



**Stockholm Convention  
on Persistent Organic  
Pollutants**

---

**Persistent Organic Pollutants Review Committee**  
**Tenth meeting**  
Rome, 27–30 October 2014

**Report of the Persistent Organic Pollutants Review Committee  
on the work of its tenth meeting**

**Addendum**

**Risk profile on decabromodiphenyl ether (commercial mixture, c-decaBDE)**

At its tenth meeting, by its decision POPRC-10/2, the Persistent Organic Pollutants Review Committee adopted a risk profile for decabromodiphenyl ether (commercial mixture, c-decaBDE) on the basis of the draft contained in the note by the secretariat (UNEP/POPS/POPRC.10/3). The text of the risk profile, as amended, is set out in the annex to the present addendum. It has not been formally edited.

**Annex**

**DECABROMODIPHENYL ETHER**

**(commercial mixture, c-decaBDE)**

**RISK PROFILE**

Prepared by the ad hoc working group on decabromodiphenyl ether  
Persistent Organic Pollutants Review Committee

October 2014

**Table of Contents**

Executive summary.....	4
1. Introduction.....	6
1.1 Chemical identity of the proposed substance .....	6
1.2 Conclusion of the Review Committee regarding Annex D information.....	7
1.3 Data sources .....	7
1.4 Status of the chemical under other international conventions and forums .....	7
2. Summary information relevant to the risk profile.....	8
2.1 Sources .....	8
2.1.1 Production, trade, stockpiles .....	8
2.1.2 Uses.....	9
2.1.3 Releases to the environment.....	9
2.2 Environmental fate .....	11
2.2.1 Persistence.....	11
2.2.2 Degradation and debromination .....	12
2.2.3 Bioavailability and tissue distribution.....	14
2.2.4 Bioaccumulation .....	14
2.2.5 Potential for long-range environmental transport.....	17
2.3 Exposure.....	18
2.3.1 Environmental levels and trends .....	18
2.3.2 Human exposure.....	20
2.4 Hazard assessment for endpoints of concern.....	21
2.4.1 Toxicity to aquatic organisms .....	22
2.4.2 Toxicity in soil organisms and plants.....	23
2.4.3 Toxicity in birds .....	24
2.4.4 Toxicity in terrestrial mammals .....	25
2.4.5 Human toxicity.....	27
2.4.6 Mixture toxicity and combined effects of multiple stressors.....	27
3. Synthesis of information.....	28
4. Concluding statement.....	31
References.....	32

