in plasma was seen. Levels of unbound thyroid hormone (T4) in plasma were found to increase linearly with the concentration of tetrabromobisphenol-A present in muscle and this was thought to result from competition of tetrabromobisphenol-A for plasma protein binding (and was consistent with the strong transthyretin binding of tetrabromobisphenol-A found in pre-screening studies). However, T3 levels were not affected and histology showed no signs of altered thyroid gland activity.

Overall it was concluded that no major endocrine effects were evident in flounder exposed to tetrabromobisphenol-A at concentrations up to 0.44 mg/l for three months.

It should be stressed that no study report is yet available for this work and so the results are considered as only provisional at this stage and are not taken into account in the PNEC derivation.

Based on the results of both the flounder and zebrafish studies, Wester *et al.* (2006) concluded that in view of the absence, or limited, effects of tetrabromobisphenol-A at the relatively high concentrations tested, the risk of disruption of the endocrine system of fish in the field appears to be small.

Jurgella *et al.* (2006) investigated the effect of tetrabromobisphenol-A on estrogen metabolism in *in vitro* cultures of kidney and liver tissue from lake trout (*Salvelinus namaycush*). The experiments were carried out by incubating liver or kidney fragments with [^{3}H]-estradiol-17β for 1 hour in the presence of a single dose of 100 μM (~54 mg/l) tetrabromobisphenol-A, and then determining the water-soluble metabolites of estradiol-17β formed. The tetrabromobisphenol-A was added as a solution in ethanol and the concentration of ethanol in the final culture was 1%. In the control cultures, around 39% and 15% of the added estradiol-17β was converted into water soluble metabolites after 1 hour in the kidney and liver cultures respectively. The extent of metabolism of estradiol-17β in the tetrabromobisphenol-A treatment was expressed as the percentage of the control value after correction for background radioactivity in the blanks and normalisation for protein content. Tetrabromobisphenol-A was found to statistically significantly (p=0.01) decrease metabolism of estradiol-17β in both the kidney (metabolism was 31.0%±9.1% of the control value) and liver (metabolisms was 17.5%±0.5% of the control value (inhibition data given as mean ± standard deviation). The authors concluded that tetrabromobisphenol-A can inhibit estradiol-17β metabolism in lake trout kidney and liver cells *in vitro*, but the toxicological significance of this effect is currently not well understood.

3.2.1.6.2 Invertebrates

No studies have been found looking specifically at possible endocrine effects of tetrabromobisphenol-A in aquatic invertebrates. The study carried out by Breitholtz *et al.* (2001) discussed in Section 3.2.1.2.2 found no effects on sex ratio in developing larvae of the brackish water copepod *Nitrocra spinipes* exposed to tetrabromobisphenol-A at concentrations up to 0.035 mg/l when compared to the control population.

Wollenberger *et al.* (2002 and 2005) carried out an *in vivo* screening study for potential ecdysteriod (steroid hormones regulating development and reproduction in arthropods) agonistic/antagonistic effects with the ecdysteroid-responsive *Drosophila melanogaster* B_{II} cell-line. The concentration of tetrabromobisphenol-A used in the bioassay was in the range 10^{-7} mol/l to 10^{-4} mole/l (0.054-54 mg/l) and 20-hydroxyecdysone was used at a concentration of 5×10^{-8} mol/l in the antagonistic version of the bioassay. Tetrabromobisphenol-A showed no agonist or antagonist activity at concentrations up to 54 mg/l. However, tetrabromobisphenol-A was found to by cytotoxic at concentrations of 27 and 54 mg/l.

3.2.1.6.3 Amphibians

The results of a Frog Embryo Teratogenic Assay: *Xenopus* (FETAX) study with tetrabromobsiphenol-A have been presented at the Second International Workshop on Brominated Flame Retardants (Garber *et al.*, 2001). The FETAX bioassay looks at the effects

on embryo development during the first 96 hours of development. The endpoints examined include mortality, malformation rate and growth inhibition/acceleration (as indicated by change in embryo length and presence of features indicative of earlier/later stages).

The test used *Xenopus laevis* eggs harvested in the mid-blastula stage and generally two clutches of 50 eggs were used per test concentration (occasionally 150 eggs in four clutches/concentration were run). Stock solutions of tetrabromobisphenol-A were prepared in ethanol and the concentrations tested were 0.1, 1, 10, 100 and 500 µg/l. Ethanol at a concentration of 0.015% was present in each test, and a solvent control as well as a control was also run.

Both sodium and potassium salts are known to influence the development of *Xenopus* embryos and it was thought that the mineral content of the test media may influence the susceptibility of the organisms to biologically active compounds. In order to investigate this possibility, the test was carried out using both standard FETAX media (containing 10.7 mM NaCl, 1.14 mM $NaHCO_3$, 0.403 mM KCl, 0.135 mM $CaCl_2$, 0.349 mM $CaSO_4.2H_2O$ and 0.623 mM $MgSO_4$) and also a mineral media that contained concentrations of sodium and potassium that barely prevented developmental retardation (containing 0.22 mM NaCl, 0.13 mM KCl, 0.41 mM $MgSO_4$ and 0.25 mM $CaCO_3$).

The results of the test are shown in **Table 3.64**. **No effects on embryo development were seen at any concentration tested. As the FETAX bioassay screens for biological activity during the first 96 hours of embryo development, hormonally active compounds that only affect later stages of development may appear to lack biological activity in this assay.**

Table 3.64 Effects of tetrabromobisphenol-A on development of *Xenopus laevis* embryos

Concentration	FETAX test media			Mineral-deficient test media		
	Mortality (%)	Malformation rate (%)	Mean length (± standard deviation) (mm)	Mortality (%)	Malformation rate (%)	Mean length (± standard deviation) (mm)
0.1 µg/l	0	10	9.5±0.5	10	3	9.3±0.4
1 µg/l	1	4	9.7±0.4	7	3	9.4±0.5
10 µg/l	5	6	9.7±0.4	5	4	9.4±0.4
100 µg/l	3	4	9.7±0.4	7	4	9.2±0.5
500 µg/l	4	6	9.6±0.4	6	6	9.3±0.4
Control	9	3	9.5±0.5	3	1	9.4±0.4
Solvent control	8	7	9.7±0.5	1	3	9.4±0.4

The effects of tetrabromobisphenol-A on the rate of tail resorption in *Xenopus laevis* tadpoles has been studied by Balch and Metcalfe (2001). Only brief details of the study are available. The test substance was dissolved in a carrier solvent (triolein) and 5 µl of this solution was administered to tadpoles using an intraperitoneal microinjection technique giving a tetrabromobisphenol-A dose of 60 µg/tadpole. The tadpoles used in the study were at developmental stage 58 (hind legs emerged and forelimbs formed but not emerged). A total of 20 tadpoles/treatment were used. Solvent control and control (not injected) populations were also used. The tail lengths of the tadpoles were measured over a 14-day period using

digitized video images. Changes in the rate of tail resorption was used as an indication of disruption of the thyroid system. Mortalities were around 10% in all treatments and the rate of tail resorption in the solvent control treatment group was not significantly different from the rate in the non-injected control group. The rate of tail resorption in the tetrabromobisphenol-A treatments was similar to that in the solvent control and control groups, indicating that tetrabromobisphenol-A did not disrupt thyroid function.

In contrast to this, Kitamura *et al.* (2005a) have recently shown that tetrabromobisphenol-A appears to act as a thyroid hormone antagonist in *Rana rugosa* tadpoles and in certain *in vitro* tests using mammalian cell lines (the cell line tests are briefly summarised in Section 3.2.4.3). The tests with *Rana rugosa* were carried out using stage X tadpoles in glass Petri dishes. Groups of tadpoles (the number per group was not given) were exposed to either chlorine-free tap water (group 1), or concentrations of tetrabromobisphenol-A (the three concentrations tested were 1×10^{-8} M (~ 5 μg/l), 1×10^{-7} M (~50 μg/l) and 1×10^{-6} M (~500 μg/l)). The tetrabromobisphenol-A-exposed tadpoles were divided into two groups (group 2 and group 3). The group 3 tadpoles were continuously exposed to tetrabromobisphenol-A for the 9-day duration of the experiment. The tadpoles in group 2 were exposed to tetrabromobisphenol-A for the first five days of the experiment. After the first four days, 5×10^{-8} M of the thyroid hormone L-3,5,3'-triiodothyronine (T_3) was added to the group 1 and group 2 tadpoles and on day 6 the tadpoles were placed in water only for the remainder of the experiment. A control group of tadpoles was maintained in water only for the entire duration of the experiment.

The tail lengths of the tadpoles in all groups did not change markedly for the first four days. The tadpoles maintained in water only but exposed to T_3 on day 4 (group 1) showed enhanced tail shortening compared with the control group (four days after exposure to T3 the tail length had decreased to about 40% of the control) and growth of limbs was also evident. The tadpoles exposed to tetrabromobisphenol-A alone (group 3) showed no significant differences from the control population. However, when tadpoles were exposed to both tetrabromobisphenol-A and T3 the amount of T3-induced tail shortening and growth of limbs was markedly decreased compared with the population exposed to T3 alone (group 1). The decrease in tail lengths was found to be dose dependent (the tail length had decreased to about 54-76% of the control value for the 1×10^{-8} M to 1×10^{-6} M tetrabromobisphenol-A treatments respectively). The difference in tail length between the tetrabromobisphenol-A and T3 exposed population (group 3) and the T3 only exposed population (group 1) was found to be statistically significant ($p=0.05$) for the 1×10^{-6} M tetrabromobisphenol-A treatment (500 μg/l). **These results suggest that tetrabromobisphenol-A shows little activity as a thyroid hormone agonist but may act as a thyroid hormone antagonist.**

Jagnytsch *et al.* (2006) has investigated the effects of exposure to tetrabromobisphenol-A on thyroid hormone-regulated biomarkers and larval development in *Xenopus laevis*. This species was chosen for the test as it is known that amphibian metamorphosis is regulated by thyroid hormones, and this provides a very sensitive model for detection of thyroid disruption. The tetrabromobisphenol-A used in the study had a purity of >98%.

The long-term experiments were carried out using the *Xenopus* metamorphosis assay (XEMA). In the assay, tadpoles at developmental stage 51 were exposed to nominal tetrabromobisphenol-A concentrations of 2.5, 25, 250 and 500 μg/l for 21 days. A total of 20 tadpoles per treatment was used, and each concentration was tested in duplicate. The test solutions were renewed three times per week, but no analytical verification of the test

concentrations was carried out. The tetrabromobisphenol-A was added to the test medium in ethanol, and so a solvent control (0.001% ethanol) was run. In addition, positive controls for agonistic activity (3,3',5,5'-tetraiodothyronine (T4) at 1 µg/l) and antagonistic activity (6-n-propyl-2-thiouracil (PTU) at 50 mg/l and ethylenethiourea (ETU) at 25 mg/l) were also run.

The parameters measured in the 21-day study included developmental stage, whole body length, tail length and hind limb length. In addition, the THSβ-mRNA levels were also determined at the end of the study to provide information on whether tetrabromobisphenol-A exposure may affect negative feedback mechanisms.

After 21-days the tadpoles in the solvent control group had developed to stage 58 (standard deviation ±2). No statistically significant (p=0.05) effect on this endpoint was evident in the groups exposed to 2.5, 25 or 250 µg/l, but the tadpoles in the 500 µg/l treatment group had developed to stage 57(±1) which was statistically significantly different from the solvent control group. The development stage reached after 21 days in the positive control groups were 53(±1) in the PTU treatment, 54(±1) in the ETU treatment and 60(±2) in the T4 treatment. Similar effects at 500 µg/l were also evident in the hind limb length after 7, 14 and 21 days, where the limb length in the treatment group (1.7, 3.7 and 10.3 mm respectively) was statistically significantly shorter than the solvent control group (2.0, 4.7 and 13.0 mm respectively). Again limb length growth was significantly stimulated in the T4 positive control and significantly retarded in the PTU and ETU positive controls compared with the solvent control group.

The whole body length and tail length was determined in the study as an indicator of possible toxic side effects on growth of the tadpoles. Tadpoles in all treatment and control groups grew continuously during the 21 day study. No treatment-related effects were evident in the 2.5, 25 or 250[17] µg/l treatment groups, but a slight but statistically significant decrease in both whole body length and tail length was evident in the 500 µg/l treatment group at day 7 and day 14 compared with the solvent control group. However, by day 21, no significant differences were evident in either whole body length or tail length between the 500 µg/l treatment group and the solvent control group. No statistically significant effect on either whole body length or tail length was evident in the positive control groups compared with the solvent control group.

No significant mortality was seen in the study (<1% of the tadpoles died in the study in all groups). However, tadpoles exposed to 500 µg/l of tetrabromobisphenol-A showed abnormal behaviour in swimming and reduced feed uptake during the first 10 days of the study compared with the control group, but survival was not affected. These effects became less marked as the study progressed, and no difference in behaviour between the 500 µg/l treatment group and the solvent control group was evident after day 10.

At the end of the study, brain tissue (including the pituitary) was taken from 8 tadpoles from each group and the TSHβ-mRNA content (a biomarker for inhibitory effects on the thyroid system) was determined. The TSHβ-mRNA expression in the treatment groups relative to the solvent control group showed no significant differences, whereas the positive controls (ETU and PTU) showed >3-fold increase in TSHβ-mRNA expression after 21 days.

[17] In the paper the text indicates that no statistically significant effects were seen at this concentration, however, one diagram in the paper appears to show a slight, but statistically significant, reduction in whole body length at this concentration.

As well as the long-term XEMA study, Jagnytsch *et al.* (2006) also carried out several **short-term bioassays** using *Xenopus laevis* tadpoles in order to determine if tetrabromobisphenol-A caused any effects directly on the thyroid hormone-upregulated biomarkers TRβ[18]-mRNA and b/ZIP[19]-mRNA, and also in a challenge experiment on the thyroid hormone-stimulated gene expression of these biomarkers.

Experiments were carried out using stage 51 tadpoles. This stage is useful for this type of gene expression determination as the thyroid gland is not yet functioning (and so no endogenous thyroid hormones circulate in the blood stream) but several tissues are already competent to respond to exogenous addition of thyroid hormone by modified gene expression patterns. In these studies, groups of 30 tadpoles per treatment were exposed to either 0.001% ethanol (solvent control), 0.1 nM or 1.0 nM 3,3',5-triioothyronine (T3; positive controls) or 100, 250 or 500 µg/l tetrabromobisphenol-A. In addition, a series of challenge experiments were carried out where tadpoles were exposed to a combination of T3 (0.1 nM and 1.0 nM) and tetrabromobisphenol-A (100, 250 and 500 µg/l). The total duration of the studies was 72 hours, but biomarker response (10 tadpoles per treatment) was also determined after 24 and 48 hours. The test solutions were changed daily during these studies.

Compared to the control group, both TRβ- and bZIP-mRNA expression was statistically significantly stimulated at both T3 concentrations after 24 hours, and this difference remained until the end of the study. The 500 µg/l treatment resulted in a slight, but statistically significant increase in TRβ-mRNA expression compared with the solvent control group after 24 hours and a statistically significant increase in bZIP-mRNA expression compared with the solvent control group after 24 and 48 hours. In the challenge experiments tetrabromobisphenol-A was found to cause a dose-dependent inhibition of T3-induced TRβ-mRNA and b/ZIP-mRNA expression and this inhibition was statistically significantly different from the positive controls at all tetrabromobisphenol-A concentrations at the T3 concentration of 0.1 nM. The effects were less marked but in many cases still statistically significant at the higher T3 concentration of 1.0 nM.

A final series of experiments by Jagnytsch *et al.* (2006) investigated the effects of tetrabromobisphenol-A on stage 57 tadpoles (which have well-established functioning thyroid systems) using a similar short-term assay as above. In these experiments only a solvent control (0.001% ethanol) and a single tetrabromobisphenol-A concentration of 500 µg/l were run. The purpose of this study was to analyse indirectly the possible effects of tetrabromobisphenol-A on the thyroid hormone-binding protein transthyretin and thyroid receptor by determining TRβ-mRNA and b/ZIP-mRNA gene expression. These experiments found that exposure to 500 µg/l tetrabromobisphenol-A resulted in a slight but not statistically significant increase in TRβ- and b/ZIP-mRNA after 12, 24 and 48 hours compared to the solvent control.

Overall the study by Jagnytsch *et al.* (2006) appears to be a high quality study that thoroughly investigates the possible thyroid-mediated effects of tetrabromobisphenol-A in amphibians. The short-term experiments demonstrate that tetrabromobisphenol-A at a concentration of 500 µg/l can result in direct stimulatory effects on thyroid hormone-dependent gene expression. Jagnytsch *et al.* (2006) suggested that this stimulatory effect could result from binding of tetrabromobisphenol-A to thyroid receptors which has

[18] TRβ (thyroid hormone receptor-β) is an early response gene from thyroid hormone.
[19] b/ZIP = basic region leucine zipper transcription factor.

been demonstrated to occur in some systems (e.g. Kitamura *et al.* (2005a); see Section 3.2.4.3). The challenge experiments showed that tetrabromobisphenol-A can inhibit thyroid hormone-dependent gene regulation at concentrations as low as 100 µg/l (and possibly lower), demonstrating a clear antithyroid hormonal activity of tetrabromobisphenol-A similar to that found by Kitamura *et al.* (2005a; see above). However the experiments with stage 57 tadpoles suggest that effects of tetrabromobisphenol-A on an already well-established thyroid system are minimal.

In the long-term XEMA experiments, concentrations of tetrabromobisphenol-A of 500 µg/l were found to cause slight, but statistically significant, reductions in the development rate of stage and the growth of hind limbs. These results might suggest a slight antithyroidal effect of tetrabromobisphenol-A. However, Jagnytsch *et al.* (2006) pointed out that the effects on whole body length and observations of abnormal swimming and feeding behaviour seen at this concentration suggest that these effects on development are a toxic side effect rather than a direct effect on thyroid function. Jagnytsch *et al.* (2006) also concluded that, although inhibition of thyroid hormone-induced gene expression was evident from the short-term assays, the lack of effects seen on the negative feedback mechanism in the long-term XEMA study indicated that the inhibitory action of tetrabromobisphenol-A is not effective enough to impact sustainable thyroid regulation via feedback mechanisms at the pituitary level. Therefore, the overall impact of tetrabromobisphenol-A on amphibian metamorphosis was thought to result from toxic effects at concentrations of 500 µg/l rather than endocrine-disrupting actions.

A further study investigating the effects of tetrabromobisphenol-A on thyroid function in *Xenopus laevis* both *in vitro* and *in vivo* has been carried out by Kudo *et al.* (2006). The purity of the tetrabromobisphenol-A tested was >98%. Several other brominated bisphenol-A derivatives were also studied including 3-bromobisphenol-A (purity 98%), 3,3'-dibromobisphenol-A (purity 98%), 3,5-dibromobisphenol-A (purity 98%) and 3,3,5'-tribromobisphenol-A. These compounds are possible intermediate products in the anaerobic degradation of tetrabromobisphenol-A (see Section 3.1.0.6.2) and so it is relevant to also consider the results for these substances here.

The *in vitro* studies included the ^{125}I-T3 binding to *Xenopus laevis* transthyretin assay (TTR assay), the ligand-binding domain of *Xenopus laevis* thyroid hormone receptor β assay (TR assay) and the T3-responsive reporter gene assay using an amphibian cell line permanently transduced with lentiviral vector containing a T3-responsive luciferase gene. The TTR assay was carried out by incubating recombinant *Xenopus laevis* transthyretin (70 ng per tube) with 0.1 nM ^{125}I-T3 in 250 µl of buffer in the presence or absence of excess unlabelled T3 for 1-1.5 hours at 4°C. The test substance was added as a solution in dimethylsulphoxide (maximum concentration in the final solution was 0.4% vol/vol, a solvent control was also run). The TR assay was carried out in a similar way, except *Xenopus laevis* thyroid hormone receptor LBD-fused glutathione-S-transferase was used (23 ng per tube). The T3-responsive reporter gene assay was carried out using recombinant *Xenopus laevis* XL58-TRE-Luc cells (which express high levels of luciferase in a T3-dependent manner). The cells were cultured in 70% Leibovitz's L-15 medium with or without 2 nM T3 in the presence or absence of the test substance (again added as a solution in dimethylsulphoxide) for 24 hours.

The results of the TRR assay showed that tetrabromobisphenol-A, 3,3',5-tribromobisphenol-A and 3,3'-dibromobisphenol-A competed strongly with ^{125}I-T3

binding to transthyretin. The 50% inhibitory concentrations (IC_{50}s) were determined to be 3.07 nM for tetrabromobisphenol-A, 1.12 nM for 3,3',5-tribromobisphenol-A and 1.80 nM for 3,3-dibromobisphenol-A. All of the compounds tested were found to be weak inhibitors of ^{125}I-T3 binding to the thyroid hormone receptor in the TR assay. The IC_{50}s determined were 360 nM for 3,3'-dibromobisphenol-A, 790 nM for 3,3',5-tribromobisphenol-A, with the other compounds displaying higher IC_{50}s (data shown graphically only in the paper for the other chemicals tested).

In the T3-responsive reported gene assay, 3,3'-dibromobisphenol-A, 3,3',5-tribromobisphenol-A and tetrabromobisphenol-A all significantly inhibited the T3-induced luciferase activity in a dose-responsive manner and hence showed antagonistic activity. Compared to controls, the mean inhibition percentage at a concentration of 0.01 μM was found to be 85% for 3,3'-dibromobisphenol-A, 67% for 3,3,',5-tribromobisphenol-A and 67% for tetrabromobisphenol-A. These percentage inhibitions were statistically significantly different (p=0.05). Some of the other compounds tested (e.g. 3-bromobisphenol-A and 3,5-dibromobisphenol-A) also demonstrated a dose-related inhibition compared to controls in this assay, although in this case the percentage inhibition was generally small and not statistically significant. In the experiments carried out in the absence of T3, statistically significant increases in the luciferase activity compared with the controls were found with 3,3',5-tribromobisphenol-A at 0.01, 0.1 and 1.0 μM and tetrabromobisphenol-A at 0.1 and 1.0 μM, indicating that both of these substances had T3 agonist activity. The other compounds tested showed little or no effect on the luciferase activity (although 3,5-dibromobisphenol-A and 3,3'-dibromobisphenol-A showed a small, dose dependent, increase in activity, this was not statistically significant).

In order to investigate the extent to which serum proteins affected the T3 agonist and antagonist activity of 3,3',5-tribromobisphenol-A in the reporter gene assay, experiments were carried out in the presence or absence of 10% serum (fetal bovine serum and bullfrog tadpole serum). It was found that the serum proteins in the culture medium weakened both the T3 agonist and antagonist activities of 3,3',5-tribromobisphenol-A.

The *in vivo* study used a short-term gene expression assay. In this assay, groups of tadpoles (five to six per replicate) at developmental stage 52-53 were placed in 1 litre glass beakers containing 0.5-0.6 litres of FETAX buffer. The test substance was added as a solution in dimethylsulphoxide (final solvent concentration was <0.4% vol/vol; a solvent control was also run), along with 2 nM of T_3 and the organisms were exposed for 2 days. After 2 days, the total RNA was extracted from the head and trunk regions of the tadpoles and the amounts of T_3-responsive gene transcripts were determined. Each experiment was carried out at least twice using tadpoles from different sets of adults.

In the control population (treated with T3 alone), the amount of thyroid hormone receptor β (TRβ) gene transcription increased 23-fold and 9-fold in the trunk and head regions respectively, and the amount of thyroid hormone/bZIP (TH/bZIP) gene transcription increased 42-fold and 13-fold in the trunk and head regions respectively after 2 days. When exposed to 3,3',5-tribromobisphenol-A at a concentration of 0.5 μM in the absence of T3, a statistically significant increase in the amounts of TRβ (200% of control value) and TH/bZIP (198% of the control) gene transcription was seen in the trunk, but no statistically significant effects were seen in the head (TRβ gene transcription was 122% of the control and TH/bZIP gene transcription was 95% of the control). When the tadpoles were co-treated with T3 and 0.5 μM 3,3',5-tribromobisphenol-A, the T3-induced increase in the amount of TH/bZIP gene

transcription in the trunk was statistically significantly inhibited compared to the control (61% of the control value), whereas induction of TRβ gene transcription was not statistically significantly inhibited (67% of control). No statistically significant effects were seen in the T3-induced gene transcription in the head (both TRβ and TH/bZIP gene transcription was 62-63% of the control). Kudo *et al.* (2006) concluded that 3,3',5-tribromobisphenol-A elicits agonist and antagonist activities in at least the trunk region of premetamorphic tadpoles. None of the other chemicals studied appear to have been tested in this *in vivo* assay.

The effects of tetrabromobisphenol-A on metamorphosis in amphibians has also been investigated by Goto *et al.* (2006). Several different assays were carried out. The first series of tests investigated the effects of tetrabromobisphenol-A on T3-induced tail shortening in *Rana rugosa* stage X tadpoles. In this study, groups of tadpoles were maintained in chlorine-free tapwater or in water containing 10^{-8} M, 10^{-7} M or 10^{-6} M tetrabromobisphenol-A (~5.4 μg/l, 54 μg/l and 544 μg/l respectively) for nine days. The tetrabromobisphenol-A was added as a solution in dimethysulphoxide, and the solvent content of the final solution was 0.1% (it is not clear if a solvent control was also run). On day five of the exposure period, T3 (5×10^{-8} M) was added to half of the tadpoles in each treatment group and on day six the T3-treated tadpoles were returned to the T3-free test media (water or tetrabromobisphenol-A solution as appropriate) for the remainder of the experiment. Exposure of non-tetrabromobisphenol-A exposed tadpoles to T3 resulted in tail shortening compared with the control population. This induced tail shortening was found to be significantly ($p=0.05$) suppressed by tetrabromobisphenol-A concentrations of 54 and 544 μg/l. A similar exposure system was also used to investigate the effects of tetrabromobisphenol-A exposure (concentration 544 μg/l) on DNA fragmentation and ladder formation in tails of T3-treated and untreated *R. rugosa* tadpoles. The DNA in tails of tadpoles treated with T3 alone showed marked fragmentation and a ladder-like profile compared with the non-exposed controls. These changes were not evident in the groups exposed to tetrabromobisphenol-A alone or T3 in combination with tetrabromobisphenol-A.

The second series of experiments carried out by Goto *et al.* (2006) investigated the effects of tetrabromobisphenol-A exposure on spontaneous metamorphosis, tail shortening and hindlimb elongation in *Silurana tropicalis* tadpoles. Stage 57 tadpoles were exposed to either 544 μg/l tetrabromobisphenol-A or a 1 mM solution of methimazole (thyroid hormone synthesis inhibitor) for up to ten days. Tadpoles raised in chlorine-free tap water acted as the control population. At various times during the test, the stage of metamorphosis, tail length and hind limb length was determined. Exposure to tetrabromobisphenol-A at 544 μg/l elicited a similar response as methimazole, and resulted in suppressed spontaneous metamorphosis, tadpole tail length shortening and hindlimb elongation compared with the control population.

The final series of experiments investigated the effects of tetrabromobisphenol-A exposure on thyroid hormone receptor-mediated gene transcription in F_2 transgenic *Xenopus laevis* tadpoles using an assay for Enhanced Green Fluorescent Protein (EGFP) activity. In the test, tadpoles were exposed to either T3 alone or T3 in combination with either 5.4, 54 or 544 μg/l tetrabromobisphenol-A for 11 days. EGFP fluorescence in the hindlimbs increased during the treatment with T3 alone, with the activity reaching around 250% of the original level by day 11. The change in EGFP activity in the T3-treated tadpoles was found to be suppressed when exposed in combination with tetrabromobisphenol-A (this suppression was found to be statistically significant ($p=0.01$) at 54 and 544 μg/l).

Overall Goto *et al.* (2006) concluded that tetrabromobisphenol-A acted as a thyroid hormone antagonist in a dose dependent manner in these test systems, with statistically significant effects being seen at concentrations of 54 µg/l and above. It was thought likely that these effects resulted from binding of tetrabromobisphenol-A to the thyroid hormone receptor in competition with T3, resulting in suppression of thyroid hormone-mediated gene transcription.

A further study investigating the effects of tetrabromobisphenol-A on tadpole metamorphosis has been carried out by Veldhoen *et al.* (2006). The species used in this study was the Pacific tree frog (*Pseudacris regilla*). The study investigated the expression of four thyroid hormone-responsive genes in tail and brain tissue during natural and T3-induced metamorphosis, and the effects of exposure to tetrabromobisphenol-A exposure on the steady-state mRNA levels. The purity of the tetrabromobisphenol-A used was not stated. The test system used was a static renewal system (48 hour renewal). All tests were carried out at 23°C. The pH of the water used (dechlorinated tap water) was in the range 7.14-7.55 and the dissolved oxygen concentration was 50-60% of saturation throughout the test.

The first series of experiments investigated the mRNA levels during natural and T3-induced metamorphosis. In these experiments, groups of ten tadpoles at Gosner stages 30-31 were placed in glass bowls containing 1 litre of water and either 0.1 ml/l dimethysulphoxide (DMSO; solvent control) or 10 nM T3 (added as a solution in DMSO). A total of four groups of tadpoles for each treatment were prepared, with one group of tadpoles for each treatment being analysed after 24, 48, 72 and 96 hours exposure. At each endpoint, the expression of mRNA from four thyroid-responsive genes (thyroid hormone receptor alpha (TRα), thyroid hormone receptor beta (Trβ), gelatinase B (gel B) and proliferating cell nuclear antigen (PCNA)) was determined and compared with the known expression of mRNA in animals undergoing natural metamorphosis (this was determined in premetamorphs (Gosner stages 30-35), prometamorphs (Gosner stages 36-41) and metamorphs (Gosner stage 42-43). Significant changes in the abundance of expressed transcripts for all four genes in tail or brain tissue were found in tadpoles undergoing natural metamorphosis. T3 exposure was found to cause a statistically significant ($p=0.05$) reduction in fin tail area of the exposed tadpoles compared with the solvent controls at 48 hours, and this tail regression continued to increase compared with the controls up to 96 hours. Statistically significant changes in tail length compared with the solvent control population were also evident in the T3 population at 72 and 96 hours ($p=0.01$ at 72 hours and $p=0.001$ at 96 hours). The levels of TRα-. TRβ-, gel B- and PCNA mRNA in tail and brain tissue of the T3-exposed population were also compared with the solvent control population. All four genes were found to display a T3-related change in the steady state concentrations of their associated transcripts, and this change was more apparent in the tail compared with the brain.

A similar test system was used for the tetrabromobisphenol-A exposures. In these experiments, groups of eight animals (premetamorphic tadpoles at Gosner stages 30-34) were treated with either 0.1 ml/l DMSO (solvent control), 10 nM T3, 10 nM or 100 nM tetrabromobisphenol-A, or a combination of T3 and tetrabromobisphenol-A. In these experiments, the expression profiles of TRα-, TRβ-, gel B and PCNA were examined after 48 hours exposure and the effects on tail regression and body length were determined after 96 hours exposure. No statistically significant ($p=0.05$) changes in body length, tail length, tail fin area or tail muscle area were evident in tadpoles in the 10 nM and 100 nM treatment groups compared with the control population. However, exposure to tetrabromobisphenol-A alone resulted in a significant (all at $p=0.05$ level) increase in the TRα- (100 nM treatment)

and gel B (10 nM but not 100 nM treatment) steady-state mRNA levels in the tail and brain respectively. In addition exposure to tetrabromobisphenol-A significantly altered the abundance of PCNA transcript in both tissues (decrease at 10 nM but not 100 nM in tail, and increase at both 10 nM and 100 nM in brain).

Exposure to 10 nM tetrabromobisphenol-A in combination with 10 nM T3 resulted in a statistically significant (p=0.05) reduction in tail muscle area compared with the T3 treatment alone (no statistically significant effects were seen with 100 nM tetrabromobisphenol-A). This decrease in muscle area corresponded to a marked increase in gel B-mRNA levels in tail in the 10 nM tetrabromobisphenol-A group but not the 100 nM tetrabromobisphenol-A group, compared with the T3 only treatment group. Exposure to tetrabromobisphenol-A was also found to affect the T3-mediated change in mRNA levels for PCNA in the tail (significantly reduced compared with the T3 only group at a tetrabromobisphenol-A level of 100 nM) and TRα in the brain (significantly reduced compared with the T3 only group at a tetrabromobisphenol-A level of 100 nM).

No explanation was given in the paper as to why statistically significant effects were seen on tail muscle area in the low dose treatment group but not the high dose treatment group. The tail muscle area data were only presented graphically in the paper, and from visual observation of the graphs, the tail muscle area in the 100 nM treatment group appeared to be slightly lower than the T3 only treatment group, but this difference was not statistically significant.

Veldhoen *et al.* (2006) concluded that tetrabromobisphenol-A can affect mRNA expression at relatively low levels (10 nM and 100 nM – these are equivalent to concentrations of around 5.4 μg/l and 54 μg/l). However, the effects seen appear to be gene- and tissue-specific, and the consequence of these altered transcript levels on postembryonic development is currently unknown. The results obtained in the absence of added T3 suggest that tetrabromobisphenol-A could be acting as a thyroid hormone agonist, however, it was also discussed in the paper the that these T3-independent effects could also possibly be mediated by other regulatory mechanisms that influence mRNA expression.

Overall, although this study showed that tetrabromobisphenol-A could affect mRNA expression at relatively low levels, there were no associated statistically significant changes in body length, tail length, tail fin area or tail muscle area in tadpoles exposed to tetrabromobisphenol-A alone. The consequences of effects on mRNA expression at a population level are not clear.

3.2.1.6.4 Summary of effects on the endocrine system

A relatively large number of studies have become available in recent years investigating the possible effects of tetrabromobisphenol-A on the endocrine system. These studies include invertebrates, fish and amphibians.

For invertebrates, the limited number of available studies indicate that there are no significant effects on the endocrine system following tetrabromobisphenol-A exposure.

The available fish studies indicate that exposure to tetrabromobisphenol-A does not cause significant effects on plasma vitellogenin levels. Although *in vitro* screening studies have shown that tetrabromobisphenol-A can bind to transthyretin, the available *in vivo* fish studies

suggest that the risk of disruption of the fish endocrine system from exposure to tetrabromobisphenol-A in the field is small. No indications of *in vivo* anti-thyroid activity are evident. Although effects on some population-relevant parameters (e.g. egg production, juvenile development of offspring) were seen in an *in vivo* zebrafish study, it was not clear if these were the result of a mechanism involving disruption of the endocrine system, and no major effects on the endocrine system were reported in an as yet unpublished *in vivo* study with flounder.

The possible effects of tetrabromobisphenol-A exposure on the endocrine system in amphibians, particularly thyroid hormone agonistic or antagonistic behaviour, has been more extensively studied. The results generally show a mixed picture, with some studies showing that tetrabromobisphenol-A can act as a thyroid hormone agonist, some showing that it can act as a thyroid hormone antagonist, and others showing little or no effect. This inconsistent behaviour appears to depend on the test system used (in particular whether or not the test was carried out with added T3), which possibly reflects the fact that tetrabromobisphenol-A can compete with T3 binding to the thyroid hormone receptor, and can also have a stimulatory effect on the thyroid hormone receptor (although this stimulatory effect is not as large as for T3 itself). It can be hypothesised that the actual effects seen in these studies may represent the result of a balance between the stimulatory effect of tetrabromobisphenol-A against the loss of activity from displacement of the T3. Thus antagonistic behaviour may be expected in systems where T3 has been added (most of the studies demonstrating antagonistic behaviour have been carried out in the presence of added T3). This hypothesis has yet to be proven experimentally, but may explain at least some of the results seen in the existing studies.

Whatever the explanation, this variation in response makes it difficult to assess the significance of the findings from many of these studies for exposures that may occur in the environment.

In terms of population effects, the available studies with fish have generally shown that tetrabromobisphenol-A has little or no adverse effects on parameters such as survival, growth and reproduction that can be assigned specifically to effects on the endocrine system. A recent lifecycle test with zebrafish did find effects on reproduction but these were thought to be not related to effects on the endocrine system. In addition, this study is not considered robust enough for PNEC derivation. Tetrabromobisphenol-A has also been shown to cause indications of oxidative stress in fish at doses of around 100 mg/kg bw and above but the method of administration used (intraperitoneal injection of a solution in oil) is of questionable relevance to exposure via the environment.

Amphibian metamorphosis is known to be governed to a large extent by thyroid hormone, and effects on amphibian metamorphosis have been seen in several studies. Therefore it is concluded that tetrabromobisphenol-A has the potential to cause adverse effects on the endocrine system in tadpoles. Although possible thyroid-mediated effects of tetrabromobisphenol-A in amphibian systems are evident in *in vitro* assays, the results of a recent well conducted *in vivo* assay (Jagnytsch *et al.*, 2006) suggests that the effects seen *in vivo* may be the result of a toxic side effect rather than direct effects on thyroid function. The concentrations at which effects on metamorphosis have been seen are generally around the 100 µg/l level or higher. Effects on various biomarkers (such as mRNA) have been seen at lower concentrations (as low as around 5.4 µg/l) but the significance of these effects on mRNA in terms of population survival is unclear.

3.2.1.7 Predicted no effect concentration (PNEC) for the aquatic compartment

3.2.1.7.1 Surface water

Short term toxicity data are available for fish (freshwater), invertebrates (freshwater and marine) and alga (freshwater and marine). The lowest acute L(E)C_{50}s for freshwater species were 0.54 mg/l for fish (*Pimephales promelas*), 0.96 mg/l for invertebrates (*Daphnia magna*) and >5.6 mg/l for alga (*Pseudocirchneriella subcapitata* (formerly *Selenastrum capricornutum*).

For marine species, the lowest acute EC_{50} was 0.09 mg/l for the alga *Skeletonema costatum*. There was some evidence that the toxicity to marine alga increased with decreasing pH in the range pH 7.6 to 8.2. A similar EC_{50} of 0.098 mg/l was obtained for effects on shell regrowth in eastern oysters (*Crassostrea virginica*) in a short-term assay.

Long-term toxicity data are also available for fish (freshwater), invertebrates (freshwater and marine) and alga (fresh water). The most relevant NOECs or EC_{10}s for consideration in the PNEC derivation are summarised below.

Freshwater		
Fish	*Pimphales promelas*	35d-NOEC = 0.16 mg/l
Invertebrates	*Daphnia magna*	21d-NOEC = 0.3 mg/l
	Chironomus tentans	14d-NOEC <0.066 mg/l
Algae	*Pseudokirchneriella subcapitata*	72h-NOEC = ≥5.6 mg/l

Marine		
Fish		No data
Invertebrates	*Acartia tonsa*	5d-EC_{10} = 0.0127 mg/l
	Mytilus edulis	70d-NOEC = 0.017 mg/l
	Crassostrea virginica	96h-EC_{10} = 0.0026-0.0062 mg/l
Algae		No NOECs are available

For freshwater species, the most sensitive endpoint investigated so far appears to be effects on the growth of *Chironomus tentans*. With this species significant effects were seen at the lowest concentration tested (0.066 mg/l) and so the actual NOEC will be below this value. The long-term NOECs for freshwater fish, *Daphnia magna* and algae are all above this concentration. It should be noted that there appear to be some uncertainties over the interpretation of the results from the growth study with *Chironomus tentans*, in that undissolved test substance was also likely to have been present in the test media and this may account for some of the effects seen.

For marine species, the lowest long-term NOEC/EC_{10} is the 5d-EC_{10} for marine copepod *Acartia tonsa* of 13 µg/l. This is very similar to the NOEC determined in a recent long-term study with *Mytilus edulis* of 17 µg/l.

Although considered an acute test (since it was of short duration and only considered one lifestage), an EC_{10} of 0.0026-0.0062 mg/l has been determined for effects on shell regrowth in eastern oysters (*Crassostrea virginica*). This test has been reviewed by experts within the

UK (EA, 2002). Although it is clear that growth of molluscs is an environmentally relevant endpoint and that adverse effects appeared to have been seen in the current test this review identified a number of uncertainties associated with the study as discussed below.

- The extrapolation to an EC_{10} below the lowest concentration tested is uncertain (0.018 and 0.075 mg/l in the two series of experiments), and the control response was slightly lower than is recommended in current test guidelines.
- When bivalves experience polluted water conditions they tend to close their valves and stop feeding. They can do so for up to three weeks which means that any toxicity test should ideally be run for a period longer than this to ensure the exposure of the animal to the toxin. In the current study (duration 96 hours only) the observed differences in shell growth could be a result of differential feeding rates over the period of the test and may have nothing to do with the direct impact of tetrabromobisphenol-A on the organisms.
- The measure of shell growth rate will depend on which specific part of the shell margin is measured. It would have been impossible to record at exactly the same point on each individual. Accurate measurement of shells is impossible and there is likely to be a major source of error when recording to 0.1 mm accuracy. These factors, combined with the relatively small amount of growth observed, suggests that the recording of results is open to extreme human error.
- The shell margins were ground back between 3 and 5 mm. This action would have disturbed all the test animals considerably, and may even have led to some animals resorbing the underlying mantle (the tissue that secretes the shell), which may have happened if 5 mm was removed. If so, it is unlikely that any shell growth would have occurred during the test period.

As a result of these uncertainties a further, long-term, mollusc growth test was instigated (using common mussel *Mytilus edulis*). The results of this test show a NOEC of 17 µg/l and this value is considered suitable for consideration in the derivation of a PNEC. Therefore the results of the test with *Crassostrea virginica* are not considered further here.

Based on the freshwater invertebrate NOEC value being <0.066 mg/l, and an assessment factor of 10 (long-term data are available for fish, invertebrates and alga), a PNEC of <0.0066 mg/l / <6.6 µg/l can be derived based on the available freshwater data. From the available data it is not clear how much below this value the actual PNEC should lie. However, studies with marine copepods (*Acartia tonsa*) and with marine molluscs (*Mytilus edulis*) have found EC_{10}s/NOECs of 0.0127 and 0.017 mg/l respectively. Therefore, in order to be protective of freshwater species, the PNEC for freshwater organisms is derived from the EC_{10} value for *Acartia*. According to the Technical Guidance Document, an assessment factor of 10 is appropriate for a situation where NOECs for three trophic levels are available (assuming the EC_{10} can be considered equivalent to a NOEC). This leads to a PNEC of 1.3 µg/l (a very similar PNEC of 1.7 µg/l would be derived if the recent high quality long term mollusc study with *Mytilus edulis* was used to derive the PNEC).

There are a number of studies available that have investigated the effects of tetrabromobisphenol-A on the endocrine system of aquatic organisms. A number of these studies have found little or no response from exposure to tetrabromobisphenol-A. However, some studies have found adverse responses from tetrabromobisphenol-A including indications that tetrabromobisphenol-A may act as a thyroid hormone antagonist in tadpoles (*Rana rugosa*) (although it should be noted that no effect on thyroid function was seen in a

FETAX study with *Xenopus laevis*). The concentrations at which these effects have been seen appear to be generally above the PNEC derived above for tetrabromobisphenol-A and so the PNEC can be considered to be protective against these effects.

One recent lifecycle study with zebrafish has found effects on some reproductive endpoints at relatively low concentrations. This study is discussed in detail in Section 3.2.1.6.1. A number of aspects of this study make the interpretation of the results of this study difficult, in particular the decline in the exposure concentrations with time, and the variability and lack of dose response seen in some of the reproductive endpoints studied. These concerns mean that the study is not sufficiently robust for derivation of a PNEC. The authors of the study (Kuiper *et al*., 2007) concluded that effects on population-relevant parameters can result at tetrabromobisphenol-A body burdens of 5-7 mg/kg lipid. Based on the data reported in this study, it has been estimated here that such body burdens would have resulted from exposure to around 3-6 µg/l. Given the uncertainties with the Kuiper *et al.* (2007) study, it is concluded that the PNEC of 1.3 µg/l derived above is probably protective of the effects seen in this study but it should be noted that no clear NOEC was derived from the Kuiper *et al.* (2007) and so effects at concentrations lower than the PNEC cannot totally be ruled out.

3.2.1.7.2 Sediment

Sediment toxicity data for tetrabromobisphenol-A are available for 14-day partial life-cycle tests (survival and growth) using midge (*Chironomus tentans*) larvae in three sediment types, a 28-day study with midge (*Chironomus riparius*) investigating emergence and development rates, a 28-day study with the amphipod *Hyalella azteca* carried out without supplementary feeding and 28-day survival/reproduction studies using oligochaetes (*Lumbriculus variegatus*) in two sediment types. For *C. tentans*, no effects were seen in the studies and the most relevant NOEC from the studies was ≥340 mg/kg dry weight in a sediment with 6.8% organic carbon content (this corresponds most closely to the Technical Guidance Document default organic carbon content of 5% for sediment). A concentration of ≥340 mg/kg dry weight is equivalent to a concentration of 74 mg/kg wet weight using the default sediment water contents from the Technical Guidance Document (conversion done using EUSES 2.0.3). It should be noted that the control and solvent control responses in this study were poor in some replicates and the results are therefore uncertain and not used to derive a PNEC.

The results of the study with *C. riparius* are considered reliable and suitable for derivation of a PNEC. The NOEC from this study was 125 mg/kg dry weight using a sediment with an organic carbon content of around 5%. A concentration of 125 mg/kg dry weight is equivalent to a concentration of 27 mg/kg wet weight.