## Executive summary

1. Commercially available decabromodiphenyl ether (c-decaBDE) is a polybrominated diphenyl ether (PBDE) formulation consisting of decabromodiphenyl ether (BDE-209), with small amounts of nonabromodiphenyl ether and octabromodiphenyl ether. C-decaBDE has been under investigation for its potential health and environmental impacts for more than a decade and has been subject to restrictions and voluntary risk management actions in some countries and regions.
2. C-decaBDE consumption peaked in the early 2000's, but c-decaBDE is still used worldwide. C-decaBDE is used as an additive flame retardant, and has a variety of applications including in plastics/ polymers/composites, textiles, adhesives, sealants, coatings and inks. C-decaBDE containing plastics are used in housings of computers and TVs, wires and cables, pipes and carpets. It is used in commercial textiles, mainly for public buildings and transport, and in textiles for domestic furnitures. Emissions of c-decaBDE to the environment occur at all its life cycle stages, but are assumed to be highest during service-life and in the waste phase. Emissions from industrial point sources can also be significant. Use of c-decaBDE in the production of textiles and electronics lead to emissions to the environment and transboundary air pollution either directly from articles or during production and disposal.
3. BDE-209 has low water solubility ( $< 0.1 \mu\text{g/L}$  at  $24^\circ\text{C}$ ) and in the environment it adsorbs strongly to organic matter and readily partitions to sediment and soil. It is very persistent and reported environmental half-lives in these media typically exceed 180 days.
4. BDE-209 is widespread and one of the most prevalent PBDEs in the global environment. When BDE-209 is detected in the environment and biota, it is typically found along with other PBDEs. Monitoring data show high concentrations of BDE-209 in sediments and soil, but is also found in biota worldwide, with high levels reported in some species. Levels are generally highest in the urban regions, near waste water discharges and in areas around electronic waste and recycling plants. In air, BDE-209 binds to particles that protect the chemical from photolytic degradation and it can be transported over long distances. The estimated atmospheric half-life is 94 days, but can exceed 200 days. BDE-209 is also detected in environmental and biological samples from remote regions and is one of the predominant PBDEs in Arctic air and deposition samples. Temporal trend data of BDE-209 in Arctic air and some Arctic organisms for 2002-2005 showed increasing levels, but levels may now be stabilizing.
5. BDE-209 has limited bioavailability because of its large size that constrains its ability to pass cell membranes via passive diffusion. However, biomonitoring data shows that BDE-209 is bioavailable and is taken up by humans and other organisms. BDE-209 has been found in a variety of different organisms and biological matrices including human blood serum, cord blood, placenta, fetus, breast milk and in milk of lactating cows. In some species reported levels are close to reported adverse effect concentrations. In rodents and birds, small amounts of BDE-209 are shown to cross the blood-brain barrier and enter the brain. There is also evidence of transfer of BDE-209 from adult stages to eggs in fish and birds and of effective transport through the placenta to foetus in mammals. For humans, the available intake estimates for BDE-209 also point out the importance of dust exposure, particularly for small children. Higher levels of PBDEs and BDE-209 are reported in toddlers and young children than in adults. In aquatic organisms intake via diet appears to be the most important exposure route.
6. Several lines of evidence show that BDE-209 is bioaccumulative, at least in some species. The equivocation in the available bioaccumulation data largely reflects species and tissue differences in uptake, metabolism and elimination, as well as differences in exposure and also analytical challenges in measuring BDE-209.
7. Debromination of BDE-209 in environmental matrices and biota to more persistent, toxic and bioaccumulative PBDEs including those already listed under the Stockholm Convention (POP-BDEs) is considered to be of concern in a number of assessments. Several PBDE congeners that are not part of any commercial mixture have been identified mainly in biota but also in the environment and are considered to provide evidence for debromination of BDE-209. Due to debromination of c-decaBDE and past releases of commercial penta- and octabromodiphenyl ether organisms are often exposed to a multitude of PBDEs.
8. BDE-209 toxicity studies provide evidence for potential adverse effects to reproductive health and output in a number of species as well as developmental and neurotoxic effects. BDE-209 and/or its degradation products may also act as endocrine disruptors and affect thyroid hormone homeostasis. On the basis of common modes of action (not fully established) and common adverse outcomes, there is concern that BDE-209 and other PBDEs may act in combination, in an additive or synergistic manner and induce developmental neurotoxicity in both humans and wildlife at environmentally relevant concentrations. Observed effect concentrations for increased mortality in birds and developmental

effects in frogs derived from controlled laboratory studies raise concern that adverse effects may occur at environmentally realistic concentrations.

9. The high persistence of BDE-209 combined with the simultaneous exposure of organisms to a wide range of PBDEs and the fact that endocrine disruptors like BDE-209 and/or its degradation products may elicit adverse effects even at low environmental levels increase the likelihood for long-term adverse effects.

10. Based on the available evidence it is concluded that c-decaBDE with its main constituent BDE-209, is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted.

## 1. Introduction

11. On 13 May 2013, Norway as a Party to the Stockholm Convention, submitted a proposal to list decabromodiphenyl ether (commercial mixture, c-decaBDE) in Annexes A, B and/or C to the Convention. The proposal (UNEP/POPS/POPRC.9/2) was submitted in accordance with Article 8 of the Convention and was reviewed by the POPs Review Committee (POPRC) at its ninth meeting in October 2013.

12. In the present document the abbreviation c-decaBDE is used for technical or commercial decabromodiphenyl ether (BDE-209) refers to the single fully brominated PBDE, which elsewhere sometimes is also denoted as decaBDE.

### 1.1 Chemical identity of the proposed substance

13. The risk profile concerns c-decaBDE and its degradation products, in accordance with Annex E of the Convention. C-decaBDE is a commercial PBDE formulation that is widely used as an additive flame retardant in textiles and plastics, additional uses are in adhesives and in coatings and inks (ECHA 2013b). C-decaBDE consist predominantly of the congener BDE-209 ( $\geq 97\%$ ), with low levels of other brominated diphenyl ether congeners such as nonabromodiphenyl ether (0.3-3%) and octabromodiphenyl ether (0-0.04%). Chen (2007a) reported that the octaBDE and nonaBDE content of two c-decaBDE products from China was in the range 8.2 to 10.4% suggesting that a higher degree of impurities may be found in some commercial mixtures. Historically a range of 77.4-98% of decaBDE, and smaller amounts of the congeners of nonaBDE (0.3-21.8 %) and octaBDE (0-0.85%) has been reported (ECHA 2012a, US EPA 2008, RPA 2014). Total tri-, tetra-, penta-, hexa- and heptaBDEs are typically present at concentrations below 0.0039% w/w (ECB 2002, ECHA 2012a). Trace amounts of other compounds, thought to be hydroxybrominated diphenyl compounds can also be present as impurities. In addition, polybrominated dibenzo-p-dioxins and polybrominated dibenzofurans (PBDD/Fs) have been reported as impurities in some c-decaBDE products (Ren 2011).

14. According to available information c-decaBDE is currently available from several producers and suppliers globally (Ren 2013a, RPA 2014) and is being marketed under different tradenames (Table 1).

15. Chemical data on the main component of c-decaBDE, BDE-209, are presented in Figure 1 and in Tables 1 and 2 below (ECHA 2012a). Like other PBDEs, BDE-209 shares structural similarities with PCBs. Chemical data on octa- and nonaBDE, which are minor constituents of commercial c-decaBDE, are provided along with other supplementary information in a supporting document for the risk profile (UNEP/POPS/POPRC.10/INF5). Information on c-decaBDE degradation products are provided in chapter 2.2.2 and in UNEP/POPS/POPRC.10/INF5.

Figure 1. Structural formula

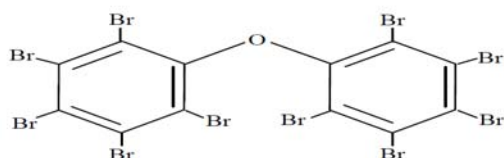


Table 1. Chemical identity of c-decaBDE and its main constituent BDE-209

CAS number:	1163-19-5 <sup>1</sup>
CAS name:	Benzene, 1,1'-oxybis[2,3,4,5,6-pentabromo-]
IUPAC name:	2,3,4,5,6-Pentabromo-1-(2,3,4,5,6-pentabromophenoxy)benzene
EC number:	214-604-9
EC name:	Bis(pentabromophenyl) ether
Molecular formula:	C <sub>12</sub> Br <sub>10</sub> O
Molecular weight:	959.2 g/mole
Synonyms:	decabromodiphenyl ether, decabromodiphenyl oxide, bis(pentabromophenyl) oxide, decabromo biphenyl oxide, decabromo phenoxybenzene, benzene 1,1' oxybis-, decabromo derivative, decaBDE, DBDPE <sup>2</sup> , DBBE, DBBO, DBDPO
Trade names	DE-83R, DE-83, Bromkal 82-ODE, Bromkal 70-5, Saytex 102 E, FR1210, Flamecut 110R, FR-300-BA, which was produced in the 1970s, is no longer commercially available (ECA, 2010).

<sup>1</sup>In the past CAS no. 109945-70-2, 145538-74-5 and 1201677-32-8 were also used. These CAS no. have now formally been deleted, but may still be in practical use by some suppliers and manufacturers.

<sup>2</sup>DBDPE is also used as an abbreviation for Decabromodiphenyl Ethane CAS no. 84852-53-9.