The study with *H. azteca* is considered reliable and suitable for derivation of a PNEC. The NOEC from this study was 250 mg/kg dry weight using a sediment with an organic carbon content of around 5.7%. A concentration of 250 mg/kg dry weight is equivalent to a concentration of 54 mg/kg wet weight.

The studies carried out with *L. variegatus* are considered reliable and suitable for derivation of a PNEC. The NOEC from the studies was found to decrease with decreasing organic carbon content, with the NOEC being around 90 mg/kg dry weight (~20 mg/kg wet weight using the default sediment water content) in a sediment of 2.5% organic carbon content and 254 mg/kg dry weight (~55 mg/kg wet weight using the default sediment water content) in sediment with a 5.9% organic carbon content. This indicates that the toxicity of

tetrabromobisphenol-A was expressed mainly through exposure via the pore water/overlying water of the sediment rather than directly via the sediment-bound fraction (the concentration of tetrabromobisphenol-A was analysed in the pore water/overlying water in this study but the results may have been influenced by the presence of sediment-bound tetrabromobisphenol-A and so are difficult to interpret in this respect). This suggests that, for derivation of the PNEC (in order to make it directly comparable with the PECs estimated for sediment) the results from these tests should be normalised to the standard organic carbon content of 5% used for sediments in the Technical Guidance Document. Using this approach, the NOECs from the two sediment types, normalised to a sediment organic carbon content of 5%, are similar at 40 mg/kg wet weight and 47 mg/kg wet weight.

According to the Technical Guidance Document, an assessment factor of 10 is appropriate to long-term toxicity data for three species. When applied to the NOEC of 27 mg/kg wet weight for *C. riparius*, this gives a $PNEC_{sed}$ of 2.7 mg/kg wet weight.

It should be noted that supplementary feeding (using food not contaminated with tetrabromobisphenol-A) was used in the tests with *L. variegatus.* Thus it is possible that the test had not fully taken into account the exposure from the ingestion of contaminated food (although it was recognised that the test had been carried out using the best available method at the time, it is possible that this could have lead to an underestimation of the actual toxicity of tetrabromobisphenol-A). The significance of this route of exposure in terms of the overall toxicity of tetrabromobisphenol-A to sediment organisms is unknown. The tests with both *Chironomus riparius* and *Hyalella azteca* were carried out without supplementary feeding (i.e. all the food needed for the study was incorporated into the sediment at the start of the test and so would contain tetrabromobisphenol-A) and so would take into account this route of exposure.

According to the Technical Guidance Document, the PNEC for sediment can also be calculated using the following equilibrium partitioning method.

$$PNEC_{sed} = \frac{K_{susp-water}}{RHO_{susp}} \times PNEC_{water} \times 1000$$

where $K_{susp\text{-}water}$ = suspended sediment-water partition coefficient = 1,826 m^3/m^3 or 25,000 m^3/m^3 for tetrabromobisphenol-A (see Section 3.1.0.7.2).
RHO_{susp} = bulk density of suspended sediment = 1,150 kg/m^3.

As discussed in Section 3.2.1.7.1 the PNEC for surface water can be estimated as 1.3 µg/l. The equivalent value for the $PNEC_{sed}$ can therefore be estimated as either 2.1 mg/kg wet weight or 28 mg/kg wet weight, depending on the value for the suspended sediment-water partition coefficient used. It can be seen that the $PNEC_{sed}$ estimated by the equilibrium partition method (using the smaller adsorption coefficient) is consistent with that derived from the sediment toxicity data directly.

The Technical Guidance Document indicates that for substances with a log Kow >5 the equilibrium partitioning method may not adequately take into account possible direct ingestion of sediment-bound substance. In this situation, it is recommended that the resulting risk characterisation ratio is increased by a factor of 10 to take this possibility into account.

As sediment toxicity data are available for three species the $PNEC_{sed}$ of 2.7 mg/kg wet weight will be used in the risk characterisation.

As discussed earlier, the adsorptive behaviour of tetrabromobisphenol-A may vary with the pH of the system. This effect is taken into account in the PNECs derived using the equilibrium partitioning approach used above, but also needs to be considered in the PNECs derived from the actual sediment toxicity data. This is because the available data indicate that the toxicity seen in sediments is best explained by exposure through the pore water/overlying water (as seen by the apparent lower toxicity to *Lumbriculus variegatus* in a sediment of 5.9% organic carbon content compared with a sediment of 2.5% organic carbon content; see Section 3.2.1.5), and so the toxicity in sediments may be expected to vary with pH. The $PNEC_{sed}$ of 2.7 mg/kg wet weight derived from the *C. riparius* data was obtained using a sediment of pH 6.1 (this refers to the pH of the sediment prior to mixing with the water; the pH of the overlying water was in the range 7.7-8.6 throughout the test, with the mean pH in the treatment groups being in the range 8.0-8.6; the pH of the sediment under these conditions was not given). Under these conditions, tetrabromobisphenol-A is expected to be present, at least in part, in an ionised form and so the suspended sediment-water partition coefficient of 1,826 m^3/m^3 (corresponding to a Koc of 49,726 l/kg) could be considered to be relevant to this sediment. Assuming this is the case, then it is possible to estimate a $PNEC_{sed}$ of 5.5 mg/kg wet weight for a sediment for which the sediment-water partition coefficient of 3,680 m^3/m^3 (corresponding to a Koc of 147,360 l/kg) would be appropriate. It is recognised that this $PNEC_{sed}$ is subject to a large uncertainty due to the underlying assumptions made but the value of 5.5 mg/kg wet weight will be considered, along with the value of 2.7 mg/kg wet weight derived directly from the toxicity data, in the risk characterisation.

3.2.1.7.3 Microorganisms

An EC_{50} 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. The Draft Technical Recommendation (Doc. ECB4/TR1/98) to the Technical Guidance Document recommends that protozoan toxicity data should be considered in the development of the PNEC for waste water treatment plants. However, this Technical Recommendation indicates that only protozoan growth impairment data should be used. Therefore it is not possible to derive a $PNEC_{microorganisms}$ for tetrabromobisphenol-A based on these data.

A NOEC of ≥15 mg/l has been determined for tetrabromobisphenol-A using the OECD Guideline 209 activated sludge respiration inhibition test. According to the Technical Guidance Document an assessment factor of 10 is appropriate for this type of test. Thus a $PNEC_{microorganisms}$ of ≥1.5 mg/l can be estimated for tetrabromobisphenol-A based on these data. This value will be used in the risk characterisation.

3.2.1.8 Predicted no effect concentration (PNEC) for the marine compartment

3.2.1.8.1 Water

The Technical Guidance recommends that the pooled data for both freshwater and marine organisms are considered in the PNEC derivation.

The overall data set for tetrabromobisphenol-A consists of NOEC values for freshwater fish (NOEC 0.16 mg/l), two species of freshwater invertebrates (lowest NOEC <0.066 mg/l), three species of marine invertebrates (lowest NOEC/EC_{10} = 0.012 mg/l), and one freshwater algal species (NOEC ≥5.6 mg/l). In addition acute EC_{50} values (but no NOEC values) are available for 1 freshwater algal species and 3 marine water algae (lowest EC_{50} is 0.09 mg/l). There is some evidence that the toxicity of tetrabromobisphenol-A to marine algae may increase with decreasing pH in the range pH 7.6 to 8.2, but, given that natural seawater is effectively buffered at around pH 8 such trends in toxicity are not likely to be important in reality.

From the Technical Guidance Document an assessment factor of 50 could be applied to the available data as there are NOECs from freshwater/marine species covering three trophic levels (algae, fish and crustaceans) with in addition a long-term NOEC from an additional marine taxonomic group (molluscs). As marine as well as fresh water species have been tested in two of the trophic levels (algae and crustaceans) it could be considered to reduce the assessment factor to a value of 10. However, there is some uncertainty over the actual NOECs for some of the species tested and no NOEC has been determined for marine algae.

Therefore it is proposed that an assessment factor of 50 will be used on 5-day EC_{10} value for *Acartia tonsa* of 0.0127 mg/l. This gives a PNEC for marine water of 0.25 µg/l.

3.2.1.8.2 Sediment

Reliable long-term toxicity tests have been carried out with the freshwater sediment oligochaete *Lumbriculus variegatus* for two sediment types. The NOEC values for the two sediments from this study, normalised to the Technical Guidance Document default organic carbon content of 5%, were 40 and 47 mg/kg wet weight. In addition, a 28-day studies have been carried out with the freshwater midge *Chironomus riparius* and the freshwater amphipod *Hyalella azteca*. These gave NOECs of 27 mg/kg wet weight and 54 mg/kg wet weight respectively.

According to the Technical Guidance Document, for marine risk an assessment factor of 50 should be applied to the results of long term tests for three freshwater species. Therefore, applying an assessment factor of 50 to the NOEC value of 27 mg/kg wet weight gives a $PNEC_{marine\ sediment}$ of 0.54 mg/kg wet weight.

3.2.2 Terrestrial compartment

3.2.2.1 Toxicity to plants

The effect of tetrabromobisphenol-A on emergence and growth of six species of plants has been determined using the proposed revision for OECD Guideline 208 (Wildlife

International, 2002a). The soil used in the test was an artificial loam soil produced by mixing kaolinite clay, industrial quartz sand and peat in the weight ratio 2:25:1. Crushed limestone was added to buffer the pH of the soil and a slow release fertiliser was added to provide nutrients. The artificial soil consisted of 49% sand, 30% silt and 21% clay, had a pH of 7.79 and an organic matter content of 2.1%.

The test soils were prepared by direct mixing of solid tetrabromobisphenol-A into the soil. After mixing, three subsamples of the soil were collected for analysis to confirm the initial concentration of the test substance within the treated soil, and also to check on the homogeneity of the treated soil.

The following six plant species were tested: Monocots - corn (*Zea mays*), onion (*Allium cepa*), ryegrass (*Lolium perenne*); Dicots - cucumber (*Cucumis sativa*), soybean (*Glycine max*) and tomato (*Lycopersicon esculentum*). A control group and five treatment groups were run for each species. Each group consisted of four replicate pots each containing ten seeds (giving 40 seeds per control or treatment group). The nominal test concentrations used were 20, 78, 313, 1,250 and 5,000 mg/kg dry soil. Analysis by HPLC indicated that the samples were homogeneous and the mean measured concentrations found in the five treatment groups were 16, 64, 253, 1,059 and 4,595 mg/kg dry soil respectively (80-92% of nominal).

During the 21-day test, weekly observations of emergence were made (number of seedlings per pot). In addition, a qualitative assessment of the condition of each seedling was made, i.e. presence or absence of signs of phytotoxicity such as necrosis, leaf wrinkle, chlorosis, plant lodging or plant stunting. At termination of the test, the growth of the seedlings was evaluated in terms of the mean shoot height and mean shoot fresh weight. The emergence and growth data are summarised in **Table 3.65**.

For corn, no treatment-related effects were seen on emergence, height or condition of seedlings during the test. A statistically significant (p=0.05) reduction in mean dry weight of shoot was seen at concentrations of 1,059 mg/kg dry soil and above, and so the NOEC for this species was determined as 253 mg/kg dry soil based on the initial mean measured concentration. The EC_{50}s (nominal concentrations) for growth was determined as >5,000 mg/kg soil.

For cucumber, no treatment-related effects were seen on emergence or condition of seedlings during the test. Some isolated individual seedlings showed signs of leaf curl, necrosis and mortality, but none of these conditions were dose-responsive. A statistically significant reduction in both the mean height and dry weight of seedlings was seen at concentrations of 64 mg/kg dry soil and above. Therefore, the NOEC for seedling growth with this species was 16 mg/kg dry soil based on the initial measured concentration. The EC_{50}s (nominal concentrations) for growth were determined as 2,603 mg/kg soil based on the mean shoot height and 1,672 mg/kg dry soil based on the mean shoot dry weight.

Table 3.65a Effects of tetrabromobisphenol-A on emergence and growth of corn, cucumber and onion seedlings

Measured exposure concentration	Corn			Cucumber			Onion		
	Mean[a] emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)	Mean [a]emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)	Mean[a] emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)
Control	9.25±0.96	39.7±4.57	0.45±0.071	8.50±1.29	9.7±1.11	0.35±0.037	9.00±1.41	7.4±0.78	0.013±0.0021
16 mg/kg dry wt.	10.0±0.00	44.1±1.04	0.48±0.008	9.50±1.00	9.4±0.53	0.32±0.014	9.00±1.55	7.9±0.85	0.013±0.0034
64 mg/kg dry wt.	9.25±0.96	41.5±3.38	0.45±0.063	8.75±1.26	7.5±1.72*	0.28±0.056*	9.50±0.58	7.6±0.46	0.011±0.0020
253 mg/kg dry wt.	9.50±0.58	39.2±2.60	0.41±0.036	8.75±1.26	6.5±1.21*	0.20±0.035*	9.75±0.50	7.2±0.62	0.010±0.0027
1,059 mg/kg dry wt.	9.25±0.50	35.9±1.86	0.36±0.038*	9.25±1.50	5.3±0.46*	0.17±0.011*	9.25±0.50	5.9±0.31*	0.009±0.0019*
4,595 mg/kg dry wt.	9.75±0.50	35.8±1.73	0.36±0.046*	7.50±2.38	4.7±0.53*	0.16±0.020*	9.00±0.00	4.9±0.28*	0.006±0.0012*

Notes: a) Mean ± standard deviation.
* Statistically significantly different from the control population at the p = 0.05 level.

Table 3.65b Effects of tetrabromobisphenol-A on emergence and growth of ryegrass, soybean and tomato seedlings

Measured exposure concentration	Ryegrass			Soybean			Tomato		
	Mean[a] emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)	Mean[a] emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)	Mean[a] emergence (number/ten seeds)	Mean[a] seedling height (cm)	Mean[a] dry weight of shoot (g)
Control	9.25±0.96	15.4±1.29	0.021±0.0012	10.0±0.00	22.1±2.03	0.46±0.014	9.50±0.58	5.6	0.044±0.0088
16 mg/kg dry wt.	9.50±0.58	15.7±1.85	0.023±0.0056	9.50±0.58	22.7±1.60	0.48±0.041	8.75±0.96	5.0	0.039±0.0115
64 mg/kg dry wt.	9.25±0.50	13.0±1.56	0.017±0.0066	10.0±0.00	22.3±2.09	0.51±0.028	9.00±0.82	5.0	0.040±0.0087
253 mg/kg dry wt.	9.00±0.82	9.6±1.75*	0.009±0.0039*	10.0±0.00	22.4±2.81	0.47±0.051	9.25±0.50	4.8	0.033±0.0065
1,059 mg/kg dry wt.	8.75±1.89	7.2±1.15*	0.007±0.0030*	9.75±0.50	22.8±2.11	0.48±0.054	9.25±1.50	4.4*	0.029±0.0055*
4,595 mg/kg dry wt.	8.25±1.26	7.5±0.93*	0.007±0.0032*	9.50±0.58	21.0±1.86	0.49±0.049	9.00±0.82	4.6*	0.022±0.0031*

Note: a) Mean ± standard deviation.
* Statistically significantly different from the control population at the p = 0.05 level.

For onion, no treatment-related effects were seen on seedling emergence or condition of seedlings. A statistically significant reduction in both the mean height and dry weight of seedlings was seen at concentrations of 1,059 mg/kg soil and above. Therefore, the NOEC for seedling growth with this species was 253 mg/kg dry soil based on the initial measured concentration. The EC_{50}s (nominal concentrations) for growth were determined as >5,000 mg/kg soil based on the mean shoot height and 4,264 mg/kg dry soil based on the mean shoot dry weight.

For ryegrass, no treatment-related effects were seen on seedling emergence or condition of seedlings. A statistically significant reduction in both the mean shoot height and mean shoot dry weight was seen at concentrations of 253 mg/kg dry soil and above. The NOEC for growth for this species was therefore 64 mg/kg dry soil. The EC_{50}s (nominal concentrations) for growth were determined as 1,801 mg/kg soil based on the mean shoot height and 459 mg/kg dry soil based on the mean shoot dry weight.

For soybean, no statistically significant effects were seen on any of the endpoints monitored. All seedlings appeared normal at the end of the test. There were a few isolated incidences of leaf curl and stem curl, however these were not considered to be treatment-related. Therefore, the NOEC for this species is ≥4,595 mg/kg dry soil based on the initial mean measured concentration.

For tomato, no treatment-related effects were seen on seedling emergence or condition of seedlings. A statistically significant reduction in both the mean shoot height and mean shoot dry weight was seen at concentrations of 1,059 mg/kg soil and above. The NOEC for growth for this species was therefore 253 mg/kg dry soil. The EC_{50}s (nominal concentrations) for growth based on both the height and weight data were >5,000 mg/kg dry soil.

Overall, treatment-related effects on seedling growth were seen in five out of the six species tested. No treatment-related effects were seen on seedling emergence or condition of seedling in any of the species tested. The NOECs obtained for the various plant species are summarised below. The lowest NOEC determined was 16 mg/kg dry soil.

Species	**NOEC (mg/kg dry soil)**
Corn	253
Cucumber	16
Onion	253
Ryegrass	64
Soybean	≥4,595
Tomato	253

The effects of tetrabromobisphenol-A on seedling emergence and growth in red clover (*Trifolium pratense*) has been determined by Sverdrup *et al.* (2006). The method used was based on the OECD 208: Terrestrial plants, Growth test method. The soil used in the test was a Danish agricultural soil (sandy loam, organic carbon content of 1.6%; further details of the soil are given in Section 3.2.2.2). The soil was dried at 80°C prior to use. The nominal concentrations of tetrabromobisphenol-A used were 3, 10, 30, 100, 300 and 1,000 mg/kg. The test substance was added to the soil as a solution in acetone (the amount of acetone added was around 20% of the dry weight of the soil) and the acetone was allowed to evaporate over 24 hours prior to the start of the test (controls and solvent control soils were also prepared). For the test, 250 g of dry, spiked, soil was used per replicate, and four replicates were used

per treatment. The soils were adjusted to 65% of the water holding capacity and then added to the test chambers (transparent plastic cylinders, 35 cm high, internal diameter 9.5 cm, with a perforated lid) and five seeds per replicate were added. The test chambers were then placed in a greenhouse for 21 days. The chambers were weighed twice each week and any water loss was replenished. The temperature of the greenhouse was a minimum of 15°C at night, and during the day the temperature increased in some cases to >25°C. No treatment related effects on growth (mean fresh weight of seedlings) were seen at any concentration tested compared with the control populations.

3.2.2.2 Toxicity to earthworms

The toxicity of tetrabromobisphenol-A has been studied in a reproduction test using earthworms (*Eisenia fetida*) (Wildlife International, 2003c). The test guideline used was based on the draft OECD guideline (2000 version) for the reproduction test, along with OECD 207 guideline for the acute toxicity to earthworms. The substance tested had a purity of 98.91% (the major stated impurities were *o,p'*-tetrabromobisphenol-A (0.05%), 2,4,6-tribromophenol (<0.01%) and tribromobisphenol-A (1.04%). The nominal concentrations tested were 313, 625, 1,250, 2,500 and 5,000 mg/kg dry weight (Study 1). However, the level of effects seen at these concentrations resulted in the testing of a lower concentration series (Study 2) of nominal concentrations 0.63, 1.3, 2.5, 5.0, 10, 20 and 40 mg/kg dry weight.

The soil used in the test was an artificial soil consisting of 10% sphagnum moss peat, 70% quartz sand and 20% kaolinite clay. The soil had an organic carbon content of 4.5% (Study 1) or 4.7% (Study 2) and a pH of around 6.5. Before use, deionized water was added to the dry soil to hydrate the soil to around 60% of the water holding capacity (~22.3% water).

The test concentrations were made up by either direct chemical addition to the dry soil (Study 1) or direct addition to sand which was then added to the soil (Study 2). The spiked soils were mixed for at least 24 hours before use. Control soils were prepared in the same way as the spiked soils. The tests were carried out in glass jars containing 500 g of dry soil. Four replicate jars were used for each treatment level and eight replicates were used for each control group, with each replicate containing 10 worms. The test was carried out at 20^{o}C. During the study the animals were fed 3-4 ml of invertebrate diet slurry just below the surface. This diet was given at least weekly during the first 21 days of the study, and thereafter at a weekly rate of 3 ml. The test substance was not added to the food. The adult worms in Study 2 were inadvertently not fed at all during the last week of the adult exposure part of the study.

Adult worms (323.9-529.8 mg wet wt. in Study 1 and 450.8-519.8 mg wet wt. in Study 2) were used at the start of the test. On day 28, all remaining parent (adult) worms were counted and removed from the test vessels and the total wet weight of worms was determined. After removal of the adult worms, each test vessel was incubated for a further 28 days to allow hatching of any egg cocoons produced by the parent worms. At the end of this time period, the number of offspring (juveniles) present was determined.

The soil concentrations in the one replicate for each treatment were determined on days 0, 28 and 56 of the experiment. The mean measured concentrations were 95-105% (Study 1) and 74-106% (Study 2) of nominal at day 0, 95-110% (Study 1) and 76-90% (Study 2) of nominal at day 28 and 71-117% (data for Study 2 only) of nominal at day 56. These results indicated that the exposures were close to the nominal values and that the exposure concentrations were

maintained throughout the study. The mean measured concentrations were 326, 640, 1,250, 2,430 and 4,840 mg/kg dry weight in Study 1 and 0.562, 1.16, 2.11, 4.50, 9.01, 16.7 and 35.4 mg/kg dry weight in Study 2.

The survival, growth and reproduction results of the study are shown in **Table 3.66.**

Parent survival was 100% and 97% in the control groups for Study 1 and Study 2 respectively. Parent survival in the treatment groups was found not to be statistically significantly reduced (p=0.05) at any concentration tested. Thus the $NOEC_{survival}$ is ≥4,840 mg/kg dry wt.

Growth of the parent organisms was determined as the percentage weight gain over days 0 to 28. The mean weight gain in the control and solvent control groups was 35% in Study 1 and 8% in Study 2. The growth in the adult worms exposed to tetrabromobisphenol-A was generally higher than found in the control population, except at 4,840 mg/kg dry weight. The growth data do not appear to have been analysed statistically in the test report but, based on this finding, the $NOEC_{growth}$ is around 2,430 mg/kg dry wt.

Reproduction of the earthworms was investigated in terms of mean number of live offspring per replicate chamber. All treatments showed a reduction in the mean number of live offspring compared with their respective control group but this reduction was only statistically significant at concentrations of 4.5 mg/kg dry weight and above. Thus the $NOEC_{reproduction}$ was determined as 2.11 mg/kg dry weight.

Table 3.66 Toxicity of tetrabromobisphenol-A to earthworms (Wildlife International, 2003c)

Exposure concentration (mg/kg dry wt.)		Parent survival	Change in weight of parents	Mean[a] number of live offspring per replicate
Nominal	Measured			
Control – Study 1		100%	35%	174±33.2
Control –Study 2		97%	8%	95±38.8
Study 1				
5,000	4,840	100%	-3.3%	0*
2,500	2,430	97%	54.7%	0*
1,250	1,250	100%	79%	1*±0.8
625	640	100%	95.8%	2*±1.7
313	326	100%	102.1%	3*±2.5
Study 2				
40	35.4	97%	87%	2.8*±1.5
20	16.7	97%	66%	2.0*±0.8
10	9.01	100%	43%	19*±12.6
5.0	4.50	100%	46%	38*±13.3
2.5	2.11	100%	57%	48±25.7
1.3	1.16	97%	30%	64±36.0
0.63	0.562	92%	27%	53±24.1

Notes: a) Mean ± standard deviation.
* Value significantly different from the solvent control population (p=0.05).

The percentage coefficient of variation in the reproduction data for the control group in Study 2 was relatively large (41%), and indeed was higher than the figure of 30% suggested in the protocol. The consequence of this is that the statistically derived $NOEC_{reproduction}$ actually refers to a concentration where around 50% effect was seen on the reproduction rate. Therefore, the variability seen in the controls means that this NOEC can be questioned owing to the actual effects seen at this concentration.

Another way of analysing the data is to derive an EC_{10} and EC_{50} from the dose-response pattern seen in Study 2. These values were estimated in the original report as EC_{10} = 0.12 mg/kg dry weight (95% confidence interval 0.00033-0.46 mg/kg dry weight) and EC_{50} = 1.7 mg/kg (95% confidence limit 0.46-3.7 mg/kg dry weight). In this case it should be noted that the calculated EC_{10} is actually a value extrapolated below the lowest concentration tested.

The reason for the high variability in the control reproduction data in Study 2 is not clear. It was noted in the test report that the adult worms in Study 2 were accidentally not fed during the last week of the adult exposure part of the study. This could have contributed to the variability seen. However, the exposure groups in Study 2 were also not fed during the same period, and here the average reproduction per treatment was much less than seen in the controls. In addition, a large effect on reproduction was also seen in Study 1 where the animals were fed over all of the adult exposure period. Thus, although there are some questions over the study, it can be concluded that the effects seen on reproduction were probably treatment-related rather than related to poor experimental procedure.

Overall, this study showed considerable effects on the reproduction of earthworms. There are some uncertainties associated with the overall NOEC, EC_{10} and EC_{50} values derived from this study (particularly related to the variability seen in the control population for Study 2 and the extrapolation of the EC_{10} to below the lowest concentration tested). As the derivation of the EC_{10} is based on the actual dose-response seen, it is probable that this represents a more reliable estimate of the true NOEC from this study than the NOEC derived by statistical comparison with the control population.

The soil used in Study 2 had an organic carbon content of 4.5% (organic matter content 7.7%). According to the Technical Guidance Document, the results from soil toxicity tests should be normalised to a standard soil organic carbon content of 2% (organic matter content 3.4%). The resulting standard NOECs, EC_{10} and EC_{50}'s obtained applying this correction (and also using a correction for the default water content of soil) obtained from Study 2 are summarised below.

NOEC = 2.11 mg/kg dry wt.	$NOEC_{standard}$ = 0.93 mg/kg dry wt . = 0.83 mg/kg wet wt.
EC_{10} = 0.12 mg/kg dry wt.	$EC_{10, standard}$ = 0.053 mg/kg dry wt. = 0.047 mg/kg wet wt.
EC_{50} = 1.7 mg/kg dry wt.	$EC_{50, standard}$ = 0.76 mg/kg dry wt. = 0.67 mg/kg wet wt.

As a result of the poor control response seen in Study 2, a further reproduction test with *Eisenia fetida* has been carried out in order to determine a more reliable NOEC or EC_{10} value (ABC Laboratories, 2005). The test was carried out according to OECD Guideline 222. The substance tested had a purity of 99.2%. The worms used in the test were around 10 months old at the start of the test (they were taken from a synchronous population where the animals were approximately the same age within a range of four weeks). The initial mean weight of

the worms used was 543 mg/worm in the control group and 475 to 591 mg/worm in the treatment groups.

The test was carried out using artificial soil consisting of 70% silica sand, 20% kaolin clay and 10% sphagnum peat moss. The pH of the soil was adjusted by addition of calcium carbonate to give an initial pH of around 6. The soil was characterized as a sandy clay loam (77% sand, 6% silt and 17% clay) with an organic carbon content of 4.4% (organic matter content of 7.6%). The soil was spiked by direct addition of pulverized tetrabromobisphenol-A into the silica sand, mixing well, and then adding aliquots (10 g) of the spiked sand to the bulk of the dry soil (2.41 kg) and mixing for at least 24 hours. After mixing, the soils were hydrated to 60% of the water holding capacity by addition of 550 ml of deionised water to each soil batch. Approximately 622g of the hydrated soil (~500 g dry soil) was then added to each replicate test chamber. A total of eight replicate chambers were used for the control and four replicate test chambers were used for each treatment level. The nominal concentrations of tetrabromobisphenol-A used in the treatments were 0.31, 0.63, 1.3, 2.5, 5.0, 10 and 20 mg/kg dry weight. The test was carried out at a temperature of 20°C (±2°C).

The test was initiated by the addition of ten worms per replicate (giving a total of 80 worms in the control and 40 worms per treatment level) onto the surface of the soil. The soil in each replicate contained 2.5 g of food (invertebrate diet) at the start of the test and additional food was added at least weekly during the test (around 0.45 to 1.36 mg of food per event). Burrowing behaviour was observed 20 minutes after addition of the worms. Mortality, growth (weight) and general observations on the health of the worms was determined after 28 days exposure and reproduction (number of juvenile worms) was determined after 56 days exposure.

The soil concentrations were determined on days 0, 28 and 56 of the experiment. The mean measured concentrations were 0.29, 0.93, 2.0, 3.7, 5.3, 11 and 18 mg/kg dry weight in the seven treatment groups respectively (in the range 90-154% of the nominal values). Samples taken to investigate the homogeneity of the soil on day 0 indicated a high degree of variability at the low dose level (three samples ranged from 67 to 682% of the nominal in the 0.31 mg/kg dry weight treatment) but this was not evident at the highest dose level (the homegeniety samples were within 99.2-119% of the nominal in the 20 mg/kg treatment). The laboratory reported that this initial homegeniety in the low-dose samples was a not uncommon finding in this type of study.

The survival, growth and reproduction results of the study are summarised in **Table 3.67**.

Parent survival was 100% in the control and all treatments at 28 days. All of the live earthworms were normal in appearance and behaviour with the exception of one small worm in the 5.3 mg/kg treatment group and one small worm in the 11 mg/kg treatment group. Similarly, no statistically significant effects were seen on the growth of the organisms (as determined by the percentage weight gain over days 0 to 28). Overall the NOEC for survival and growth from this study ($NOEC_{survival\ and\ growth} \geq 18$ mg/kg dry weight) was in agreement with the results from the first two studies.

Table 3.67 Toxicity of tetrabromobisphenol-A to earthworms (ABC Laboratories, 2005)

Exposure concentration (mg/kg dry wt.)		Parent survival	Change in weight of parents	Mean[a] number of live offspring per replicate
Nominal	Measured			
Control		100%	76%	175
20	18	100%	107%	0.5*
10	11	100%	107%	1*
5.0	5.3	100%	111%	6*
2.5	3.7	100%	101%	34*
1.3	2.0	100%	85%	90*
0.63	0.93	100%	80%	75*
0.31	0.29	100%	84%	162

Notes: a) Mean values only were given (the standard deviation was not reported although it could be calculated from the raw data)..
* Value significantly different from the solvent control population (p=0.05).

For the reproduction endpoint, the average reproduction in the control animals was 175 juveniles per replicate. Percent coefficient of variation in the control response was 19% which is within the 30% figure recommended in the protocol. Statistically significant (p=0.05) (and dose-dependent) reductions in the number of juveniles per replicate were found in the groups exposed to 0.93 mg/kg dry weight and above. The NOEC for reproduction was therefore determined as 0.29 mg/kg dry weight. The EC_{50} for reproduction was determined to be 0.91 mg/kg dry weight (95% confidence interval 0.66 to 1.2 mg/kg dry weight).

The most recent earthworm study confirms the findings on reproduction from the first two studies, and allows a reliable NOEC for this endpoint of 0.29 mg/kg dry weight to be determined. As the control response in this study was within the recommendations of the test guideline, this result will be used in the risk assessment in preference to the data obtained in from Study 2 above.

The NOEC of 0.29 mg/kg dry weight was obtained using a soil of 4.4% organic carbon content. The Technical Guidance Document recommends that the NOEC from such a study should be normalised to a standard organic carbon content of 2%. The resulting $NOEC_{standard}$ = 0.13 mg/kg dry weight = 0.12 mg/kg wet weight.

A further study on the toxicity of tetrabromobisphenol-A to earthworms has been carried out (Sverdrup *et al.*, 2006). The species used in the test was *Enchytraeus crypticus* and the endpoints investigated were survival and reproduction. The tests were performed according to an ISO standardised procedure (ISO, 2002). The soil used in the test was a Danish agricultural soil. The soil was dried at 80°C and sieved (2 mm mesh) prior to use. The soil was classified as a sandy loam with a total organic carbon content of 1.6% (humus content was 2.8%) and a pH of 6.2. The particle size distribution was coarse sand – 38.4%, fine sand – 23.6%, coarse silt – 12.7%, fine silt 12.3% and clay 13.0%.

Stock solutions of the test substance were prepared in acetone. The acetone solution (the amount of acetone added was around 20% of the soil dry weight) was added to the dry soil and thoroughly mixed into the soil. The acetone was allowed to evaporate at room temperature over 24 hours. The soil was adjusted to 65% of the water holding capacity and

transferred to sealed plastic jars (5 cm high, internal diameter 3.5 cm) for the experiment. A total of 20 g dry soil were used for each replicate and both a control and solvent control were also prepared. Four replicates were used for each treatment. Prior to addition of the test organisms, approximately 30 mg of cooked oatmeal was mixed into the soil. The test was started by adding 10 adult enchytraeids (sexually mature animals of approximately the same size were used) and the test chambers were incubated at 20°C for 21 days. The test chambers were opened on day 7 and day 14 for feeding, and addition of water if needed.

The nominal concentrations of tetrabromobisphenol-A used in the test were 1, 3, 10, 30, 100, 300 and 1,000 mg/kg dry weight. Analytical verification of the actual concentrations was carried out at the start and the end of the test, and showed that the concentrations, although slightly lower than the nominal values, were relatively stable over the 21 day period. The mean measured concentrations over the course of the 21 day period were as follows - 0.59, 5.0, 70 and 853 mg/kg dry weight for the nominal 1, 10, 100 and 1,000 mg/kg dry weight treatments respectively (note the measured concentrations were taken in pooled samples of soil from this test, as well as the test with red clover described in Section 3.2.2.1and the test on soil nitrification described in Section 3.2.2.3). The results in the test were expressed in terms of nominal concentrations. No significant differences were seen in the control and solvent control populations and control populations were pooled for comparison with the treatment groups.

No effect on enchytraeid survival was seen in any treatment group compared with the pooled control population. However, statistically significant (p=0.05) effects on reproduction (reduced number of juveniles per replicate) were evident compared with the pooled control population at nominal concentration of 10 mg/kg dry weight and above (the results were shown graphically only in the paper; the pooled control response was >600 juveniles per replicate). The EC_{10} for reproduction was estimated to be 2.7 mg/kg dry weight, again based on nominal concentrations. Owing to the lack of raw data presented in the paper it is not currently possible to recalculate this value on a measured concentration basis, but, as the measured concentrations were generally in the range 59%-87% of the nominal value, this would likely only result in a slightly lower EC_{10} value.

3.2.2.3 Toxicity to soil microorganisms

The toxicity of tetrabromobisphenol-A to soil microorganisms has been investigated in an OECD 216 soil microorganisms: nitrogen transformation test (Wildlife International, 2005c). The substance tested was a composite sample from the three major suppliers of the substance and had a purity of >99%. The soil used in the test was a pesticide-free sandy loam collected from a pine forest area in Grand Forks County, North Dakota, United States. The soil had a sand content of 69%, a silt content of 12%, a clay content of 19%, a pH of 6.9, an organic carbon content of 1.3% and a microbial biomass of 127 mg/kg dry weight soil. For the test the soil was adjusted to approximately 50% of its water holding capacity and pre-incubated in the dark at 20°C for 24 days. After the pre-incubation, the soil was amended with powdered alfalfa (*Medicago sativa*) at a rate of 5 g/kg dry soil. The alfalfa had a carbon to nitrogen ratio of approximately 15:1. The tetrabromobisphenol-A was then added by direct weight addition of the powder and distributed homogeneously throughout the soil. The treated soils were then incubated in the dark at 20°C for 28 days. A total of five nominal tetrabromobisphenol-A concentrations (10, 32, 100, 316 and 1,000 mg/kg dry weight) were tested along with a control. Three replicates were used for each treatment level and control. Samples for ammonium, nitrite and nitrate analysis were collected on days 0, 7, 14 and 28.

The moisture content of the soil was maintained between 18.2 and 20.8% throughout the test. An increase in soil nitrate concentration was seen in each treatment and control from day 0 to day 28. The average concentration of nitrate present (± standard deviation) at day 28 was 117.4±5.4 mg/kg dry weight in the control, and 107.3±3.8, 108.4±1.5, 108.1±0.4, 109.0±5.4 and 106.4±3.7 mg/kg dry weight in the 10, 32, 100, 316 and 1,000 mg/kg dry weight treatment groups respectively. The percentage inhibition was therefore <10% in all treatment groups. The variation between the rates of nitrate formation measured on day 28 in all control sample replicates was less than 15%, which fulfils the validity criteria of the test. In addition, a reference toxicant (2-chloro-6(trichloromethyl) pyridine) showed 85.1% inhibition of the average nitrate formation rate at a concentration of 500 mg/kg dry weight compared to the control using a similar test systems. It was concluded that the EC_{10} for tetrabromobisphenol-A was >1,000 mg/kg dry weight.

A further soil nitrification inhibition test with tetrabromobisphenol-A has been carried out by Sverdrup *et al.* (2006). The test method was based on an ISO method (ISO, 1997). The soil used in the test and the method of addition of the test substance to the soil were the same as used for the *Enchytraeus* sp. test described in Section 3.2.2.2. As this soil was dried at 80°C, and large amounts of acetone were added to the soil during spiking with the test substance, the test method was modified to take into account that the soil microbial diversity and biomass may have been affected by this treatment. Thus, an inoculum prepared from fresh soil samples, and a nitrogen source (horn meal at 1 g/kg dry soil), was added to the soil following evaporation of the acetone. The inoculum was prepared by mixing 20 g fresh soil and 180 ml deionised water to produce a slurry. The final water content of the soil was adjusted to 57% of the water holding capacity. The tetrabromobisphenol-A concentrations tested were 1, 3, 10, 30, 100, 300 and 1,000 mg/kg dry weight (nominal values).

The test chambers (height 5 cm, internal diameter 3.5 cm containing 20 g dry weight soil) were sealed and incubated for four weeks at 20°C in the dark. The chambers were weighed twice each week and water was added if necessary to compensate for water loss during the study. At the end of the study, the nitrate/nitrite content of the soils was determined. A statistically significant (p=0.05) effect on soil nitrification compared to the control group was seen at the highest concentration tested (nominal concentration of 1,000 mg/kg dry weight). Thus the NOEC was determined to be 300 mg/kg dry weight (nominal).

3.2.2.4 Predicted no effect concentration (PNEC) for the terrestrial compartment

A $PNEC_{soil}$ can be derived from the available toxicity data for terrestrial species. Tests are available for plants, earthworms and soil microorganisms. The lowest reliable $NOEC_{standard}$ obtained was 0.12 mg/kg wet wt. for earthworms.

As data are available for both plants, earthworms and soil microorganisms, an assessment factor of 10 is applicable. Applying this factor to the earthworm data gives a $PNEC_{soil,\ standard}$ of 0.012 mg/kg wet weight.

In addition, a PNEC for this endpoint can be estimated using the equilibrium partitioning approach given in the Technical Guidance Document.

$$PNEC_{soil} = \frac{K_{soil-water}}{RHO_{soil}} \times PNEC_{water} \times 1000$$

where $K_{soil-water}$ = soil-water partition coefficient = 4,982 m^3/m^3 or 4,420 m^3/m^3 for tetrabromobisphenol-A.
RHO_{soil} = bulk density of wet soil = 1,700 kg/m^3.

Using the PNEC for surface water of 1.3 µg/l, a PNEC for soil of 3.8 mg/kg wet weight or 3.4 mg/kg wet weight can be estimated for tetrabromobisphenol-A depending on the value for the soil-water partition coefficient used. The equilibrium partitioning method may underestimate the actual toxicity of substances with log Kow values >5 as it does not take into account the possible direct ingestion of soil-bound substance. In order to take this possibility into account, the Technical Guidance Document recommends that the risk characterisation ratio is increased by a factor of 10.

A comparison between the $PNEC_{soil,\ standard}$ derived from the available soil toxicity data and that derived by the equilibrium partitioning method is complicated by the fact that, as indicated earlier, the soil-water partition coefficient for tetrabromobisphenol-A varies depending on, amongst other parameters, the pH. The NOEC for earthworms was obtained from a soil of pH of around 6.1-6.2 at the start of the test, rising to around 6.9 -7.3 day 28 and falling to around 5.8-6.5 at the end of the test. This pH change may mean that the adsorption characteristics for tetrabromobisphenol-A may have varied during the test (the soil-water partition coefficient would be expected to decrease with increasing pH for an acidic substance). Therefore, it is difficult to compare the $PNEC_{soil,\ standard}$ derived from the soil toxicity data with the PNECs derived by the equilibrium partitioning method. However, it is clear that the PNECs derived from the soil toxicity data are considerably lower than those derived from equilibrium partitioning.

The $PNEC_{soil,\ standard}$ of 0.012 mg/kg wet weight will be considered in the risk characterisation.

3.2.3 Atmosphere

No information is available on the toxicity of tetrabromobisphenol-A to plants and other organisms exposed via air. The very low vapour pressure of the substance means that volatilisation to the atmosphere is likely to be limited and the resulting concentrations are likely to be very low. This means that the possibility of tetrabromobisphenol-A contributing to atmospheric effects such as global warming, ozone depletion and acid rain is likely to be very small.

The available information on the long-range atmospheric transport of this substance indicates that the substance has a low, but not zero, potential to be transported over long distances via the atmosphere. The substance is thought to adsorb strongly onto atmospheric particulates and that it is the transport behaviour of these particulates that effectively govern the transport behaviour of tetrabromobisphenol-A itself. Tetrabromobisphenol-A has been found in samples of moss from Norway and this may provide an indication that transport via the environment may occur for tetrabromobisphenol-A by the mechanism outlined above.

An in-depth assessment of the potential for long-range transport of tetrabromobisphenol-A has been carried out by de Wit *et al.* (2006). This review considered both data available in the literature and unpublished monitoring data on levels in air, sediment and biota samples from

Arctic regions (many of these data are already included in this assessment). It was found that there were relatively few data on the levels of tetrabromobisphenol-A in such samples. However, it was suggested that the finding of tetrabromobisphenol-A in air, moss, marine sediments, atlantic cod liver and in Norwegian peregrine falcon and golden eagle eggs was suggestive that long-range transport to the Arctic could occur. However it was also recognised that the available database was small.

3.2.4 Non-compartment specific effects relevant for the food chain (secondary poisoning)

3.2.4.1 Avian toxicity

No standard avian toxicity data are available for tetrabromobisphenol-A. Studies looking at the estrogenic effects of tetrabromobisphenol-A on avian systems are described in Section 3.1.4.3.

3.2.4.2 Mammalian toxicity

The mammalian toxicity data for tetrabromobisphenol-A are described in detail in Section 4. A summary of the available relevant data is given below.

- Repeated dose toxicity. No toxicologically significant effects in rats over 13 weeks at oral doses of up to 1,000 mg/kg bw/day (no effects at the highest concentration tested)[20].
- Fertility. No effects on fertility or reproductive performance or any other toxicologically significant effects were seen in a 2-generation reproduction study with rats at doses up to 1,000 mg/kg bw/day (no effects at the highest concentration tested).
- Development. Doses up to 10,000 mg/kg bw/day shown to have no effects on development in the rat (no effects at the highest concentration tested).
- Developmental neurotoxicity. No convincing evidence of an adverse effect on neurodevelopment at doses up to 1,000 mg/kg bw/day in rates (no effects at the highest concentration tested; part of a 2-generation study in rats). No evidence of adverse effects in a post-natal developmental neurotoxicity study with mice (only relatively low concentrations were tested in this study, 0.75 and 11.5 mg/kg bw).
- Nephrotoxicity. NOAEL of 40 mg/kg bw/day for newborn rats exposed on day 4 up to 21 after birth by gavage. According to the current version of the risk assessment for human health, it is likely that the effects seen in this study resulted from the unconventional direct gavage administration of very high doses of tetrabromobisphenol-A to such young animals and so this endpoint is not considered relevant for the PNEC derivation.

As discussed in the human health assessment (Section 4.1.2.9), one or two Member States were of the opinion that an effect on neurobehavioural development was observed and that a NOAEL of 50 mg/kg bw/day could be derived for this endpoint in rats. However, the

[20] Note: As discussed in the human health assessment (see Section 4.1.2.6), one or two Member States expressed concern regarding the significance of some observations in the study (the decrease in T_4 levels observed in rats). However, the majority of Member States agreed with the position of the rapporteur that these effects are not considered to be adverse.

majority of Member States were in agreement with the position of the rapporteur described above.

3.2.4.3 Endocrine activity

Berg *et al.* (2001) investigated the effects of tetrabromobisphenol-A on sex organ development in avian embryos. The substance tested was recrystallised before use and had a purity of >99%. Both quail and chicken eggs were used in the study. The substance was dissolved in a mixture of peanut oil and lecithin which was then emulsified in water prior to injection into the yolk of the eggs on day 3 of incubation (quail eggs) or day 4 of incubation (chicken eggs). The amount of test solution injected into each egg was 20 µl/egg for quail eggs and 100 µl/egg for chicken eggs. The control eggs received the corresponding amount of solvent but not tetrabromobisphenol-A. Two concentrations of tetrabromobisphenol-A were tested in each species, 15 and 45 µg/g egg, and a minimum of 24 eggs were used per treatment.

The effects on the embryos were determined on day 15 of incubation for quails and day 19 of incubation for chickens. This corresponded to approximately two days before the expected hatching day for each species.