**Table 2.** Overview of relevant physicochemical properties of c-decaBDE and its main constituent BDE-209

Property	Value	Reference
Physical state at 20°C and 101.3 kPa	Fine, white to off-white crystalline powder	ECB (2002)
Melting/freezing point	300-310°C	Dead Sea Bromine Group (1993), cited in ECB (2002)
Boiling point	Decomposes at >320°C	Dead Sea Bromine Group (1993), cited in ECB (2002)
Vapour pressure	4.63×10 <sup>-6</sup> Pa at 21°C	Wildlife International Ltd (1997), cited in ECB (2002)
Water solubility	<0.1 µg/L at 25°C (column elution method)	Stenzel and Markley (1997), cited in ECB (2002)
n-Octanol/water partition coefficient, K <sub>ow</sub> (log value)	6.27 (measured – generator column method) 9.97 (estimated using an HPLC method)	MacGregor and Nixon (1997), Watanabe and Tatsukawa (1990), respectively, cited in ECB (2002)
Octanol-air partition coefficient K <sub>oa</sub> (log value)	13.1	Kelly (2007)

## 1.2 Conclusion of the Review Committee regarding Annex D information

16. The POPs Review Committee examined the proposal by Norway to list c-decaBDE under the Stockholm Convention on Persistent Organic Pollutants as well as additional scientific information provided by members and observers at its ninth meeting and concluded that decabromodiphenyl ether met the screening criteria specified in Annex D (decision POPRC-9/4).

## 1.3 Data sources

17. The risk profile is not an exhaustive review of all available data, but rather, it presents the most critical studies and lines of evidence with relevance to the criteria in Annex E and Annex D of the Convention. It centres on the main constituent of c-decaBDE, BDE-209, and its degradation products, in particular lower brominated PBDEs which are formed via abiotic and biotic degradation (described in 2.2.2). As several of the lower brominated PBDE degradation products are widely recognized as Persistent, Bioaccumulative and Toxic/very Persistent, very Bioaccumulative PBT/vPvB substances and/or POPs a re-assessment of the properties of these compounds were considered redundant (POPRC 2006, POPRC 2007, ECHA 2013a,b, ECA 2010, Table 3.2-3.4, UNEP/POPS/POPRC.10/INF5). However, the potential for mixture toxicity between BDE-209 and other PBDEs is discussed in chapter 2.4.6.

18. The risk profile was developed using the Annex D information submitted by Norway in 2013 and Annex E information submitted by parties and other stakeholders including non-governmental organizations as well as industry. The following parties and observers submitted information under the Annex E process: Argentina, Austria, Bulgaria, Canada, China, Croatia, Denmark, Germany, Japan, Mexico, Morocco, Nepal, Netherlands, New Zealand, Serbia, Sweden, USA, Bromine Science and Environmental Forum (BSEF) and International POPs Elimination Network (IPEN) together with Inuit Circumpolar Council. All Annex E submissions are available on the Convention website ([www.pops.int](http://www.pops.int)).

19. Updated scientific literature obtained from scientific databases such as ISI Web of Science and PubMed was assessed as well as "grey" literature such as government reports, risk- and hazard assessments, industry fact sheets etc. To provide the best possible overview of the existing data/literature which covers more than 984 reports and peer-reviewed scientific publications (Kortenkamp 2014), an emphasis was put on providing excerpts of existing risk assessments and reports when such information was available as well as more detailed descriptions of newer literature.

20. In the past, assessments of c-decaBDE and its main constituent BDE-209 were conducted and published by the EU, Canada, the United Kingdom and the United States (ECB 2002 2004, ECHA 2012a, ECA 2006, 2010, UK EA 2009, US EPA 2008). Status of the chemical under other international conventions and forums

21. C-decaBDE has been under scrutiny for its potential health and environmental impacts for more than a decade. Steps to restrict the use of c-decaBDE have been taken in several countries and regions, as well as by some of the major electronic companies (for an overview: UNEP/POPS/POPRC.9/2, Ren 2011).

22. In 1992, c-decaBDE and other brominated flame retardants (BFRs) were given priority in the OSPAR action plan and in 1998 BDE-209 along with the other PBDEs was included in the list of

"Chemicals for Priority Action" as well in the Joint Assessment and Monitoring Programme in OSPAR. OSPAR has promoted actions in the EU on risk-reduction strategies for c-decaBDE and electronic waste legislation.

23. In 1995, OECD Member countries agreed to oversee a voluntary industry commitment (VIC) by some of the global manufacturers of BFRs, among them c-decaBDE, to take certain risk management actions. The VIC was implemented in the United States, Europe and Japan. C-decaBDE production has since ceased in Europe and continues to be phased out in the United States (see Section 2.1.1 below). In Japan, compliance with the VIC is on-going. In parallel to this work, OECD conducted an investigation of the waste management practices in member countries with respect to products containing BFRs. The results of this investigation are documented in the Report on the Incineration of Products Containing Brominated Flame Retardants (OECD 1998). A SIDS Initial Assessment Profile (SIAP) on BDE-209 was prepared under the Environment, Health and Safety (EHS) Programme of the OECD and adopted by SIAM 16 and later endorsed by the OECD Joint Meeting in 2003. The Hazard/Risk Information Sheets for c-decaBDE and four other BFRs were updated in 2005, 2008 and 2009 (OECD 2014). PBDEs, including BDE-209, are listed as chemicals of concern in the WHO/UNEP "State of the science of endocrine disrupting chemicals" (UNEP/WHO 2013). In the EU, c-decaBDE is included in the Candidate List of Substances of Very High Concern for Authorisation under the REACH Regulation (EC) 1907/2006 based on its PBT and vPvB properties, high volumes and wide dispersive uses.

## 2. Summary information relevant to the risk profile

### 2.1 Sources

#### 2.1.1 Production, trade, stockpiles

24. Global industrial c-decaBDE consumption peaked in the early 2000's (Earnshaw 2013). Yet, due to limited regulatory restrictions, c-decaBDE is still used worldwide (Table 2.1-2.3, UNEP/POPS/POPRC.10/INF5). Past, production data indicate that about 75% of all the world production of PBDEs was c-decaBDE (RPA 2014). Total production of c-decaBDE in the period 1970-2005 was between 1.1-1.25 million tonnes, similar to the scale of production of PCBs (POPRC 2010c, Breivik 2002). Globally, the total market demand for c-decaBDE differs considerably between countries and continents (Table 2.2 and 2.3, UNEP/POPS/POPRC.10/INF5).

25. The overall scale of c-decaBDE production today is currently unknown, and data on production, trade and stockpiles is only available for some countries. There is also very little information on the tonnages that may be imported in mixtures (chemical formulations, also resins, polymers and other substrates) and articles (either in semi-finished articles, materials or components, or in finished products). Production facilities for BFRs exist in all global regions (e.g. ACAP 2007, RPA 2014, Annex E IPEN). At present it is unknown how many of these produce c-decaBDE. Among the main BFR producing countries China and India are known to produce and export c-decaBDE (Xiang 2007, Chen 2007b, Xia 2005, Zou 2007, Annex E IPEN and China). Japan produces c-decaBDE, but consumes all domestically (Annex E Japan). Production of c-decaBDE no longer takes place in the EU or Canada and continues to be phased out in the United States (ECB 2002, ECHA 2012a,b, ECA 2008, US EPA 2012).

26. At present, China is the largest producer and supplier of c-decaBDE with an annual production of around 21,000 tonnes (Ni 2013). Around 20 different Chinese companies claim to be suppliers of c-decaBDE (Annex E IPEN). Japan produces an estimated 600 metric tonnes of c-decaBDE per year (Annex E Japan), and there are currently two Japanese producers (Annex E IPEN). In 2002, the demand for c-decaBDE in Japan was 2200 tonnes/year and the stock level was about 60,000 tonnes (Sakai 2006). In 2013, the c-decaBDE import to Japan was 1,000 tonnes adding to a total consumption of 1,600 assuming that no exports occurred. India has six manufacturers and or suppliers (Annex E IPEN), but total production is unknown. In Europe, production of c-decaBDE ceased in 1999, but c-decaBDE is still imported in considerable quantities (ECB 2002, ECHA 2012a, c, RPA 2014 (in press)). In the United States the main producers and importers committed to end all uses by the end of 2013. In 2012 the national production volume which includes both domestic production and import was 8215 tonnes/year. In Canada manufacture of octa-, nona- and decaBDE was banned in 2008 and, the three main manufacturers have committed to voluntarily phase-out all exports to Canada by 2013 (ECA 2008, 2013).

27. Besides any stocks of pure c-decaBDE, substantial stocks of c-decaBDE are also present in treated articles in the technosphere (UK EA 2009, Sakai. 2006).