The highest dose of tetrabromobisphenol-A (45 µg/g egg) caused 80% mortality in quail and 96% mortality in chicken. These mortality rates were statistically significantly different (p=0.05) from the mortalities seen in the control populations (13% in quail and 8% in chicken). The mortalities in the 15 µg/g egg treatment groups were 23% for quail and 25% for chicken and were not significantly different (p=0.05) from the control populations.

As well as mortality, the gross morphology of the Müllerian ducts in females and the occurrence of ovotestis in males was also investigated in the 15 µg/g egg treatment groups (the mortalities in the 45 µg/g egg treatment groups were too high to allow these endpoints to be investigated). In the exposed quail embryos, 0% of the females were found to have abnormal Müllerian ducts and 50% of the males were found to have ovotestis. These values were not significantly different (p=0.05) from the control population (0% of females with abnormal Müllerian ducts and 45% of males with an ovotestis), however, the high occurrence of ovotestis in the control means that this endpoint may not be suitable for investigating possible estrogenic effects in quail.

In the chicken embryo experiments 0% of the exposed females were found to have abnormal Müllerian ducts and 0% of the exposed males had an ovotestis. These were not significantly different (p=0.05) from the control population (0% of females with abnormal Müllerian ducts and 0% of males with an ovotestis).

Overall, it was concluded that tetrabromobisphenol-A, at a concentration of 15 µg/g egg, had no significant effects on development of Müllerian ducts and did not induce ovotestis formation. It was not possible to conclude on these endpoints at the higher concentration (45 µg/g egg) tested. Under similar conditions, bisphenol-A at a concentration of 200 µg/g egg induced significant Müllerian duct malformations in female quail embryos and caused a significant induction of ovotestis in male chicken embryo, whereas no statistically significant effects were seen in these endpoints in embryos exposed to 67 µg bisphenol-A/egg (Berg *et al.*, 2001).

The estrogenic activity of tetrabromobisphenol-A to quail embryos has been studied further by Halldin *et al.* (2001 and 2005). In this study 3-day-old fertilised eggs were injected with tetrabromobisphenol-A (purity >98%, recrystallised before use) dissolved in a mixture of peanut oil and lecithin emulsified in water. The amount of test solution injected was 20 µl/egg and the resulting concentration of tetrabromobisphenol-A was 15 µg/g egg. The eggs were incubated at 37.5^{o}C until day 15, when the eggs were placed in hatching boxes. After hatching (day 17-19) the chicks were raised in heterosexual groups fed with turkey starter.

When the males were eight weeks old, tests were carried out to investigate effects of the treatment on sexual behaviour over five consecutive days. A few days after these behavioural tests had been carried out blood samples were collected for analysis of the testosterone levels and the body weights and testis weights of the birds were determined. No statistically significant differences were found between the tetrabromobisphenol-A exposed population (12 birds) and the control population (17 birds) in respect to the sexual behaviour, gonado-somatic index, testis weight asymmetry, plasma testosterone levels and body weight.

The female offspring were individually separated when they were 11 weeks old and the number of eggs produced by each female was counted over the course of five days. The body weights and oviduct weights were then determined three to five days after the last egg sampling, and the oviducts were examined for gross abnormalities and retention of right oviduct. No statistically significant differences were found between the tetrabromobisphenol-A exposure population (8 birds) and the control population (8 birds) in respect to the number of eggs produced, retention of right oviduct, body weight or weight of left oviduct.

The endpoints investigated in this study, in particular effects on male sexual behaviour, testis weight asymmetry, oviduct malformation (including presence of right oviduct) and impairment of egg laying are endpoints that are known to be sensitive to embryonic estrogen exposure. Overall, no significant effects were seen in any of these endpoints resulting from exposure to tetrabromobisphenol-A.

The Halldin *et al.* (2001) study also investigated the tissue distribution of the tetrabromobisphenol-A within the developing embryo. These data are summarised in Section 3.1.0.7.4.

The endocrine activity of tetrabromobisphenol-A in mammalian systems is described in detail in Section 4. Overall it is concluded that the weight of evidence from *in vitro* screening assays indicates that tetrabromobisphenol-A has no significant estrogenic potential in mammalian systems. In addition, although the potential for tetrabromobisphenol-A to compete with binding of thyroxine to transthyretin (TTR; thyroid hormone-binding transport protein) has been demonstrated *in vitro*, no firm conclusions regarding the affinity of tetrabromobisphenol-A for TTR *in vivo* could be drawn from the limited data available.

Tetrabromobisphenol-A is, however, currently being studied further for possible *in vivo* endocrine disrupting effects in the FIRE project by the Cluster of Research into Endocrine Disruption in Europe (CREDO, 2005 and 2006b). Full details of all of these studies are not yet available but a 4-week repeated dose subchronic (OECD 407) study investigating endocrinological parameters and a one generation reproduction study with rats have been carried out. It should be borne in mind that a valid GLP 90 day study and full GLP

2-generation study with neurotoxicity investigations in the F2 generation are already available (Section 4) and were negative.

In addition, other recent published information (that is not yet considered in Section 4 of this assessment) appears to indicate that tetrabromobisphenol-A showed effects on the endocrine system in some *in vitro* and *in vivo* tests. For example, Kitamura *et al.* (2005a) found that tetrabromobisphenol-A markedly inhibited the binding of ^{125}I-T3 to the thyroid hormone receptor in the concentration range 1×10^{-7} M (~54 μg/l) to 1×10^{-4} M (~54 mg/l) (the IC_{50} was determined to be 3.5×10^{-6} M (~2 mg/l)) using the nuclear fraction of the rat pituitary cell line (GH3), and found that tetrabromobisphenol-A acted as thyroid hormone antagonist, but not agonist, in the luciferase reported assay using CHO-K1 cells (Chinese hamster ovary cell line) in the concentration range 3×10^{-6}-5×10^{-5} M (~1.6-27 mg/l). However, when considering the Kitamura *et al.* (2005a) study it should be born in mind that no biologically significant toxic effects on the thyroid have been reported *in vivo* at dose levels of to 1,000 mg/kg/bw/day (see Section 4).

Some results from the EU FIRE project have recently become available for tetrabromobisphenol-A in an extended abstract (Van der Ven *et al.*, 2006 and CREDO, 2006b). Tetrabromobisphenol-A was tested in an OECD 407 28 day repeated dose study and an OECD 415 one generation reproduction study. Both studies were modified to included several endocrine and immunological endpoints. The substance was administered by mixing into the diet. To enable a precise dose-response analysis to be undertaken, a total of eight doses (including the control) were used, with the tetrabromobisphenol-A dose in the range 3 to 3,000 mg/kg bodyweight/day. The relatively large number of doses used allowed benchmark doses to be estimated (the 5th percentile lower confidence bound of the critical effect dose at a critical effect size (taken to be a 10% change for most parameters)). In the 28-day study, tetrabromobisphenol-A was found to induce increased T3 levels in females, and caused a decrease in T4 levels in both males and females. In the reproduction study, it was found the tetrabromobisphenol-A exposure resulted in an increase in pituitary weight (males only) and a slight activation of the thyroid gland in females. The paper also suggests that developmental effects in neurophysiological functions may have been seen in the reproduction study, but gives no further details (see below). The benchmark doses for the effects seen in these studies were determined to be 0.6 mg/kg bw/day for pituitary weight in males, 19 mg/kg bw/day for plasma total T3 levels in females, 17 mg/kg bw/day for plasma total T4 levels in males and 28 mg/kg bw/day for plasma total T4 levels in females. Currently, this study has not been evaluated and its reliability is therefore uncertain. The Rapporteur has obtained the raw data from the study authors and is currently evaluating it (see below). If further discussion of the data is required, the results will be submitted to the human health experts at TCNES.

Further details of the OECD 415 one generation reproduction study in rats carried out as part of the FIRE project have also become available (Lilienthal *et al.*, 2006) but only in abstract form. The test was carried out using the, using a benchmark design. In the study, groups of Wistar rats were dosed with tetrabromobisphenol-A (concentrations 3, 10, 30, 100, 300, 1,000 or 3,000 mg/kg bw/day plus control) continuously from before conception, through mating, gestation, lactation and after weaning of the offspring). The endpoint investigated was brain stem auditory evoked potentials (BAEPs) in adult offspring. Exposure to tetrabromobisphenol-A was reported to cause elevated thresholds and prolonged latencies in BAEP in adult rat offspring and benchmark calculations indicated that the lowest bench mark dose values were 0.9 mg/kg bw/day for threshold at 2 khz in female offspring and 7.7 and 8.3

mg/kg bw/day for latencies of wave IV at 0.5 kHz in males and females respectively. Currently, this study has not been evaluated and its reliability is therefore uncertain. The Rapporteur has obtained the raw data from the study authors and is currently evaluating it (see below). If further discussion of the data is required, the results will be submitted to the human health experts at TCNES.

Kitamura *et al.* (2005b) carried out a range of *in vitro* endocrine disruption screening tests investigating estrogenic and anti-estrogenic (using human breast cancer cell line MCF-7), androgenic and anti-androgenic (using mouse fibroblast cell line NIH3T3) and thyroid hormonal and anti-thyroid hormonal (using rate pituitary cell line GH3) activities. The authors found some estrogenic activity for tetrabromobisphenol-A in an estrogen luciferase reporter assay with MCF-7 cells (the EC_{50} was 19 µM (~10 mg/l)), anti-estrogenic activity for tetrabromobisphenol-A against 17ß-estradiol using MCF-7 cells at a concentration of around 1×10^{-5} M (~5 mg/l)), and found that tetrabromobisphenol-A acted as a thyroid hormone agonist, but not antagonist, in an assay measuring the induction of growth hormone production in GH3 cells. Tetrabromobisphenol-A showed no adverse response in any of the other *in vitro* test systems.

Kitamura *et al.* (2005b) also carried out an *in vivo* uterotrophic assay using ovariectomised mice. The animals were dosed by intraperitoneal injection (the mice were treated once a day for three days). A positive estrogenic response was found in this study (a statistically significant (p=0.05) 124% increase in uterus weight was seen over the castrated control at a dose of 20 mg/kg bw.). It should be considered that, despite the positive effect found *in vitro* in the Kitamura *et al.* (2005b) study, there is a well conducted 2-generation reproduction study available in which no treatment-related toxicity was reported in rats (dams or pups) administered doses of up to 1,000 mg/kg bw/day (see Section 4).

Other studies that have been carried out on the endocrine disrupting potential of tetrabromobisphenol-A in mammalian systems include those by Ghisari and Bonefeld-Jorgensen (2005), Okada *et al.* (2005), Germer *et al.* (2006), Marchesini *et al.* (2006) and Canton *et al.* (2005 and 2006) amongst others. These papers are also potentially relevant to the human health assessment and have not be reviewed here.

There is clearly a significant amount of new information being generated on the possible endocrine disrupting effects of tetrabromobisphenol-A, the significance of which may not be fully apparent until the FIRE Project is completed. Therefore the assessment of endocrine disruption in mammalian systems may need to be revisited once the full details of these studies are available. In terms of the risk assessment, effects appear to have been seen in some of these studies at relatively low doses (e.g. the FIRE project reports benchmark doses as low as 0.6 mg/kg bw/day for pituitary weights and 0.9 mg/kg bw/day for neurotoxicological effects in the one generation study) and so are potentially important to the assessment of secondary poisoning. These data have not yet been fully validated and discussed by the TCNES in relation to the human health assessment and so the data cannot yet be considered in the derivation of the PNEC for secondary poisoning. It should also be noted that the results of a fully valid two-generation reproductive toxicity study that also investigated neurotoxicological endpoints are available and this study found no convincing evidence for adverse effects at doses up to 1,000 mg/kg bw/day.

In relation to the results from the FIRE project, the Rapporteur has carried out a preliminary review of the results of the 28-day range-finding study and the 1-generation study. Draft

manuscripts submitted for publication were obtained by the Rapporteur from the authors of the studies. An initial evaluation of the data reveals several methodological problems including the detection of TBBPA and its metabolites in the liver and plasma of control rats. These raise a number of questions about the reliability of the claimed findings. The Rapporteur is of the view that a thorough, critical appraisal of these studies should be performed once the data get published in peer-reviewed journals and that for the time being the original NOAELs identified in the RAR still apply.

3.2.4.4 PNEC for secondary poisoning

The most relevant data for derivation of the PNEC for secondary poisoning for tetrabromobisphenol-A are from a 2-generation rat reproduction study investigating the effects of exposure on fertility and developmental neurotoxicty. The highest concentration tested in this study (1,000 mg/kg bw/day[21]) showed no toxicologically significant effects. This result is supported by the results from other studies that showed no clear toxicologically significant effects at doses up to 1,000 mg/kg bw/day in a 13-week repeated dose study with rats and studies showing that tetrabromobisphenol-A has no effect on development of rats at concentrations up to 2,500 mg/kg bw/day.

Using the conversion factors given in the Technical Guidance Document, a dose of 1,000 mg/kg bw is equivalent to a concentration of 20,000 mg/kg food.

According to the Technical Guidance Document an assessment factor of 30 is appropriate for the results of a reproduction study. Therefore, applying this assessment factor to the highest concentration tested in the reproduction study gives a PNEC for secondary poisoning of >667 mg/kg food. This value is also applicable for the assessment of secondary poisoning in the marine environment.

As discussed in the human health assessment (Section 4.1.2.9), one or two Member States were of the opinion that an effect on neurobehavioural development was observed and that a NOAEL of 50 mg/kg bw/day could be derived for this endpoint in rats. However, the majority of Member States were in agreement with the position of the rapporteur described above.

It should be noted that some recent studies carried out as part of the FIRE project have reported effects at doses much lower than currently used for the PNEC derivation. These data have not yet been fully validated and discussed by the TCNES in relation to the human health assessment and so the data cannot yet be considered in the derivation of the PNEC for secondary poisoning.

[21] As discussed in the human health assessment, one or two Member States expressed concern over the oral absorption of undissolved particles of tetrabromobisphenol-A, particularly when administered as a suspension at high dose levels. In the opinion of these Member States, there was some uncertainty as to whether 100% of the administered dose would be absorbed at these higher dose levels and consequently whether the dosing of particles in suspension will underestimate the toxicity. However, the majority of Member States agreed with the position of the UK rapporteur that, although this concept is important, the data do not allow a quantitative estimate of oral absorption at such high dose levels to be determined. Therefore, it was agreed to assume that 100% of an orally administered dose of tetrabromobisphenol-A is absorbed.

3.3 RISK CHARACTERISATION

3.3.1 Aquatic compartment (including sediment)

3.3.1.1 Water

The $PNEC_{water}$ for water for tetrabromobisphenol-A has been derived as 1.3 µg/l. The resulting risk characterisation ratios obtained using this value for the various scenarios considered in this assessment are shown in **Table 3.68**.

Table 3.68 Risk characterisation ratios for surface water

Scenario			PEC (µg/l)		Risk characterisation ratio	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.23	0.114	0.18[a]	0.11[a]
	Processing of epoxy resins		1.7×10^{-3}	1.5×10^{-3}	1.3×10^{-3}	1.2×10^{-3}
	Processing of polycarbonate resins		1.7×10^{-3}	1.5×10^{-3}	1.3×10^{-3}	1.2×10^{-3}
Additive flame retardant use[b]	ABS	Compounding	9.2	5.6	**7.1[b]**	**4.3**
		Conversion	0.42	0.25	0.32	0.19
Regional scenario			1.3×10^{-3}	1.3×10^{-3}	1.0×10^{-3}	1.0×10^{-3}

Note: a) Risk characterisation ratios given are for a generic site. The available site specific information for eight epoxy resin manufacturing companies leads to risk characterisation ratios of between 1.0×10^{-3} and 0.16 using a Koc of 49,726 l/kg and 1.0×10^{-3} and 0.10 using a Koc of 147,360 l/kg (see Appendix F).
b) Risk characterisation ratios given are for a generic site. Site specific information for a site using tetrabromobisphenol-A as an additive flame retardant in the EU leads to risk characterisation ratios of 6.9 using a Koc of 49,726 and 6.5 using a Koc of 147,360 (see Appendix F).

The risk characterisation ratios indicate that risk to surface water is low from regional sources, and also from manufacturing and processing of epoxy and polycarbonate resins, where tetrabromobisphenol-A is used as a reactive flame retardant, and conversion sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS. For the other areas, the risk characterisation ratios indicate a risk. The risk for additive flame retardant use is identified based on realistic worst case calculations for a generic site, and measured emission data from an actual site in the EU.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

This currently applies to the assessment of regional sources, and also from manufacture and processing of epoxy and polycarbonate resins, where tetrabromobisphenol-A is used as a reactive flame retardant, and conversion sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion applies to compounding sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

3.3.1.2 Sediment

A $PNEC_{sed}$ of 2.7 mg/kg wet weight has been derived from the available sediment toxicity data. This will be used in the risk characterisation. However, as discussed in Section 3.2.1.7.2, the toxicity seen with tetrabromobisphenol-A in sediments appears to be best explained in terms of exposure mainly through the pore water. This implies that the $PNEC_{sed}$ should vary depending on how strongly tetrabromobisphenol-A adsorbs onto the sediment. In order to take this into account a second $PNEC_{sed}$ of 5.5 mg/kg wet weight has been estimated for tetrabromobisphenol-A for a sediment where tetrabromobisphenol-A may show a stronger adsorption than may have occurred in the available test. The derivation of this second $PNEC_{sed}$ is based on several assumptions and so is somewhat uncertain, but it will be used, along with the $PNEC_{sed}$ of 2.7 mg/kg wet weight derived directly from the toxicity data, for comparison with the PECs obtained using the higher Koc value of 147,360 l/kg in order to test the sensitivity of the risk characterisation to this effect. The risk characterisation ratios are shown in **Table 3.69**.

Table 3.69 Estimated PEC/PNEC ratios for sediment

Scenario			PEC (mg/kg wet wt.)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49.726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.36	0.44	0.13[a, c]	0.16[a, c] or 0.080[b, c]
	Processing of epoxy resins		2.7×10^{-3}	4.9×10^{-3}	1.0×10^{-3} [a]	1.8×10^{-3} [a] or 8.9×10^{-4} [b]
	Processing of polycarbonate resins		2.7×10^{-3}	4.9×10^{-3}	1.0×10^{-3} [a]	1.8×10^{-3} [a] or 8.9×10^{-4} [b]
Additive flame retardant use[d]	ABS	Compounding	14.6	17.8	**5.4[a]**	**6.6[a] or 3.2[b]**
		Conversion	0.66	0.81	0.24[a]	0.30[a] or 0.15[b]
Regional scenario			4.0×10^{-3}	8.1×10^{-3}	1.5×10^{-3} [a]	3.0×10^{-3} [a] or 1.5×10^{-3} [a]

Note: a) Ratio based on the $PNEC_{sed}$ of 2.7 mg/kg wet weight.
b) Ratio based on the $PNEC_{sed}$ of 5.5 mg/kg wet weight, for a Koc of 147,360 l/kg.
c) Ratios given are for a generic site. The available site specific information for eight epoxy resin manufacturing companies leads to risk characterisation ratios of between 7.4×10^{-4} and 0.12 using a Koc of 49,726 l/kg and a $PNEC_{sed}$ of 2.7 mg/kg wet weight, between 1.5×10^{-3} and 0.15 using a Koc of 147,360 l/kg and a $PNEC_{sed}$ of 2.7 mg/kg wet weight, and between 7.5×10^{-4} and 0.075 using a Koc of 147,360 l/kg and a $PNEC_{sed}$ of 5.5 mg/kg wet weight (see Appendix F).
d) Risk characterisation ratios given are for a generic site. Site specific information for a site using tetrabromobisphenol-A as an additive flame retardant in the EU leads to risk characterisation ratios of 5.5 using a Koc of 49,726 and a $PNEC_{sed}$ of 2.7 mg/kg wet weight, 10 using a Koc of 147,360 and a $PNEC_{sed}$ of 2.7 mg/kg wet weight and 4.9 using a Koc of 147,360 and a $PNEC_{sed}$ of 5.5 mg/kg wet weight (see Appendix F).

The risk characterisation ratios indicate a risk for one of the life cycle stages covered and so it can be concluded that a risk to sediment is possible from the use of tetrabromobisphenol-A as an additive flame retardant in ABS from compounding sites. This risk is identified based on

realistic worst case calculations for generic sites, and measured emission data from an actual site using tetrabromobisphenol-A as an additive flame retardant in the EU.

It should be borne in mind that any risk management measures for the water compartment will also have consequences for risks identified to the sediment compartment.

The risk to sediment from the use of tetrabromobisphenol-A during the manufacture and processing of epoxy and polycarbonate resins (reactive flame retardant use), from conversion sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS, and from regional sources appears to be low based on the effects of tetrabromobisphenol-A itself.

It is possible that tetrabromobisphenol-A may be degraded to bisphenol-A in anaerobic sediments. This degradation route has been shown to occur in laboratory studies with several different freshwater, marine and highly polluted sediments, and it is likely that such reactions will also occur in anaerobic sediments in the environment. There is also some evidence that bisphenol-A may be formed under aerobic conditions, although it is not clear if this is a result of 'pockets' of anaerobic conditions within the aerobic (soil) test systems used. The consequences of this degradation are considered (alongside other sources of bisphenol-A in the environment) in the updated risk assessment of bisphenol-A (ECB, 2008). No risks are identified based on the PNEC derived in that report. However, further work is on-going at present within the UK that could affect the aquatic and hence sediment PNEC.

Result

i) There is a need for further information and/or testing.

No risks to sediment are currently identified from the formation of bisphenol-A via degradation of tetrabromobisphenol-A for any use. However, further work is on-going at present within the UK that could affect the aquatic and hence sediment PNEC. This conclusion should therefore be re-examined when the sediment PNEC for bisphenol-A has been finally agreed. This applies to the assessment for sediment from regional sources, and also from manufacturing and processing of epoxy and polycarbonate resins and conversion sites using tetrabromobisphenol-A as an additive flame retardant in ABS.

iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion applies to the use of tetrabromobisphenol-A as an additive flame retardant in ABS from compounding. The realistic worst case PEC/PNEC ratios for this scenario are estimated to be >1 based on both generic calculations and site specific information.

3.3.1.3 Sewage treatment processes

A $PNEC_{microorganisms}$ of ≥1.5 mg/l has been derived for tetrabromobisphenol-A. The resulting PEC/PNEC ratios for are shown in **Table 3.70**.

Table 3.70 Estimated PEC/PNEC ratios for sewage treatment processes

Scenario			C*local*$_{eff}$ (µg/l)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		2.5	1.7	$\leq 1.7\times10^{-3}$	$\leq 1.1\times10^{-3}$
	Processing of epoxy resins		4.6×10^{-3}	3.1×10^{-3}	$\leq 3.1\times10^{-6}$	$\leq 2.1\times10^{-6}$
	Processing of polycarbonate resins		4.6×10^{-3}	3.1×10^{-3}	$\leq 3.1\times10^{-6}$	$\leq 2.1\times10^{-6}$
Additive flame retardant use	ABS	Compounding	102	67.7	≤0.068	≤0.045
		Conversion	4.6	3.1	$\leq 3.1\times10^{-3}$	$\leq 2.1\times10^{-3}$

Based on these PEC/PNEC ratios, no risk to sewage treatment processes is identified from the use of tetrabromobisphenol-A.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

This applies to the assessment of sewage treatment processes from all uses of tetrabromobisphenol-A.

3.3.2 Terrestrial compartment

A $PNEC_{soil}$ of 0.012 mg/kg wet weight has been derived from the available soil toxicity data. This value will be used in the risk characterisation. However, as discussed in Section 3.2.2.2, the $PNEC_{soil}$ would be expected to vary depending on how strongly tetrabromobisphenol-A adsorbs onto the soil. The risk characterisation ratios are shown in **Table 3.71**.

Table 3.71 PEC/PNEC ratios for agricultural soil (30 day average)

Scenario			PEC (mg/kg wet wt.)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[c]		0.40 [8.5×10^{-4}][d]	0.44 [1.6×10^{-3}][d]	**33**[a] [0.071][d]	**37**[a] [0.13][d]
	Processing of epoxy resins		9.9×10^{-4} [2.6×10^{-4}][d]	1.8×10^{-3} [1.0×10^{-3}][d]	0.083 [0.022][d]	0.15 [0.083][d]
	Processing of polycarbonate resins		9.9×10^{-4} [2.6×10^{-4}][d]	1.8×10^{-3} [1.0×10^{-3}][d]	0.083 [0.022][d]	0.15 [0.071][d]
Additive flame retardant use[b]	ABS	Compounding[c]	16.1 [3.8×10^{-4}][d]	17.9 [1.2×10^{-3}][d]	**1,342** [0.032][d]	**1,492** [0.10][d]
		Conversion	0.73 [8.8×10^{-4}][d]	0.81 [1.7×10^{-3}][d]	**60.8** [0.073][d]	**67.5** [0.14][d]
Electronic equipment collection/recycling site			2.6×10^{-4}	1.0×10^{-3}	0.022	0.083
Regional scenario			1.5×10^{-3}	9.9×10^{-3}	0.13	0.83

Note: a) Ratios given are for a generic site. The available site specific information for eight epoxy resin manufacturing companies indicates that sludge containing tetrabromobisphenol-A will not be applied to agricultural land. The resulting local PEC/PNEC ratios for these sites (taking into account atmospheric deposition and the regional background contribution) are between 0.022 and 0.19 using a Koc value of 49,726 l/kg and 0.083 and 0.26 using a Koc value of 147,360 l/kg (see Appendix F).
b) Ratios given are for a generic site. Site specific information is available for a site using tetrabromobisphenol-A as an additive flame retardant. Sludge from the site is not applied to agricultural land. The resulting local PEC/PNEC ratio for this site (taking into account atmospheric deposition and the regional background contribution) is 3.0 using a Koc of 49,726 l/kg or 3.3 using a Koc of 147,360 l/kg.
c) Industry have indicated that the main sites using tetrabromobisphenol-A in these operations do not apply sewage sludge to agricultural land.
d) The resulting PECs and PEC/PNEC ratios in soil assuming no sludge is applied to land are shown in [ ].

Based on the risk characterisation ratios derived above for generic sites it can be concluded that a risk to soil could exist from sites using tetrabromobisphenol-A as a reactive flame retardant in the manufacture of epoxy and/or polycarbonate resins and compounding and conversion sites using tetrabromobisphenol-A as an additive in ABS. Industry have indicated that the major manufacturing sites using tetrabromobisphenol-A as a reactive flame retardant, and the major compounding sites using tetrabromobisphenol-A as an additive flame retardant, either do not generate sludge or do not apply sludge to agricultural land. When this is taken into account, then no risk is identified for the generic scenarios. The Industry survey covers all of the main customers of the EU suppliers of tetrabromobisphenol-A (the main suppliers are members of BSEF/EBFRIP who carried out the survey).

The fate of sewage sludge at ABS conversion sites in the EU is not totally clear at present, but again no risk to soil would be expected from these sites based on the generic calculation if sludge from the site is not applied to land.

It is important to note, however, that information on the actual emissions from a site using tetrabromobisphenol-A as an additive flame retardant in the EU have been provided. Although sludge from the site is not applied to agricultural land, a risk to soil from the site is still identified based on estimates of atmospheric deposition to soil from the site. The applicability of these data to other additive use sites in the EU is unclear. Therefore it has to

be concluded that a risk to soil still exists from such sites in the EU even if no sludge is applied to agricultural land from the sites.

The risks to the soil compartment from sites processing epoxy or polycarbonate resins, electronic equipment collection/recycling sites, and at the regional level, are all thought to be low.

A major source of tetrabromobisphenol-A in soil can arise from spreading of sewage sludge on agricultural land. Tetrabromobisphenol-A has been found to be present in actual municipal sewage sludge samples from around Europe and the rest of the world (see Section 3.1.2.2) and one of the higher concentrations found in sludge (approximate 90^{th} percentile estimated as 94 µg/kg dry weight) would lead to a predicted soil concentration of around 1.3×10^{-3} to 1.4×10^{-3} mg/kg wet weight after 10 years continual application. This concentration would give a PEC/PNEC ratio of 0.11-0.12. One possible explanation for the occurrence of tetrabromobisphenol-A in municipal sewage sludge could be from emissions from articles in use (e.g. volatilisation loss with subsequent condensation on surfaces, particulate loss, etc.). However other possibilities also exist (for example as indicated in Section 3.1.0.4.2, tetrabromobisphenol-A has been reported to be found in toilet paper). The significance of these sources in relation to the levels found in municipal sewage sludge is not clear.

In addition, it is possible that tetrabromobisphenol-A may be degraded to bisphenol-A during anaerobic sewage sludge treatment processes, which could lead to bisphenol-A being applied to soil (this is considered in Section 3.1.0.6.2). This degradation route has been shown to occur in some laboratory experiments using sewage sludge, and it cannot be ruled out that such a reaction could also occur in anaerobic sludge treatment processes such as sludge digestion. There is also some evidence that bisphenol-A may be formed under aerobic conditions, although it is not clear if this is a result of 'pockets' of anaerobic conditions within the aerobic (soil) test systems used. The consequences of this degradation are considered (alongside other sources of bisphenol-A in the environment) in the updated risk assessment of bisphenol-A (ECB, 2008). No risks to soil are identified from the formation of bisphenol-A from tetrabromobisphenol-A in that report.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

This applies to the assessment of risk to soil from tetrabromobisphenol-A from regional sources, and processing of epoxy and polycarbonate resins. In addition this conclusion also applies to sites manufacturing epoxy and/or polycarbonate resins where sewage sludge is not applied to agricultural land (Industry have indicated that this is the case at all of the major manufacturing sites in the EU).

No risks to soil are identified in the updated risk assessment of bisphenol-A (ECB, 2008) from the formation of bisphenol-A via degradation of tetrabromobisphenol-A for these uses.

iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion applies to the use of tetrabromobisphenol-A as an additive flame retardant in ABS from compounding and conversion. The PEC/PNEC ratios for these scenarios are >1 if sewage sludge from the site is applied to land. Although Industry have indicated that sludge from the major compounding sites in the EU is not applied to agricultural land, site specific information for one site using tetrabromobisphenol-A as an additive flame retardant still indicates a risk to soil based on atmospheric deposition from the site. The fate of sewage sludge at ABS conversion sites is currently unclear (no risk would be identified for sites where sewage sludge is not applied to agricultural land).

3.3.3 Atmosphere

Neither biotic nor abiotic effects on the atmosphere are likely because of the low predicted environmental concentrations of tetrabromobisphenol-A (all concentrations are around 7.5×10^{-4} mg/m^3 or below).

Tetrabromobisphenol-A in the atmosphere can be degraded by reaction with photochemically generated oxidants such as hydroxyl radicals, or by direct photolysis reactions. As discussed in Section 3.1.0.6.1 a number of bromine-containing degradation products have been identified, including bromophenols, bromobisphenols and compounds with higher molecular weights than tetrabromobisphenol-A. A quantitative assessment of the risks from these products is beyond the scope of this assessment. However, it should be considered that the amount of tetrabromobisphenol-A present in the atmosphere (both in terms of the predicted concentration (see above) and the total amount (the results of a level III fugacity model indicate only a very small percentage (2.2×10^{-5}-9.2×10^{-3}%) of the total environmental burden of tetrabromobisphenol-A will be in the atmosphere at steady state) see Section 3.1.0.7.3) is predicted to be very small and so the amounts and concentrations of any degradation products formed will also be very small. These are therefore unlikely to constitute a risk to the environment.

The available information on the long-range atmospheric transport of this substance indicates that the substance has a low, but not zero, potential to be transported over long distances via the atmosphere. The substance is thought to adsorb strongly onto atmospheric particulates and that it is the transport behaviour of these particulates that effectively govern the transport behaviour of tetrabromobisphenol-A itself. Tetrabromobisphenol-A has been found in samples of moss from Norway and this may provide an indication that transport via the environment may occur for tetrabromobisphenol-A by the mechanism outlined above.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

3.3.4 Non-compartment specific effects relevant for the food chain (secondary poisoning)

The PNEC for secondary poisoning has been determined as >667 mg/kg food. The resulting risk characterisation ratios are given in **Table 3.72** for the fish food chain and **Table 3.73** for the earthworm food chain.

Table 3.72 Estimated PEC/PNEC ratios for secondary poisoning by the fish food chain

Scenario			Predicted concentration in fish (mg/kg)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.046[a] or 0.12[b]	0.028[a] or 0.071[b]	$<6.9\times10^{-5}$ [a] or $<1.8\times10^{-4}$ [b]	$<4.2\times10^{-5}$ [a] or $<1.1\times10^{-4}$ [b]
	Processing of epoxy resins		6.3×10^{-4} [a] or 1.6×10^{-3} [b]	6.2×10^{-4} [a] or 1.6×10^{-3} [b]	$<9.4\times10^{-7}$ [a] or $<2.4\times10^{-6}$ [b]	$<9.3\times10^{-7}$ [a] or $<2.4\times10^{-6}$ [b]
	Processing of polycarbonate resins		6.3×10^{-4} [a] or 1.6×10^{-3} [b]	6.2×10^{-4} [a] or 1.6×10^{-3} [b]	$<9.4\times10^{-7}$ [a] or $<2.4\times10^{-6}$ [b]	$<9.3\times10^{-7}$ [a] or $<2.4\times10^{-6}$ [b]
Additive flame retardant use	ABS	Compounding	1.0[a] or 2.7[b]	0.63[a] or 1.6[b]	$<1.5\times10^{-3}$ [a] or $<4.0\times10^{-3}$ [b]	$<9.4\times10^{-4}$ [a] or $<2.4\times10^{-3}$ [b]
		Conversion	0.048[a] or 0.12[b]	0.029[a] or 0.075[b]	$<7.2\times10^{-5}$ [a] or $<1.8\times10^{-4}$ [b]	$<4.3\times10^{-5}$ [a] or $<1.1\times10^{-4}$ [b]

Note: a) Estimate for tetrabromobisphenol-A alone using a BCF of 485 l/kg.
b) Estimate for tetrabromobisphenol-A plus metabolites using a BCF of 1,234 l/kg.

Table 3.73 Estimated PEC/PNEC ratios for secondary poisoning assessment via the earthworm food chain

Scenario			Predicted concentration in earthworms (mg/kg)		PEC/PNEC[c]	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.60[a] or 1.2[b] [3.6×10^{-3} [a] or 6.8×10^{-3} [b]][d]	0.76[a] or 1.3[b] [0.020 [a] or 0.033 [b]][d]	<9.0×10^{-4} [a] or <1.8×10^{-3} [b] [<5.4×10^{-6} [a] or <1.0×10^{-5} [b]][d]	<1.1×10^{-3} [a] or <1.9×10^{-3} [b] [<3.0×10^{-5} [a] or <4.9×10^{-5} [b]][d]
	Processing of epoxy resins		3.8×10^{-3} [a] or 7.2×10^{-3} [b] [2.7×10^{-3} [a] or 5.1×10^{-3} [b]][d]	0.020[a] or 0.034[b] [0.019 [a] or 0.032 [b]][d]	<5.7×10^{-6} [a] or <1.1×10^{-5} [b] [<4.0×10^{-6} [a] or <7.6×10^{-6} [b]][d]	3.0×10^{-5} [a] or <5.1×10^{-5} [b] [<2.8×10^{-5} [a] or <4.8×10^{-5} [b]][d]
	Processing of polycarbonate resins		3.8×10^{-3} [a] or 7.2×10^{-3} [b] [2.7×10^{-3} [a] or 5.1×10^{-3} [b]][d]	0.020[a] or 0.034[b] [0.019 [a] or 0.032 [b]][d]	<5.6×10^{-6} [a] or <1.1×10^{-5} [b] [<4.0×10^{-6} [a] or <7.6×10^{-6} [b]][d]	3.0×10^{-5} [a] or <5.1×10^{-5} [b] [<2.8×10^{-5} [a] or <4.8×10^{-5} [b]][d]
Additive flame retardant use	ABS	Compounding	24.2[a] or 46.7[b] [2.9×10^{-3} [a] or 5.5×10^{-3} [b]][d]	30.3[a] or 51.9[b] [0.019 [a] or 0.032 [b]][d]	<0.036[a] or <0.070[b] [<4.3×10^{-6} [a] or <8.2×10^{-6} [b]][d]	<0.045[a] or <0.078[b] [<2.8×10^{-5} [a] or <4.8×10^{-5} [b]][d]
		Conversion	1.1[a] or 2.1[b] [3.6×10^{-3} [a] or 6.9×10^{-3} [b]][d]	1.4[a] or 2.4[b] [0.020 [a] or 0.034 [b]][d]	<1.6×10^{-3} [a] or <3.1×10^{-3} [b] [<5.4×10^{-6} [a] or <1.0×10^{-5} [b]][d]	<2.1×10^{-3} [a] or <3.6×10^{-3} [b] [<3.0×10^{-5} [a] or <5.1×10^{-5} [b]][d]
Electronic equipment collection/recycling site			2.7×10^{-3}[a] or 5.1×10^{-3} [b]	0.019[a] or 0.032[b]	<4.0×10^{-6} [a] or <7.6×10^{-6} [b]	<2.8×10^{-5} [a] or <4.8×10^{-5} [b]

Notes: a) Estimated using $BCF_{earthworm}$ = 9,533 l/kg.
b) Estimated using $BCF_{earthworm}$ = 5.8 on a wet weight worm/wet weight soil basis.
c) The PEC/PNEC ratios given assume that sewage sludge are applied to land. Significantly lower ratios would be obtained for sites where sludge is not applied to land. The resulting PECs and PEC/PNEC ratios in soil assuming no sludge is applied to land are shown in [ ].

The PEC/PNEC ratios are all <1 for both the fish and earthworm food chains and so it can be concluded that the risk of secondary poisoning from the use of tetrabromobisphenol-A is low. It should be noted that the calculations for the earthworm food chain assume that the main source of tetrabromobisphenol-A to soil from local sites results from spreading of sewage sludge. As indicated earlier, spreading of sewage sludge to agricultural land is not carried out at the sites of the main manufacturers of epoxy/polycarbonate resins (reactive uses of tetrabromobisphenol-A) or the main compounding sites for ABS (additive use of tetrabromobisphenol-A). Significantly lower ratios than indicated in **Table 3.72** would be obtained for sites where sewage sludge is not applied to agricultural land.

The PNEC for secondary poisoning is derived using a NOAEL of 1,000 mg/kg from a 2-generation rat reproduction study investigating the effects of exposure on fertility and developmental neurotoxicty. As discussed in the human health assessment (Section 4.1.2.9), one or two Member States were of the opinion that an effect on neurobehavioural development was observed and that a NOAEL of 50 mg/kg bw/day could be derived for this

endpoint in rats. However, the majority of Member States were in agreement with the position of the rapporteur described above.

It should be noted that some recent mammalian toxicity studies reported effects at doses much lower than currently used for the PNEC derivation. These data have not yet been fully validated and discussed by the TCNES in relation to the human health assessment and so the data cannot yet be considered in the derivation of the PNEC for secondary poisoning.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Based on the currently derived PNEC, the risk from secondary poisoning is low for all uses considered. The results from more recent mammalian toxicity tests are available but it is not possible to determine if these have any implications for the PNEC for secondary poisoning until full details of the studies are available and the validity of the data has been established.

3.3.5 Marine risk assessment

3.3.5.1 PBT assessment

The final part of the draft marine risk assessment procedure requires a screening of the properties of a substance to see if is considered as a persistent (P), bioaccumulative (B) and toxic (T) substance. The risk assessment of substances that meet the criteria given in the Technical Guidance Document is considered too uncertain to rely on a PEC/PNEC approach.

3.3.5.1.1 Persistence

The persistence criteria currently laid down in the marine risk assessment guidance require a half-life >60 days in marine water (or >40 days in fresh water) or >180 days in marine sediment (or >120 days in freshwater sediment).

The available screening studies, although showing that primary biodegradation does occur under some situations, indicate that tetrabromobisphenol-A is unlikely to be considered as readily biodegradable or inherently biodegradable. The half-life for primary degradation in freshwater aerobic sediments is estimated to be of the order of 50 to 70 days at 25^{o}C, but no mineralization was observed over 56 days. Recent studies with soil have indicated a mineralisation half-life of >6 months. It can therefore be concluded that tetrabromobisphenol-A is persistent or potentially very persistent under the criteria used.

The degradation of tetrabromobisphenol-A has been studied under anaerobic conditions. In particular, one study has been carried out in estuarine sediment. This showed that tetrabromobisphenol-A was degraded and the main product formed was bisphenol-A, which was stable under the anaerobic conditions used. This is an important finding for the marine risk assessment for tetrabromobisphenol-A as the substance is predicted to adsorb strongly onto sediment. Thus, if tetrabromobisphenol-A is transported to the marine environment, it is expected that it will degrade to bisphenol-A in anaerobic sediments, which will itself persist under anaerobic conditions. However, bisphenol-A does not adsorb as strongly onto sediment

as tetrabromobisphenol-A and so re-partitioning from sediment to water is likely to occur, where bisphenol-A may be degraded (bisphenol-A is considered to be readily biodegradable under aerobic conditions). Further consideration of this degradation product, and other possible degradation products of tetrabromobisphenol-A in relation to the PBT assessment is given in Section 3.3.5.1.4.

3.3.5.1.2 Bioaccumulation

The criterion used in the draft marine risk assessment for bioaccumulation is a bioconcentration factor (BCF) >2,000 l/kg. The highest measured BCF value for (freshwater) fish with tetrabromobisphenol-A is around 1,234 l/kg. This value was based on ^{14}C measurements and so may represent accumulation of metabolites as well as tetrabromobisphenol-A. There are several other fish bioconcentration factors below this value. No BCF data are available for marine fish species, but a BCF value of 780 l/kg has been determined for a marine mollusc *Crassostrea virginica*. Therefore, the available BCF data indicate that tetrabromobisphenol-A does not meet the bioaccumulation criterion. However, it should be noted that the available monitoring data suggest that the substance is present at low levels in the tissues of a wide variety of marine organisms, including top predators, and also human breast milk from remote areas (e.g. the Faro Islands). The available monitoring data for biota are summarised in Section 3.1.4.2.

3.3.5.1.3 Toxicity

The toxicity criterion used in the draft marine risk assessment guidance is a chronic NOEC <0.01 mg/l. The lowest valid NOECs/EC_{10} values available for tetrabromobisphenol-A are a 5d-EC_{10} of 0.0127 mg/l for the marine copepod *Acartia tonsa* and a 70d-NOEC of 0.017 mg/l for marine mussels *Mytilus edulis*. In addition tetrabromobisphenol-A is thought to show relatively low toxicity to mammalian systems. Therefore it can be concluded that tetrabromobisphenol-A does not meet the T-criterion.

The possible effects of tetrabromobisphenol-A on the endocrine system have been studied in several aquatic and mammalian systems (see Sections 3.2.1.6, 3.2.4.3 and 4). The evidence available so far appears to indicate that, although there are a number of tests showing little or no effects, there are indications of potential effects on the endocrine system in some *in vitro* tests with aquatic organisms, particularly thyroid hormone antagonist/agonist effects in amphibians. Although possible thyroid-mediated effects of tetrabromobisphenol-A are evident in *in vitro* assays, the results of a recent, well conducted, *in vivo* assay (Jagnytsch *et al.*, 2006; See Section 3.2.1.6.3) suggest that the effects seen *in vivo* may be the result of a toxic side effect rather than direct effects on thyroid function. The concentrations at which adverse effects on amphibian metamorphosis have been seen are generally around 100 µg/l and above (and so are above the criteria for T). Effects on various biomarkers have been seen at lower concentration (as low as around 5.4 µg/l) but the significance of these effects in terms of population survival is unclear.

One recent lifecycle study with zebrafish has found effects on some reproductive endpoints at relatively low concentrations (note: the effects seen were not necessarily related to disruption of the endocrine system). This study is discussed in detail in Section 3.2.1.6.1. A number of aspects of this study make the interpretation of the results difficult, in particular the decline in the exposure concentrations with time, and the variability and lack of dose response seen in some of the reproductive endpoints studied. The authors of the study (Kuiper *et al.*, 2007)

concluded that effects on population-relevant parameters can result at tetrabromobisphenol-A body burdens of 5-7 mg/kg lipid. Based on the data reported in this study, it has been estimated here that such body burdens would have resulted from exposure to around 3-6 μg/l. Based on this interpretation, it could be considered that tetrabromobisphenol-A may meet the T-criterion. However, the limitations of this study mean that it is not possible to derive a reliable NOEC for tetrabromobisphenol-A. Therefore it cannot be concluded that tetrabromobisphenol-A meets the T-criterion based on the results from this study.

For mammalian systems, the human health assessment concludes that the weight of evidence from *in* vitro screening assays indicates that tetrabromobisphenol-A has no significant estrogenic potential in mammalian systems. In addition, although the potential for tetrabromobisphenol-A to compete with binding of thyroxine to transthyretin (TTR) has been demonstrated *in vitro*, no firm conclusions regarding the affinity of tetrabromobisphenol-A for TTR *in vivo* could be drawn from the limited data available. It should, however, be noted that the effects of tetrabromobisphenol-A on the endocrine system are currently subject to much current research (e.g. in the EU FIRE project) and so this endpoint may need to be reconsidered once the full results of these studies are available.

3.3.5.1.4 Consideration of environmental degradation products and metabolites of tetrabromobisphenol-A

A number of degradation products (or metabolites) of tetrabromobisphenol-A have been postulated (and in some cases identified experimentally). These include the formation of bisphenol-A by the sequential debromination of tetrabromobisphenol-A under certain anaerobic conditions and the possible formation of the dimethylated derivative of tetrabromobisphenol-A (tetrabromobisphenol-A bis(methyl ether), a substance that has been found to occur in the environment) via O-methylation of tetrabromobisphenol-A (see Section 3.1.0.6.2 for further details).

With the exception of bisphenol-A (for which an EU risk assessment exists (EC, 2003a; ECB, 2008)) very little is known about the bioaccumulation, persistence and toxicity of these potential degradation products and metabolites.

In order to evaluate the possible PBT properties of the various possible degradation products and metabolites of tetrabromobisphenol-A, the USEPA EPI estimation program (version 3.12) has been used to estimate the key properties of the dimethylated derivative and tribromo-, dibromo- and bromobisphenol-A (possible intermediaries in the debromination to bisphenol-A). The results are shown in **Table 3.74**. In addition, the same estimation software was used to predict the properties of tetrabromobisphenol-A itself and bisphenol-A in order that some comparison could be made between the predicted values and actual known experimental data.

Table 3.74 Estimated properties of possible degradation products of tetrabromobisphenol-A

Substance	EPI Estimated data				Known experimental data
	Log Kow[b]	Aerobic biodegradation	Ecotoxicity[a]	Water solubility	
Tetrabromobisphenol-A	7.2	Not expected to degrade rapidly	30 day fish chronic value = 0.007 mg/l 21 day chronic value for *Daphnia* = 0.006 mg/l	0.001-0.289 mg/l	Log Kow = 5.9 Inherently biodegradable 35 day NOEC for fish = 0.16 mg/l. 21 day NOEC for *Daphnia* = 0.30 mg/l. Effects on other invertebrates at lower concentrations (NOEC of 0.017 mg/l for mussels and EC_{10} = 0.0127 mg/l for a copepod) Water solubility 0.063-2.34
Tribromobisphenol-A	6.31 (corrected value = 5.3)	Not expected to degrade rapidly	30 day fish chronic value = 0.021 mg/l 21 day chronic value for *Daphnia* = 0.017 mg/l	0.019-1.46 mg/l	3,3',5-Tribromobisphenol-A showed thyroid hormone agonist/antagonist activity in tadpoles (Kudo *et al.*, 2006).
Dibromobisphenol-A	5.42 (corrected value = 4.6)	Not expected to degrade rapidly	30 day fish chronic value = 0.063 mg/l 21 day chronic value for *Daphnia* = 0.049 mg/l	0.33-7.12 mg/l	
Bromobisphenol-A	4.53 (corrected value = 4.0)	Not expected to degrade rapidly but equivocal results obtained	30 day fish chronic value = 0.180 mg/l 21 day chronic value for *Daphnia* = 0.136 mg/l	3.6-33.4 mg/l	
Bisphenol-A	3.64	Not expected to degrade rapidly but equivocal results obtained	30 day fish chronic value = 0.41 mg/l 21 day chronic value for *Daphnia* = 0.36 mg/l	21.6-146 mg/l	Log Kow = 3.4 Readily biodegradable. Long-term fish NOEC = 0.016 mg/l 21 day NOEC for *Daphnia* = >3 mg/l Effects on the endocrine systems of fish and certain invertebrates at lower concentrations. Water solubility 300 mg/l. (Values all taken from EC, 2003a)
Tetrabromobisphenol-A bis(methyl ether)	8.33 (corrected value 6.7)	Not expected to degrade rapidly	30 day fish chronic value = 1.7×10^{-4} mg/l 16 day EC_{50} for *Daphnia* = 6.5×10^{-4} mg/l	1.9×10^{-5}-8.9×10^{-4} mg/l	Water solubility 6.8×10^{-5} mg/l (Huntingdon Life Sciences, 2006)

Note: a) The results are given as chronic values. These are taken to represent the geometric mean of the NOEC and LOEC.
b) Corrected log Kow is estimated from a plot of actual against predicted log Kow constructed with the data for tetrabromobisphenol-A and bisphenol-A (see text).

The water solubility of tetrabromobisphenol-A bis(methyl ether) has recently been determined in a GLP study using the generator column method at 20°C (Huntingdon Life Sciences, 2006). The substance tested had a purity of 98.1%. The columns used were

stainless steel (25 cm long, 4.6 mm internal diameter) packed with samples of sand (1 g) coated with the test substance at a rate of 0.05 g/g. Purified water was allowed to flow through the column at one of two flow rates (0.4 ml/minute and 0.2 ml/minute) and the first five bed volumes of water were discarded. Samples of effluent (14 ml samples) were then collected for analysis (separated by time periods corresponding to the passage of at least ten bed volumes) until an equilibrium concentration was present (as demonstrated over five successive samples). The mean water solubility (±standard deviation) determined was 66±6 ng/l at a flow rate of 0.4 ml/minute and 69±8 ng/l at a flow rate of 0.2 ml/l. The overall mean solubility was 68±7 ng/l.

Comparing the predicted results with the available experimental data for tetrabromobisphenol-A, bisphenol-A and tetrabromobisphenol-A bis(methyl ether) it can be seen that the water solubilities are predicted reasonably well for all three substances but that, although the log Kow for bisphenol-A is predicted well, that for tetrabromobisphenol-A is overpredicted. The biodegradation predictions generally agree with the available data for tetrabromobisphenol-A but underestimate the degradability of bisphenol-A. The toxicity predictions for tetrabromobisphenol-A generally overestimate slightly the actual toxicity of the substance.

The situation for bisphenol-A is more complex as the substance shows effects on the endocrine system of certain species at low concentrations but overall it can be concluded that the predictions of toxicity for bisphenol-A underestimate the actual toxicity of this substance.

In order to try to obtain more reliable predictions of log Kow for the other substances, a corrected log Kow has been estimated from a plot of predicted against actual log Kow based on the data points for bisphenol-A and tetrabromobisphenol-A. It is recognised that such an approach is very uncertain (given the small number of datapoints used).

Overall it can be concluded that the data presented in **Table 3.74** are reasonable estimates for the log Kow (based on the corrected values), water solubility and the persistence (particularly for the more highly brominated degradation products). The situation with regards to the toxicity predictions is less clear. For tetrabromobisphenol-A bis(methyl ether), it should be noted that the predicted toxicity of the substance is above the actual water solubility of the substance. This means that it is unlikely that the substance is sufficiently soluble enough to meet the T-criterion based on aquatic toxicity. Using these data as the basis of a screening PBT assessment for the degradation products, the following tentative conclusions can be reached.

Substance	**Tentative PBT assessment**	
Tetrabromobisphenol-A bis(methyl ether)	P or vP	B or vB
Tribromobisphenol-A	P or vP	B or vB (but BCF would be expected to be lower than for tetrabromo-bisphenol-A)
Dibromobisphenol-A	P or vP	
Bromobisphenol-A	P?	

On this basis tetrabromobisphenol-A bis(methyl ether) potentially meets the screening vPvB criteria. It is worth noting that this substance has been found in 28 out of 32 samples of Peregrine falcon (*Falco peregrinus*) egg samples from South Greenland analysed by

Sørensen *et al.*,(2004). The levels found were in the range 0.1-940 µg/kg lipid (see Section 3.1.4.2). In addition, tetrabromobisphenol-A bis(methyl ether) has been detected in mussels and sediment samples (see Section 3.1.4.2 and Section 3.1.1.2.2) although there are some uncertainties with the data.

The lower brominated bisphenol-A derivatives would not be expected to meet the PBT criteria as they are expected to show lower bioaccumulation (based on lower log Kow values) and lower toxicity than tetrabromobisphenol-A itself.

The presence of tetrabromobisphenol-A bis(methyl ether) has been investigated in some recent studies of anaerobic transformation in freshwater aquatic sediment and sewage sludge, and anaerobic and aerobic soil transformation. The results of these investigations were, however, inconclusive but did provide some indication that, if tetrabromobisphenol-A bis(methyl ether) was formed it was generally only present in small amounts.

Overall, although it is concluded that tetrabromobisphenol-A bis(methyl ether) potentially meets the screening criteria for a vPvB substance, and the substance has been found to be present in the environment, the available information of the degradation of tetrabromobisphenol-A are suggestive that such degradation is not a major source of the substance in the environment. In addition, it should also be borne in mind that the need for risk reduction measures has already been identified for tetrabromobisphenol-A for some uses, and this will reduce the burden of tetrabromobisphenol-A present in the environment. Therefore, although there are some concerns that tetrabromobisphenol-A bis(methyl ether) could be formed from the degradation of tetrabromobisphenol-A it is concluded that further investigation of this is not warranted at present.

3.3.5.1.5 Monitoring data

The available monitoring data for tetrabromobisphenol-A are summarised in Section 3.1.1.2.1 (water), Section 3.1.1.2.2 (sediment), Section 3.1.2.2 (soil, sewage sludge and terrestrial plants), 3.1.3.2 (air) and Section 3.1.4.2 (biota). The vast majority of the data are associated with industrial or urban sources of tetrabromobisphenol-A and so are not very relevant to the PBT assessment. However, there are a limited amount of data from more remote regions, including the Arctic that are relevant. For example, tetrabromobisphenol-A has been detected in eleven out of eleven samples of moss from Norway (SFT, 2002; see Section 3.1.2.2) and this is thought to suggest that transport via the atmosphere could be a possibility (the distance to the nearest village/town was at least 10 km for these samples). There is also a report that tetrabromobisphenol-A was present in an air filter sample taken from the Russian Arctic (de Wit, 2004 and 2006; see Section 3.1.3.2).

For the levels in biota, Herzke *et al.* (2003 and 2005; see Section 3.1.4.2) found that tetrabromobisphenol-A was present in eight samples of predatory birds eggs from Norway (including some sampled from within the Arctic circle[22]). In contrast to this, tetrabromobisphenol-A was not detectable in thirty two samples of peregrine falcon eggs from South Greenland (Sørensen *et al*., 2004 and Vorkamp *et al.*, 2005; see Section 3.1.4.2).

[22] The Arctic circle starts at 66° 33’ 39’’ N. The samples included in the Herzke *et al.* (2003 and 2005) study were taken from between 61°N and 68°N (white-tailed eagle eggs), 59°N and 71°N (peregrine falcon eggs), 59°N and 71°N (golden eagle eggs) and 59°N and 62°N (osprey eggs).

There is a more extensive database of monitoring data in aquatic organisms. These data are discussed in Section 3.1.4.2. The data show that tetrabromobisphenol-A has been detected at low levels in a number of aquatic species, including some top predators such as harbour porpoise, but most of these data were collected from sites that may be influenced by local or regional sources of emission and so are difficult to interpret in terms of the PBT assessment. In addition, it should be noted that there are a significant number of samples analysed where tetrabromobisphenol-A was not detectable.

Tetrabromobisphenol-A has been detected in a single sample of human breast milk from the Faroe Islands (Kemmlein, 2000; see Section 3.1.4.2).

3.3.5.1.6 Summary of PBT assessment

For the PBT assessment, tetrabromobisphenol-A is considered to be persistent (P) or potentially very persistent (vP) based on its ultimate mineralisation.

The available information on bioaccumulation shows that tetrabromobisphenol-A does not meet the B or vB criterion. However, it should be noted that the available monitoring data suggest that the substance is present at low levels in the tissues of a wide variety of marine organisms (although tetrabromobisphenol-A was not detectable in a significant number of the samples analysed), including some top predators, predatory birds from remote areas (e.g. northern and Arctic regions of Norway) and human breast milk from remote areas (e.g. the Faro Islands). The T criterion is not met.

Overall it is concluded that tetrabromobisphenol-A is considered to be very persistent (vP).

Although tetrabromobisphenol-A is considered to be very persistent based on its ultimate mineralisation, primary degradation has been demonstrated under aerobic and anaerobic conditions. Consideration of some of the possible metabolites of tetrabromobisphenol-A indicates that one of these, tetrabromobisphenol-A bis(methyl ether) (CAS No. 67853-61-5) that may be formed by O-methylation of tetrabromobisphenol-A, can be considered to meet the screening criteria for a vPvB substance.

It is currently unclear whether this substances is commercially produced, although there is some information that it is used at low tonnage as a flame retardant in expanded polystyrene (WHO, 1997). Tetrabromobisphenol-A producers who are members of BSEF have confirmed that they have neither produced tetrabromobisphenol-A bis(methyl ether) nor has it been present as an impurity in their products (Rothenbacher, 2005). However, it is still possible that other companies may synthesise tetrabromobisphenol-A bis(methyl ether) from commercially supplied tetrabromobisphenol-A. The presence of tetrabromobisphenol-A bis(methyl ether) has been investigated in some recent studies of anaerobic transformation in freshwater aquatic sediment and sewage sludge, and anaerobic and aerobic soil transformation. The results of these investigations were, however, inconclusive but did provide some indication that if tetrabromobisphenol-A bis(methyl ether) was formed it was generally only present in small amounts. This finding, coupled with the fact that a need for risk reduction measures already identified for some uses of tetrabromobisphenol-A will reduce the burden of tetrabromobisphenol-A present in the environment, means that, although there are some concerns that tetrabromobisphenol-A bis(methyl ether) could be formed from the degradation of tetrabromobisphenol-A it is concluded that further investigation of this is not warranted at present (conclusion (i) on-hold).

Another possible degradation product of tetrabromobisphenol-A is bisphenol-A. This substance is currently also undergoing a risk assessment under the Existing Substances Regulation and further work with this substance is currently underway to determine the potential effects of this substance on the endocrine system. It is recommended that the possible formation of bisphenol-A from degradation of tetrabromobisphenol-A is considered further in the bisphenol-A risk assessment.

Also of relevance is that tetrabromobisphenol-A has been shown act as a thyroid hormone agonist/antagonist in amphibians *in vitro*, and exposure to tetrabromobisphenol-A has been shown to lead to effects on metamorphosis in tadpoles *in vivo*, although it is possible that the effects seen *in vivo* may be a result of a toxic side effect rather than direct effects on thyroid function. These effects occur at concentrations above the T-criterion and, given that the substance also does not meet the B-criterion, it is thought that the PNEC derived for water would also be protective of these effects and so any possible risks would be covered with the standard PEC/PNEC approach to the secondary poisoning risk assessment.

3.3.5.2 Risk characterisation for the marine environment

The provisional risk characterisation ratios for water, sediment and predators/top-predators are shown in **Tables 3.75**, **3.76** and **3.77** respectively. The PNECs for marine water, sediment and predators/top-predators are respectively 0.25 µg/l, 0.54 mg/kg wet weight and >667 mg/kg food respectively.

Table 3.75 Risk characterisation ratios for marine water

Scenario	Step	PEC (µg/l)	Risk characterisation ratio
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[a]	0.023	0.092
	Processing of epoxy resins	3.6×10^{-4}	1.4×10^{-3}
	Processing of polycarbonate resins	3.6×10^{-4}	1.4×10^{-3}
Additive flame retardant use - ABS	Compounding[a]	0.92	**3.7**
	Conversion	0.23	0.92

Note a) The calculations for these scenarios assume that the effluent from the site is treated in a waste water treatment plant prior to discharge to the marine environment.

Table 3.76 Risk characterisation ratios for marine sediment

Scenario	Step	PEC (mg/kg wet weight)	Risk characterisation ratio
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[a]	0.036	0.067
	Processing of epoxy resins	5.6×10^{-4}	1.0×10^{-3}
	Processing of polycarbonate resins	5.6×10^{-4}	1.0×10^{-3}
Additive flame retardant use - ABS	Compounding[a]	1.5	**2.8**
	Conversion	0.36	0.66

Note a) The calculations for these scenarios assume that the effluent from the site is treated in a waste water treatment plant prior to discharge to the marine environment.

Table 3.77 Risk characterisation ratios for secondary poisoning in the marine environment

Scenario	Step	Risk characterisation ratio for predators		Risk characterisation ratio for top predators	
		a	b	a	B
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins[c]	$<1.8\times10^{-5}$	$<6.9\times10^{-6}$	$<3.6\times10^{-6}$	$<1.4\times10^{-6}$
	Processing of epoxy resins	$<2.5\times10^{-7}$	$<1.0\times10^{-7}$	$<2.4\times10^{-7}$	$<9.6\times10^{-8}$
	Processing of polycarbonate resins	$<2.5\times10^{-7}$	$<1.0\times10^{-7}$	$<2.4\times10^{-7}$	$<9.6\times10^{-8}$
Additive flame retardant use - ABS	Compounding[c]	$<4.0\times10^{-4}$	$<1.5\times10^{-4}$	$<7.9\times10^{-4}$	$<3.1\times10^{-5}$
	Conversion	$<9.7\times10^{-5}$	$<3.9\times10^{-5}$	$<1.9\times10^{-5}$	$<7.8\times10^{-6}$

Notes: a) Based on $BCF_{fish.}$= 1,234 l/kg.
b) Based on BCF_{fish} = 485 l/kg.
c) The calculations for these scenarios assume that the effluent from the site is treated in a waste water treatment plant prior to discharge to the marine environment.

The risk assessment for the marine environment indicates a potential risk to water and sediment from compounding sites where tetrabromobisphenol-A is used as an additive flame retardant. Manufacture and processing of epoxy and polycarbonate resins, and conversion of ABS containing tetrabromobisphenol-A as an additive, do not appear to present a risk. It would be possible to revise the PECs for the other endpoints by collection of further exposure information. Industry have indicated that none of the major manufacturing sites using tetrabromobisphenol-A as a reactive flame retardant, or compounding sites using tetrabromobisphenol-A as an additive flame retardant, are situated close to coastal areas, and so the relevance of a local marine risk assessment for these uses is questionable.

It would also be possible to revise the PNEC for water and sediment by carrying out further testing.

The risk from secondary poisoning appears to be low for all scenarios.

Result

i) There is a need for further information and/or testing.

The risk characterisation ratios for the marine environment indicate a possible risk from some applications. The need for further toxicity data with marine organisms should be evaluated once the implications of any risk reduction activities resulting from the assessment for fresh water and freshwater sediment are known. Industry have indicated that none of the major manufacturing sites using tetrabromobisphenol-A as a reactive flame retardant, or compounding sites using tetrabromobisphenol-A as an additive flame retardant, are situated close to coastal areas, and so the relevance of a local marine risk assessment for these uses is questionable.

Tetrabromobisphenol-A does not meet all of the PBT criteria (it is vP). However, the substance has been shown to break down in estuarine sediments to another substance (bisphenol-A) that is known to be toxic and shows effects on the endocrine system. Thus this indicates that tetrabromobisphenol-A may have the potential to cause long-term adverse effects on marine ecosystems if sufficient exposure occurs. It is not clear how this finding fits in with the current Marine Risk Assessment Technical Guidance. The effects of bisphenol-A itself on aquatic organisms are currently being investigated further for an EU risk assessment, and this should also be considered in any further discussion of this endpoint.

In addition, another potential metabolite/degradation product (tetrabromobisphenol-A bis(methyl ether) that may be formed by O-methylation of tetrabromobisphenol-A, can be considered to meet the screening criteria for a vPvB substance. However The presence of tetrabromobisphenol-A bis(methyl ether) has been investigated in some recent studies of anaerobic transformation in freshwater aquatic sediment and sewage sludge, and anaerobic and aerobic soil transformation. The results of these investigations were, however, inconclusive but did provide some indication that, if tetrabromobisphenol-A bis(methyl ether) was formed it was generally only present in small amounts. This finding, coupled with the fact that a need for risk reduction measures has already been identified for some uses which will reduce the burden of tetrabromobisphenol-A present in the environment, means that, although there are some concerns that tetrabromobisphenol-A bis(methyl ether) could be formed from the degradation of tetrabromobisphenol-A it is concluded that further investigation of this is not warranted at present. Therefore no further specific work is recommended to address this issue at the current time.

3.3.6 Combustion processes

An area of potential concern for both direct toxicity and secondary poisoning is the possible formation of brominated dibenzo-*p*-dioxins and dibenzofurans from articles containing the substance during combustion or other high temperature processes (e.g. incineration, landfill (where fires could occur) or accidental fires) (discussed in Appendix A). Overall it can be concluded that tetrabromobisphenol-A, as a source of bromine, can contribute to the formation of halogenated dibenzo-*p*-dioxins and dibenzofurans generated during such processes. It is not possible from the available data (and it is beyond the scope of this risk assessment) to quantify the actual contribution that tetrabromobisphenol-A makes to the total "toxic" products (fires etc. can generate products other than halogenated dibenzo-*p*-dioxins and dibenzofurans that are considered toxic (e.g. polycyclic aromatic compounds)). Formation of halogenated dibenzo-p-dioxins and dibenzofurans in some of these processes is well known and emission control technology is available for incinerators and metal recycling facilities that can reduce emissions to acceptable levels. Although incineration or metal recycling could take place at installations without suitable emission reduction equipment, it should be noted that in most situations tetrabromobisphenol-A is unlikely to be the only

source of halogenated dioxins/furans. Emission control technology cannot be applied to landfill or other accidental fires. Recycling of plastics containing the substance does not appear to contribute to brominated dibenzo-*p*-dioxin or furan formation.

3.3.7 Other issues relevant to the risk assessment

A study in Norway has detected tetrabromobisphenol-A in the eggs of a number of predatory bird species. No information is available about possible trends, and the route of exposure of these birds is unknown (it could be from sources other than food), and so the levels can not be linked with any particular source at present.

The presence of a synthetic substance in the tissues of top predators is clearly undesirable, but does not by itself necessarily constitute a risk. However, tetrabromobisphenol-A is expected to be highly persistent in the environment, and a single study has been performed involving exposure of birds' eggs that demonstrates toxicity. The presence of tetrabromobisphenol-A in the eggs of top predators is therefore an important and serious finding that cannot be overlooked.

Since the normal PEC/PNEC comparison methods described in the Technical Guidance Document do not apply to this situation, it is proposed to derive an indicative estimate of the significance of these levels as follows:

- It is not possible to estimate a 90^{th} percentile concentration in eggs. The maximum concentration was 0.013 µg/kg wet weight for osprey.

- A dose of tetrabromobisphenol-A of 45 µg/g egg caused 80% mortality in quail and 96% mortality in chicken. These mortality rates were statistically significantly different from the mortalities seen in the control populations (13% in quail and 8% in chicken). No statistically significant mortalities occurred in the 15 µg/g egg treatment groups compared to control populations. No other significant effects were observed at this dose in either of two studies.

- When the lower of these two doses is compared to the highest concentration in osprey eggs, the ratio obtained is $>10^6$.

Such a large 'margin of safety' suggests that the significance of the levels detected in predatory bird eggs is low. There is therefore currently no reason for concern, even in the absence of information on trends.

Result

ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

3.3.8 Areas of uncertainty in the environmental risk assessment

As with any "generic" risk assessment, there are uncertainties inherent in the approach taken. For tetrabromobisphenol-A these are compounded by the fact that the substance is a weak dibasic acid and likely to be present as both the ionised and unionised form under certain pH conditions in the environment, and the environmental behaviour of the two forms is likely to

be different. There are insufficient data available to fully understand the actual behaviour of the two forms, although the assessment has attempted to take into account the variation in the available data where possible (at present this is only possible for the adsorption onto sediment and soil).

There is some uncertainty about the biodegradation rates for the substance in the environment. The available information indicates that it undergoes primary biodegradation under a range of conditions, but there is indication of only limited mineralisation or ultimate degradation in these studies. The biodegradation rate has a large effect on some of the concentrations predicted, particularly for the regional soil compartment. This is considered in Appendix E.

Another area of uncertainty is over the actual emission estimates. For most of the scenarios considered, the best information available to the specific industries has been used in preference to the default values. However, in most cases this information was not generated for tetrabromobisphenol-A itself, but has been extrapolated from other substances. This necessarily introduces uncertainties into the estimates.

Another area where information is lacking is in the assessment of the “waste remaining in the environment”. Here, there are no agreed methodologies available in the Technical Guidance Document for estimating PECs for this type of release, and there are uncertainties associated with the actual (bio)availability and environmental behaviour of the substance when released in this form, which is essentially polymer particulates containing the substance.

4 HUMAN HEALTH

The human health risk assessment has been published separately (EC, 2006). The section on indirect exposure via the environment was based on earlier calculations, and an updated section is included below. This includes some recent additional literature on levels in human food stuffs. Although the calculated levels are similar in the two reports, there are differences (some values are higher). No risks were identified in the published report, and the risk characterisation section can be considered by the relevant experts if the health assessment is reviewed at a future date.

4.1 HUMAN HEALTH (TOXICITY)

4.1.1 Exposure assessment

4.1.1.1 Occupational exposure

4.1.1.2 Consumer exposure

4.1.1.3 Indirect exposure via the environment

The EUSES 2.0.3 model has been used to estimate the concentrations of tetrabromobisphenol-A in food, air and drinking water. In the EUSES model, a log Kow value of 5.9 has been used. For fish, a measured BCF value of 1,234 l/kg (representing accumulation of bisphenol-A plus metabolites) has been used in the calculations but for other parts of the food chain, particularly root crops, leaf crops, meat and milk, EUSES estimates the concentrations using methods that rely on the log Kow as no equivalent measured accumulation factors exist for tetrabromobisphenol-A. It is not known if these methods would be applicable to tetrabromobisphenol-A.

The calculations have been carried out twice, using different values for the organic carbon-water partition coefficient (see Section 3.1.0.7.2). The results of the calculations are shown in **Table 4.1** (for Koc = 49,726 l/kg) and **Table 4.2** (for Koc = 147,360 l/kg).

The total predicted daily human uptake figures, particularly the higher figures estimated, are dominated by the predicted contribution from root crops, which accounts for up to around 99% of the total dose.

A total diet survey has been carried out for tetrabromobisphenol-A (Food Standards Agency, 2004). The study was intended to model the average domestic diet in the United Kingdom and included a total of 121 categories of food and drink (these were assigned to one of twenty broad food groups). The food samples were purchased fortnightly from 24 randomly selected locations representative of the UK as a whole, and the food samples were prepared and cooked prior to analysis. The survey for tetrabromobisphenol-A was carried out in 2001 and the concentration of tetrabromobisphenol-A was below the detection limit in all of the main food groups (the detection limit was 2 µg/kg fat in carcass meat, 4.4 µg/kg fat in offals, 1.5 µg/kg fat in meat products, 3/5 µg/kg fat in poultry, 3.6 µg/kg fat in fish, 0.78 µg/kg fat in fats and oils, 9.4 µg/kg fat in potatoes, 15 µg/kg fat in milk, 1.4 µg/kg fat in milk products, 3.2 µg/kg fat in eggs, 5.7 µg/kg fat in miscellaneous cereals, 13.7 µg/kg fat in bread, 1.4 µg/kg fat in nuts, 2.5 µg/kg fat in sugar and preserves, 30 µg/kg fat in fruit products,

30 μg/kg fat in green vegetables, 15 μg/kg fat in other vegetables, 30 μg/kg fat in canned vegetables and 30 μg/kg fat in fresh fruit).

Another survey of the levels of tetrabromobisphenol-A in certain foodstuffs from the United Kingdom has recently been carried out (Food Standards Agency, 2006a). This survey investigated the levels present in composite samples of 24 species of wild fish, seven species of farmed fish, seven species of shellfish and ten species of canned or process fish consumed in the United Kingdom. The samples were collected between 2002 and 2004 and each composite sample consisted of 30 or 60 individual samples. In addition to this, ten samples of fish oil dietary supplements (including cold liver oil, halibut liver oil, salmon oil, tuna oil and shark liver oil) were also analysed. Tetrabromobisphenol-A was not found above the limit of detection in any of the samples analysed (the detection limit was not stated but was probably <1 μg/kg fresh weight).

A further report by Food Standards Agency (2006b) estimated the average adult dietary intake for the whole diet to be <1.6 ng/kg body weight/day for tetrabromobisphenol-A based on the results of a survey of nineteen composite food group samples representative of the UK total diet collected in 2004. Tetrabromobisphenol-A was not detectable in any of the food groups sampled (the detection limit of the analytical method used was generally 0.36 μg/kg whole weight).

de Winter-Sorkina (2003 and 2006) estimated that the mean dietary intake of tetrabromobisphenol-A by the Dutch population was around 0.04 ng/kg body weight/day, based on a food survey carried out in 2001/2002. The food survey included a total of 91 samples covering dairy products, eggs, meat and poultry, animal fats, fish and vegetable oil. The concentration of tetrabromobisphenol-A found in the survey was <0.15 μg/kg in chicken drumsticks, <0.5 μg/kg in pork, <1.1 μg/kg in pork fat, <0.1 μg/kg in beef, <0.2 μg/kg in beef fat, <0.2 μg/kg in soft cheese, 0.06-0.09 in cheese (Frico and Uniekaas), <0.02 μg/kg in milk, <0.02 μg/kg in chocolate milk, <0.02 μg/kg in coffee creamer, <0.2 μg/kg in whipped cream, <0.03 μg/kg in eggs, <0.05 μg/kg in salmon and plaice, <0.19 μg/kg in mackerel, <0.12-0.6 μg/kg in herring, <0.2 μg/kg in smoked eel, <0.1 μg/kg in Ijsselmeer eel, 0.2-3.4 μg/kg in hatched eel, <0.1-1.3 μg/kg in imported eel, up to 0.001 μg/kg in mussel and <0.03 μg/kg in shrimp. It was not possible to quantify tetrabromobisphenol-A in a number of samples (e.g. poultry, beef, soft cheese, olive oil and vegetable oil).

Peters (2006) analysed twenty seven food items for the presence of tetrabromobisphenol-A. The samples were collected from several EU countries and included butter, cheese (two samples), bacon, sausages, eggs, milk, olive oil, chicken breast, fish fingers, salmon, tuna, honey, brown bread and orange juice from the United Kingdom, frankfurter and reindeer meat from Finland, minced beef and pickled herring from Sweden, pork chops and cottage cheese from Poland, Salami and cheese from Italy, ham and cheese from Spain and hard cheese and steak from Greece. Tetrabromobisphenol-A was not detectable in any of the samples analysed. The detection limit of the analytical method used was 0.1 μg/kg wet weight.

Table 4.1 Estimated concentrations of tetrabromobisphenol-A in human intake media using a Koc of 49,726 l/kg

Scenario			Predicted concentration in human intake media							Total human daily intake (mg/kg bw/day)
			Wet fish (mg/kg)	Root crops (mg/kg)	Leaf crops (mg/kg)	Drinking water (mg/l)	Meat (mg/kg)	Milk (mg/kg)	Air (mg/m^3)	
Production of tetrabromobisphenol-A	Example calculation		115	389	0.052	0.068	0.84	0.27	1.0×10^{-7}	2.3
Use as an intermediate in the production of derivatives	Example calculation		98.6	501	0.092	0.087	1.11	0.35	3.8×10^{-6}	2.9
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.23	0.77	0.042	1.4×10^{-4}	0.058	0.018	6.2×10^{-6}	5.7×10^{-3}
	Processing of epoxy resins		1.6×10^{-3}	1.9×10^{-3}	1.5×10^{-5}	3.4×10^{-7}	2.6×10^{-5}	8.2×10^{-6}	2.5×10^{-9}	1.4×10^{-5}
	Processing of polycarbonate resins		1.6×10^{-3}	1.9×10^{-3}	1.4×10^{-5}	3.4×10^{-7}	2.5×10^{-5}	7.8×10^{-6}	2.4×10^{-9}	1.4×10^{-5}
Additive flame retardant use	ABS	Compounding	5.3	31.5	0.013	5.5×10^{-3}	0.080	0.025	1.3×10^{-6}	0.18
		Conversion	0.24	1.4	0.044	2.5×10^{-4}	0.063	0.020	6.5×10^{-6}	9.5×10^{-3}
Electronic equipment collection/recycling site			1.6×10^{-3}	5.1×10^{-4}	2.9×10^{-4}	3.2×10^{-7}	3.9×10^{-4}	1.2×10^{-4}	4.3×10^{-8}	1.3×10^{-5}
Regional sources			1.6×10^{-3}	3.0×10^{-3}	7.2×10^{-6}	5.2×10^{-7}	2.4×10^{-5}	7.7×10^{-6}	1.0×10^{-9}	1.9×10^{-5}

Table 4.2 Estimated concentrations of tetrabromobisphenol-A in human intake media using a Koc of 147,360 l/kg

Scenario			Predicted concentration in human intake media							Total human daily intake (mg/kg bw/day)
			Wet fish (mg/kg)	Root crops (mg/kg)	Leaf crops (mg/kg)	Drinking water (mg/l)	Meat (mg/kg)	Milk (mg/kg)	Air (mg/m^3)	
Production of tetrabromobisphenol-A	Example calculation		69.6	489	0.065	0.085	0.95	0.30	4.2×10^{-8}	2.8
Use as an intermediate in the production of derivatives	Example calculation		59.7	629	0.11	0.11	1.25	0.40	3.8×10^{-6}	3.6
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.14	0.97	0.042	1.7×10^{-4}	0.058	0.018	6.2×10^{-6}	6.7×10^{-3}
	Processing of epoxy resins		1.6×10^{-3}	4.1×10^{-3}	1.7×10^{-5}	7.0×10^{-7}	3.7×10^{-5}	1.2×10^{-5}	2.5×10^{-9}	2.5×10^{-5}
	Processing of polycarbonate resins		1.6×10^{-3}	4.1×10^{-3}	1.6×10^{-5}	7.0×10^{-7}	3.5×10^{-5}	1.1×10^{-5}	2.4×10^{-9}	2.5×10^{-5}
Additive flame retardant use	ABS	Compounding	3.2	39.5	0.014	6.9×10^{-3}	0.089	0.028	1.3×10^{-6}	0.22
		Conversion	0.15	1.8	0.044	3.1×10^{-4}	0.063	0.020	6.5×10^{-6}	0.011
Electronic equipment collection/recycling site			1.6×10^{-3}	2.3×10^{-3}	2.9×10^{-4}	3.9×10^{-7}	4.0×10^{-4}	1.3×10^{-4}	4.3×10^{-8}	2.3×10^{-5}
Regional sources			1.6×10^{-3}	0.022	1.2×10^{-5}	3.8×10^{-6}	1.1×10^{-4}	3.5×10^{-5}	1.3×10^{-9}	1.2×10^{-4}

5 RESULTS

Environment

(x) i) There is a need for further information and/or testing.

It is possible that tetrabromobisphenol-A may be degraded to bisphenol-A in anaerobic freshwater and marine sediments. The potential risks to sediment have been assessed in the updated risk assessment of bisphenol-A, for both reactive and additive flame retardant uses (ECB, 2008). No risks are identified based on the PNECs derived in that report. However, further work is on-going at present within the UK that could affect the aquatic and hence the sediment PNEC. The conclusion should therefore be reconsidered once the bisphenol-A sediment PNEC is finally agreed (conclusion (i) on-hold). This conclusion applies to regional sources, and also for sites manufacturing and processing epoxy and polycarbonate resins, and sites carrying out conversion of ABS.

Another possible metabolite/degradation product – tetrabromobisphenol-A bis(methyl ether) – possibly meets the screening criteria for a PBT substance using mainly estimated data. The presence of this substance has been investigated in some recent studies of anaerobic transformation in freshwater aquatic sediment and sewage sludge, and anaerobic and aerobic soil transformation. Although inconclusive, the results suggest that it is a very minor degradation product. Given that a need for risk reduction measures has already been identified for some uses (which should reduce the environmental burden of the parent compound), no further specific work is recommended to address this issue at the present time (conclusion (i) on-hold).

The risk characterisation ratios for the marine environment indicate a possible risk from some applications. The need for further toxicity data with marine organisms should be evaluated once the implications of any risk reduction activities resulting from the assessment for fresh water and freshwater sediment are known (conclusion (i) on-hold).

(x) ii) There is at present no need for further information and/or testing, or for risk reduction measures beyond those which are being applied already.

This applies to the assessment of the risks to sewage treatment processes, the atmosphere and from secondary poisoning (based on the currently derived PNEC[23]) for all sources of tetrabromobisphenol-A.

For surface water this conclusion applies to the assessment of regional sources, and also for manufacture and processing of epoxy and polycarbonate resins, where tetrabromobisphenol-A is used as a reactive flame retardant, and conversion sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

For the terrestrial compartment this conclusion applies to the assessment of risks from regional sources, and also from processing of epoxy and polycarbonate resins. In addition this conclusion also applies to sites manufacturing epoxy and/or polycarbonate resins where sewage sludge is not applied to agricultural land (Industry have indicated that this is the case

[23] The results from more recent mammalian toxicity tests are available but it is not possible to determine if these have any implications for the PNEC for secondary poisoning until full details of the studies are available and the validity of the data has been established by the relevant human health experts.

at all of the known major epoxy resin and/or polycarbonate manufacturing sites in the EU). It is possible that tetrabromobisphenol-A may be degraded to bisphenol-A during anaerobic sewage sludge treatment processes (which could lead to bisphenol-A being applied to soil). The potential risks to soil have been assessed in the updated risk assessment for bisphenol-A, for both reactive and additive flame retardant uses (ECB, 2008). This indicated no risk to the soil compartment from these applications.

This conclusion also applies to the finding of the substance in the eggs of predatory birds.

Tetrabromobisphenol-A is not a PBT substance (it is vP).

(x) iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

For surface water and sediment, this conclusion applies to compounding sites where tetrabromobisphenol-A is used as an additive flame retardant in ABS.

For the terrestrial compartment, this conclusion applies to the use of tetrabromobisphenol-A as an additive flame retardant in ABS from compounding and conversion sites. The conclusion for conversion sites is dependent on whether or not sewage sludge from the site is applied to agricultural land (no risk is identified where sewage sludge is not applied to land). For ABS compounding sites a risk is identified regardless of the assumptions made over the spreading of sewage sludge.

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APPENDIX A TETRABROMOBISPHENOL-A AND FORMATION OF BROMINATED DIBENZO-*P*-DIOXINS AND DIBENZOFURANS

Much concern has been expressed over the possible formation of brominated dibenzofurans, and brominated dibenzo-*p*-dioxins from certain brominated flame retardants during production, processing, use, accidental fires and disposal (e.g. incineration). This Appendix reviews the known data on tetrabromobisphenol-A on this issue and attempts to draw some conclusions from the data with regards to the environmental exposure.

In the following Sections the general abbreviations used will be:

PBDF	-	Polybrominated dibenzofuran
PBDD	-	Polybrominated dibenzo-*p*-dioxin

The following abbreviations will be used in some of the Tables in this Appendix:

MBDF	-	Monobromodibenzofuran	MBDD	-	Monobromodibenzo-*p*-dioxin
DiBDF	-	Dibromodibenzofuran	DiBDD	-	Dibromodibenzo-*p*-dioxin
TrBDF	-	Tribromodibenzofuran	TrBDD	-	Tribromodibenzo-*p*-dioxin
TeBDF	-	Tetrabromodibenzofuran	TeBDD	-	Tetrabromodibenzo-*p*-dioxin
PeBDF	-	Pentabromodibenzofuran	PeBDD	-	Pentabromodibenzo-*p*-dioxin
HxBDF	-	Hexabromodibenzofuran	HxBDD	-	Hexabromodibenzo-*p*-dioxin
HpBDF	-	Heptabromodibenzofuran	HpBDD	-	Heptabromodibenzo-*p*-dioxin
OBDF	-	Octabromodibenzofuran	OBDD	-	Octabromodibenzo-*p*-dioxin

Dibenzo-*p*-dioxin and dibenzofuran impurities present in tetrabromobisphenol-A

Kurz (1998) reported the levels of brominated dibenzo-*p*-dioxins and dibenzofurans present in tetrabromobisphenol-A and also a diglycidyl ether derivative of tetrabromobisphenol-A. The results are shown in **Table A1**. No brominated dibenzofurans or dibenzo-*p*-dioxins were found in either of the two flame retardants analysed.

Table A1 Impurities present in tetrabromobisphenol-A and tetrabromobisphenol-A glycidyl ether (Kurz, 1998)

Congener	Concentration (µg/kg flame retardant)	
	Tetrabromobisphenol-A	Tetrabromobisphenol-A glycidyl ether
2,3,7,8-TeBDD	<0.01	<0.02
1,2,3,7,8-PeBDD	<0.02	<0.05
1,2,3,4,7,8-HxBDD	<0.05	<0.1
1,2,3,6,7,8-HxBDD	<0.05	<0.1
1,2,3,7,8,9-HxBDD	<0.05	<0.1
1,2,3,4,6,7,8-HpBDD		<0.2
2,3,7,8-TeBDF	<0.01	<0.02
1,2,3,7,8-PeBDF	<0.02	<0.05
2,3,4,7,8-PeBDF	<0.02	<0.05

Table A1 continued overleaf.

Table A1 continued.

Congener	Concentration (µg/kg flame retardant)	
	Tetrabromobisphenol-A	Tetrabromobisphenol-A glycidyl ether
1,2,3,4,7,8-HxBDF		<0.1
1,2,3,6,7,8-HxBDF		<0.2
1,2,3,7,8,9-HxBDF		<0.2
2,3,4,6,7,8-HxBDF		<0.2
1,2,3,4,6,7,8-HpBDF		<0.2
1,2,3,4,7,8,9-HpBDF		<0.2

Freiberg (1995) carried out an analysis for trace levels of brominated dibenzo-*p*-dioxins and dibenzofurans in tetrabromobisphenol-A. The method used was designed to meet the limit of quantification laid down in the USEPA test rule for these impurities. The results are shown in **Table A2**. Again, no brominated dibenzo-*p*-dioxins of dibenzofurans were found at the limit of quantification required by the test rule.

Table A2 Analysis of tetrabromobisphenol-A according to the USEPA test rule (Freiberg, 1995)

Congener	Limit of quantification (µg/kg flame retardant)	Level found (µg/kg flame retardant)
2,3,7,8-TeBDD	0.1	<0.1
2,3,7,8-TeBDF	1.0	<1.0
1,2,3,7,8-PeBDD	0.5	<0.5
1,2,3,7,8-PeBDF	5	<5
2,3,4,7,8-PeBDF	5	<5
1,2,3,4,7,8-HxBDD	2.5	<2.5
1,2,3,6,7,8-HxBDD	2.5	<2.5
1,2,3,7,8,9-HxBDD	2.5	<2.5
1,2,3,4,7,8-HxBDF	25	<25
1,2,3,6,7,8-HxBDF	25	<25
1,2,3,7,8,9-HxBDF	25	<25
2,3,4,6,7,8-HxBDF	25	<25
1,2,3,4,6,7,8-HpBDD	100	<100
1,2,3,4,6,7,8-HpBDF	1,000	<1,000
1,2,3,4,7,8,9-HpBDF	1,000	<1,000

Ranken *et al.* (1994) analysed samples of commercial tetrabromobisphenol-A for the presence of fifteen brominated dibenzofurans and dibenzo-*p*-dioxins with the 2,3,7,8- substitution pattern. The analytical method used was a GC-MS method (SIM mode) but extensive sample clean-up was undertaken to allow the brominated furans to be analysed at low limits of detection free from interferences. Several analytical standards were used in the analysis (at least one pure brominated dibenzofuran and dibenzo-*p*-dioxin isomer for each degree of bromination between tetra- and heptabromo). Originally, ten samples of tetrabromobisphenol-A were collected from each of three manufacturers. Seven out of the ten

samples from each manufacturer were randomly selected for analysis. None of the fifteen dibenzofurans and dibenzo-*p*-dioxins were detected in any of the samples analysed at concentrations above the limit of quantitation specified by the USEPA (see **Table A2**). The limits of quantitation varied from 0.1 µg/kg for 2,3,7,8-tetrabromo-*p*-dioxin to 1.0 µg/kg for 2,3,7,8-tetrabromodibenzofuran to 1,000 µg/kg for 1,2,3,4,6,7,8- and 1,2,3,4,7,8,9-heptabromodibenzofuran.

The levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in tetrabromobisphenol-A have been determined by Thies *et al.* (1990). The results are shown in **Table A3**. In these samples, trace amounts of some polybrominated dibenzo-*p*-dioxins and dibenzofurans were found.

Table A3 Levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in a commercial tetrabromobisphenol-A (Thies *et al.*, 1990)

Congener	Level (µg/kg)
MBDD	<0.5
DiBDD	<0.5
TrBDD	<0.5
TeBDD	1
2,3,7,8-TeBDD	<0.5
PeBDD	2
HxBDD	5
MBDF	2
DiBDF	1
TrBDF	<0.5
TeBDF	<1
2,3,7,8-TeBDF	<0.5
PeBDF	<2
HxBDF	<14[a]

Note: a) Interference from a co-eluting peak.

The levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in technical grade tetrabromobisphenol-A have been reported by Thoma *et al.* (1986a) and Dumler *et al.* (1989b). The levels found are shown in **Table A4**. In these samples small amounts of penta- to octabromodibenzofurans were found to be present, but, although individual isomers were not identified in this study, it is clear that the concentrations present are below those required in the USEPA test rule (see **Table A2** for limits).

Table A4 Levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans in technical grade tetrabromobisphenol-A (Thoma *et al.* (1986a) and Dumler *et al.* (1989b))

Congener	Level (µg/kg)
TrBDD	nd
TeBDD	nd
DiBDF	nd
TrBDF	nd
TeBDF	nd
PeBDF	1.0
HxBDF	12.2
HpBDF	31.5
OBDF	18.9

Note: nd = Not detected. Detection limit not given.

Brenner and Knies (1993a and 1993b) determined the levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in a tetrabromobisphenol-A carbonate oligomer flame retardant. The method used determined the concentrations of di- to octabrominated congeners. Around 6 ng/kg of tetrabromodibenzo-*p*-dioxins were found in the sample, but these were not 2,3,7,8-substituted. No other polybrominated dibenzo-*p*-dioxins or dibenzofurans were detected in the sample (the detection limits were in the range 0.001 to 0.4 µg/kg for the di- to octabromodibenzo-*p*-dioxins and dibenzofurans).

Summary of levels in tetrabromobisphenol-A

Several studies have investigated the levels of brominated dibenzo-*p*-dioxins and dibenzofurans present in tetrabromobisphenol-A. All studies have indicated that the levels are very low. A few studies have occasionally indicated the presence of small amounts of some congeners. It is possible that the apparent differences between some of the studies in terms of the levels found could be due to the use of improved analytical methods that eliminate possible interferences rather than actual differences in the amounts present. In all cases the concentrations found appear to be below the levels specified in the USEPA test rule.

In terms of the environmental risk assessment, as the effects data used in the assessment has been derived from the commercially supplied product, the results obtained will also account for any toxic impurities present.

Polymer manufacture and use

Bonilla *et al.* (1990) carried out analysis of the amounts of brominated dibenzo-*p*-dioxins and dibenzofurans present in ABS resin containing tetrabromobisphenol-A both before and after extrusion. In the resin prior to extrusion no brominated dibenzo-*p*-dioxins were found but brominated dibenzofurans were present at a total level of 1.09 µg/kg resin (the brominated dibenzofurans found in the resin were tentatively identified as being 2,3,7,8-substituted). In the resin after extrusion, no brominated dibenzofurans could be detected but the total concentration of brominated dibenzo-*p*-dioxins was 6.16 µg/kg resin. As well as the resin samples themselves, fumes from the extruded plastic were also analysed for the presence of brominated dibenzo-*p*-dioxins and dibenzofurans. The total amount of brominated

dibenzo-*p*-dioxins and dibenzofurans present in the fume was 0.006 and 0.020 µg/kg extruded resin respectively.

Thies *et al.* (1990) looked at the amounts of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in various polymers containing tetrabromobisphenol-A or tetrabromobisphenol-A derivatives produced under normal conditions. The results are shown in **Table A5**.

Table A5 Amounts of polybrominated dibenzo-*p*-dioxins and dibenzofurans in polymers containing tetrabromobisphenol-A or derivatives (Thies *et al.*, 1990)

Congener	Level (µg/kg polymer)		
	ABS with 16% tetrabromobisphenol-A and 6% Sb_2O_3	Polybutylene terephthalate with 10% tetrabromobisphenol-A oligomer and 5% Sb_2O_3	ABS with tetrabromobisphenol-A - bisphenol-A polycarbonate blend (6% copolymerised tetrabromobisphenol-A)
MBDD	<1	<0.2	<0.5
DiBDD	<1	<0.2	<0.5
TrBDD	<1	<0.2	<0.5
TeBDD	<1	<0.2	<1
2,3,7,8-TeBDD	<1	<0.1	<1
PeBDD	<2	<0.1	<1
HxBDD	<10	<1	<1
MBDF	3	4	<0.5
DiBDF	3	<0.2	<1
TrBDF	<1	<0.2	<0.5
TeBDF	<2	<0.2	<1
2,3,7,8-TeBDF	<2	<0.1	<1
PeBDF	<3	<0.1	<1
HxBDF	<20	<1	<10

Brenner and Knies (1993a and 1993b) found no polybrominated dibenzo-*p*-dioxins in three samples of extruded polybutylene terephthalate polymer granulate containing antimony trioxide, glass fibre and around 50% tetrabromobisphenol-A carbonate oligomer, and also in two test articles formed by injection moulding of the resin. The detection limits were in the range 0.01 µg/kg to 17 µg/kg for di- to octabromodibenzo-*p*-dioxin respectively. The levels of polybrominated dibenzofurans found are shown in **Table A6**.

Table A6 Levels of polybrominated dibenzofurans in polybutylene terephthalate containing tetrabromobisphenol-A carbonate (Brenner and Knies, 1993a)

Congener	Level in polymer (µg/kg)				
	Granulate	Granulate	Granulate	Test article	Test article
DiBDF	nd	nd	nd	0.07	0.29
TrBDF	nd	nd	nd	0.2	0.31
TeBDF	nd	nd	nd	0.2	0.17
PeBDF	nd	nd	nd	nd	0.06
HxBDF	0.8	0.4	0.51	2.2	1.5
HpBDF	3.5	0.6	1.6	3.8	1.9

Notes: nd = Not detected. The detection limit was not clear.

Fluthwedel and Pohle (1993) reported results of analysis for the presence of polybrominated dibenzofurans and polybrominated dibenzo-*p*-dioxins in various electronic equipment casings and parts. Total levels of between 0.0067 and 4.24 mg/kg were found. Of the 16 samples analysed, 11 exceeded the proposed German limit value of 1 µg/kg for the sum of 4 tetra-/pentabrominated dibenzofurans/dibenzo-*p*-dioxins (maximum level measured 32.7 µg/kg) and the proposed limit value of 5 µg/kg for the sum of 8 tetra- to hexabrominated dibenzofurans/dibenzo-*p*-dioxins (maximum level measured 74.6 µg/kg). The proportion of 2,3,7,8-substituted congeners was around 5.8% of the total. It is not clear if the plastic parts analysed in this study contained tetrabromobisphenol-A. Other flame retardants, in particular the polybrominated diphenyl ethers could have been present in the samples, and so it is not possible to attribute the levels found solely to tetrabromobisphenol-A usage.

Fluthwedel and Pohle (1993) also reported the results of a series of experiments looking at the emissions of polybrominated dibenzofurans from various electronic equipment in use including televisions, printers and monitors. After 3 days sampling, the sum of polybrominated dibenzofurans released was estimated at around 320-1,800 pg/device. Investigations of air levels in a room containing electronic equipment gave a total air concentration of 1.27 pg/m^3 of polybrominated dibenzofurans. It is not known if tetrabromobisphenol-A was present in the electronic equipment used in this study. Again, other flame retardants, in particular the polybrominated diphenyl ethers, are also likely to be present, and so it is not possible to attribute the levels found solely to tetrabromobisphenol-A.

The levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in samples of printed circuit board have been determined (Lorenz and Bahadir, 1993). As well as the original printed circuit board sample, samples were also heated in an oven at either 150^{o}C, 200^{o}C, 250^{o}C or 300^{o}C for 30 minutes in order to investigate the effects of thermal stress on the levels found. Under these conditions, no obvious physical changes occurred to the samples at 150^{o}C and 200^{o}C, there was some discolouration of the sample treated at 250^{o}C and carbonisation occurred in the sample treated at 300^{o}C. The results of the analyses are shown in **Table A7**. The results showed that only very low levels of some polybrominated dibenzo-*p*-dioxin and dibenzofuran congeners are present in the original printed circuit board, and that very small amounts of mono- to tribromo congeners appear to be formed when the samples are heated to high temperatures for prolonged periods.

Table A7 Levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in printed circuit boards (Lorenz and Bahadir, 1993)

Congener	Concentration present (µg/kg)				
	Original sample	Sample heated at 150°C	Sample heated at 200°C	Sample heated at 250°C	Sample heated at 300°C
MBDD	<0.05	<0.05	<0.05	0.10	0.49
DiBDD	<0.04	<0.1	<0.1	0.16	0.30
TrBDD	<0.02	<0.05	<0.05	0.10	0.09
TeBDD	0.22	0.56	0.33	1.06	0.19
2,3,7,8-TeBDD	<0.04	<0.1	<0.1	<0.04	<0.04
PeBDD	<0.1	<0.2	<0.2	<0.2	<0.2
HxBDD	<0.1	<0.2	<0.2	<0.2	<0.2
HpBDD	<1	<3	<3	<3	<3
OBDD	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]
MBDF	<0.05	<0.05	<0.05	1.68	2.49
DiBDF	<0.05	0.18	0.26	0.67	0.82
TrBDF	<0.02	<0.02	<0.02	<0.04	0.13
TeBDF	<0.05	<2	<2	<0.5	<2
2,3,7,8-TeBDF	<0.01	<0.04	<0.04	<0.04	<0.04
PeBDF	<0.05	<0.1	<0.1	<0.1	<0.1
HxBDF	<0.5	<1	<1	<1	<1
HpBDF	<1	<2	<2	<2	<2
OBDF	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]

Note: a) Not detected. Detection limit not given.

Thies *et al.* (1990) investigated the concentrations of polybrominated dibenzo-*p*-dioxins and dibenzofurans in the off-gas from a compounding machine where ABS containing tetrabromobisphenol-A was being processed at 180°C, the workplace atmosphere where injection moulding of ABS containing 16% tetrabromobisphenol-A and 6% antimony trioxide was taking place, and in ambient air near to a television cabinet. The results are shown in **Table A8**.

Table A8 Levels of polybrominated dibenzo-*p*-dioxins and furans in air associated with processing of tetrabromobisphenol-A (Thies *et al.*, 1990)

Congener	Level in air (ng/m³)			
	Off-gas from a compounding machine	Workplace atmosphere - injection moulding	15 cm above TV cabinet	2.2 m away from TV cabinet
MBDD	<8	<1	<0.001	<0.001
DiBDD	<6	<1	<0.001	<0.002[a]
TrBDD	<3	<1	<0.001	<0.001
TeBDD	6-8	<1	<0.001	<0.001
2,3,7,8-TeBDD	<2	<0.1	<0.0005	<0.0005
PeBDD	<8	<0.1	<0.001	<0.001
1,2,3,7,8-PeBDD	nd	<0.1	<0.5	<0.5
HxBDD	<20	<0.1	<0.008	<0.008
MBDF	12[a]-13	<1	<0.5[a]	<0.5[a]
DiBDF	12-200	<1	<0.1[a]	<0.1[a]
TrBDF	<6	<1	<0.001	<0.001
TeBDF	<4	<1	0.003	<0.001
2,3,7,8-TeBDF	<1	<0.1	<0.0005	<0.0005
PeBDF	<10	<1	0.008	<0.001
1,2,3,7,8-PeBDF	<1	<0.1	<0.0005	<0.0005
HxBDF	<40	<1	<0.008	<0.008

Note: a) Interference from a co-eluting peak.
ND = Not determined.

Brenner and Knies (1993a and 1993b) investigated the levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans in workplace air at a facility using a derivative of tetrabromobisphenol-A. In this study samples were taken during extruder production and injection moulding of a polybutylene terephthalate polymer blended with glass fibre, antimony trioxide (3.5%) and tetrabromobisphenol-A carbonate (11%). The levels found are shown in **Table A9**. No 2,3,7,8-substituted polybrominated dibenzo-*p*-dioxins of dibenzofurans were detected in this study.

Table A9 Levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans in air processing of polybutylene terephthalate containing tetrabromobisphenol-A carbonate (Brenner and Knies, 1993a)

Congener	Level in air (ng/m³)					
	Workplace during extrusion	Extruder	Granulator	Workplace during injection moulding	Injection head	Storage area
DiBDD	nd[a]	0.94	nd[a]	nd[b] (<0.001)	nd[b] (<0.001)	nd[b] (<0.001)
TrBDD	nd[b] (<0.001)	0.07	0.02	nd[b] (<0.001)	nd[b] (<0.001)	nd[b] (<0.001)
TeBDD	nd[b] (<0.001)	0.08	nd[b] (<0.001)	nd[b] (<0.001)	nd[b] (<0.001)	nd[b] (<0.001)
PeBDD	nd[b] (<0.003)	nd[b] (<0.003)	nd[b] (<0.003)	nd[b] (<0.003)	nd[b] (<0.001)	nd[b] (<0.004)
HxBDD	nd[b] (<0.02)	nd[b] (<0.1)	nd[b] (<0.02)	nd[b] (<0.016)	nd[b] (<0.003)	nd[b] (<0.058)
HpBDD	nd[b] (<0.04)	nd[b] (<0.2)	nd[b] (<0.02)	nd[b] (<0.032)	nd[b] (<0.006)	nd[b] (<0.116)
OBDD	nd[b] (<0.08)	nd[b] (<0.4)	nd[b] (<0.08)	nd[b] (<0.064)	nd[b] (<0.012)	nd[b] (<0.232)
DiBDF	0.34	0.42	0.23	nd[a]	0.04	0.04
TrBDF	0.11	0.48	0.29	nd[a]	0.012	nd[a]
TeBDF	0.05	0.24	0.17	0.029	0.014	0.02
PeBDF	0.07	0.04	0.02	0.187	0.013	nd[a]
HxBDF	0.05	0.18	nd[a]	0.262	0.039	nd[a]
HpBDF	nd[b] (<0.04)	nd[b] (<0.1)	nd[b] (<0.04)	nd[b] (<0.013)	nd[a]	nd[a]
OBDF	nd[b] (<0.08)	nd[b] (<0.3)	nd[b] (<0.08)	nd[b] (<0.026)	nd[a]	nd[a]

Notes: a) nd = Not detected. The detection limit was not clear.
b) nd = Not detected. Detection limit given in ( ).

Summary of levels during polymer manufacture and use

The available data on the levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans associated with the use of tetrabromobisphenol-A in polymers generally show that only very low levels of these impurities are present in, or are emitted from, polymer systems under normal conditions of manufacture or use. Polybrominated dibenzo-*p*-dioxins have been found in only a few of the available studies where elevated temperatures have been used (formation during pyrolysis/combustion is considered in the next Section). Polybrominated dibenzofurans have been found in most studies, but again the levels are low, and the mono- and dibrominated congeners appear to dominate. In particular, it should be noted that the levels of 2,3,7,8-substituted congeners of both polybrominated dibenzo-*p*-dioxins and dibenzofurans are very low and are usually not detectable by the analytical methodologies used.

Pyrolysis studies

Several laboratory studies have been carried out to determine the extent of formation of polybrominated dibenzo-*p*-dioxins and dibenzofurans when tetrabromobisphenol-A (or in some cases a derivative of tetrabromobisphenol-A) is heated or burned at high temperatures. As can be seen, many different experimental designs have been used, with different pyrolysis times, making direct comparison from one experiment to another difficult. However, some of

the results may have relevance to the possible formation of these products during accidental fires and incineration and other high temperature processes.

Pyrolysis of tetrabromobisphenol-A and derivatives

Thoma *et al.* (1986b) studied the pyrolysis of a purified sample of tetrabromobisphenol-A. In the experiment, the flame retardant was heated in open quartz tubes at either 700°C, 800°C or 900°C for 10 minutes. The residue was then analysed by a GC/MS technique, using 1,2,3,4-tetrabromodibenzo-*p*-dioxin as a standard for quantifying both polybrominated dibenzo-*p*-dioxins and dibenzofurans. The results are shown in **Table A10**. No higher brominated products were reported to be formed and the maximum formation of mono- to tribrominated dibenzo-*p*-dioxins and furans was found to occur at 800°C.

Table A10 Pyrolysis of tetrabromobisphenol-A (Thoma *et al.*, 1986b)

Congener	Concentration (mg/kg flame retardant)		
	700°C	800°C	900°C
MBDD	19	129	71
DBDD	32	233	129
TrBDD	11	109	64
TeBDD	1	27	6
MBDF	77	270	182
DBDF	49	623	421
TrBDF	6	236	160
TeBDF	nd	21	16

Note: nd = Not detected (detection limit not given).

Thies *et al.* (1990) determined the levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans in a sample of tetrabromobisphenol-A that had been heated at 240°C or 600°C for 20 minutes in a BIS-apparatus. Both the solid residue and the gas condensate were analysed. The results are shown in **Table A11**. The levels found in the condensate were much higher in the sample heated to 600°C than in the sample heated to 240°C. Mono- to tetrabrominated congeners dominated the products formed.

Dumler *et al.* (1989b) carried out pyrolysis experiments with tetrabromobisphenol-A using a DIN-apparatus, a BIS-apparatus and a VCI-apparatus over a temperature range of 300-800°C. It was reported that polybrominated dibenzo-*p*-dioxins and dibenzofurans were formed in mg/kg amounts, and that these were mainly mono- and dibrominated products. Few other details of this study were reported.

It has been reported that 1,3,6,8- and 1,3,7,9-tetrabromodibenzo-*p*-dioxins were formed in pyrolysis experiments using tetrabromobisphenol-A (Ramalingam *et al.*, 1985). Few other details of this study were reported.

Table A11 Levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in tetrabromobisphenol-A after heating at 240°C or 600°C for 20 minutes (Thies *et al.*, 1990)

Congener	Level (µg/kg tetrbromobisphenol-A)		
	240°C		600°C
	Condensate	Residue	Condensate
MBDD	<7	<7	46,000
DiBDD	<11[a]	<14[a]	130,000
TrBDD	<7	<7	70,000
TeBDD	<7	<7	17,000
2,3,7,8-TeBDD	<75	<7	12-15
PeBDD	<14	<14	480
1,2,3,7,8-PeBDD	not determined	not determined	21-25
HxBDD	<70	<70	330
MBDF	<7	<7	18,000
DiBDF	<11[a]	<8[a]	40,000
TrBDF	<7	<7	60,000
TeBDF	<14	<14	7,000
2,3,7,8-TeBDF	<14	<7	9-10
PeBDF	<30	<30	500
1,2,3,7,8-PeBDF	not determined	not determined	20-50
HxBDF	<140	<140	500

Note: a) Interference from a co-eluting peak.

Pyrolysis of flame retarded polymers

The pyrolysis of ABS containing tetrabromobisphenol-A has been studied using a horizontal quartz tube reactor (Luijk and Govers, 1992). The sample used had a bromine content of 15.12%, which is equivalent to a tetrabromobisphenol-A content of around 25.7%. The sample (0.1 g) was placed inside a furnace for 20 minutes at temperatures between 400°C and 700°C. A carrier gas (990 ml/minute) was continually passed through the reactor and the volatile products were collected in a cold trap. Nitrogen, a mixture of nitrogen and 5% oxygen or a mixture of nitrogen 10% oxygen were used as the carrier gas. The report indicates that there were problems with the clean-up procedure and interferences in the analyses and so not all samples tested could be analysed for polybrominated dibenzo-*p*-dioxins and dibenzofurans. However, it was reported that the pyrolysis experiments predominantly yielded lower brominated dibenzofurans, and that the yields appeared to increase in the presence of oxygen. The results are shown in **Table A12**. The paper indicates that the concentrations reported should be considered as estimates due to a lack of analytical standards for the congeners found. No 2,3,7,8-substituted congeners were found in any samples.

Table A12 Pyrolysis of ABS containing tetrabromobisphenol-A (Luijk and Govers, 1992)

Congener	Yield (µg/kg polymer)											
	Nitrogen atmosphere				Nitrogen + 5% air atmosphere				Nitrogen + 10% air atmosphere			
	400	500	600	700	400	500	600	700	400	500	600	700
MBDD	nd	nd	2	na	1	3	5	100	nd	6	6	5
DiBDD	nd	0.5	5	na	1	15	250	225	2	70	225	75
TrBDD	0.05	0.5	2	na	1	15	145	35	5	40	220	30
TeBDD	nd	nd	nd	na	nd	nd	3	nd	1	2	6	nd
PeBDD	nd	nd	nd	na	nd	nd	nd	nd	nd	nd	nd	nd
MBDF	10	50	10	nd	10	5	10	200	nd	20	265	130
DiBDF	35	30	170	840	25	40	925	2,250	55	190	1,550	2,400
TrBDF	6	11	50	50	3	15	200	230	15	15	220	420
TeBDF	4	13	80	50	10	50	100	15	20	15	70	85
PeBDF	13	15	30	nd	10	50	50	4	nd	20	35	35

Note: nd = Not detected. The detection limit not given.
na = Not analysed due to analytical interferences.

In a study by Dumler *et al.* (1989a), polymers containing one of several brominated flame retardants, including tetrabromobisphenol-A and tetrabromobisphenol-A bis(2,3-dibromopropyl ether), were pyrolysed at either 600 or 800°C in three different oven designs (DIN-apparatus, BSI-apparatus and VCI-apparatus). The polymer samples were in granulate form and the sample size was 1-5 g in the DIN- and BSI-ovens and 20-50 mg in the VCI-oven. No information on the pyrolysis time was given. After pyrolysis, analysis (GC/MS) was carried out for PBDDs and PBDFs in both the pyrolysis gases and the solid residues and the yield of these products was estimated on a mass of flame retardant basis (e.g. mg PBDF/kg flame retardant). The analyses were carried out using GC-MS in SIM mode with external standards of one isomer of each brominated congener of dibenzofuran and dibenzo-*p*-dioxin. The following combinations of tetrabromobisphenol-A, derivatives and polymers were tested:

Epoxy laminate/tetrabromobisphenol-A.
Epoxy laminate/copper/tetrabromobisphenol-A.
Polybutylene terephthalate/tetrabromobisphenol-A.
Polycarbonate/tetrabromobisphenol-A.
Polypropylene/5.9% tetrabromobisphenol-A bis(2,3-dibromopropyl ether)/1.5% polystyrene.

The experiments with tetrabromobisphenol-A indicated that polymers containing the flame retardant generated only small quantities of polybrominated dibenzo-*p*-dioxins and dibenzofurans, with the yields ranging up to a few mg/kg polymer. Only mono- to tribrominated congeners were found. The experiments with the tetrabromobisphenol-A bis(2,3-dibromopropyl ether) derivative showed only very low or not detectable amounts of polybrominated dibenzo-*p*-dioxins and dibenzofurans were formed, with no significant differences being seen between the two temperatures studied. When detected, the products again were mainly mono- to tribrominated dibenzo-*p*-dioxin or dibenzofuran congeners.

Hutzinger *et al.* (1989) reported the results of very similar pyrolysis studies (possibly even the same experiments as Dumler *et al.* (1989a)) using an epoxy laminate containing tetrabromobisphenol-A and these results are reproduced in **Table A13**. In these tests, samples of the polymer were pyrolysed for ten minutes at 800^{o}C in each of the three ovens. Analysis for brominated dibenzofurans and dibenzo-*p*-dioxins was carried out by GC-MS in SIM mode, quantification being made by comparison with dioxin and furan congeners of every bromination degree (except for pentabromodibenzofuran which used pentabromodibenzo-*p*-dioxin as standard and hexabromodibenzofuran and all other higher dioxins and furans which were quantified with hexabromodibenzo-*p*-dioxin).

Table A13 Results of polymer pyrolysis experiments at 800°C (Hutzinger *et al.*, 1989)

PBDD/ PBDF	Level (µg/kg polymer)		
	DIN-apparatus	BIS-apparatus	VCI-apparatus
MBDD	680	3,100	10,080
DiBDD	4	77	1,860
TrBDD	2	58	nd
TeBDD	nd	nd	nd
PeBDD	nd	nd	nd
HxBDD	nd	nd	nd
HpBDD	nd	nd	nd
MBDF	5,060	5,010	21,000
DiBDF	23	190	780
TrBDF	3	160	810
TeBDF	nd	81	4,910
PeBDF	nd	29	nd
HxBDF	nd	nd	nd
HpBDF	nd	nd	nd

Note: nd = Not detected. Detection limit not given.

Thies *et al.* (1990) looked at the amounts of polybrominated dibenzo-*p*-dioxins and dibenzofurans present in various polymers containing tetrabromobisphenol-A or tetrabromobisphenol-A derivatives after heating at 240°C for 20 minutes in a BIS-apparatus or at 600°C for 20 minutes in a BIS-apparatus or at 600°C for 10 minutes in a DIN-apparatus. The concentrations present in both the residue and gas condensate were determined. The results are shown in **Table A14**.

Lahaniatis *et al.* (1991) studied the formation of 2,3,7,8-tetrabromodibenzo-*p*-dioxin and 2,3,7,8-tetrabromodibenzofuran during the pyrolysis of several epoxy resin/tetrabromobisphenol-A formulations. The experiments were carried out at 400-800°C using a BIS apparatus. Around 100 mg of the sample was pyrolysed for 10 minutes with an air flow of 500 ml/minute and the products formed were analysed by GC-ECD using external standards and by GC-MS (SIM mode) using ^{13}C-labelled 2,3,7,8-tetrabromodibenzofuran or dibenzo-*p*-dioxin as internal standard. The samples tested were an epoxy resin containing 6% tetrabromobisphenol-A with 5% antimony trioxide and copper oxide, an epoxy resin containing 6% tetrabromobisphenol-A and copper oxide, and an epoxy resin containing 6% tetrabromobisphenol-A and copper. The results are shown in **Table A15**. Clausen *et al.* (1987) reported similar findings that tetrabromobisphenol-A in epoxy resins showed no tendency to form polybrominated dibenzo-*p*-dioxins and dibenzonfurans under similar thermolytic conditions, even in the presence of antimony trioxide.

Table A14 Amounts of polybrominated dibenzo-*p*-dioxins and dibenzofurans in polymers containing tetrabromobisphenol-A or derivatives (Thies *et al.*, 1990)

Congener	Level (µg/kg polymer)											
	ABS with 16% tetrabromobisphenol-A and 6% Sb_2O_3				Polybutylene terephthalate with 10% tetrabromobisphenol-A oligomer and 5% Sb_2O_3		Polycarbonate with 10% copolymerised tetrabromobisphenol			ABS with tetrabromobisphenol-A - bisphenol-A polycarbonate blend (6% copolymerised tetrabromobisphenol-A)		
	240°C		600°C		240°C	600°C	240°C		600°C	240°C		600°C - BIS- apparatus
	Condensate	Residue	Condensate - BIS- apparatus	Condensate - DIN-apparatus	Condensate + residue	Condensate - BIS- apparatus	Condensate	Residue	Condensate - BIS- apparatus	Condensate	Residue	Condensate
MBDD	<5	<5	7	<7	<2	<2	<5[a]	<60[a]	485	<5	<5	<6
DiBDD	<5	<5	70-350	<7	<2	2	<2	<5	7,240	<5	<5	<50[a]
TrBDD	<5	<5	40-200	<7	<2	<1	<2	<2	345	<5	<5	<70[a]
TeBDD	<10	<40[a]	10-60	<14	1.2	<15	<2	<5	165	<5	<5	50
2,3,7,8- TeBDD	<10	<30[a]	<5[a]	<7	<1	4	<0.2	<0.5	<3	<5	<5	<6
PeBDD	<10	<30	<35	<35	<2	<7	<0.2	<10	80	<10	<10	<20
HxBDD	<50	<50	<70	<70	<2	<35	<5	<20	18	<50	<50	<100
MBDF	<5	70	<50[a]	<7	13	17	10	50	1,110	<5	<30[a]	<50[a]
DiBDF	<5	30	670-1,430	70	10	80	5	31	3,500	<5	7	210
TrBDF	<5	<5	370-530	70	<2	10	<2	<5	770	<5	<5	150
TeBDF	<10	<10	40-130	<14	<5	3	<2	<5	70	<10	<10	12
2,3,7,8- TeBDF	<10	<10	<15[a]	<7	<1	2	<0.5	<0.5	<16[a]	<10	<10	<10[a]
PeBDF	<20	<30	<35	<35	<2	<7	<5	<10	33	<20	<20	<20
HxBDF	<100	<100	<100[a]	<70	<2	<35	<10	<20	22	<100	<1	<100

Note: a) Interference from a co-eluting peak.

Table A15 Formation of 2,3,7,8-tetrabromodibenzofuran and dibenzo-*p*-dioxin from pyrolysis of various polymer/flame retardant formulations (Lahaniatis *et al.*, 1991)

Polymer sample	2,3,7,8-TeBDD (mg/kg polymer)			2,3,7,8-TeBDF (mg/kg polymer)		
	400°C	600°C	800°C	400°C	600°C	800°C
Epoxy resin/6% tetrabromobisphenol-A/ 5% Sb_2O_3/ CuO	nd	nd [6.0][a]	nd [4.4][a]	nd	nd	nd
Epoxy resin/6% tetrabromobisphenol-A/ CuO	nd	nd [3.4][a]	nd [2.0][a]	nd	nd	nd
Epoxy resin/6% tetrabromobisphenol-A/ Cu	nd	nd [5.3][a]	nd [4.0][a]	nd	nd	nd

Notes: nd - Not detected, detection limit 0.01 mg/kg.
a) 2,3,7,8-Tetrabromodibenzo-*p*-dioxin was not detected in these samples. The figure given in brackets indicates the concentration of 1,3,6,8-tetrabromodibenzo-*p*-dioxin and/or 1,3,7,9-tetrabromodibenzo-*p*-dioxin found in the sample.

WHO (1995) reported the results of unpublished studies by Satoh and Sugie (1993) investigating the pyrolysis of ABS containing either tetrabromobisphenol-A, or EP-type or EC-type brominated epoxy oligomer derivatives of tetrabromobisphenol-A. In the study the polymer samples were heated to 600°C and the gas and ash were collected and analysed for the presence of 2,3,7,8-substituted polybrominated dibenzo-*p*-dioxins and dibenzofurans. The experiments using ABS with tetrabromobisphenol-A yielded around 0.9 µg/kg of 2,3,7,8-substituted brominated dibenzo-p-dioxins (including some penta- and hexabrominated congeners) and around 22 µg/kg of 2,3,7,8-substituted brominated dibenzofurans. The ABS with the EP-type and EC-type brominated epoxy oligomers yielded respectively <0.5 µg/kg and 0.5 µg/kg of 2,3,7,8-substituted brominated dibenzo-*p*-dioxins and <4 µg/kg and <4 µg/kg of 2,3,7,8-substituted brominated dibenzofurans.

Wichmann *et al.* (2002) recently investigated the formation of polybrominated dibenzo-*p*-dioxins and dibenzofurans in a series of pyrolysis/combustion experiments in a laboratory-scale incinerator from a variety of polymer systems flame retarded with tetrabromobisphenol-A (both as an additive and reactive flame retardant). The incinerator system used consisted of a furnace containing a quartz tube through which a constant flow of gases (both air and hydrogen bromide) was maintained. The temperature in the combustion zone was 600°C and the gas had a retention time in the combustion zone of 3-4 seconds. The polymer samples used in the test included both brominated and non-brominated epoxy resin mixed with polyethylene. The samples were pulverised before being placed in the combustion tube (0.5 g was used for each polymer) and combusted for ten minutes, followed by a further 10 minutes with the furnace switched off. The air flow rate through the tube was set at 1 l/minute and the flow rate of HBr (when used) was 80 ml/minute. The HBr was used to simulate the effect of a more constant concentration of HBr in the combustion zone (as may be found during actual incineration processes) during the experiment as experiments with tetrabromobisphenol-A alone under similar conditions had indicated that most of the bromine in the molecule had been released (resulting in flow rates of HBr of up to 167 ml/minute) during the first 60 seconds of the experiment. The condensed products, combined from both the combustion tube and the gas stream, were analysed for the presence of polybrominated dibenzo-*p*-dioxins and furans using a GC-MS method. The results of the experiment are shown in **Table A16**.

Table A16 Formation of polybrominated dibenzo-*p*-dioxins and furans from various polymers at 600°C (Wichmann *et al.*, 2002)

Polymer system	Comment	Amount of PBDD		Amount of PBDF	
		mg/kg polymer	mg/kg TBBPA	mg/kg polymer	mg/kg TBBPA
Polyethylene incorporating non-brominated epoxy resin	HBr used in gas flow. Ignition occurred.	11.1	-	1.06	-
Polyethylene incorporating non-brominated epoxy resin and TBBPA as an additive	Bromine content of polymer 3.6%. Ignition occurred.	0.14	2.17	0.97	15.3
Polyethylene incorporating brominated epoxy resin	Bromine content of polymer 3.6%. Ignition occurred.	0.16	2.5	1.08	17.1

In the experiments with the flame-retarded polyethylene, mostly low brominated dibenzofurans were formed with the monobromodibenzofuran congeners being predominant. However, the experiments with the non-flame-retarded polyethylene using a HBr atmosphere resulted in a predominance of tri- and tetrabromodibenzo-*p*-dioxins. The paper concluded that the predominance of brominated dibenzofurans seen in the experiments with flame-retarded polyethylene could probably be attributed to formation from the tetrabromobisphenol-A component (either as an additive or reactively bound into the polymer) of the polymer. However, it should be borne in mind that the effect of different HBr concentrations on product distribution, particularly the predominance of dioxins over furans, was not investigated in detail. Experiments with polyethylene or epoxy resin (both non-flame-retarded) alone in a similar HBr atmosphere yielded a total polybrominated dibenz-*p*-dioxin/furan concentration of 8.47 mg/kg polymer for polyethylene and 18.1 mg/kg polymer for the epoxy resin. In this case a predominance of hexa- to octabromodibenzofuran congeners was formed from the polyethylene and a predominance of di- to tetrabrominated dibenzofurans.

Other experiments

Fluthwedel and Pohle (1993) compared the levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins in combustion residues of electronic equipment from both laboratory studies and real fires. The analysis looked at both the total levels formed and the sum of the levels for the congeners prescribed under the German Dioxin Ordinance (which gives a limit of 2 µg/kg for the sum of eight 2,3,7,8-substituted congeners). The results of the analysis are shown in **Table A17**. In the test fire results, 2,3,7,8-substituted congeners accounted for around 3.1-8.7% of the total congeners found in the fire residues and 2.6-5.2% of the total congeners found in the soot deposits. In real fires, the proportion of 2,3,7,8-substituted congeners was around 5.4% of the total for the fire residues and 8.7-19.9% of the total for the soot deposits. The results show that the levels found in real fires are around 2-3 orders of magnitude lower than those seen in laboratory studies, although a direct comparison is not possible as few experimental details are reported in the paper. In particular, it is probable that flame retardants other than tetrabromobisphenol-A were also present in the materials tested.

Table A17 Comparison of polybrominated dibenzofuran and dibenzo-*p*-dioxins formed during combustion in laboratory tests and real fires (Fluthwedel and Pohle, 1993)

		Fire residues		Soot deposits on walls	
		Total PBDD/F (µg/kg)	PBDD/F as in GefStoffV (µg/kg)	Total PBDD/F (µg/m²)	PBDD/F as in GefStoffV (µg/m²)
Test fires	min	1,310	22	6,220	64
	max	8,700,000	116,540	1,610,000	26,310
Real fires	min	1	1	134	17
	max	107,000	1,148	13,100	149

The results of an unpublished study by Neupert and Pump (1992) into the combustion residues at a large-scale fire involving plastics containing tetrabromobisphenol-A has been reported by WHO (1995). The fire occurred in a storage area of a plastics production plant in Germany, and involved a large quantity of polycarbonate and polybutylene terephthalate as well as around 180 tonnes of polybutylene terephthalate that was flame retarded with tetrabromobisphenol-A or tetrabromobisphenol-A derivatives. The maximum concentration of 2,3,7,8-substituted polybrominated dibenzo-*p*-dioxins and dibenzofurans (in total eight tetra-, penta- and hexabrominated congeners were analysed for) found in samples of the burnt polybutylene terephthalate material and in ash/slag samples was 0.5 µg/kg. Three soil samples collected from a distance of 1,340 m, 1,460 m and 1,740 m from the fire were also analysed and the concentrations found were <0.5-1.0 ng/kg.

Summary and conclusions from pyrolysis experiments

From the available information it is clear that polybrominated dibenzo-*p*-dioxins and dibenzofurans are formed in the pyrolysis experiments with tetrabromobisphenol-A and its derivatives. The main products formed appear to be the mono- to tribrominated congeners and the yield of these products is generally up to a few tens of mg/kg polymer. Tetrabrominated congeners are also formed in some experiments at lower levels, and higher brominated congeners are found only occasionally. The amounts of 2,3,7,8-substituted congeners formed are very low, frequently below the analytical limit of detection. Since many different test systems have been used, it is difficult to compare directly the results from one test system to the other. It is not possible to relate these findings directly to the likely behaviour of tetrabromobisphenol-A during actual fires or controlled incineration.

Disposal

It has been estimated that in England, Wales, Germany, France and Spain, approximately 63% of old personal computers are disposed of to landfills, 22% are incinerated and 15% are subject to recycling (WWF, 1998). In the United Kingdom, it is thought that currently the vast majority of electrical and electronic equipment is disposed of to landfill or is incinerated. Recycling of equipment is in its infancy and is not currently carried out to a significant extent. A Proposal for a draft Directive on Waste Electrical and Electronic Equipment (WEEE Directive) was adopted on 13th June 2000 by the European Commission. This sets future targets for reuse and recycling this type of equipment. This means that the current disposal practices may change in the future.

When considering the disposal of articles containing tetrabromobisphenol-A, it should be born in mind that they will be mixed with other waste prior or during disposal. As a result, their contribution to formation of hazardous products (e.g. halogenated dibenzo-*p*-dioxins and furans) as to be considered along with the contribution from all other sources.

Incineration

The chlorine and bromine loads of municipal solid waste incinerator feeds have been estimated by various sources and were summarised by Hardy (1997). Chlorine is the most abundant halogen present in municipal solid waste and a typical concentration of 0.7% wt. (i.e. 7 g/kg) has been given. A study of the chlorine content of municipal wastes in the United Kingdom found that the chlorine level was in the range 5-15 g/kg (Clayton *et al.*, no date). The refuse was broken down into various types and these are shown in **Table A18**.

Table A18 Chlorine content of municipal wastes (Clayton *et al.*, no date)

Refuse type	% of total refuse	Chlorine content (% by weight)
Paper	33%	0.37%
Plastic film	3%	2.69%
Dense plastic	3%	6.79%
Textiles	4%	0.70%
Miscellaneous combustibles	5%	2.44%
Putrescibles	20%	0.67%
<10 mm fraction	10%	0.32%
Ferrous metals	7%	nd
Non-ferrous metals	1%	nd
Miscellaneous non-combustibles	5%	nd
Glass	9%	nd

Bromine is present at much lower concentrations than chlorine in municipal waste, and typical bromine levels of around 15 mg/kg (Hardy, 1997) and 20-90 mg/kg of the total waste (Wilken *et al.*, 1990) or 1-4% (Buser, 1987) and 1-15% of the total chlorine (Hardy, 1997) have been reported.

Several studies have looked at the effect of the total bromine load in waste on the formation of halogenated dibenzo-*p*-dioxins and furans and the results are summarised below.

Ten Berge (1995) reported data on the halogen contents on dioxin emissions (as TCDD-equivalents) from municipal waste incinerators in the Netherlands. The results are shown in **Table A19**, and show no relationship between the bromine level in the waste and the dioxin emissions from the incinerators.

Table A19 Bromine and chlorine levels of waste at municipal incinerators in the Netherlands

Waste incinerator	Bromine content of waste (g Br/tonne)	Chlorine content of waste (g Cl/tonne)	Bromine content of waste (% of total Cl)	Dioxin emission from incinerator (µg TEQ/tonne)
A	8.4	2,982	0.28%	28
B	33	3,684	0.90%	262
C	15.6	3,700	0.42%	45
D	9.6	5.274	0.18%	507
E	5.4	1,920	0.28%	42
F	5.4	4,284	0.13%	277

Similarly, Öberg *et al.* (1987) found very little difference in the amounts of chlorinated dibenzo-*p*-dioxins and furans formed at an industrial waste incinerator (afterburner temperature 1000-1030^{o}C) in Sweden when high loads of bromine were present. Low levels of monobromochloro dibenzo-*p*-dioxins and furans were found in the cleaned flue gas.

A study by Söderström and Marklund (2001 and 2002) compared bromine and chlorine in their ability to form halogenated dibenzo-*p*-dioxins and furans during co-combustion of tetrabromobisphenol-A or other brominated flame retardants (hexabromocyclododecane and decabromodiphenyl ether) as a source of bromine with municipal solid waste. The results showed that, using either a bromine source or chlorine source alone, more brominated dibenzofurans are formed than chlorinated ones under equal combustion conditions. The co-combustion of bromine- and chlorine-containing waste resulted in the formation of mixed chloro-bromo products. The results also indicated that under normal combustion conditions, the flame retardants were completely destroyed and that no differences could be seen between the three flame retardants studied in the formation of halogenated dibenzo-*p*-dioxins and furans. The report concluded that it is likely to be unfavourable to co-combust (batchwise) large amounts of bromine with municipal solid waste due to the increased formation of halogenated dibenzo-*p*-dioxins and furans.

Tange *et al.* (2001) reported the results of studies to investigate the effect of different bromine loads on the formation of halogenated dibenzo-*p*-dioxins and furans using a small-scale model grate combustion furnace. The materials tested included printed wiring board mixtures, TV backplates and other mixed electronic waste typically found at dismantlers. The actual brominated flame retardants present were not given. In the experiments the amount of electrical and electronic equipment in the waste feed was artificially increased to 20-25% of the total feed, resulting in increased bromine levels in the feed of up to 2,750 mg/kg compared with the typical levels in waste of around 30-100 mg/kg. The formation of bromine-containing dibenzo-*p*-dioxins and especially furans was found to increase with increasing bromine input into the reactor feed, but appeared to reach a constant level at bromine loads of ~500-1,000 mg/kg. The major products found contained 1 bromine atom/molecule and it was shown that the total load of halogenated dioxins remained almost constant during the experiments despite the increased load of bromine-containing material. Overall it was concluded that the formation of halogenated dibenzo-*p*-dioxins and furans was dependent on the products of incomplete combustion and if the burnout of the reactor is optimised, the amounts of halogen present in the fuel had no significant influence on the amounts of halogenated dibenzo-*p*-dioxins or furans formed.

During incineration, it is well known that the halogenated dibenzo-*p*-dioxins and furans are formed in the cooler post combustion zone of the waste incinerator via *de novo* synthesis. The relative proportions of bromine to chlorine in most waste prior to incineration indicates that the major dibenzo-*p*-dioxins and furans formed will contain chlorine only, with mixed bromine/chlorine containing species (most likely containing 1 bromine) making only a very minor contribution. The amounts of bromine only containing dibenzo-*p*-dioxins and furans will be similarly small (Buser, 1987; Hardy, 1997). In addition to this, European Regulations exist on the design of municipal incinerators in order to minimise the formation of chlorinated dibenzo-*p*-dioxins and furans (EEC, 1989a and 1989b) during incineration. Proper incinerator design should also reduce the potential for release to the environment from the brominated dibenzo-*p*-dioxins and furans.

Landfill

A large proportion of waste containing tetrabromobisphenol-A may ultimately end up in landfill. The waste for landfill is likely to be of a similar composition to that considered above for incineration. Once in the landfill, the potential for formation of halogenated dibenzo-*p*-dioxins and dibenzofurans is likely to be small unless a landfill fire occurs. Although these fires are unintentional, they are known to occur and the temperature in a landfill fire can reach up to 800^{o}C (FRS, 1998). As high temperatures are involved, there is the possibility for formation of halogenated dibenzo-*p*-dioxins and furans under these conditions. However, the residence time of the substance in a landfill fire is likely to be much longer than found in the laboratory pyrolysis studies that have been carried out and so it is not possible to say anything about the extent of formation under these conditions.

Summary of disposal

Disposal of tetrabromobisphenol-A-containing products by both incineration and landfill has the potential to lead to the formation of polyhalogenated dibenzo-*p*-dioxins and dibenzofurans. In both cases, tetrabromobisphenol-A will act as one of a number of sources of halogen and so its presence will contribute to, but will not be the major source of, the formation of these products. Control measures are already in place for municipal and hazardous waste incinerators to minimise the formation of chlorinated dibenzo-*p*-dioxins and dibenzofurans, and these same control measures should also reduce the potential for release to the environment of polybrominated dibenzo-*p*-dioxins and dibenzofurans.

Recycling

Plastics

The concentration of polybrominated dibenzo-*p*-dioxins and furans present in air and plastics during grinding and milling of printed circuit board waste containing tetrabromobisphenol-A has been studied by Lorenz and Bahadir (1993). The waste studied was a mixture of printed circuit board waste derived from punch processes, basic plate material containing copper and faulty printed circuit boards. The tests were carried out in a pilot granulation plant containing a hammer mill and impact grinder. The hammer mill was equipped with a separation cyclone and a vibration filter unit and the samples were supplied to the mill either by conveyor belt or by hand. The impact grinder was equipped with a separation cyclone and a six-element filter, and samples were supplied by screw conveyor. The plant was designed to separate the metal-containing fraction from the plastic fraction, and to reduce the amount of waste.

The test with the hammer mill was carried out over a 180-minute period. During the first 35 minutes, the hammer mill was operated at the maximum permissible load rate, during which time 400 kg of shredded material was produced and the temperature of the hammer mill and shredded material reached 90°C and 100-120°C respectively. In total, 1,486 kg of shredded material was produced over the 180-minute period. The shredded material from the mill was immediately bagged and then introduced to the impact grinder. The impact grinder was operated continuously for 180 minutes. During this time, 1,440 kg of shredded material was produced and the temperature of the grinder increased from 30°C to 180°C.

During the test, air particulate samples were collected near to the hammer mill and impact grinder. These samples, along with samples of the shredded material, were analysed for the concentrations of polybrominated dibenzo-*p*-dioxins and furans. The results of this analysis are shown in **Table A20**.

Table A20 Levels of polybrominated dibenzo-*p*-dioxins and furans in air and shredded material at a pilot printed circuit board shredding plant (Lorenz and Bahadir, 1993)

Congener	Printed circuit board (µg/kg)	Hammer mill		Impact grinder		Separated waste	
		Air (ng/m³)	Shred (µg/kg)	Air (ng/m³)	Shred (µg/kg)	Metal fraction[a] (µg/kg)	Plastic fraction[b] (µg/kg)
MBDD	<0.05	<0.05	<0.04	<0.1	<0.05	<0.04	<0.05
DiBDD	<0.04	<0.04	<0.3	<0.08	<0.1	<0.04	<0.1
TrBDD	<0.02	<0.02	<0.02	<0.02	<0.05	<0.01	<0.05
TeBDD	0.22	<0.05	0.67	<0.02	0.73	0.03	0.58
2,3,7,8-TeBDD	<0.04	<0.02	<0.04	<0.02	<0.02	<0.01	<0.05
PeBDD	<0.1	<0.1	<0.4	<0.05	<0.2	<0.02	<0.2
HxBDD	<0.1	<0.1	<0.2	<0.1	<0.2	<0.02	<0.2
HpBDD	<1	<2	<3	<2	<3	<0.3	<3
OBDD	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]
MBDF	<0.05	<0.05	<0.06	<0.1	0.05	<0.04	0.32
DiBDF	<0.05	<0.04	<0.1	<0.08	<0.1	<0.02	0.23
TrBDF	<0.02	<0.02	<0.02	<0.02	<0.1	<0.01	<0.2
TeBDF	<0.05	<0.04	<0.4	<0.02	<0.2	<0.1	<0.2
2,3,7,8-TeBDF	<0.01	<0.02	<0.04	<0.02	<0.04	<0.01	<0.04
PeBDF	<0.05	<0.03	<0.2	<0.03	<0.1	<0.01	<0.1
HxBDF	<0.5	<0.2	<1	<0.2	<1	<0.1	<1
HpBDF	<1	<0.4	<2	<0.4	<2	<2	<2
OBDF	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]	nd[c]

Notes: a) Metal fraction of the shredded and separated waste. This had a metal content of 97.3%.
b) Plastic fraction of the shredded and separated waste. This had a metal content of 4.1%.
c) Not detected. The detection limit for the octabromo congeners was not given.

No polybrominated dibenzo-*p*-dioxins or furans were detected in the air samples. The levels present in the shredded samples were also very low, and appear to be mainly related to contamination of the starting printed circuit board material rather than the grinding/milling process.

Meyer *et al.* (1993) and van Riel (1995) reported the levels of polybrominated dibenzo-*p*-dioxins and dibenzofurans ABS containing tetrabromobisphenol-A with respect to the German Dioxin Ordinance. The results are shown in **Table A21**. The limits under the Regulations are 1 µg/kg for the sum of isomers 1-4 and 5 µg/kg for the sum of isomers 1-7 (higher limits of 10 µg/kg for the sum of isomers 1-4 and 60 µg/kg for the sum of isomers 1-7 applied until 15 July 1999; van Riel, 1995). The study looked at virgin granulate material, granulate after recompounding and recompounded and remoulded material. All three materials were shown to meet the German Dioxin Ordinance. Similar results were obtained for reprocessing of a polycarbonate/ABS blend containing tetrabromobisphenol-A polycarbonate as a flame retardant (Meyer *et al.*, 1993).

Table A21 Levels of brominated dibenzofurans and dibenzo-p-dioxins in ABS containing tetrabromobisphenol-A both before and after recycling (van Riel, 1995; Meyer *et al.*, 1993)

No	Isomer	Level (µg/kg polymer)		
		Virgin granulate	Recompounded granulate	Recompounded and remoulded material
1	2,3,7,8-TeBDD	<0.05	<0.05	<0.05
2	1,2,3,7,8-PeBDD	<0.05	<0.05	<0.05
3	2,3,7,8-TeBDF	<0.05	<0.05	<0.05
4	2,3,4,7,8-PeBDF	<0.2	<0.2	<0.2
5	1,2,3,4,7,8-HxBDD + 1,2,3,6,7,8-HxBDD	<0.05	<0.05	2
6	1,2,3,7,8,9-HxBDD	<0.05	<0.05	<0.05
7	1,2,3,7,8-PeBDF	<0.05	<0.05	0.4
Sum 1-4		<1	<1	<1
Sum 1-7		<5	<5	<5

Meyer *et al.* (1993) also studied the levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins (as per the German Dioxin Ordinance) in ABS containing tetrabromobisphenol-A newly moulded parts (first processing) and parts that were reground and subsequently reprocessed. The results are shown in **Table A22**. The levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins were below the detection limit of the method in all samples analysed and showed that the plastic still met the requirements of the German Dioxin Ordinance even after multiple reprocessing steps.

Table A22 Levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins in ABS during processing and reprocessing (Meyer *et al.*, 1993)

PBDD/PBDF	Concentration (µg/kg or ppb)				
	1st Processing	2nd Processing	3rd Processing	4th Processing	5th Processing
2,3,7,8-TeBDD	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,7,8-PeBDD	<0.2	<0.1	<0.1	<0.1	<0.1
2,3,7,8-TeBDF	<0.1	<0.1	<0.1	<0.1	<0.1
2,3,4,7,8-PeBDF	<0.2	<0.1	<0.1	<0.1	<0.1
1,2,3,4,7,8-HxBDD + 1,2,3,6,7,8-HxBDD	<0.3	<0.5	<0.5	<0.5	<0.5
1,2,3,7,8,9-HxBDD	<0.3	<0.5	<0.5	<0.5	<0.5
1,2,3,7,8-PeBDF	<0.2	<0.1	<0.1	<0.1	<0.1

A further investigation of the recyclability of commercially available ABS containing tetrabromobisphenol-A (and also ABS containing a brominated epoxy oligomer) has recently been carried out by Imai (2003). The flame-retarded plastic samples were subjected to a sequence of extrusion steps in which the material was extruded at 210^{o}C, pelletized and then dried, and then re-extruded, pelletized and dried. This recycling sequence was repeated four times and after the last recycling step the material was analysed for the polybrominated dibenzofurans and dibenzo-*p*-dioxins prescribed in the German Dioxin Ordinance. The results of these analyses are shown in **Table A23** for ABS containing tetrabromobisphenol-A and show that none of the prescribed polybrominated dibenzofurans and dibenzo-*p*-dioxins were detetected (the detection limits used in this study are around 10 times lower than those required in the German Dioxin Ordinance). Identical results were obtained for the ABS sample containing the brominated epoxy oligomer. In addition, the mechanical strength, melt flow rate and the fire safety rating of both plastics was determined after each recycling step. Even after four recycling passes these properties in the recycled material were similar to those in the virgin material.

Table A23 Levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins in ABS containing tetrabromobisphenol-A during repeated extrusion and pelletization (Imai *et al.*, 1993)

PBDD/PBDF	Concentration after four recycling steps (µg/kg or ppb)
2,3,7,8-TeBDD	<0.01
1,2,3,7,8-PeBDD	<0.03
2,3,7,8-TeBDF	<0.02
2,3,4,7,8-PeBDF	<0.04
1,2,3,4,7,8-HxBDD + 1,2,3,6,7,8-HxBDD	<0.08
1,2,3,7,8,9-HxBDD	<0.08
1,2,3,7,8-PeBDF	<0.04

The information available on the levels of polybrominated dibenzofurans and dibenzo-*p*-dioxins in plastics containing tetrabromobisphenol-A indicates that the levels are well below those prescribed in the German Dioxin Ordinance, even after repeated recycling.

At present there is little recycling of thermoplastics containing tetrabromobisphenol-A in the EU. Recycling of many plastics is currently at the experimental stage. This picture, however, may change in the future. Products such as epoxy resins, where tetrabromobisphenol-A is used reactively, cannot easily be recycled by re-melting, instead recycling can theoretically be achieved by depolymerisation back to the starting monomers. This type of recycling is not routinely carried out, and, as it is essentially a chemical process, would appear to have little potential for formation of polybrominated dibenzo-*p*-dioxins and dibenzofurans.

Metals

Except for precious metals, the only other non-ferrous metals that are of economic importance for recycling are aluminium, copper, lead and zinc (Richardson, 1996). Of these, recycling of copper from printed circuit boards is likely to be the main processes that is associated with tetrabromobisphenol-A use.

Harless *et al.* (1989) detected bromochlorinated dibenzo-*p*-dioxins and furans (containing 1 bromine) in ash from a secondary copper furnace in the United States, but these were found at much lower concentrations (6-27 times lower) than the chlorinated dibenzo-*p*-dioxins and furans. In this study, the source of bromine was not identified.

Little information is reported on the potential for formation of brominated dibenzo-*p*-dioxins and furans from metal recycling as a result of use of tetrabromobisphenol-A flame retardants. However, since the process again involves relatively high temperatures, the potential for formation of these compounds exists if plastic containing halogen enters into the recycling process along with the metal. Again, tetrabromobisphenol-A is unlikely to be the only source of halogen in these processes. The possibility for formation of chlorinated dibenzo-*p*-dioxins and furans during, for example, secondary copper production is well known and various emission control techniques, similar to those used in incinerators, can be used to reduce the emissions of these compounds to the environment (HMIP, 1994).

Summary of recycling

The available information shows little or no potential for formation of polybrominated dibenzo-*p*-dioxins and dibenzofurans during the recycling of plastics containing tetrabromobisphenol-A.

Formation of polybrominated dibenzo-*p*-dioxins and furans could, in principle, occur during recycling of metals if plastic containing tetrabromobisphenol-A enters into the recycling stream. However, similar to the case with incineration, other sources of halogen are also likely to be present, and emission control techniques can be used in the process.

Conclusions

The conclusions here only consider the processes which may lead to a significant release of decomposition products to the environment. The available information indicates that the

levels of these products in tetrabromobisphenol-A itself, and polymers (either virgin or recycled) containing tetrabromobisphenol-A, are low.

From the available information it is clear that tetrabromobisphenol-A can form small amounts of mono- to tribrominated dibenzo-*p*-dioxins and dibenzofurans in laboratory studies when heated to high temperatures. This means that the same or similar products have the potential to be formed in processes where high temperatures are reached during disposal and recycling. Such processes could include waste disposal (incineration or landfill (where fires could occur)), or recycling of plastics or metals contaminated with plastics. In addition, actual fires involving articles containing the flame retardant could also be considered similarly.

In the case of incineration, landfill, metal recycling and accidental fires, the tetrabromobisphenol-A flame retardant is likely to represent a small part of the total halogen available in the process. The available information indicates, particularly in the case of waste incineration and landfill, that chlorine is the prevalent halogen present, and that the main dioxin and furans formed are chlorinated analogues. Monobromo-polychloro analogues have been found, but generally at lower concentrations than the analogues containing chlorine only. This indicates that the majority of the halogenated dioxins and furans in these processes are likely to be formed by *de novo* synthesis. Thus the amounts of halogenated dibenzo-*p*-dioxins formed in these processes are likely to be a function of the total amount of halogen present, to which tetrabromobisphenol-A will make a contribution, rather than solely on the amount of tetrabromobisphenol-A present. The available laboratory studies using tetrabromobisphenol-A cannot distinguish between *de novo* synthesis and direct formation of the brominated dibenzo-*p*-dioxins and furans. It is, therefore, theoretically possible that direct formation of these products could also occur during incineration etc, followed by halogen exchange to give the mainly chlorinated species. In the case of accidental fires, many other toxic products may also be formed, for example polycyclic aromatic hydrocarbons, which will also contribute to the overall toxicity of the fire products (Spindler, 1997). These products are not related to the presence of tetrabromobisphenol-A.

It should also be noted that halogenated dioxin and furan formation from some of these processes is well known and emission control technology is available for incinerators and metal recycling, that can be used to reduce the amounts of these substances formed in the process to acceptable levels. However, it may be possible that metal recycling and incineration could take place at installations without suitable emission reduction equipment. As landfill fires and other fires are considered to be accidental, no such emission control technology exists for these.

Overall, for disposal by incineration and landfill, metal recycling and accidental fires, it can be concluded that tetrabromobisphenol-A, as a source of bromine, 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.

The available information for recycling of flame retarded plastics indicates that there is little or no increase in the amounts of brominated dibenzofurans and dibenzo-*p*-dioxins formed. Low levels of these products have also been measured in processed plastics, although in all cases the levels are well below those specified in the German Dioxin Ordinance. The recycling of many plastics is still at an experimental stage and is not currently routinely carried out at present. In terms of the environment, the potential for environmental exposure

to these substances from plastics processing and recycling appears to be lower than for some of the other processes mentioned above.

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APPENDIX B EUSES MODELLING

This Appendix contains copies of the EUSES printouts for tetrabromobisphenol-A. The EUSES 2.0.3 program was run twice for the above scenarios, firstly using a Koc value of 49,726 l/kg (and the appropriately derived values for the various adsorption coefficients (see Section 3.1.0.7.2 of the assessment)) and secondly using a Koc value of 147,360 l/kg. The printouts shown show the calculations using a fish BCF of 1,234 l/kg.

Part A - Calculations using Koc = 49,726 l/kg

The results from the following scenarios are included in the printout.

EUSES Printout	Scenario
USE PATTERN 1	Production
production	example calculation for a production site
USE PATTERN 2	Manufacture of derivatives of tetrabromobisphenol-A
processing	example calculation for a site manufacturing tetrabromobisphenol-A derivatives
USE PATTERN 3	Use in epoxy and polycarbonate resins
formulation	epoxy and/or polycarbonate manufacture
processing	use of epoxy resins
private use	use of polycarbonate resins
USE PATTERN 4	Use in ABS
formulation	compounding site
processing	conversion site
private use	compounding/conversion site (example calculation only – not used in the risk assessment)
USE PATTERN 5	Use in phenolic resins (example calculations only – not used in the risk assessment)
formulation	compounding site
processing	conversion site
private use	compounding/conversion site
USE PATTERN 6	Recycling of electronic equipment
private use	electronic equipment collection/recycling site
USE PATTERN 7	Losses over lifetime of products

IDENTIFICATION OF THE SUBSTANCE

General name	Tetrabromobisphenol-A		S
CAS-No	79-94-7		S
EC-notification no.	R402_0605_env		S
EINECS no.	201-236-9		S
Molecular weight	543.9	[g.mol-1]	S

PHYSICO-CHEMICAL PROPERTIES

Melting point	180	[oC]	S
Boiling point	316	[oC]	S
Vapour pressure at 25 [oC]	6.24E-09	[kPa]	S
Water solubility at test temperature	0.063	[mg.l-1]	S
Temperature at which solubility was measured	21	[oC]	S
Water solubility at 25 [oC]	0.24	[mg.l-1]	S
Octanol-water partition coefficient	5.9	[log10]	S
Henry's law constant	0.0141	[Pa.m3.mol-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION

Tonnage of substance in Europe	1.38E+04	[tonnes.yr-1]	O
Regional production volume of substance	0	[tonnes.yr-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[1 "PRODUCTION OF TBBPA", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		S
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	1	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRODUCTION]

Use specific emission scenario	No		D
Emission tables	A1.1 (general table), B1.4 (specific uses)		S
Emission scenario	no special scenario selected/available		S
Main category production	Ic Intermed. stored off-site/dedicated equip.		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	1.02E-03	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	O
Number of emission days per year	300	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	13.6	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33]

Industry category	3 Chemical industry: chemicals used in synthesis		S
Use category	33 Intermediates		S
Extra details on use category	Wet process		D
Fraction of tonnage for application	0	[-]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.3 (IC-specific), B3.2 (general table)		S
Emission scenario	no special scenario selected/available		S
Main category industrial use	III Multi-purpose equipment		S
Fraction of tonnage released to air	1E-05	[-]	S
Fraction of tonnage released to waste water	7E-03	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	200	[-]	S
Local emission to air during episode	0.025	[kg.d-1]	S
Local emission to wastewater during episode	17.5	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.9	[-]	S
Fraction of chemical in formulation	0.34	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	1E-05	[-]	S
Fraction of tonnage released to waste water	1E-05	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	300	[-]	O
Local emission to air during episode	0.027	[kg.d-1]	S
Local emission to wastewater during episode	0.027	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	1E-04	[-]	S
Fraction of tonnage released to waste water	1E-04	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	S
Number of emission days per year	32	[-]	S
Local emission to air during episode	5E-05	[kg.d-1]	S
Local emission to wastewater during episode	5E-05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	1E-04	[-]	S
Fraction of tonnage released to waste water	1E-04	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	28	[-]	S
Local emission to air during episode	5E-05	[kg.d-1]	S
Local emission to wastewater during episode	5E-05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.2	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0.8	[-]	O
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.01	[kg.d-1]	S
Local emission to wastewater during episode	1.1	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.05	[kg.d-1]	S
Local emission to wastewater during episode	0.05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	S
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.06	[kg.d-1]	S
Local emission to wastewater during episode	1.15	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.15	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0.8	[-]	O
Number of emission days per year	48	[-]	S
Local emission to air during episode	2E-03	[kg.d-1]	S
Local emission to wastewater during episode	0.223	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	48	[-]	S
Local emission to air during episode	0.01	[kg.d-1]	S
Local emission to wastewater during episode	0.01	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	48	[-]	S
Local emission to air during episode	0.012	[kg.d-1]	S
Local emission to wastewater during episode	0.233	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymer processing		S
Extra details on use category	Thermoplastics: additives, pigments, fillers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.04	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[WASTE TREATMENT]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	300	[-]	S
Local emission to air during episode	1.83E-04	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[7 "LOSSES OVER LIFETIME OF PRODUCT", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	2.899	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	365	[-]	S
Local emission to air during episode	0	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[SERVICE LIFE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	365	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[WASTE TREATMENT]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	365	[-]	S
Local emission to air during episode	0	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
TOTAL REGIONAL EMISSIONS TO COMPARTMENTS

Total regional emission to air	0.078	[kg.d-1]	S
Total regional emission to wastewater	0.355	[kg.d-1]	S
Total regional emission to surface water	0.094	[kg.d-1]	S
Total regional emission to industrial soil	0.0164	[kg.d-1]	S
Total regional emission to agricultural soil	0	[kg.d-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
TOTAL CONTINENTAL EMISSIONS TO COMPARTMENTS

Total continental emission to air	0.701	[kg.d-1]	S
Total continental emission to wastewater	3.186	[kg.d-1]	S
Total continental emission to surface water	0.847	[kg.d-1]	S
Total continental emission to industrial soil	0.148	[kg.d-1]	S

ENVIRONMENT-EXPOSURE
PARTITION COEFFICIENTS

Organic carbon-water partition coefficient	4.9726E+04	[l.kg-1]	S

ENVIRONMENT-EXPOSURE
PARTITION COEFFICIENTS
SOLIDS-WATER PARTITION COEFFICIENTS

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

ENVIRONMENT-EXPOSURE
PARTITION COEFFICIENTS
BIOTA-WATER PARTITION COEFFICIENTS

Bioconcentration factor for aquatic biota	1.234E+03	[l.kgwwt-1]	S

ENVIRONMENT-EXPOSURE
DEGRADATION AND TRANSFORMATION

Characterization of biodegradability	Not biodegradable		D
Degradation calculation method in STP	First order, standard OECD/EU tests		D
Rate constant for biodegradation in STP	0	[d-1]	O
Rate constant for biodegradation in surface water	4.7E-03	[d-1] (12[oC])	S
Rate constant for biodegradation in bulk soil	2.31E-05	[d-1] (12[oC])	S
Rate constant for biodegradation in aerated sediment	2.31E-05	[d-1] (12[oC])	S
Rate constant for hydrolysis in surface water	6.93E-07	[d-1] (12[oC])	O
Rate constant for photolysis in surface water	6.93E-07	[d-1]	O
Total rate constant for degradation in bulk soil	2.31E-05	[d-1] (12[oC])	S
Total rate constant for degradation in bulk sediment	2.31E-05	[d-1] (12[oC])	S

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	6.8	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	1.26	[mg.l-1]	O
Concentration in effluent exceeds solubility	Yes		O
Concentration in dry sewage sludge	1.4E+04	[mg.kg-1]	O
PEC for micro-organisms in the STP	1.26	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	8.75	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	1.62	[mg.l-1]	O
Concentration in effluent exceeds solubility	Yes		O
Concentration in dry sewage sludge	1.81E+04	[mg.kg-1]	O
PEC for micro-organisms in the STP	1.62	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.0135	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	2.5E-03	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	27.9	[mg.kg-1]	O
PEC for micro-organisms in the STP	2.5E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	2.5E-05	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	4.62E-06	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0.0516	[mg.kg-1]	O
PEC for micro-organisms in the STP	4.62E-06	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	2.5E-05	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	4.62E-06	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0.0516	[mg.kg-1]	O
PEC for micro-organisms in the STP	4.62E-06	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.55	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.102	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	1.13E+03	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.102	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.025	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	4.62E-03	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	51.6	[mg.kg-1]	O
PEC for micro-organisms in the STP	4.62E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.575	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.106	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	1.19E+03	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.106	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.112	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0206	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	230	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0206	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	5E-03	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	9.25E-04	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	10.3	[mg.kg-1]	O
PEC for micro-organisms in the STP	9.25E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	3.23E-05	[-]	O
Fraction of emission directed to water by STP	0.185	[-]	O
Fraction of emission directed to sludge by STP	0.815	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.117	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0215	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	240	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0215	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]
OUTPUT

Fraction of emission directed to air by STP	0	[-]	O
Fraction of emission directed to water by STP	0	[-]	O
Fraction of emission directed to sludge by STP	0	[-]	O
Fraction of the emission degraded in STP	0	[-]	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

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
REMOVAL RATE CONSTANTS SOIL

Total rate constant for degradation in bulk soil	2.31E-05	[d-1] (12[oC])	S

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

Concentration in air during emission episode	1.22E-07	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1E-07	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0.113	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0.0932	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	0.113	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	0.0932	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	180	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0.0613	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0.0504	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	0.0613	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	0.0504	[mg.l-1]	O
Local PEC in marine sediment during emission episode	97.3	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	198	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	198	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	79.2	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	0.0676	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Concentration in air during emission episode	6.95E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	3.81E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0.146	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0.0799	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	0.146	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	0.0799	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	232	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0.0789	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0.0432	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	0.0789	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	0.0432	[mg.l-1]	O
Local PEC in marine sediment during emission episode	125	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	255	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	255	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	102	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	0.087	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	7.51E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	6.17E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	2.25E-04	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.85E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	2.26E-04	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.86E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.359	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.25E-05	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.85E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	2.26E-05	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.86E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.0359	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.395	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.394	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.159	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.35E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	1.39E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.22E-09	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	4.17E-07	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	3.65E-08	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.7E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.32E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	2.69E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.25E-07	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.98E-08	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	3.55E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.5E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	5.64E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	9.85E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	9.84E-04	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	5.46E-04	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	3.36E-07	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	1.39E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.07E-09	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	4.17E-07	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	3.2E-08	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.7E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.31E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	2.69E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.25E-07	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.73E-08	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	3.55E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.47E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	5.64E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	9.85E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	9.84E-04	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	5.46E-04	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	3.36E-07	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	2.78E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.3E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	9.17E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	4.29E-03	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	9.17E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	4.3E-03	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	14.6	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	9.17E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	4.29E-04	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	9.17E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	4.3E-04	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.46	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	16.1	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	16	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	6.4	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	5.47E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	1.39E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	6.51E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	4.17E-04	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.95E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	4.18E-04	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.96E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.664	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.25E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.06E-04	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	2.25E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.06E-04	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.358	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.73	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.729	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.293	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	2.49E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	1.67E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	7.81E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	9.58E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	4.49E-03	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	9.59E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	4.49E-03	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	15.2	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	9.58E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	4.49E-04	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	9.59E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	4.49E-04	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.52	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	16.8	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	16.8	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	6.7	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	5.72E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	5.56E-07	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	7.31E-08	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	1.86E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	2.44E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.86E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	2.46E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	2.95	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	1.86E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	2.44E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.86E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	2.46E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.295	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	3.25	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	3.25	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.3	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.11E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	2.78E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	3.66E-07	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	8.33E-05	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.1E-05	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	8.46E-05	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.22E-05	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.134	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	4.51E-05	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	5.93E-06	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	4.52E-05	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	6.06E-06	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.0717	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.146	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.146	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.0585	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	4.98E-05	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	3.34E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	4.39E-07	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	1.94E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	2.55E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.94E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	2.57E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	3.08	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	1.94E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	2.55E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.94E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	2.57E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.308	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	3.4	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	3.39	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.36	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.16E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Concentration in air during emission episode	5.09E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	4.18E-08	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.28E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.28E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	2.03E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.3E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.3E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	2.06E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	2.59E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	2.59E-04	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	2.63E-04	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	8.85E-08	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
REGIONAL AND CONTINENTAL SCALE
CONTINENTAL

Continental PEC in surface water (dissolved)	2.3E-07	[mg.l-1]	O
Continental PEC in sea water (dissolved)	2.35E-10	[mg.l-1]	O
Continental PEC in air (total)	1.25E-10	[mg.m-3]	O
Continental PEC in agricultural soil (total)	1.57E-04	[mg.kgwwt-1]	O
Continental PEC in pore water of agricultural soils	5.34E-08	[mg.l-1]	O
Continental PEC in natural soil (total)	3.17E-05	[mg.kgwwt-1]	O
Continental PEC in industrial soil (total)	2E-04	[mg.kgwwt-1]	O
Continental PEC in sediment (total)	7.19E-04	[mg.kgwwt-1]	O
Continental PEC in sea water sediment (total)	7.17E-07	[mg.kgwwt-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
REGIONAL AND CONTINENTAL SCALE
REGIONAL

Regional PEC in surface water (dissolved)	1.28E-06	[mg.l-1]	O
Regional PEC in sea water (dissolved)	1.3E-07	[mg.l-1]	O
Regional PEC in air (total)	1.01E-09	[mg.m-3]	O
Regional PEC in agricultural soil (total)	1.51E-03	[mg.kgwwt-1]	O
Regional PEC in pore water of agricultural soils	5.15E-07	[mg.l-1]	O
Regional PEC in natural soil (total)	2.55E-04	[mg.kgwwt-1]	O
Regional PEC in industrial soil (total)	1.88E-03	[mg.kgwwt-1]	O
Regional PEC in sediment (total)	4.01E-03	[mg.kgwwt-1]	O
Regional PEC in sea water sediment (total)	3.96E-04	[mg.kgwwt-1]	O

ENVIRONMENT-EXPOSURE
BIOCONCENTRATION

Bioconcentration factor for earthworms	9.53E+03	[l.kgwwt-1]	O
Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S
Bioconcentration factor for aquatic biota	1.234E+03	[l.kgwwt-1]	S

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

Concentration in fish for secondary poisoning (fresh water)	57.5	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	31.1	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	6.22	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	300	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	49.3	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	26.7	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	5.33	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	385	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	0.116	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.0116	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	2.44E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.598	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	1.6E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.72E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.63E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	3.77E-03	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	1.6E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.71E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.62E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	3.77E-03	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	2.65	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.265	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.0532	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	24.2	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	0.122	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.0653	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.0132	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	1.1	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	2.77	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.277	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.0556	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	25.3	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	0.152	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.0152	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	3.18E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	4.91	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	8.34E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	3.82E-03	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	8.92E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.223	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	0.159	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.0159	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	3.31E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	5.13	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Concentration in fish for secondary poisoning (fresh water)	1.58E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.6E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.6E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	2.68E-03	[mg.kg-1]	O

ENVIRONMENT - EFFECTS
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
PNEC for micro-organisms in a STP	>1.5	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC micro	10	[-]	O

ENVIRONMENT - EFFECTS
FRESH_WATER ORGANISMS

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
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
PNEC for aquatic organisms	1.3E-03	[mg.l-1]	O
PNEC for aquatic organisms, intermittent releases	9E-04	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC Aqua	10	[-]	S

ENVIRONMENT - EFFECTS
MARINE ORGANISMS

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
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
PNEC for marine organisms	2.54E-04	[mg.l-1]	O

ENVIRONMENT - EFFECTS
FRESH-WATER SEDIMENT ORGANISMS

LC50 for fresh-water sediment organism	??	[mg.kgwwt-1]	D
EC10 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 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.kgdwt-1]	S
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
PNEC for fresh-water sediment-dwelling organisms	0.543	[mg.kgwwt-1]	O

ENVIRONMENT - EFFECTS
MARINE SEDIMENT ORGANISMS

LC50 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
PNEC for marine sediment organisms	0.0543	[mg.kgwwt-1]	O

ENVIRONMENT - EFFECTS
TERRESTRIAL ORGANISMS

LC50 for plants	??	[mg.kgwwt-1]	D
LC50 for earthworms	??	[mg.kgwwt-1]	D
EC50 for microorganisms	??	[mg.kgwwt-1]	D
LC50 for other terrestrial species	??	[mg.kgwwt-1]	D
NOEC for plants	25.9	[mg.kgdwt-1]	S
NOEC for earthworms	0.29	[mg.kgdwt-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
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
PNEC for terrestrial organisms	0.012	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in soil?	No		O
Assessment factor applied in extrapolation to PNEC Terr	10	[-]	S

ENVIRONMENT - EFFECTS
BIRDS AND MAMMALS

Duration of (sub-)chronic oral test	28 days		D
NOEC via food for secondary poisoning	??	[mg.kg-1]	O
PNEC for secondary poisoning of birds and mammals	>667	[mg.kg-1]	O
Assessment factor applied in extrapolation to PNEC oral	30	[-]	S

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

RCR for the local fresh-water compartment	87.2	[-]	O
RCR for the local fresh-water compartment, statistical method	122	[-]	O
RCR for the local marine compartment	241	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	331	[-]	O
RCR for the local marine sediment compartment	1.79E+03	[-]	O
RCR for the local soil compartment	1.65E+04	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.838	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<0.0862	[-]	O
RCR for fish-eating birds and mammals (marine)	<0.0466	[-]	O
RCR for top predators (marine)	<9.32E-03	[-]	O
RCR for worm-eating birds and mammals	<0.449	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

RCR for the local fresh-water compartment	112	[-]	O
RCR for the local fresh-water compartment, statistical method	157	[-]	O
RCR for the local marine compartment	310	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	426	[-]	O
RCR for the local marine sediment compartment	2.3E+03	[-]	O
RCR for the local soil compartment	2.13E+04	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<1.08	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<0.074	[-]	O
RCR for fish-eating birds and mammals (marine)	<0.04	[-]	O
RCR for top predators (marine)	<8E-03	[-]	O
RCR for worm-eating birds and mammals	<0.578	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	0.174	[-]	O
RCR for the local fresh-water compartment, statistical method	0.243	[-]	O
RCR for the local marine compartment	0.0891	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	0.661	[-]	O
RCR for the local marine sediment compartment	0.661	[-]	O
RCR for the local soil compartment	32.9	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<1.66E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.74E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<1.74E-05	[-]	O
RCR for top predators (marine)	<3.66E-06	[-]	O
RCR for worm-eating birds and mammals	<8.97E-04	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	1.31E-03	[-]	O
RCR for the local fresh-water compartment, statistical method	1.82E-03	[-]	O
RCR for the local marine compartment	1.4E-03	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	4.96E-03	[-]	O
RCR for the local marine sediment compartment	0.0104	[-]	O
RCR for the local soil compartment	0.0821	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<3.08E-06	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.4E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.59E-07	[-]	O
RCR for top predators (marine)	<2.44E-07	[-]	O
RCR for worm-eating birds and mammals	<5.66E-06	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	1.31E-03	[-]	O
RCR for the local fresh-water compartment, statistical method	1.82E-03	[-]	O
RCR for the local marine compartment	1.4E-03	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	4.96E-03	[-]	O
RCR for the local marine sediment compartment	0.0104	[-]	O
RCR for the local soil compartment	0.0821	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<3.08E-06	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.4E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.56E-07	[-]	O
RCR for top predators (marine)	<2.44E-07	[-]	O
RCR for worm-eating birds and mammals	<5.66E-06	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	7.05	[-]	O
RCR for the local fresh-water compartment, statistical method	9.84	[-]	O
RCR for the local marine compartment	3.61	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	26.8	[-]	O
RCR for the local marine sediment compartment	26.8	[-]	O
RCR for the local soil compartment	1.34E+03	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0678	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<3.98E-03	[-]	O
RCR for fish-eating birds and mammals (marine)	<3.98E-04	[-]	O
RCR for top predators (marine)	<7.97E-05	[-]	O
RCR for worm-eating birds and mammals	<0.0363	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	0.322	[-]	O
RCR for the local fresh-water compartment, statistical method	0.449	[-]	O
RCR for the local marine compartment	0.888	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	1.22	[-]	O
RCR for the local marine sediment compartment	6.59	[-]	O
RCR for the local soil compartment	60.9	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<3.08E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.83E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<9.79E-05	[-]	O
RCR for top predators (marine)	<1.98E-05	[-]	O
RCR for worm-eating birds and mammals	<1.66E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	7.37	[-]	O
RCR for the local fresh-water compartment, statistical method	10.3	[-]	O
RCR for the local marine compartment	3.77	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	28	[-]	O
RCR for the local marine sediment compartment	28	[-]	O
RCR for the local soil compartment	1.4E+03	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0709	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<4.16E-03	[-]	O
RCR for fish-eating birds and mammals (marine)	<4.16E-04	[-]	O
RCR for top predators (marine)	<8.34E-05	[-]	O
RCR for worm-eating birds and mammals	<0.038	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	1.43	[-]	O
RCR for the local fresh-water compartment, statistical method	2	[-]	O
RCR for the local marine compartment	0.732	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	5.43	[-]	O
RCR for the local marine sediment compartment	5.43	[-]	O
RCR for the local soil compartment	271	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0137	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.29E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.29E-05	[-]	O
RCR for top predators (marine)	<4.76E-06	[-]	O
RCR for worm-eating birds and mammals	<7.37E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	0.0651	[-]	O
RCR for the local fresh-water compartment, statistical method	0.0909	[-]	O
RCR for the local marine compartment	0.178	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	0.247	[-]	O
RCR for the local marine sediment compartment	1.32	[-]	O
RCR for the local soil compartment	12.2	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<6.16E-04	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.25E-05	[-]	O
RCR for fish-eating birds and mammals (marine)	<5.73E-06	[-]	O
RCR for top predators (marine)	<1.34E-06	[-]	O
RCR for worm-eating birds and mammals	<3.34E-04	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	1.49	[-]	O
RCR for the local fresh-water compartment, statistical method	2.09	[-]	O
RCR for the local marine compartment	0.765	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	5.68	[-]	O
RCR for the local marine sediment compartment	5.68	[-]	O
RCR for the local soil compartment	283	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0144	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.39E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.39E-05	[-]	O
RCR for top predators (marine)	<4.97E-06	[-]	O
RCR for worm-eating birds and mammals	<7.7E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

RCR for the local fresh-water compartment	9.85E-04	[-]	O
RCR for the local fresh-water compartment, statistical method	1.37E-03	[-]	O
RCR for the local marine compartment	5.11E-04	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	3.74E-03	[-]	O
RCR for the local marine sediment compartment	3.79E-03	[-]	O
RCR for the local soil compartment	0.0216	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.37E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.4E-07	[-]	O
RCR for top predators (marine)	<2.4E-07	[-]	O
RCR for worm-eating birds and mammals	<4.01E-06	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
REGIONAL

RCR for the regional fresh-water compartment	9.85E-04	[-]	O
RCR for the regional fresh-water compartment, statistical method	1.37E-03	[-]	O
RCR for the regional marine compartment	5.11E-04	[-]	O
RCR for the regional marine compartment, statistical method	??	[-]	O
RCR for the regional fresh-water sediment compartment	7.38E-03	[-]	O
RCR for the regional marine sediment compartment	7.29E-03	[-]	O
RCR for the regional soil compartment	0.126	[-]	O
RCR for the regional soil compartment, statistical method	??	[-]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE

Purification factor for surface water	0.25	[-]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
BIOCONCENTRATION AND BIOACCUMULATION FACTORS

Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

Local concentration in wet fish	115	[mg.kg-1]	O
Local concentration in root tissue of plant	389	[mg.kg-1]	O
Local concentration in leaves of plant	0.0524	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0213	[mg.kg-1]	O
Local concentration in drinking water	0.0676	[mg.l-1]	O
Local concentration in meat (wet weight)	0.837	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.265	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

Daily dose through intake of drinking water	1.93E-03	[mg.kg-1.d-1]	O
Daily dose through intake of fish	0.189	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	8.98E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.13	[mg.kg-1.d-1]	O
Daily dose through intake of meat	3.6E-03	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.12E-03	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.9E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [1 "PRODUCTION OF TBBPA", IC=11/UC=22][PRODUCTION]

Fraction of total dose through intake of drinking water	8.29E-04	[-]	O
Fraction of total dose through intake of fish	0.081	[-]	O
Fraction of total dose through intake of leaf crops	3.85E-04	[-]	O
Fraction of total dose through intake of root crops	0.915	[-]	O
Fraction of total dose through intake of meat	1.54E-03	[-]	O
Fraction of total dose through intake of milk	9.1E-04	[-]	O
Fraction of total dose through intake of air	1.24E-08	[-]	O
Local total daily intake for humans	2.33	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Local concentration in wet fish	98.6	[mg.kg-1]	O
Local concentration in root tissue of plant	501	[mg.kg-1]	O
Local concentration in leaves of plant	0.0922	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0523	[mg.kg-1]	O
Local concentration in drinking water	0.087	[mg.l-1]	O
Local concentration in meat (wet weight)	1.11	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.351	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Daily dose through intake of drinking water	2.49E-03	[mg.kg-1.d-1]	O
Daily dose through intake of fish	0.162	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1.58E-03	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.75	[mg.kg-1.d-1]	O
Daily dose through intake of meat	4.78E-03	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.81E-03	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.09E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	8.51E-04	[-]	O
Fraction of total dose through intake of fish	0.0555	[-]	O
Fraction of total dose through intake of leaf crops	5.42E-04	[-]	O
Fraction of total dose through intake of root crops	0.941	[-]	O
Fraction of total dose through intake of meat	1.64E-03	[-]	O
Fraction of total dose through intake of milk	9.64E-04	[-]	O
Fraction of total dose through intake of air	3.73E-07	[-]	O
Local total daily intake for humans	2.92	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	0.23	[mg.kg-1]	O
Local concentration in root tissue of plant	0.774	[mg.kg-1]	O
Local concentration in leaves of plant	0.0418	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0417	[mg.kg-1]	O
Local concentration in drinking water	1.35E-04	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0579	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0183	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	3.84E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	3.78E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	7.17E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	4.25E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	2.49E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.47E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.76E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	6.69E-04	[-]	O
Fraction of total dose through intake of fish	0.0657	[-]	O
Fraction of total dose through intake of leaf crops	0.125	[-]	O
Fraction of total dose through intake of root crops	0.74	[-]	O
Fraction of total dose through intake of meat	0.0434	[-]	O
Fraction of total dose through intake of milk	0.0256	[-]	O
Fraction of total dose through intake of air	3.07E-04	[-]	O
Local total daily intake for humans	5.74E-03	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	1.63E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	1.93E-03	[mg.kg-1]	O
Local concentration in leaves of plant	1.53E-05	[mg.kg-1]	O
Local concentration in grass (wet weight)	1.52E-05	[mg.kg-1]	O
Local concentration in drinking water	3.36E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	2.59E-05	[mg.kg-1]	O
Local concentration in milk (wet weight)	8.2E-06	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	9.59E-09	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.67E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.62E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.06E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.11E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	6.57E-08	[mg.kg-1.d-1]	O
Daily dose through intake of air	6.36E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	6.99E-04	[-]	O
Fraction of total dose through intake of fish	0.195	[-]	O
Fraction of total dose through intake of leaf crops	0.0191	[-]	O
Fraction of total dose through intake of root crops	0.773	[-]	O
Fraction of total dose through intake of meat	8.13E-03	[-]	O
Fraction of total dose through intake of milk	4.79E-03	[-]	O
Fraction of total dose through intake of air	4.64E-05	[-]	O
Local total daily intake for humans	1.37E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	1.62E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	1.93E-03	[mg.kg-1]	O
Local concentration in leaves of plant	1.43E-05	[mg.kg-1]	O
Local concentration in grass (wet weight)	1.42E-05	[mg.kg-1]	O
Local concentration in drinking water	3.36E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	2.45E-05	[mg.kg-1]	O
Local concentration in milk (wet weight)	7.76E-06	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	9.59E-09	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.66E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.45E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.06E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.06E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	6.22E-08	[mg.kg-1.d-1]	O
Daily dose through intake of air	5.93E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	7.01E-04	[-]	O
Fraction of total dose through intake of fish	0.194	[-]	O
Fraction of total dose through intake of leaf crops	0.0179	[-]	O
Fraction of total dose through intake of root crops	0.775	[-]	O
Fraction of total dose through intake of meat	7.71E-03	[-]	O
Fraction of total dose through intake of milk	4.55E-03	[-]	O
Fraction of total dose through intake of air	4.33E-05	[-]	O
Local total daily intake for humans	1.37E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	5.3	[mg.kg-1]	O
Local concentration in root tissue of plant	31.5	[mg.kg-1]	O
Local concentration in leaves of plant	0.013	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0105	[mg.kg-1]	O
Local concentration in drinking water	5.47E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0795	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0251	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	1.56E-04	[mg.kg-1.d-1]	O
Daily dose through intake of fish	8.71E-03	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.23E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.173	[mg.kg-1.d-1]	O
Daily dose through intake of meat	3.42E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.02E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	3.72E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	8.57E-04	[-]	O
Fraction of total dose through intake of fish	0.0478	[-]	O
Fraction of total dose through intake of leaf crops	1.22E-03	[-]	O
Fraction of total dose through intake of root crops	0.947	[-]	O
Fraction of total dose through intake of meat	1.88E-03	[-]	O
Fraction of total dose through intake of milk	1.11E-03	[-]	O
Fraction of total dose through intake of air	2.04E-06	[-]	O
Local total daily intake for humans	0.182	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	0.242	[mg.kg-1]	O
Local concentration in root tissue of plant	1.43	[mg.kg-1]	O
Local concentration in leaves of plant	0.0442	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0441	[mg.kg-1]	O
Local concentration in drinking water	2.49E-04	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0625	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0198	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	7.11E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	3.98E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	7.58E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	7.86E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	2.69E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.58E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.86E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	7.53E-04	[-]	O
Fraction of total dose through intake of fish	0.0422	[-]	O
Fraction of total dose through intake of leaf crops	0.0802	[-]	O
Fraction of total dose through intake of root crops	0.831	[-]	O
Fraction of total dose through intake of meat	0.0284	[-]	O
Fraction of total dose through intake of milk	0.0168	[-]	O
Fraction of total dose through intake of air	1.97E-04	[-]	O
Local total daily intake for humans	9.45E-03	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	5.54	[mg.kg-1]	O
Local concentration in root tissue of plant	32.9	[mg.kg-1]	O
Local concentration in leaves of plant	0.0572	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0546	[mg.kg-1]	O
Local concentration in drinking water	5.72E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.142	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0449	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	1.63E-04	[mg.kg-1.d-1]	O
Daily dose through intake of fish	9.11E-03	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	9.8E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.18	[mg.kg-1.d-1]	O
Daily dose through intake of meat	6.11E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	3.6E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.23E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	8.52E-04	[-]	O
Fraction of total dose through intake of fish	0.0475	[-]	O
Fraction of total dose through intake of leaf crops	5.11E-03	[-]	O
Fraction of total dose through intake of root crops	0.941	[-]	O
Fraction of total dose through intake of meat	3.18E-03	[-]	O
Fraction of total dose through intake of milk	1.88E-03	[-]	O
Fraction of total dose through intake of air	1.16E-05	[-]	O
Local total daily intake for humans	0.192	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	0.303	[mg.kg-1]	O
Local concentration in root tissue of plant	6.38	[mg.kg-1]	O
Local concentration in leaves of plant	1.35E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	8.4E-04	[mg.kg-1]	O
Local concentration in drinking water	1.11E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0144	[mg.kg-1]	O
Local concentration in milk (wet weight)	4.55E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	3.17E-05	[mg.kg-1.d-1]	O
Daily dose through intake of fish	4.98E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.31E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.035	[mg.kg-1.d-1]	O
Daily dose through intake of meat	6.19E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	3.65E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.12E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	8.89E-04	[-]	O
Fraction of total dose through intake of fish	0.014	[-]	O
Fraction of total dose through intake of leaf crops	6.48E-04	[-]	O
Fraction of total dose through intake of root crops	0.982	[-]	O
Fraction of total dose through intake of meat	1.74E-03	[-]	O
Fraction of total dose through intake of milk	1.02E-03	[-]	O
Fraction of total dose through intake of air	5.94E-07	[-]	O
Local total daily intake for humans	0.0356	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	0.0151	[mg.kg-1]	O
Local concentration in root tissue of plant	0.287	[mg.kg-1]	O
Local concentration in leaves of plant	2.52E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	2.49E-03	[mg.kg-1]	O
Local concentration in drinking water	4.98E-05	[mg.l-1]	O
Local concentration in meat (wet weight)	3.96E-03	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.25E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	1.42E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.48E-05	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	4.31E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.57E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.7E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.05E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	8.53E-04	[-]	O
Fraction of total dose through intake of fish	0.0149	[-]	O
Fraction of total dose through intake of leaf crops	0.0258	[-]	O
Fraction of total dose through intake of root crops	0.942	[-]	O
Fraction of total dose through intake of meat	0.0102	[-]	O
Fraction of total dose through intake of milk	6.01E-03	[-]	O
Fraction of total dose through intake of air	6.28E-05	[-]	O
Local total daily intake for humans	1.67E-03	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	0.317	[mg.kg-1]	O
Local concentration in root tissue of plant	6.67	[mg.kg-1]	O
Local concentration in leaves of plant	3.86E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	3.33E-03	[mg.kg-1]	O
Local concentration in drinking water	1.16E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0183	[mg.kg-1]	O
Local concentration in milk (wet weight)	5.8E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	3.31E-05	[mg.kg-1.d-1]	O
Daily dose through intake of fish	5.2E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	6.61E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.0366	[mg.kg-1.d-1]	O
Daily dose through intake of meat	7.89E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	4.65E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.26E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	8.87E-04	[-]	O
Fraction of total dose through intake of fish	0.0139	[-]	O
Fraction of total dose through intake of leaf crops	1.77E-03	[-]	O
Fraction of total dose through intake of root crops	0.98	[-]	O
Fraction of total dose through intake of meat	2.11E-03	[-]	O
Fraction of total dose through intake of milk	1.25E-03	[-]	O
Fraction of total dose through intake of air	3.37E-06	[-]	O
Local total daily intake for humans	0.0373	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Local concentration in wet fish	1.58E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	5.09E-04	[mg.kg-1]	O
Local concentration in leaves of plant	2.89E-04	[mg.kg-1]	O
Local concentration in grass (wet weight)	2.89E-04	[mg.kg-1]	O
Local concentration in drinking water	3.2E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	3.93E-04	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.24E-04	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Daily dose through intake of drinking water	9.15E-09	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.6E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	4.96E-06	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.79E-06	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.69E-06	[mg.kg-1.d-1]	O
Daily dose through intake of milk	9.97E-07	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.22E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Fraction of total dose through intake of drinking water	7E-04	[-]	O
Fraction of total dose through intake of fish	0.199	[-]	O
Fraction of total dose through intake of leaf crops	0.38	[-]	O
Fraction of total dose through intake of root crops	0.214	[-]	O
Fraction of total dose through intake of meat	0.129	[-]	O
Fraction of total dose through intake of milk	0.0763	[-]	O
Fraction of total dose through intake of air	9.37E-04	[-]	O
Local total daily intake for humans	1.31E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
CONCENTRATIONS IN INTAKE MEDIA

Regional concentration in wet fish	1.58E-03	[mg.kg-1]	O
Regional concentration in root tissue of plant	2.97E-03	[mg.kg-1]	O
Regional concentration in leaves of plant	7.21E-06	[mg.kg-1]	O
Regional concentration in grass (wet weight)	7.21E-06	[mg.kg-1]	O
Regional concentration in drinking water	5.15E-07	[mg.l-1]	O
Regional concentration in meat (wet weight)	2.43E-05	[mg.kg-1]	O
Regional concentration in milk (wet weight)	7.68E-06	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
DOSES IN INTAKE MEDIA

Daily dose through intake of drinking water	1.47E-08	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.6E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1.24E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.63E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.04E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	6.16E-08	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.88E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
FRACTIONS OF TOTAL DOSE

Fraction of total dose through intake of drinking water	7.68E-04	[-]	O
Fraction of total dose through intake of fish	0.135	[-]	O
Fraction of total dose through intake of leaf crops	6.44E-03	[-]	O
Fraction of total dose through intake of root crops	0.849	[-]	O
Fraction of total dose through intake of meat	5.45E-03	[-]	O
Fraction of total dose through intake of milk	3.21E-03	[-]	O
Fraction of total dose through intake of air	1.5E-05	[-]	O
Regional total daily intake for humans	1.92E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - RISK CHARACTERIZATION
CURRENT CLASSIFICATION

Corrosive (C, R34 or R35)	No	D
Irritating to skin (Xi, R38)	No	D
Irritating to eyes (Xi, R36)	No	D
Risk of serious damage to eyes (Xi, R41)	No	D
Irritating to respiratory system (Xi, R37)	No	D
May cause sensitisation by inhalation (Xn, R42)	No	D
May cause sensitisation by skin contact (Xi, R43)	No	D
May cause cancer (T, R45)	No	D
May cause cancer by inhalation (T, R49)	No	D
Possible risk of irreversible effects (Xn, R40)	No	D

Part B - Calculations using Koc = 147,360 l/kg

The results from the following scenarios are included in the printout.

EUSES Printout	Scenario
USE PATTERN 1	Production
production	example calculation for a production site
USE PATTERN 2	Manufacture of derivatives of tetrabromobisphenol-A
processing	example calculation for a site manufacturing tetrabromobisphenol-A derivatives
USE PATTERN 3	Use in epoxy and polycarbonate resins
formulation	epoxy and/or polycarbonate manufacture
processing	use of epoxy resins
private use	use of polycarbonate resins
USE PATTERN 4	Use in ABS
formulation	compounding site
processing	conversion site
private use	compounding/conversion site (example calculation only – not used in the risk assessment)
USE PATTERN 5	Use in phenolic resins (example calculations only – not used in the risk assessment)
formulation	compounding site
processing	conversion site
private use	compounding/conversion site
USE PATTERN 6	Recycling of electronic equipment
private use	electronic equipment collection/recycling site
USE PATTERN 7	Losses over lifetime of products

IDENTIFICATION OF THE SUBSTANCE

General name	Tetrabromobisphenol-A		S
CAS-No	79-94-7		S
EC-notification no.	R402_0605_env		S
EINECS no.	201-236-9		S
Molecular weight	543.9	[g.mol-1]	S

PHYSICO-CHEMICAL PROPERTIES

Melting point	180	[oC]	S
Boiling point	316	[oC]	S
Vapour pressure at 25 [oC]	6.24E-09	[kPa]	S
Water solubility at test temperature	0.063	[mg.l-1]	S
Temperature at which solubility was measured	21	[oC]	S
Water solubility at 25 [oC]	0.24	[mg.l-1]	S
Octanol-water partition coefficient	5.9	[log10]	S
Henry's law constant	0.0141	[Pa.m3.mol-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION

Tonnage of substance in Europe	1.38E+04	[tonnes.yr-1]	O
Regional production volume of substance	0	[tonnes.yr-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents	S	
Extra details on use category	Polymerization processes		S
Extra details on use category	Wet: monomers		S
Fraction of tonnage for application	1	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRODUCTION]

Use specific emission scenario	No		D
Emission tables	A1.1 (general table), B1.4 (specific uses)	S	
Emission scenario	no special scenario selected/available	S	
Main category production	Ic Intermed. stored off-site/dedicated equip.	S	
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	1.02E-03	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	O
Number of emission days per year	300	[-]	O
Local emission to air during episode	0	[kg.d-1]	O
Local emission to wastewater during episode	13.6	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33]

Industry category	3 Chemical industry: chemicals used in synthesis	S	
Use category	33 Intermediates		S
Extra details on use category	Wet process		D
Fraction of tonnage for application	0	[-]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.3 (IC-specific), B3.2 (general table)	S	
Emission scenario	no special scenario selected/available	S	
Main category industrial use	III Multi-purpose equipment		S
Fraction of tonnage released to air	1E-05	[-]	S
Fraction of tonnage released to waste water	7E-03	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	200	[-]	S
Local emission to air during episode	0.025	[kg.d-1]	S
Local emission to wastewater during episode	17.5	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents	S	
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.9	[-]	S
Fraction of chemical in formulation	0.34	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	1E-05	[-]	S
Fraction of tonnage released to waste water	1E-05	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	300	[-]	O
Local emission to air during episode	0.027	[kg.d-1]	S
Local emission to wastewater during episode	0.027	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	1E-04	[-]	S
Fraction of tonnage released to waste water	1E-04	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	S
Number of emission days per year	32	[-]	S
Local emission to air during episode	5E-05	[kg.d-1]	S
Local emission to wastewater during episode	5E-05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	1E-04	[-]	S
Fraction of tonnage released to waste water	1E-04	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	O
Number of emission days per year	28	[-]	S
Local emission to air during episode	5E-05	[kg.d-1]	S
Local emission to wastewater during episode	5E-05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.2	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0.8	[-]	O
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.01	[kg.d-1]	S
Local emission to wastewater during episode	1.1	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.05	[kg.d-1]	S
Local emission to wastewater during episode	0.05	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0	[-]	S
Number of emission days per year	171	[-]	S
Local emission to air during episode	0.06	[kg.d-1]	S
Local emission to wastewater during episode	1.15	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.15	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[FORMULATION]

Use specific emission scenario	No		D
Emission tables	A2.1 (general table), B2.3 (specific uses)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Main category formulation	III Multi-purpose equipment		D
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	0.8	[-]	O
Number of emission days per year	48	[-]	S
Local emission to air during episode	2E-03	[kg.d-1]	S
Local emission to wastewater during episode	0.223	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[INDUSTRIAL USE]

Use specific emission scenario	No		D
Emission tables	A3.10 (specific uses), B3.9 (general table)		S
Emission scenario	Local waste water emission (ELocalWater)		S
Fraction of tonnage released to air	0	[-]	S
Fraction of tonnage released to waste water	0	[-]	S
Fraction of tonnage released to surfacewater	0	[-]	S
Fraction of tonnage released to industrial soil	0	[-]	S
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	48	[-]	S
Local emission to air during episode	0.01	[kg.d-1]	S
Local emission to wastewater during episode	0.01	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	48	[-]	S
Local emission to air during episode	0.012	[kg.d-1]	S
Local emission to wastewater during episode	0.233	[kg.d-1]	S
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymerization processes		D
Extra details on use category	Wet: monomers		D
Fraction of tonnage for application	0.1	[-]	S
Fraction of chemical in formulation	0.04	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[WASTE TREATMENT]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	300	[-]	S
Local emission to air during episode	1.83E-04	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[7 "LOSSES OVER LIFETIME OF PRODUCTS", IC=11/UC=22]

Industry category	11 Polymers industry		S
Use category	22 Flame-retardants and fire preventing agents		S
Extra details on use category	Polymer processing		S
Extra details on use category	Thermoplastics: additives, pigments, fillers		D
Fraction of tonnage for application	2.899	[-]	S

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[PRIVATE USE]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	365	[-]	S
Local emission to air during episode	0	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
[WASTE TREATMENT]

Use specific emission scenario	No		D
Emission tables	No applicable emission tables		S
Emission scenario	no special scenario selected/available		S
Fraction of tonnage released to air	0	[-]	O
Fraction of tonnage released to waste water	0	[-]	O
Fraction of tonnage released to surfacewater	0	[-]	O
Fraction of tonnage released to industrial soil	0	[-]	O
Fraction of tonnage released to agricultural soil	0	[-]	O
Fraction of the main local source	1	[-]	S
Number of emission days per year	365	[-]	S
Local emission to air during episode	0	[kg.d-1]	S
Local emission to wastewater during episode	0	[kg.d-1]	O
Intermittent release	No		D

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
TOTAL REGIONAL EMISSIONS TO COMPARTMENTS

Total regional emission to air	0.078	[kg.d-1]	S
Total regional emission to wastewater	0.355	[kg.d-1]	S
Total regional emission to surface water	0.094	[kg.d-1]	S
Total regional emission to industrial soil	0.0164	[kg.d-1]	S
Total regional emission to agricultural soil	0	[kg.d-1]	O

ENVIRONMENT-EXPOSURE
RELEASE ESTIMATION
TOTAL CONTINENTAL EMISSIONS TO COMPARTMENTS

Total continental emission to air	0.701	[kg.d-1]	S
Total continental emission to wastewater	3.186	[kg.d-1]	S
Total continental emission to surface water	0.847	[kg.d-1]	S
Total continental emission to industrial soil	0.148	[kg.d-1]	S

ENVIRONMENT-EXPOSURE
PARTITION COEFFICIENTS

Organic carbon-water partition coefficient	1.4736E+05	[l.kg-1]	S

ENVIRONMENT-EXPOSURE
PARTITION COEFFICIENTS
BIOTA-WATER PARTITION COEFFICIENTS

Bioconcentration factor for aquatic biota	1.234E+03	[l.kgwwt-1]	S

ENVIRONMENT-EXPOSURE
DEGRADATION AND TRANSFORMATION

Characterization of biodegradability	Not biodegradable		D
Degradation calculation method in STP	First order, standard OECD/EU tests		D
Rate constant for biodegradation in STP	0	[d-1]	O
Rate constant for biodegradation in surface water	4.7E-03	[d-1] (12[oC])	S
Rate constant for biodegradation in bulk soil	2.31E-06	[d-1] (12[oC])	S
Rate constant for biodegradation in aerated sediment	2.31E-06	[d-1] (12[oC])	S
Rate constant for hydrolysis in surface water	6.93E-07	[d-1] (12[oC])	O
Rate constant for photolysis in surface water	6.93E-07	[d-1]	O
Total rate constant for degradation in bulk soil	2.31E-06	[d-1] (12[oC])	S
Total rate constant for degradation in bulk sediment	2.31E-06	[d-1] (12[oC])	S

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	6.8	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.838	[mg.l-1]	O
Concentration in effluent exceeds solubility	Yes		O
Concentration in dry sewage sludge	1.51E+04	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.838	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	8.75	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	1.08	[mg.l-1]	O
Concentration in effluent exceeds solubility	Yes		O
Concentration in dry sewage sludge	1.94E+04	[mg.kg-1]	O
PEC for micro-organisms in the STP	1.08	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.0135	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	1.66E-03	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	30	[mg.kg-1]	O
PEC for micro-organisms in the STP	1.66E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	2.5E-05	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	3.08E-06	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0.0555	[mg.kg-1]	O
PEC for micro-organisms in the STP	3.08E-06	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	2.5E-05	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	3.08E-06	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	0.0555	[mg.kg-1]	O
PEC for micro-organisms in the STP	3.08E-06	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.55	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0678	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	1.22E+03	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0678	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.025	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	3.08E-03	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	55.5	[mg.kg-1]	O
PEC for micro-organisms in the STP	3.08E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.575	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0708	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	1.28E+03	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0708	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.112	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0137	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	248	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0137	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	5E-03	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	6.16E-04	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	11.1	[mg.kg-1]	O
PEC for micro-organisms in the STP	6.16E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]
OUTPUT

Fraction of emission directed to air by STP	1.33E-05	[-]	O
Fraction of emission directed to water by STP	0.123	[-]	O
Fraction of emission directed to sludge by STP	0.877	[-]	O
Fraction of the emission degraded in STP	0	[-]	O
Concentration in untreated wastewater	0.117	[mg.l-1]	O
Concentration of chemical (total) in the STP-effluent	0.0144	[mg.l-1]	O
Concentration in effluent exceeds solubility	No		O
Concentration in dry sewage sludge	259	[mg.kg-1]	O
PEC for micro-organisms in the STP	0.0144	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
SEWAGE TREATMENT
LOCAL STP [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]
OUTPUT

Fraction of emission directed to air by STP	0	[-]	O
Fraction of emission directed to water by STP	0	[-]	O
Fraction of emission directed to sludge by STP	0	[-]	O
Fraction of the emission degraded in STP	0	[-]	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

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
REMOVAL RATE CONSTANTS SOIL

Total rate constant for degradation in bulk soil	2.31E-06	[d-1] (12[oC])	S

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

Concentration in air during emission episode	5.02E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	4.12E-08	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0.0686	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0.0564	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	0.0686	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	0.0564	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	220	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0.0557	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0.0458	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	0.0557	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	0.0458	[mg.l-1]	O
Local PEC in marine sediment during emission episode	178	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	221	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	221	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	88.2	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	0.0849	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Concentration in air during emission episode	6.95E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	3.81E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0.0883	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0.0484	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	0.0883	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	0.0484	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	283	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0.0717	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0.0393	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	0.0717	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	0.0393	[mg.l-1]	O
Local PEC in marine sediment during emission episode	230	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	284	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	284	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	114	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	0.109	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	7.51E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	6.17E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	1.36E-04	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.12E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.37E-04	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.13E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.44	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	1.36E-05	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.12E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.38E-05	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.13E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.0441	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.44	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.44	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.177	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.69E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	1.39E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.22E-09	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	2.52E-07	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	2.21E-08	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.52E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.29E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	4.87E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.05E-07	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.8E-08	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	3.41E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.54E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.09E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	1.83E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	1.83E-03	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.34E-03	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	7.03E-07	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	1.39E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.07E-09	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	2.52E-07	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.93E-08	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.52E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.29E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	4.87E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.05E-07	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.57E-08	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	3.41E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.52E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.09E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	1.83E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	1.83E-03	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.34E-03	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	7.03E-07	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	2.78E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	1.3E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	5.55E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	2.6E-03	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	5.55E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	2.6E-03	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	17.8	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	5.55E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	2.6E-04	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	5.55E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	2.6E-04	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.78	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	17.9	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	17.9	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	7.14	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	6.87E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	1.39E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	6.51E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	2.52E-04	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.18E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	2.53E-04	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.19E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.812	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	2.05E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	9.59E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	2.05E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	9.61E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.656	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.814	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.814	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.327	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	3.13E-04	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	1.67E-05	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	7.81E-06	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	5.8E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	2.72E-03	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	5.8E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	2.72E-03	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	18.6	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	5.8E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	2.72E-04	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	5.8E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	2.72E-04	[mg.l-1]	O
Local PEC in marine sediment during emission episode	1.86	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	18.7	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	18.7	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	7.46	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	7.18E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Concentration in air during emission episode	5.56E-07	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	7.31E-08	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	1.12E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.48E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.13E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.49E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	3.61	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	1.12E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.48E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.13E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.49E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.361	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	3.62	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	3.62	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.45	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.39E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in air during emission episode	2.78E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	3.66E-07	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	5.04E-05	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	6.63E-06	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	5.17E-05	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	7.9E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	0.166	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	4.09E-05	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	5.39E-06	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	4.11E-05	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	5.52E-06	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.132	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	0.163	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	0.163	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	0.066	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	6.29E-05	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in air during emission episode	3.34E-06	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	4.39E-07	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	1.18E-03	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	1.55E-04	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.18E-03	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.56E-04	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	3.77	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	1.18E-04	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	1.55E-05	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.18E-04	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.56E-05	[mg.l-1]	O
Local PEC in marine sediment during emission episode	0.377	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	3.79	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	3.78	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.51	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	1.46E-03	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
LOCAL SCALE
[6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Concentration in air during emission episode	5.09E-08	[mg.m-3]	O
Annual average concentration in air, 100 m from point source	4.18E-08	[mg.m-3]	O
Concentration in surface water during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in surface water (dissolved)	0	[mg.l-1]	O
Local PEC in surface water during emission episode (dissolved)	1.27E-06	[mg.l-1]	O
Annual average local PEC in surface water (dissolved)	1.27E-06	[mg.l-1]	O
Local PEC in fresh-water sediment during emission episode	4.06E-03	[mg.kgwwt-1]	O
Concentration in sea water during emission episode (dissolved)	0	[mg.l-1]	O
Annual average concentration in sea water (dissolved)	0	[mg.l-1]	O
Local PEC in sea water during emission episode (dissolved)	1.36E-07	[mg.l-1]	O
Annual average local PEC in sea water (dissolved)	1.36E-07	[mg.l-1]	O
Local PEC in marine sediment during emission episode	4.35E-04	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 30 days	1.02E-03	[mg.kgwwt-1]	O
Local PEC in agric. soil (total) averaged over 180 days	1.02E-03	[mg.kgwwt-1]	O
Local PEC in grassland (total) averaged over 180 days	1.02E-03	[mg.kgwwt-1]	O
Local PEC in groundwater under agricultural soil	3.92E-07	[mg.l-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
REGIONAL AND CONTINENTAL SCALE
CONTINENTAL

Continental PEC in surface water (dissolved)	2.07E-07	[mg.l-1]	O
Continental PEC in sea water (dissolved)	2.51E-10	[mg.l-1]	O
Continental PEC in air (total)	1.59E-10	[mg.m-3]	O
Continental PEC in agricultural soil (total)	1.03E-03	[mg.kgwwt-1]	O
Continental PEC in pore water of agricultural soils	3.96E-07	[mg.l-1]	O
Continental PEC in natural soil (total)	1.26E-04	[mg.kgwwt-1]	O
Continental PEC in industrial soil (total)	6.54E-04	[mg.kgwwt-1]	O
Continental PEC in sediment (total)	1.32E-03	[mg.kgwwt-1]	O
Continental PEC in sea water sediment (total)	1.58E-06	[mg.kgwwt-1]	O

ENVIRONMENT-EXPOSURE
DISTRIBUTION
REGIONAL AND CONTINENTAL SCALE
REGIONAL

Regional PEC in surface water (dissolved)	1.27E-06	[mg.l-1]	O
Regional PEC in sea water (dissolved)	1.36E-07	[mg.l-1]	O
Regional PEC in air (total)	1.28E-09	[mg.m-3]	O
Regional PEC in agricultural soil (total)	9.91E-03	[mg.kgwwt-1]	O
Regional PEC in pore water of agricultural soils	3.81E-06	[mg.l-1]	O
Regional PEC in natural soil (total)	1.02E-03	[mg.kgwwt-1]	O
Regional PEC in industrial soil (total)	6.13E-03	[mg.kgwwt-1]	O
Regional PEC in sediment (total)	8.08E-03	[mg.kgwwt-1]	O
Regional PEC in sea water sediment (total)	8.57E-04	[mg.kgwwt-1]	O

ENVIRONMENT-EXPOSURE
BIOCONCENTRATION

Bioconcentration factor for earthworms	9.53E+03	[l.kgwwt-1]	O
Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S
Bioconcentration factor for aquatic biota	1.234E+03	[l.kgwwt-1]	S

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

Concentration in fish for secondary poisoning (fresh water)	34.8	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	28.2	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	5.65	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	375	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	29.8	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	24.2	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	4.85	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	482	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	0.0706	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	7.07E-03	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.55E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.764	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	1.58E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.79E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.7E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.0199	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	1.58E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.77E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.7E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.0199	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	1.61	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.161	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.0322	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	30.3	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	0.0745	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.0594	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.012	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	1.4	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	1.68	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	0.168	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	0.0337	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	31.7	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Concentration in fish for secondary poisoning (fresh water)	0.0928	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	9.29E-03	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.99E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	6.16	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Concentration in fish for secondary poisoning (fresh water)	5.66E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	3.49E-03	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	8.32E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.294	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Concentration in fish for secondary poisoning (fresh water)	0.0969	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	9.7E-03	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	2.07E-03	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	6.44	[mg.kg-1]	O

ENVIRONMENT-EXPOSURE
SECONDARY POISONING [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Concentration in fish for secondary poisoning (fresh water)	1.56E-03	[mg.kgwwt-1]	O
Concentration in fish for secondary poisoning (marine)	1.68E-04	[mg.kgwwt-1]	O
Concentration in fish-eating marine top-predators	1.68E-04	[mg.kgwwt-1]	O
Concentration in earthworms from agricultural soil	0.0186	[mg.kg-1]	O

ENVIRONMENT - EFFECTS
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
PNEC for micro-organisms in a STP	>1.5	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC micro	10	[-]	O

ENVIRONMENT - EFFECTS
FRESH_WATER ORGANISMS

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
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
PNEC for aquatic organisms	1.3E-03	[mg.l-1]	O
PNEC for aquatic organisms, intermittent releases	9E-04	[mg.l-1]	O
Assessment factor applied in extrapolation to PNEC Aqua	10	[-]	S

ENVIRONMENT - EFFECTS
MARINE ORGANISMS

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
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
PNEC for marine organisms	2.5E-04	[mg.l-1]	O

ENVIRONMENT - EFFECTS
FRESH-WATER SEDIMENT ORGANISMS

LC50 for fresh-water sediment organism	??	[mg.kgwwt-1]	D
EC10 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 for fresh-water sediment organism	90	[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.kgdwt-1]	S
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
NOEC for fresh-water sediment organism	??	[mg.kgwwt-1]	D
PNEC for fresh-water sediment-dwelling organisms	0.543	[mg.kgwwt-1]	O

ENVIRONMENT - EFFECTS
MARINE SEDIMENT ORGANISMS

LC50 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
EC10 for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
NOEC for marine sediment organism	??	[mg.kgwwt-1]	D
PNEC for marine sediment organisms	0.0543	[mg.kgwwt-1]	O

ENVIRONMENT - EFFECTS
TERRESTRIAL ORGANISMS

LC50 for plants	??	[mg.kgwwt-1]	D
LC50 for earthworms	??	[mg.kgwwt-1]	D
EC50 for microorganisms	??	[mg.kgwwt-1]	D
LC50 for other terrestrial species	??	[mg.kgwwt-1]	D
NOEC for plants	25.9	[mg.kgdwt-1]	S
NOEC for earthworms	0.29	[mg.kgdwt-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
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
NOEC for additional taxonomic group	??	[mg.kgwwt-1]	D
PNEC for terrestrial organisms	0.012	[mg.kgwwt-1]	O
Equilibrium partitioning used for PNEC in soil?	No		O
Assessment factor applied in extrapolation to PNEC Terr	10	[-]	S

ENVIRONMENT - EFFECTS
BIRDS AND MAMMALS

Duration of (sub-)chronic oral test	28 days		D
NOEC via food for secondary poisoning	??	[mg.kg-1]	O
PNEC for secondary poisoning of birds and mammals	>667	[mg.kg-1]	O
Assessment factor applied in extrapolation to PNEC oral	30	[-]	S

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

RCR for the local fresh-water compartment	52.8	[-]	O
RCR for the local fresh-water compartment, statistical method	73.7	[-]	O
RCR for the local marine compartment	223	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	404	[-]	O
RCR for the local marine sediment compartment	3.28E+03	[-]	O
RCR for the local soil compartment	1.84E+04	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.558	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<0.0522	[-]	O
RCR for fish-eating birds and mammals (marine)	<0.0424	[-]	O
RCR for top predators (marine)	<8.47E-03	[-]	O
RCR for worm-eating birds and mammals	<0.562	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

RCR for the local fresh-water compartment	67.9	[-]	O
RCR for the local fresh-water compartment, statistical method	94.8	[-]	O
RCR for the local marine compartment	287	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	520	[-]	O
RCR for the local marine sediment compartment	4.22E+03	[-]	O
RCR for the local soil compartment	2.37E+04	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.719	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<0.0448	[-]	O
RCR for fish-eating birds and mammals (marine)	<0.0363	[-]	O
RCR for top predators (marine)	<7.27E-03	[-]	O
RCR for worm-eating birds and mammals	<0.724	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	0.106	[-]	O
RCR for the local fresh-water compartment, statistical method	0.148	[-]	O
RCR for the local marine compartment	0.055	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	0.81	[-]	O
RCR for the local marine sediment compartment	0.811	[-]	O
RCR for the local soil compartment	36.7	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<1.11E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.06E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<1.06E-05	[-]	O
RCR for top predators (marine)	<2.32E-06	[-]	O
RCR for worm-eating birds and mammals	<1.15E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	1.17E-03	[-]	O
RCR for the local fresh-water compartment, statistical method	1.63E-03	[-]	O
RCR for the local marine compartment	1.36E-03	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	8.96E-03	[-]	O
RCR for the local marine sediment compartment	0.0201	[-]	O
RCR for the local soil compartment	0.152	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<2.05E-06	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.37E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.68E-07	[-]	O
RCR for top predators (marine)	<2.55E-07	[-]	O
RCR for worm-eating birds and mammals	<2.99E-05	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	1.17E-03	[-]	O
RCR for the local fresh-water compartment, statistical method	1.63E-03	[-]	O
RCR for the local marine compartment	1.36E-03	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	8.96E-03	[-]	O
RCR for the local marine sediment compartment	0.0201	[-]	O
RCR for the local soil compartment	0.152	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<2.05E-06	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.36E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.66E-07	[-]	O
RCR for top predators (marine)	<2.54E-07	[-]	O
RCR for worm-eating birds and mammals	<2.99E-05	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	4.27	[-]	O
RCR for the local fresh-water compartment, statistical method	5.96	[-]	O
RCR for the local marine compartment	2.22	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	32.7	[-]	O
RCR for the local marine sediment compartment	32.7	[-]	O
RCR for the local soil compartment	1.49E+03	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0452	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.41E-03	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.41E-04	[-]	O
RCR for top predators (marine)	<4.84E-05	[-]	O
RCR for worm-eating birds and mammals	<0.0455	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	0.195	[-]	O
RCR for the local fresh-water compartment, statistical method	0.272	[-]	O
RCR for the local marine compartment	0.82	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	1.49	[-]	O
RCR for the local marine sediment compartment	12.1	[-]	O
RCR for the local soil compartment	67.8	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<2.05E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.12E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<8.9E-05	[-]	O
RCR for top predators (marine)	<1.8E-05	[-]	O
RCR for worm-eating birds and mammals	<2.1E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	4.46	[-]	O
RCR for the local fresh-water compartment, statistical method	6.23	[-]	O
RCR for the local marine compartment	2.32	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	34.2	[-]	O
RCR for the local marine sediment compartment	34.2	[-]	O
RCR for the local soil compartment	1.56E+03	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0.0472	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.52E-03	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.52E-04	[-]	O
RCR for top predators (marine)	<5.06E-05	[-]	O
RCR for worm-eating birds and mammals	<0.0476	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

RCR for the local fresh-water compartment	0.866	[-]	O
RCR for the local fresh-water compartment, statistical method	1.21	[-]	O
RCR for the local marine compartment	0.45	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	6.64	[-]	O
RCR for the local marine sediment compartment	6.64	[-]	O
RCR for the local soil compartment	302	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<9.16E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.39E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<1.39E-05	[-]	O
RCR for top predators (marine)	<2.99E-06	[-]	O
RCR for worm-eating birds and mammals	<9.25E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

RCR for the local fresh-water compartment	0.0398	[-]	O
RCR for the local fresh-water compartment, statistical method	0.0555	[-]	O
RCR for the local marine compartment	0.164	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	0.305	[-]	O
RCR for the local marine sediment compartment	2.42	[-]	O
RCR for the local soil compartment	13.6	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<4.11E-04	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<8.49E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<5.24E-06	[-]	O
RCR for top predators (marine)	<1.25E-06	[-]	O
RCR for worm-eating birds and mammals	<4.41E-04	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

RCR for the local fresh-water compartment	0.905	[-]	O
RCR for the local fresh-water compartment, statistical method	1.26	[-]	O
RCR for the local marine compartment	0.471	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	6.94	[-]	O
RCR for the local marine sediment compartment	6.94	[-]	O
RCR for the local soil compartment	315	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<9.57E-03	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<1.45E-04	[-]	O
RCR for fish-eating birds and mammals (marine)	<1.46E-05	[-]	O
RCR for top predators (marine)	<3.11E-06	[-]	O
RCR for worm-eating birds and mammals	<9.66E-03	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
LOCAL [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

RCR for the local fresh-water compartment	9.75E-04	[-]	O
RCR for the local fresh-water compartment, statistical method	1.36E-03	[-]	O
RCR for the local marine compartment	5.43E-04	[-]	O
RCR for the local marine compartment, statistical method	??	[-]	O
RCR for the local fresh-water sediment compartment	7.47E-03	[-]	O
RCR for the local marine sediment compartment	8.01E-03	[-]	O
RCR for the local soil compartment	0.085	[-]	O
RCR for the local soil compartment, statistical method	??	[-]	O
RCR for the sewage treatment plant	<0	[-]	O
RCR for fish-eating birds and mammals (fresh-water)	<2.35E-06	[-]	O
RCR for fish-eating birds and mammals (marine)	<2.51E-07	[-]	O
RCR for top predators (marine)	<2.51E-07	[-]	O
RCR for worm-eating birds and mammals	<2.78E-05	[-]	O

ENVIRONMENT - RISK CHARACTERIZATION
REGIONAL

RCR for the regional fresh-water compartment	9.75E-04	[-]	O
RCR for the regional fresh-water compartment, statistical method	1.36E-03	[-]	O
RCR for the regional marine compartment	5.43E-04	[-]	O
RCR for the regional marine compartment, statistical method	??	[-]	O
RCR for the regional fresh-water sediment compartment	0.0149	[-]	O
RCR for the regional marine sediment compartment	0.0158	[-]	O
RCR for the regional soil compartment	0.826	[-]	O
RCR for the regional soil compartment, statistical method	??	[-]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE

Purification factor for surface water	0.25	[-]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
BIOCONCENTRATION AND BIOACCUMULATION FACTORS

Bioconcentration factor for fish	1.234E+03	[l.kgwwt-1]	S

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

Local concentration in wet fish	69.6	[mg.kg-1]	O
Local concentration in root tissue of plant	489	[mg.kg-1]	O
Local concentration in leaves of plant	0.0652	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0262	[mg.kg-1]	O
Local concentration in drinking water	0.0849	[mg.l-1]	O
Local concentration in meat (wet weight)	0.947	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.299	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

Daily dose through intake of drinking water	2.43E-03	[mg.kg-1.d-1]	O
Daily dose through intake of fish	0.114	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1.12E-03	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.68	[mg.kg-1.d-1]	O
Daily dose through intake of meat	4.07E-03	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.4E-03	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.21E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [1 "PRODUCTION OF TETRABROMOBISPHENOL A", IC=11/UC=22][PRODUCTION]

Fraction of total dose through intake of drinking water	8.65E-04	[-]	O
Fraction of total dose through intake of fish	0.0408	[-]	O
Fraction of total dose through intake of leaf crops	3.99E-04	[-]	O
Fraction of total dose through intake of root crops	0.956	[-]	O
Fraction of total dose through intake of meat	1.45E-03	[-]	O
Fraction of total dose through intake of milk	8.55E-04	[-]	O
Fraction of total dose through intake of air	4.33E-09	[-]	O
Local total daily intake for humans	2.81	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Local concentration in wet fish	59.7	[mg.kg-1]	O
Local concentration in root tissue of plant	629	[mg.kg-1]	O
Local concentration in leaves of plant	0.109	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0591	[mg.kg-1]	O
Local concentration in drinking water	0.109	[mg.l-1]	O
Local concentration in meat (wet weight)	1.25	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.396	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Daily dose through intake of drinking water	3.12E-03	[mg.kg-1.d-1]	O
Daily dose through intake of fish	0.0981	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1.87E-03	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	3.45	[mg.kg-1.d-1]	O
Daily dose through intake of meat	5.39E-03	[mg.kg-1.d-1]	O
Daily dose through intake of milk	3.17E-03	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.09E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [2 "MANUFACTURE OF DERIVATIVES OF TBBPA", IC=3/UC=33][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	8.77E-04	[-]	O
Fraction of total dose through intake of fish	0.0275	[-]	O
Fraction of total dose through intake of leaf crops	5.26E-04	[-]	O
Fraction of total dose through intake of root crops	0.969	[-]	O
Fraction of total dose through intake of meat	1.51E-03	[-]	O
Fraction of total dose through intake of milk	8.91E-04	[-]	O
Fraction of total dose through intake of air	3.06E-07	[-]	O
Local total daily intake for humans	3.56	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	0.14	[mg.kg-1]	O
Local concentration in root tissue of plant	0.974	[mg.kg-1]	O
Local concentration in leaves of plant	0.0418	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0418	[mg.kg-1]	O
Local concentration in drinking water	1.69E-04	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0582	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0184	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	4.84E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.3E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	7.17E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	5.34E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	2.5E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.47E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.76E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	7.22E-04	[-]	O
Fraction of total dose through intake of fish	0.0343	[-]	O
Fraction of total dose through intake of leaf crops	0.107	[-]	O
Fraction of total dose through intake of root crops	0.798	[-]	O
Fraction of total dose through intake of meat	0.0374	[-]	O
Fraction of total dose through intake of milk	0.022	[-]	O
Fraction of total dose through intake of air	2.63E-04	[-]	O
Local total daily intake for humans	6.69E-03	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	1.59E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	4.05E-03	[mg.kg-1]	O
Local concentration in leaves of plant	1.74E-05	[mg.kg-1]	O
Local concentration in grass (wet weight)	1.73E-05	[mg.kg-1]	O
Local concentration in drinking water	7.03E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	3.65E-05	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.15E-05	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	2.01E-08	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.61E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.99E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.22E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.57E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	9.25E-08	[mg.kg-1.d-1]	O
Daily dose through intake of air	7.14E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	7.92E-04	[-]	O
Fraction of total dose through intake of fish	0.103	[-]	O
Fraction of total dose through intake of leaf crops	0.0118	[-]	O
Fraction of total dose through intake of root crops	0.875	[-]	O
Fraction of total dose through intake of meat	6.19E-03	[-]	O
Fraction of total dose through intake of milk	3.65E-03	[-]	O
Fraction of total dose through intake of air	2.81E-05	[-]	O
Local total daily intake for humans	2.54E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	1.59E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	4.05E-03	[mg.kg-1]	O
Local concentration in leaves of plant	1.64E-05	[mg.kg-1]	O
Local concentration in grass (wet weight)	1.62E-05	[mg.kg-1]	O
Local concentration in drinking water	7.03E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	3.51E-05	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.11E-05	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	2.01E-08	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.61E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.81E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	2.22E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.51E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	8.9E-08	[mg.kg-1.d-1]	O
Daily dose through intake of air	6.7E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [3 "USE IN EPOXY AND POLYCARBONATE RESINS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	7.93E-04	[-]	O
Fraction of total dose through intake of fish	0.103	[-]	O
Fraction of total dose through intake of leaf crops	0.0111	[-]	O
Fraction of total dose through intake of root crops	0.876	[-]	O
Fraction of total dose through intake of meat	5.96E-03	[-]	O
Fraction of total dose through intake of milk	3.51E-03	[-]	O
Fraction of total dose through intake of air	2.64E-05	[-]	O
Local total daily intake for humans	2.53E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	3.21	[mg.kg-1]	O
Local concentration in root tissue of plant	39.5	[mg.kg-1]	O
Local concentration in leaves of plant	0.0141	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0109	[mg.kg-1]	O
Local concentration in drinking water	6.87E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0885	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.028	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	1.96E-04	[mg.kg-1.d-1]	O
Daily dose through intake of fish	5.27E-03	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.41E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.217	[mg.kg-1.d-1]	O
Daily dose through intake of meat	3.8E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.24E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	3.72E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	8.8E-04	[-]	O
Fraction of total dose through intake of fish	0.0236	[-]	O
Fraction of total dose through intake of leaf crops	1.08E-03	[-]	O
Fraction of total dose through intake of root crops	0.972	[-]	O
Fraction of total dose through intake of meat	1.7E-03	[-]	O
Fraction of total dose through intake of milk	1E-03	[-]	O
Fraction of total dose through intake of air	1.67E-06	[-]	O
Local total daily intake for humans	0.223	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	0.147	[mg.kg-1]	O
Local concentration in root tissue of plant	1.8	[mg.kg-1]	O
Local concentration in leaves of plant	0.0443	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.0441	[mg.kg-1]	O
Local concentration in drinking water	3.13E-04	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0629	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0199	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	8.94E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.42E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	7.59E-04	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	9.88E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	2.7E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.59E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.86E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	7.9E-04	[-]	O
Fraction of total dose through intake of fish	0.0214	[-]	O
Fraction of total dose through intake of leaf crops	0.067	[-]	O
Fraction of total dose through intake of root crops	0.873	[-]	O
Fraction of total dose through intake of meat	0.0239	[-]	O
Fraction of total dose through intake of milk	0.0141	[-]	O
Fraction of total dose through intake of air	1.64E-04	[-]	O
Local total daily intake for humans	0.0113	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	3.36	[mg.kg-1]	O
Local concentration in root tissue of plant	41.3	[mg.kg-1]	O
Local concentration in leaves of plant	0.0583	[mg.kg-1]	O
Local concentration in grass (wet weight)	0.055	[mg.kg-1]	O
Local concentration in drinking water	7.18E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.151	[mg.kg-1]	O
Local concentration in milk (wet weight)	0.0479	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	2.05E-04	[mg.kg-1.d-1]	O
Daily dose through intake of fish	5.51E-03	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1E-03	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.227	[mg.kg-1.d-1]	O
Daily dose through intake of meat	6.51E-04	[mg.kg-1.d-1]	O
Daily dose through intake of milk	3.83E-04	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.23E-06	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [4 "ADDITIVE FLAME RETARDANT USE - ABS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	8.75E-04	[-]	O
Fraction of total dose through intake of fish	0.0235	[-]	O
Fraction of total dose through intake of leaf crops	4.26E-03	[-]	O
Fraction of total dose through intake of root crops	0.967	[-]	O
Fraction of total dose through intake of meat	2.78E-03	[-]	O
Fraction of total dose through intake of milk	1.64E-03	[-]	O
Fraction of total dose through intake of air	9.52E-06	[-]	O
Local total daily intake for humans	0.234	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Local concentration in wet fish	0.184	[mg.kg-1]	O
Local concentration in root tissue of plant	8.02	[mg.kg-1]	O
Local concentration in leaves of plant	1.57E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	9.28E-04	[mg.kg-1]	O
Local concentration in drinking water	1.39E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0162	[mg.kg-1]	O
Local concentration in milk (wet weight)	5.13E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Daily dose through intake of drinking water	3.98E-05	[mg.kg-1.d-1]	O
Daily dose through intake of fish	3.02E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	2.69E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.044	[mg.kg-1.d-1]	O
Daily dose through intake of meat	6.97E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	4.11E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	2.13E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][FORMULATION]

Fraction of total dose through intake of drinking water	8.95E-04	[-]	O
Fraction of total dose through intake of fish	6.8E-03	[-]	O
Fraction of total dose through intake of leaf crops	6.05E-04	[-]	O
Fraction of total dose through intake of root crops	0.989	[-]	O
Fraction of total dose through intake of meat	1.57E-03	[-]	O
Fraction of total dose through intake of milk	9.24E-04	[-]	O
Fraction of total dose through intake of air	4.78E-07	[-]	O
Local total daily intake for humans	0.0445	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Local concentration in wet fish	9.75E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	0.362	[mg.kg-1]	O
Local concentration in leaves of plant	2.53E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	2.5E-03	[mg.kg-1]	O
Local concentration in drinking water	6.29E-05	[mg.l-1]	O
Local concentration in meat (wet weight)	4.05E-03	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.28E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Daily dose through intake of drinking water	1.8E-06	[mg.kg-1.d-1]	O
Daily dose through intake of fish	1.6E-05	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	4.33E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.98E-03	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.74E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.03E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.05E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][INDUSTRIAL USE]

Fraction of total dose through intake of drinking water	8.66E-04	[-]	O
Fraction of total dose through intake of fish	7.73E-03	[-]	O
Fraction of total dose through intake of leaf crops	0.0209	[-]	O
Fraction of total dose through intake of root crops	0.957	[-]	O
Fraction of total dose through intake of meat	8.4E-03	[-]	O
Fraction of total dose through intake of milk	4.95E-03	[-]	O
Fraction of total dose through intake of air	5.06E-05	[-]	O
Local total daily intake for humans	2.07E-03	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Local concentration in wet fish	0.192	[mg.kg-1]	O
Local concentration in root tissue of plant	8.37	[mg.kg-1]	O
Local concentration in leaves of plant	4.09E-03	[mg.kg-1]	O
Local concentration in grass (wet weight)	3.42E-03	[mg.kg-1]	O
Local concentration in drinking water	1.46E-03	[mg.l-1]	O
Local concentration in meat (wet weight)	0.0202	[mg.kg-1]	O
Local concentration in milk (wet weight)	6.4E-03	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Daily dose through intake of drinking water	4.16E-05	[mg.kg-1.d-1]	O
Daily dose through intake of fish	3.16E-04	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	7E-05	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	0.0459	[mg.kg-1.d-1]	O
Daily dose through intake of meat	8.7E-05	[mg.kg-1.d-1]	O
Daily dose through intake of milk	5.13E-05	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.26E-07	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [5 "ADDITIVE FLAME RETARDANT USE - PHENOLIC RESINS", IC=11/UC=22][PRIVATE USE]

Fraction of total dose through intake of drinking water	8.94E-04	[-]	O
Fraction of total dose through intake of fish	6.79E-03	[-]	O
Fraction of total dose through intake of leaf crops	1.51E-03	[-]	O
Fraction of total dose through intake of root crops	0.988	[-]	O
Fraction of total dose through intake of meat	1.87E-03	[-]	O
Fraction of total dose through intake of milk	1.1E-03	[-]	O
Fraction of total dose through intake of air	2.7E-06	[-]	O
Local total daily intake for humans	0.0465	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
CONCENTRATIONS IN INTAKE MEDIA [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Local concentration in wet fish	1.56E-03	[mg.kg-1]	O
Local concentration in root tissue of plant	2.26E-03	[mg.kg-1]	O
Local concentration in leaves of plant	2.92E-04	[mg.kg-1]	O
Local concentration in grass (wet weight)	2.92E-04	[mg.kg-1]	O
Local concentration in drinking water	3.92E-07	[mg.l-1]	O
Local concentration in meat (wet weight)	4.03E-04	[mg.kg-1]	O
Local concentration in milk (wet weight)	1.28E-04	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
DOSES IN INTAKE MEDIA [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Daily dose through intake of drinking water	1.12E-08	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.57E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	5E-06	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.24E-05	[mg.kg-1.d-1]	O
Daily dose through intake of meat	1.73E-06	[mg.kg-1.d-1]	O
Daily dose through intake of milk	1.02E-06	[mg.kg-1.d-1]	O
Daily dose through intake of air	1.23E-08	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
LOCAL SCALE
FRACTIONS OF TOTAL DOSE [6 "RECYCLING OF ELECTRONIC EQUIPMENT", IC=11/UC=22][WASTE TREATMENT]

Fraction of total dose through intake of drinking water	4.93E-04	[-]	O
Fraction of total dose through intake of fish	0.113	[-]	O
Fraction of total dose through intake of leaf crops	0.22	[-]	O
Fraction of total dose through intake of root crops	0.545	[-]	O
Fraction of total dose through intake of meat	0.0763	[-]	O
Fraction of total dose through intake of milk	0.045	[-]	O
Fraction of total dose through intake of air	5.42E-04	[-]	O
Local total daily intake for humans	2.27E-05	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
CONCENTRATIONS IN INTAKE MEDIA

Regional concentration in wet fish	1.56E-03	[mg.kg-1]	O
Regional concentration in root tissue of plant	0.0219	[mg.kg-1]	O
Regional concentration in leaves of plant	1.16E-05	[mg.kg-1]	O
Regional concentration in grass (wet weight)	1.16E-05	[mg.kg-1]	O
Regional concentration in drinking water	3.81E-06	[mg.l-1]	O
Regional concentration in meat (wet weight)	1.12E-04	[mg.kg-1]	O
Regional concentration in milk (wet weight)	3.53E-05	[mg.kg-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
DOSES IN INTAKE MEDIA

Daily dose through intake of drinking water	1.09E-07	[mg.kg-1.d-1]	O
Daily dose through intake of fish	2.57E-06	[mg.kg-1.d-1]	O
Daily dose through intake of leaf crops	1.98E-07	[mg.kg-1.d-1]	O
Daily dose through intake of root crops	1.2E-04	[mg.kg-1.d-1]	O
Daily dose through intake of meat	4.8E-07	[mg.kg-1.d-1]	O
Daily dose through intake of milk	2.83E-07	[mg.kg-1.d-1]	O
Daily dose through intake of air	3.66E-10	[mg.kg-1.d-1]	O

HUMAN HEALTH - EXPOSURE ASSESSMENT
HUMANS EXPOSED VIA THE ENVIRONMENT
REGIONAL SCALE
FRACTIONS OF TOTAL DOSE

Fraction of total dose through intake of drinking water	8.79E-04	[-]	O
Fraction of total dose through intake of fish	0.0207	[-]	O
Fraction of total dose through intake of leaf crops	1.6E-03	[-]	O
Fraction of total dose through intake of root crops	0.971	[-]	O
Fraction of total dose through intake of meat	3.87E-03	[-]	O
Fraction of total dose through intake of milk	2.28E-03	[-]	O
Fraction of total dose through intake of air	2.95E-06	[-]	O
Regional total daily intake for humans	1.24E-04	[mg.kg-1.d-1]	O

HUMAN HEALTH - RISK CHARACTERIZATION
CURRENT CLASSIFICATION

Corrosive (C, R34 or R35)	No	D
Irritating to skin (Xi, R38)	No	D
Irritating to eyes (Xi, R36)	No	D
Risk of serious damage to eyes (Xi, R41)	No	D
Irritating to respiratory system (Xi, R37)	No	D
May cause sensitisation by inhalation (Xn, R42)	No	D
May cause sensitisation by skin contact (Xi, R43)	No	D
May cause cancer (T, R45)	No	D
May cause cancer by inhalation (T, R49)	No	D
Possible risk of irreversible effects (Xn, R40)	No	D

APPENDIX C FUGACITY MODELLING

The EQC Model (v1.0) has been used to estimate the environmental partitioning of tetrabromobisphenol-A. This model is based on the fugacity concept and has been run using the input data shown in **Table C1**. The results are summarised in **Table C2** and are shown diagramatically in **Figures C1** to **C6**.

Table C1 Input data for fugacity model

Property	Value
Molecular weight	544 g/mole
Vapour pressure	6.24×10^{-6} Pa
Water solubility	0.063-2.34 mg/l
Henry's law constant	0.054 Pa m^3 $mole^{-1}$
Log Kow	5.9
Degradation half-life in air	130 hours
Degradation half-life in water	3,600 hours (150 days)
Degradation half-life in soil	720,000 hours (30,000 days)
Degradation half-life in sediment	720,000 hours (30,000 days)
Chemical input into level I model	100,000 kg)
Chemical input into level II model	1,000 kg/hour
Chemical input into level III model	Example A - 1,000 kg/hour to air
	Example B - 1,000 kg/hour to water
	Example C - 1,000 kg/hour to soil
	Example D - 1,000 kg/hour to air - 1,000 kg/hour to water - 1,000 kg/hour to soil

Table C2 Results of fugacity model

Model	Predicted environmental distribution			
	Air	Water	Sediment	Soil
Level I	1.5×10^{-3}%	0.14%	2.17%	97.6%
Level II	1.5×10^{-3}%	0.14%	2.17%	97.6%
Level III – Example A	9.2×10^{-3}%	0.014%	0.54%	99.4%
Level III – Example B	3.0×10^{-4}%	2.43%	94.3%	3.30%
Level III - Example C	2.2×10^{-5}%	6.6×10^{-3}%	0.25%	99.7%
Level III - Example D	2.7×10^{-3}%	0.047%	1.81%	98.1%

Figure C1

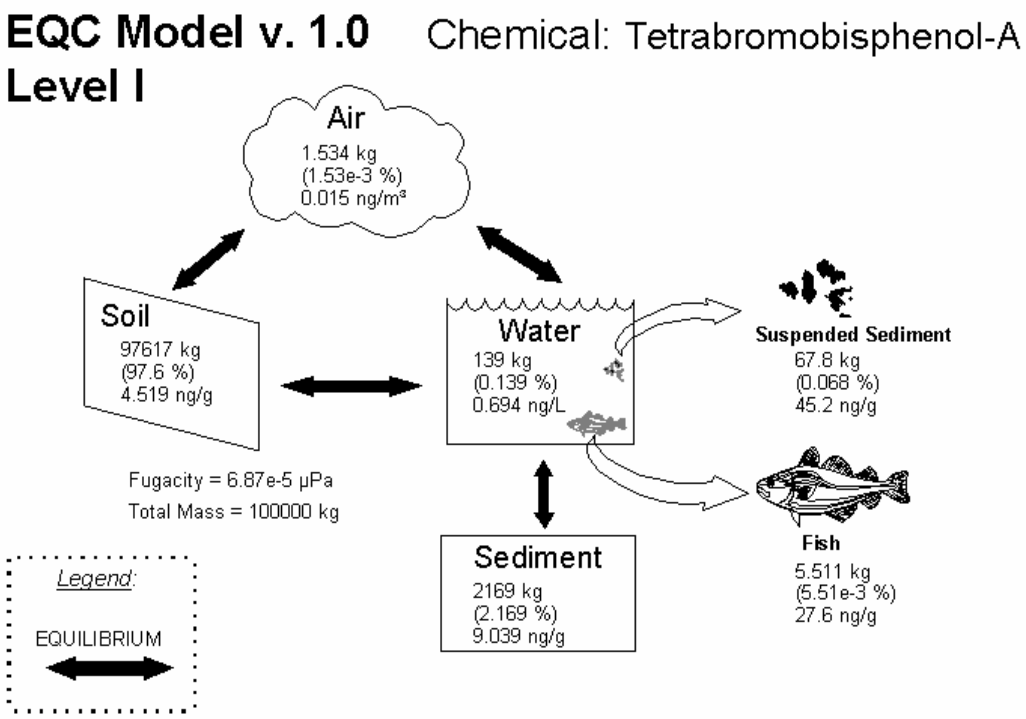


Figure C2

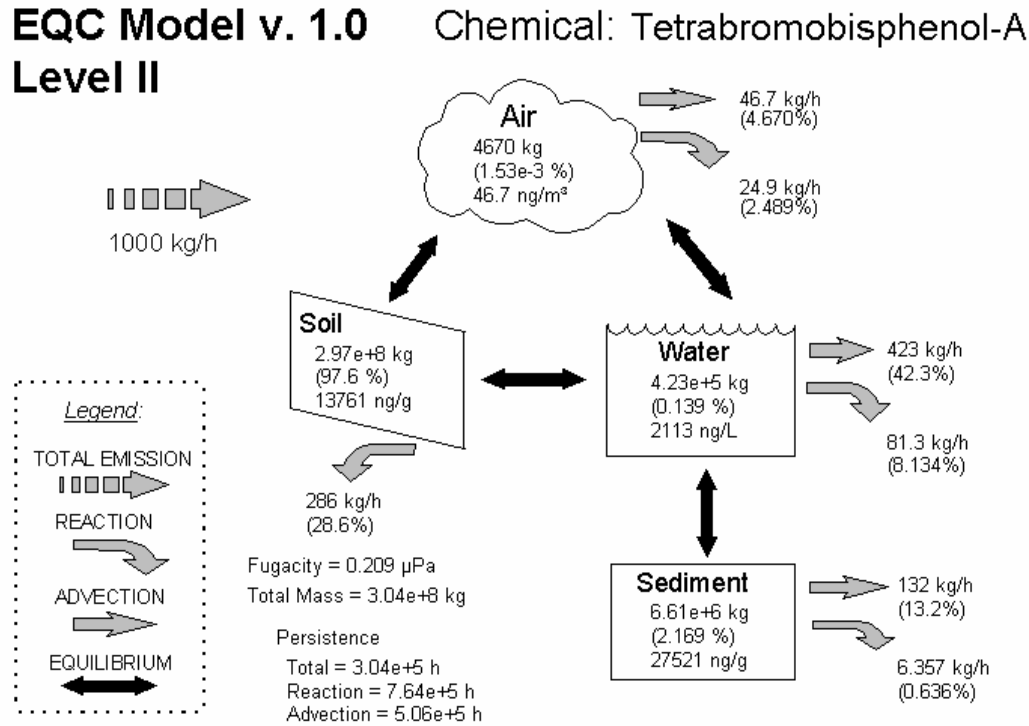


Figure C3

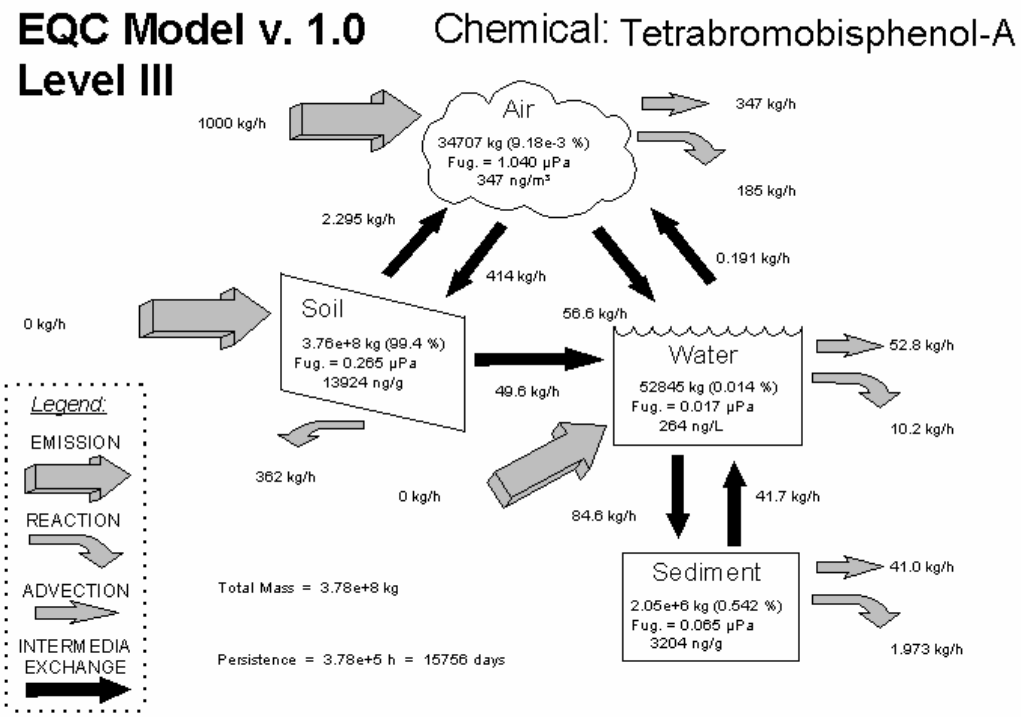


Figure C4

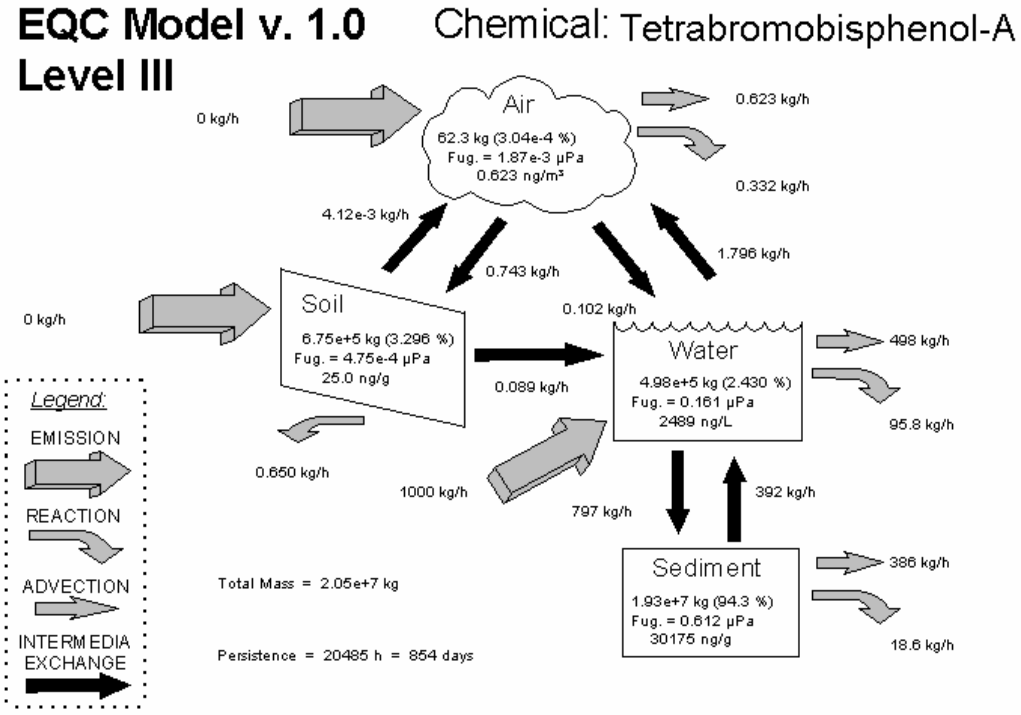


Figure C5

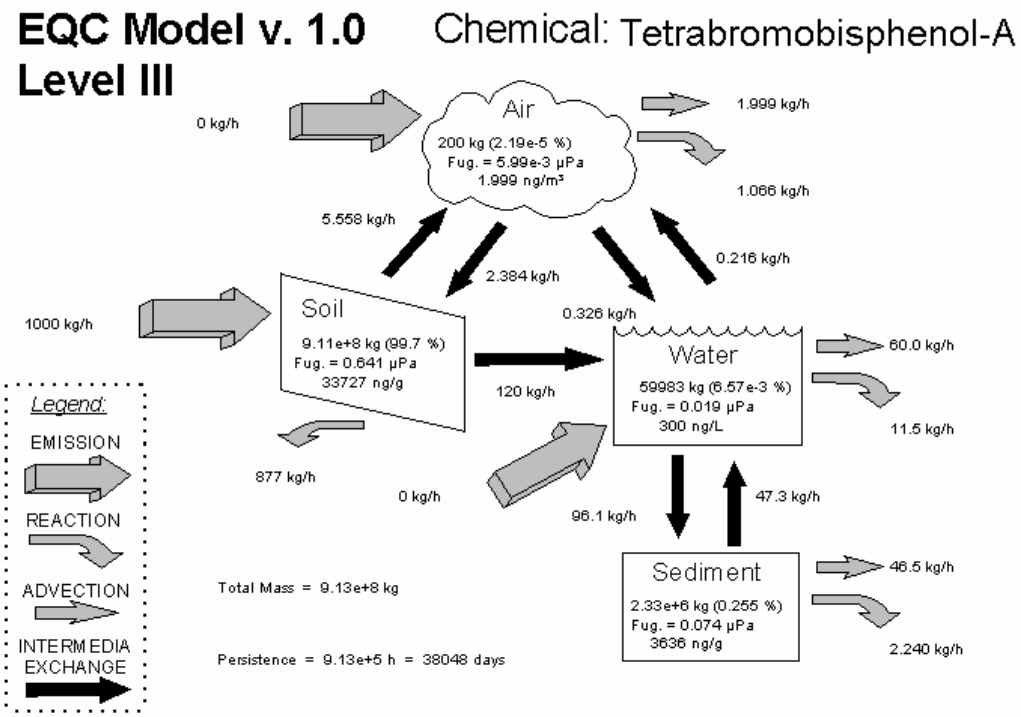
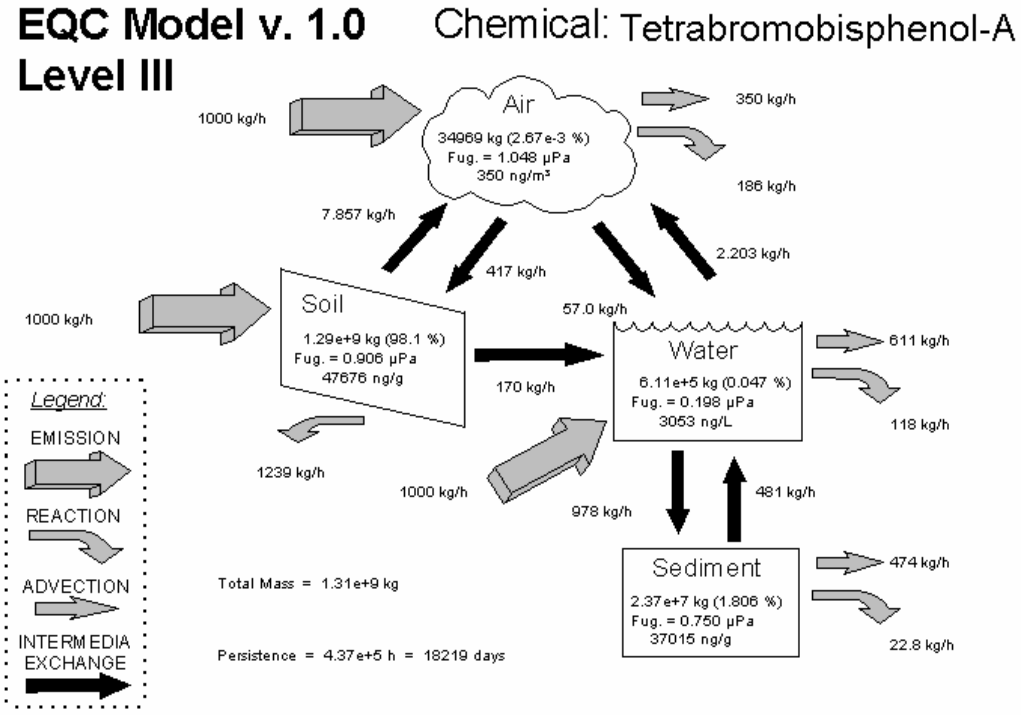


Figure C6



APPENDIX D CONSIDERATION OF POSSIBLE FUTURE INCREASED USE OF TETRABROMOBISPHENOL-A

Introduction

It has been reported that the use of octabromodiphenyl ether as an additive flame retardant in ABS has been falling in recent years (ECB, 2001). Directive 2003/11/EC[24] prohibits the marketing and use in the EU of octabromodiphenyl ether and articles containing octabromodiphenyl ether from the 15th August 2004. As tetrabromobisphenol-A is a possible alternative for octabromodiphenyl ether, it could be expected that the use of tetrabromobisphenol-A in this application will increase in future years. In addition, higher amounts of tetrabromobisphenol-A itself have been used in the EU than is currently the case. This Appendix considers the effects of a possible future increase in use of tetrabromobisphenol-A on the conclusions of the risk assessment.

The amount of octabromodiphenyl ether used in ABS in the EU in the late 1990s/early 2000s was estimated at around 450 tonnes/year, with a further 900 tonnes/year imported in finished goods or masterbatch. This Appendix considers a scenario where the octabromodiphenyl ether currently used in ABS is eventually replaced by tetrabromobisphenol-A.

Estimated emissions

The estimated emissions from the use of tetrabromobisphenol-A in ABS are already considered in the main risk assessment report. Here the emissions have been scaled up to reflect the possible increased use of tetrabromobisphenol-A in ABS, and taking into account the fact that the use of tetrabromobisphenol-A in recent years was higher than is currently used in the EU (i.e. a baseline figure of around 13,800 as was the case in the late 1990s is used). The calculations assume that around 1,380 tonnes/year of tetrabromobisphenol-A are used directly in the EU as an additive flame retardant (as was the case in the late 1990s), and that a further 450 tonnes may be used in the future if tetrabromobisphenol-A eventually replaces octabromodiphenyl ether in ABS. It will also be assumed that the amount of tetrabromobisphenol-A present in finished goods or masterbatch will increase by a similar proportion from the current estimate of 4,000 tonnes/year to 5,300 tonnes/year as a result of this possible replacement.

The estimated total emissions of tetrabromobisphenol-A as a result of this possible replacement are outlined in **Table D1**. These estimates are based on those given in the main report, taking into account the increased use of tetrabromobisphenol-A in ABS.

Estimated concentrations and PEC/PNEC ratios

The estimated PECs and risk characterisation ratios obtained using these release estimates are shown in **Table D1** (surface water), **Table D2** (sediment), **Table D3** (soil), **Table D4** (secondary poisoning via the fish food chain) and **Table D5** (secondary poisoning via the earthworm food chain).

[24] Directive 2003/11/EEC. Official Journal of the European Union, L42, pages 45-46, 15.2.2003.

Table D1 Summary of estimated future environmental release for tetrabromobisphenol-A

Lifecycle step	Comment		Estimated release										
			Local scenario			Regional scenario				Continental scenario[a]			
			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 kg/day	300	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
Use as an intermediate in the production of derivatives	Example calculation		0.025 kg/day	17.5 kg/day	200	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.041 kg/day	0.041 kg/day	300	12.4 kg/year	9.9 kg/year	2.5 kg/year	0	111.8 kg/year	89.4 kg/year	22.4 kg/year	0
	Processing of epoxy resins[d]		5×10^{-5}	5×10^{-5}	32	0.105 kg/year	0.084 kg/year	0.021 kg/year	0	0.963 kg/year	0.770 kg/year	0.193 kg/year	0
	Processing of polycarbonate resins[d]		5×10^{-5}	5×10^{-5}	28								
Additive flame retardant use	ABS	Compounding[c]	0.010 kg/day	1.1 kg/day	171	30.0 kg/year	343 kg/year	85.8 kg/year	0	269 kg/year	3,088 kg/year	772 kg/year	0
		Conversion[d]	0.050 kg/day	0.050 kg/day	171								

Table D1 continued overleaf.

Table D1 continued.

Lifecycle step	Comment	Estimated release										
		Local scenario			Regional scenario				Continental scenario[a]			
		Air	Waste water	Number of days	Air	Waste water	Surface water	Industrial/ urban soil	Air	Waste water	Surface water	Industrial/ urban soil
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				4.2				38.2			
"Waste remaining in the environment"	Particulate loss over lifetime and during disposal				0.011	0	2.65	7.96	0.095	0	23.9	71.6
Release during recycling and disposal	Collection, separation and shredding of plastic[g]	1.0×10^{-6}-1.83×10^{-4}		300	0.042-5.84				0.38-49.3			
Use of tetrabromobisphenol-A derivatives as flame retardants					0[f]	0[f]	0[f]	0[f]	0[f]	0[f]	0[f]	0[f]
Total					46.8-54.0[g]	353	91.0	7.96	421-486[g]	3,179	818	71.6

Note: a) Continental emissions = total EU emissions - regional emissions.
b) A 80% connection rate to waste water treatment plants is assumed in the regional and continental model. Therefore 30% 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 as no sites are 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.

The PECs have been estimated using EUSES with the same physico-chemical properties and degradation rates as assumed in the main risk assessment report. The PNECs used to estimate the risk characterisation ratios are also the same as used in the main risk assessment and are summarised below.

$PNEC_{water}$ = 1.3 µg/l.
$PNEC_{sed}$ (based on sediment toxicity data) = 2.7 mg/kg wet weight and 5.5 mg/kg wet weight.
$PNEC_{soil}$ (based on soil toxicity data) = 0.012 mg/kg wet weight.
$PNEC_{secondary\ poisoning}$ >667 mg/kg food

Table D2 Risk characterisation ratios for surface water

Scenario			PEC (µg/l)		Risk characterisation ratio	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.35	0.21	0.27	0.16
	Processing of epoxy resins		3.8×10^{-3}	3.6×10^{-3}	2.9×10^{-3}	2.8×10^{-3}
	Processing of polycarbonate resins		3.8×10^{-3}	3.6×10^{-3}	2.9×10^{-3}	2.8×10^{-3}
Additive flame retardant use	ABS	Compounding	9.2	5.6	7.1	4.3
		Conversion	0.42	0.26	0.32	0.20
Regional scenario			3.4×10^{-3}	3.3×10^{-3}	2.6×10^{-3}	2.5×10^{-3}

Table D3 PEC/PNEC ratios for sediment

Scenario			PEC (mg/kg wet wt.)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.55	0.67	0.20[a]	0.25[a] or 0.12[b]
	Processing of epoxy resins		6.1×10^{-3}	0.012	2.3×10^{-3} [a]	4.4×10^{-3} [a] or 2.2×10^{-3} [b]
	Processing of polycarbonate resins		6.1×10^{-3}	0.012	2.3×10^{-3} [a]	4.4×10^{-3} [a] or 2.2×10^{-3} [b]
Additive flame retardant use	ABS	Compounding	14.6	17.8	5.4[a]	6.6[a] or 3.2[b]
		Conversion	0.67	0.82	0.25[a]	0.30[a] or 0.15[b]
Regional scenario			0.011	0.021	4.1×10^{-3} [a]	7.8×10^{-3} [a] or 3.8×10^{-3} [b]

Notes: a) Using $PNEC_{sed}$ = 2.7 mg/kg wet weight.
b) Using $PNEC_{sed}$ = 5.5 mg/kg wet weight.

Table D4 PEC/PNEC ratios for agricultural soil (30 day average)

Scenario			PEC (mg/kg wet wt.)		PEC/PNEC	
			Koc = 49,726l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.60	0.67	50	56
	Processing of epoxy resins		1.2×10^{-3}	2.9×10^{-3}	0.10	0.24
	Processing of polycarbonate resins		1.2×10^{-3}	2.9×10^{-3}	0.10	0.24
Additive flame retardant use	ABS	Compounding	16.1	17.9	1,342	1,492
		Conversion	0.73	0.82	61	68
Electronic equipment collection/recycling site			5.0×10^{-4}	2.1×10^{-3}	0.042	0.17
Regional scenario	Agricultural soil		4.1×10^{-3}	0.027	0.34	2.3

Table D5 Risk characterisation ratios for secondary poisoning via the fish food chain

Scenario			PEC (mg/kg.)		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.070[a] or 0.18[b]	0.043[a] or 0.11[b]	$<1.0\times10^{-4}$ [a] or $<2.7\times10^{-4}$ [b]	$<6.4\times10^{-5}$ [a] or $<1.6\times10^{-4}$ [b]
	Processing of epoxy resins		1.7×10^{-3} [a] or 4.2×10^{-3} [b]	1.6×10^{-3} [a] or 4.1×10^{-3} [b]	$<2.5\times10^{-6}$ [a] or $<6.3\times10^{-6}$ [b]	$<2.4\times10^{-6}$ [a] or $<6.1\times10^{-6}$ [b]
	Processing of polycarbonate resins		1.7×10^{-3} [a] or 4.2×10^{-3} [b]	1.6×10^{-3} [a] or 4.1×10^{-3} [b]	$<2.5\times10^{-6}$ [a] or $<6.3\times10^{-6}$ [b]	$<2.4\times10^{-6}$ [a] or $<6.1\times10^{-6}$ [b]
Additive flame retardant use	ABS	Compounding	1.0[a] or 2.7[b]	0.63[a] or 1.6[b]	$<1.5\times10^{-3}$ [a] or $<4.0\times10^{-3}$ [b]	$<9.4\times10^{-4}$ [a] or $<2.4\times10^{-3}$ [b]
		Conversion	0.049[a] or 0.13[b]	0.030[a] or 0.077[b]	$<7.3\times10^{-5}$ [a] or $<1.9\times10^{-4}$ [b]	$<4.5\times10^{-5}$ [a] or $<1.2\times10^{-4}$ [b]

Note: a) Calculations using BCF_{fish} = 485 l/kg.
b) Calculations using BCF_{fish} = 1,234 l/kg.

Table D6 Provisional risk characterisation ratios for secondary poisoning via the earthworm food chain

Scenario			PEC (mg/kg wet wt.)[a]		PEC/PNEC	
			Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Reactive flame retardant use	Manufacture of epoxy and/or polycarbonate resins		0.91	1.2	$<1.4\times10^{-3}$	$<1.8\times10^{-3}$
	Processing of epoxy resins		8.0×10^{-3}	0.050	$<1.2\times10^{-5}$	$<7.5\times10^{-5}$
	Processing of polycarbonate resins		8.0×10^{-3}	0.050	$<1.2\times10^{-5}$[b]	$<7.5\times10^{-5}$
Additive flame retardant use	ABS	Compounding	24.2	30.4	<0.036	<0.046
		Conversion	1.1	1.4	$<1.7\times10^{-3}$	$<2.1\times10^{-3}$ [a]
Electronic equipment collection/recycling site			6.9×10^{-3}	0.049	$<1.0\times10^{-5}$ [b]	$<7.3\times10^{-5}$

Note: a) PEC estimated using the default $BCF_{earthworm}$ of 9,533 l/kg (calculated using the method outlined in the Technical Guidance Document).

Conclusions

Overall, consideration of the possible future increased use of tetrabromobisphenol-A as an additive flame retardant appears to have little effect over the estimated risk characterisation ratios for most scenarios.

For the local scenarios, a new risk would be identified for soil for the manufacture of epoxy resins. This results from the increased amount of tetrabromobisphenol-A being assumed to be used at a generic site, based on the default assumptions in the Technical Guidance Document. The risk to the soil compartment is indicated based on an assumption that sewage sludge from the site is applied to agricultural land. or the sites currently carrying out this process in the EU, it is known that no sewage sludge is applied to agricultural land (see main risk assessment report) and so no risk to soil would be expected even if an increased use in this area occurred.

The largest effect is apparent in the predicted regional concentrations, but even here the predicted regional concentrations have only increased modestly. For example, the $PEC_{regional}$ for water has increased from 1.3×10^{-3}µg/l to 3.3×10^{-3}-3.4×10^{-3} µg/l, and a similar increase is also seen in the predicted regional concentrations for sediment (increased from 4.0×10^{-3}-8.1×10^{-3} mg/kg wet weight to 0.011-0.021 mg/kg wet weight) and agricultural soil (increased from 1.5×10^{-3}-9.9×10^{-3} mg/kg wet weight to 4.1×10^{-3}-0.027 mg/kg wet weight). However, the predicted increase in the soil concentration is sufficient to indicate a possible risk to the soil compartment.

Thus it can be concluded that consideration of a foreseeable future increase in use of tetrabromobisphenol-A has little impact on the overall conclusions for the local scenarios in the current risk assessment. However, an increased risk to the soil compartment at the regional level may occur, especially if there is an increase in the amount of sewage sludge containing relatively high levels of tetrabromobisphenol-A that is applied to agricultural land.

References

ECB (2002). European Union Risk Assessment Report: Diphenyl ether, Octabromo derivative. European Chemicals Bureau. Final Draft.

APPENDIX E EXAMPLE CALCULATIONS USING PRIMARY BIODEGRADATION RATES FOR TETRABROMOBISPHENOL-A

In the main risk assessment report, the biodegradation rates used for sediment, soil and surface water are intended to represent the ultimate mineralisation of tetrabromobisphenol-A. However, tetrabromobisphenol-A has been shown to undergo primary degradation in soil and sediment with a half-life of the order of 60 days at 20-25°C, leading to the formation of various (sometimes unidentified) products. This Appendix considers the effect of this rate constant on the PECs calculated for tetrabromobisphenol-A. It should be noted, however, that these calculations are for information only and the risk assessment is based on the estimated rates for ultimate mineralisation, as this then also takes into account the possible formation of toxic metabolites.

The calculations are based on the example scenario for a generic production site and the regional scenario. The emissions used in the calculations are the same as included in the main risk assessment report. **Table E1** outlines the rate constants used, and the resulting PECs for tetrabromobisphenol-A.

Table E1 Example calculations based on primary degradation rate for tetrabromobisphenol-A

Scenario/Property	Value from main risk assessment report		Value assuming primary degradation rate	
	Koc = 49,726 l/kg	Koc = 147,360 l/kg	Koc = 49,726 l/kg	Koc = 147,360 l/kg
Half-life in surface water	150 days	150 days	60 days	60 days
Half-life in sediment	30,000 days	300,000 days	60 days	60 days
Half-life in soil	30,000 days	300,000 days	60 days	60 days
$PEC_{local(water)}$[a]	113 µg/l	68.6 µg/l	113 µg/l	68.6 µg/l
$PEC_{local(sediment)}$[a]	180 mg/kg wet weight	220 mg/kg wet weight	180 mg/kg wet weight	220 mg/kg wet weight
$PEC_{local(agricultural\ soil)}$ - average over 30 days[a]	198 mg/kg wet weight	221 mg/kg wet weight	17.7 mg/kg wet weight	19.0 mg/kg wet weight
$PEC_{local(fish)}$[a, b]	57.5 mg/kg	34.8 mg/kg	57.5 mg/kg	11.9 mg/kg
$PEC_{local(earthworm)}$[a, c]	300 mg/kg	375 mg/kg	13.3 mg/kg	2.9 mg/kg
$PEC_{regional(water)}$	1.3×10^{-3} µg/l	1.3×10^{-3} µg/l	3.9×10^{-4} µg/l	1.7×10^{-4} µg/l
$PEC_{regional(sediment)}$	4.0×10^{-3} mg/kg wet weight	8.1×10^{-3} mg/kg wet weight	2.2×10^{-4} mg/kg wet weight	4.6×10^{-8} mg/kg wet weight
$PEC_{regional(agricultural\ soil)}$	1.5×10^{-3} mg/kg wet weight	9.9×10^{-3} mg/kg wet weight	3.2×10^{-6} mg/kg wet weight	3.5×10^{-6} mg/kg wet weight

Note: a) Local concentrations are for the generic production site scenario.
b) A BCF_{fish} of 1,234 l/kg was used in the calculations.
c) Calculation uses the $BCF_{earthworm}$ of 9,533 l/kg.

As can be seen from **Table E1**, consideration of the primary degradation rate for tetrabromobisphenol-A has little effect on the predicted local concentrations in surface water, sediment or fish. The predicted local concentrations in soil are reduced by a factor of around 10 and the predicted concentration in earthworms is reduced by a factor of around 20.

The effect in the predicted regional concentrations is more marked, particularly for the sediment and soil compartments. This would be expected since the regional concentrations

are steady state concentrations and so will be influenced to a large degree by the rate of removal or degradation from the system.

For comparison, when no biodegradation at all is assumed in the regional model, the predicted regional are:

	Koc = 49,726 l/kg	Koc = 147,360 l/kg
$PEC_{regional,\ water}$	5.3×10^{-3} µg/l	1.8×10^{-3} µg/l
$PEC_{regional,\ sediment}$	0.017 mg/kg wet wt.	0.012 mg/kg wet wt.
$PEC_{regional,\ agric.\ soil}$	0.034 mg/kg wet wt.	0.017 mg/kg wet wt.

APPENDIX F SITE-SPECIFIC EXPOSURE INFORMATION

As discussed in Section 3.1.0.2.2 of the main risk assessment, some limited site specific information has been obtained from two surveys. The information mainly relates to the actual tonnage used at a site, but some emission-related information was provided, and in some cases details of the size of the waste water treatment plant were also provided. One of the companies included in the survey operated on more than one site, but only the total tetrabromobisphenol-A consumption for the company was given. Therefore the analysis here assumes the total consumption of tetrabromobisphenol-A reported in the survey for each company occurs on one site.

PECs have been estimated below for the eight known companies in the EU identified in the survey manufacturing epoxy resins using tetrabromobisphenol-A. The approach taken assumes (in the absence of actual information on emissions) an emission factor to waste water of 0.001% to water from wet processes (see Section 3.1.0.2.2) and 0% to water from dry processes (as recommended in the Technical Guidance Document). For air an emission factor of 0.001% is used (see Section 3.1.0.2.2). For some sites, both a wet and dry process are used. In these cases the known split of the tonnage between the two processes was used in order to estimate the total emission from the company. The estimated PECs are summarised in Table F1.

Table F1 Site specific PEC calculations for epoxy resin manufacturers (using 2003 consumption data)

	Company							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
$PEC_{surface\ water}$ (µg/l)	1.3×10^{-3} [a] 1.3×10^{-3} [b]	0.21[a] 0.13[b]	1.4×10^{-3} [a] 1.3×10^{-3} [b]	0.13[a] 0.077[b]	0.057[a] 0.035[b]	1.3×10^{-3} [a] 1.3×10^{-3} [b]	1.3×10^{-3} [a] 1.3×10^{-3} [b]	1.3×10^{-3} [a] 1.3×10^{-3} [b]
$PEC/PNEC_{surface\ water}$[d]	**1.0×10^{-3} [a]** **1.0×10^{-3} [b]**	**0.16[a]** **0.10[b]**	**1.1×10^{-3} [a]** **1.0×10^{-3} [b]**	**0.10[a]** **0.059[b]**	**0.043[a]** **0.027 [b]**	**1.0×10^{-3} [a]** **1.0×10^{-3} [b]**	**1.0×10^{-3} [a]** **1.0×10^{-3} [b]**	**1.0×10^{-3} [a]** **1.0×10^{-3} [b]**
$PEC_{sediment}$ (mg/kg wet wt.)	2.0×10^{-3} [a] 4.1×10^{-3} [b]	0.33[a] 0.41[b]	2.2×10^{-3} [a] 4.3×10^{-3} [b]	0.20[a] 0.25[b]	0.091[a] 0.11[b]	2.0×10^{-3} [a] 4.1×10^{-3} [b]	2.0×10^{-3} [a] 4.1×10^{-3} [b]	2.0×10^{-3} [a] 4.1×10^{-3} [b]
$PEC/PNEC_{sediment}$[d]	**7.4×10^{-4} [a]** **1.5×10^{-3} [b]**	**0.12[a]** **0.15[b]**	**8.1×10^{-4} [a]** **1.6×10^{-3} [b]**	**0.074[a]** **0.093[b]**	**0.034[a]** **0.041[b]**	**7.4×10^{-4} [a]** **1.5×10^{-3} [b]**	**7.4×10^{-4} [a]** **1.5×10^{-3} [b]**	**7.4×10^{-4} [a]** **1.5×10^{-3} [b]**
$PEC_{agric.\ soil}$ (mg/kg wet wt.)[c]	4.3×10^{-4} [a] 1.2×10^{-3} [b]	6.2×10^{-4} [a] 1.4×10^{-3} [b]	3.4×10^{-4} [a] 1.1×10^{-3} [b]	$7.4\times10^{-4.a}$ 1.5×10^{-3} [b]	4.0×10^{-4} [a] 1.2×10^{-3} [b]	2.3×10^{-3} [a] 3.1×10^{-3} [b]	4.5×10^{-4} [a] 1.2×10^{-3} [b]	7.6×10^{-4} [a] 1.5×10^{-3} [b]
$PEC/PNEC_{soil}$[d]	**0.036[a]** **0.10[b]**	**0.051[a]** **0.12[b]**	**0.028[a]** **0.092[b]**	**0.062[a]** **0.13[b]**	**0.033[a]** **0.10[b]**	**0.19[a]** **0.26[b]**	**0.038[a]** **0.10[b]**	**0.063[a]** **0.13[b]**

Note: a) Calculation uses a Koc value of 49,726 l/kg.
b) Calculation uses a Koc value of 147,360 l/kg.
c) Calculation assumes no application of sewage sludge to soil (as indicated in the information available for each company). The calculated PEC results from atmospheric deposition from the site and the regional background contribution.
d) The PNECs used in the calculations were 1.3 µg/l for surface water, 2.7 mg/kg wet weight for sediment and 0.012 mg/kg wet weight for soil.

Based on these calculations, no risks are identified for these sites for surface water, sediment and soil. This is in agreement with the conclusions drawn for a generic epoxy resin site in the main risk assessment.

Subsequent to the survey carried out for Table F1, actual monitoring of emissions has been carried out at three sites within the EU. The monitoring was carried out as part of the BSEF Product Stewardship Program for tetrabromobisphenol-A. Details of the surveys are confidential. The PECs and PEC/PNEC ratios estimated using the monitoring data are summarised below.

Site I – Reactive flame retardant use

Koc = 49,726 l/kg

	PEC	**PEC/PNEC**
Surface water	5.5×10^{-3} µg/l	4.2×10^{-3}
Sediment	8.7×10^{-3} mg/kg wet wt.	0.032
Soil	2.8×10^{-4} mg/kg wet wt.	0.023

Koc = 147,360 l/kg

	PEC	**PEC/PNEC**
Surface water	3.8×10^{-3} µg/l	2.9×10^{-3}
Sediment	0.012 mg/kg wet wt.	4.4×10^{-4}
Soil	1.0×10^{-3} mg/kg wet wt.	0.083

Site II – Reactive flame retardant use

Koc = 49,726 l/kg

	PEC	**PEC/PNEC**
Surface water	1.8×10^{-3} µg/l	1.4×10^{-3}
Sediment	2.8×10^{-3} mg/kg wet wt.	1.0×10^{-3}
Soil	2.6×10^{-4} mg/kg wet wt.	0.022

Koc = 147,360 l/kg

	PEC	**PEC/PNEC**
Surface water	1.6×10^{-3} µg/l	1.2×10^{-3}
Sediment	5.0×10^{-3} mg/kg wet wt.	1.9×10^{-3}
Soil	1.0×10^{-3} mg/kg wet wt.	0.083

Site III – Additive flame retardant use

Koc = 49,726 l/kg

	PEC	**PEC/PNEC**
Surface water	9.3 µg/l	6.9
Sediment	14.8 mg/kg wet wt.	5.5
Soil	0.036 mg/kg wet wt.	3.0

Koc = 147,360 l/kg

	PEC	PEC/PNEC
Surface water	8.5 µg/l	6.5
Sediment	27.1 mg/kg wet wt.	10.0
Soil	0.039 mg/kg wet wt.	3.3

Thus for this site, a risk to surface water, sediment and soil can be deduced. The risk to soil is predicted to arise from atmospheric deposition from emissions to air at the site.

It should be noted that the representivity of the monitoring data for this site to other sites in the EU is unknown. However, the conclusions reached here based on the site specific information are similar to those reached using the generic scenario in the main risk assessment report.

It has been confirmed that none of the ABS compounding sites are located close to the sea, and so a marine risk assessment is not considered necessary for this scenario.

Further information has been provided on the disposal of sludge generated at ABS compounding sites. All customers of the three EU suppliers were contacted. In one case sludge was generated but was treated as chemical waste and not applied to land. In all other cases the processes used are non-aqueous and therefore there is no opportunity for the tetrabromobisphenol-A to come into contact with water discharged into the sewage system and hence sewage sludge. Therefore it is unlikely that sewage sludge containing tetrabromobisphenol-A is applied to agricultural land from such sites.

The report provides the comprehensive risk assessment of the substance 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol.

It has been prepared by theUnited Kingdom in the frame of Council Regulation (EEC) No. 793/93 on the evaluation and control of the risks of existing substances, following the principles for assessment of the risks to humans and the environment, laid down in Commission Regulation (EC) No. 1488/94.

Part I – Environment

This part of the evaluation considers the emissions and the resulting exposure to the environment in all life cycle steps. Following the exposure assessment, the environmental risk characterisation for each protection goal in the aquatic, terrestrial and atmospheric compartment has been determined.

The environmental risk assessment concludes that there is a need for limiting the risks for the surface water and sediment compartments in case when the evaluated substance is used as an additive flame retardant in ABS.
There is a need for better information to adequately characterise the risks for the marine ecosystems and to verify degradation possibilities and characteristics of formed metabolites.
There is at present no concern for the atmosphere, for macro-organisms in the sewage treatment plant and for the top predators via accumulation up the food chain (secondary poisoning).

Part II – Human Health

This part of the evaluation is published in a separate document.

The conclusions of this report will lead to risk reduction measures to be proposed by the Commission's committee on risk reduction strategies set up in support of Council Regulation (EEC) N. 793/93.