### 2.1.2 Uses

28. C-decaBDE is a general purpose additive flame retardant, that is physically combined with the material in which it is used to inhibit the ignition and slow the rate at which flames spread. It is compatible with a wide variety of materials. Applications include plastics/polymers/composites, textiles, adhesives, sealants, coatings and inks (e.g. ECHA 2012c, 2013a, RPA 2014 (in press), Sakai 2006, Table 2.4, UNEP/POPS/POPRC.10/INF5).
29. End uses in plastics/ polymers include housings of computers and TV sets, wires and cables, pipes and carpets (BSEF 2013, US EPA 2014, Table 2.5, UNEP/POPS/POPRC.10/INF5). Typically c-decaBDE is used in plastics/polymers at loadings of 10-15% by weight, though in some cases loadings as high as 20% have been reported (ECHA 2012c). In a Japanese study, c-decaBDE is reported to account for about 98% of the bromine content found in plastic parts of older TVs (Tasaki 2004). BDE-209 is also found in products made from recycled plastics, including food contact materials (Samsonik and Puype, 2013).
30. In the textile sector, c-decaBDE can be used to treat a wide range of synthetic, blended and natural fibres (ECHA 2013a). Main end uses are upholstery, window blinds, curtains, mattress textiles, tentage (e.g. military tents and textiles, also commercial marquees, tents and canvasses) and transportation (e.g. interior fabrics in cars, rail passenger rolling stock and aircraft). The most common method of applying flame retardants to textiles is back coating. The amount that is applied will usually be in the range 7.5-20%. Padding processes and printing processes may also be used to apply flame retardant treatments (ECHA 2012a,c).
31. Information from public consultations in Europe report that c-decaBDE can be used in adhesives in the aeronautic sector for civil and defense applications (ECHA 2012d). Norwegian Authorities also identified uses of c-decaBDE in the adhesive layer of reflective tapes on work wear which are used as fire fighter uniforms, by the staff at oil platforms, in the energy sector, etc (CPAN 2012a). The reflective tapes contained c-decaBDE in the range 1-5% (by weight of reflective material). Other uses can be coatings used in applications for the building and construction sector and in inks (RPA 2014 (in press)).
32. According to VECAP data, textiles and plastics account for 52% and 48% of the c-decaBDE volume sold in Europe, respectively (VECAP 2012). In Japan 60% of the c-decaBDE is used in vehicle seats, 19% in construction materials and 15% in textiles. The remaining 6% is used for other purposes. In Switzerland 45% of c-decaBDE consumed were in electrical and electronic (EE) products, 30% was in imported motor vehicles and 25% in construction material (Buser 2007b). The consumption of c-decaBDE in the United States could be broken down as follows (excluding import in articles): automotive and transportation 26%, building and construction 26%, textiles 26%, electrical and electronic equipment (EEE) 13% and others 9% (Levchick 2010).

### 2.1.3 Releases to the environment

33. As an additive flame retardant, c-decaBDE is not chemically bound to the product or the material in which it is used. It therefore has the potential to 'leak' to the surrounding environment. Emissions of c-decaBDE to the environment may occur at all its life cycle stages, e.g. during production, formulation and other first- and second-line uses at industrial/professional sites, as well as during service life of articles, their disposal as waste and during recycling operations (ECHA 2012c, Ren 2014, Gao 2013, VECAP 2010a,b, 2014). The release and distribution of c-decaBDE to the environment via these routes is confirmed by monitoring data (see Section 2.3.1-2.3.4), and are likely to occur over a long time frame.
34. As a general purpose flame retardant c-decaBDE is used and released to the surrounding environment at many industrial and professional sites (e.g. VECAP 2012, 2014, Li 2013, Gao 2011, Odabasi 2009). In the EU alone there are more than 100 sites of second-line use (compounders/formulators, master batchers, injection moulders and finishers) (ECHA 2012a). Globally there are additional point sources (Annex E IPEN) contributing to the emissions of c-decaBDE including production sites for c-decaBDE as well as other industrial sources such as second-line users, recycling facilities and steel-production plants as well as other metallurgical facilities (e.g. Odabasi 2009, Wang 2010d, Lin 2012, Ren 2014, Gao 2011, Tang 2014). Elevated BDE-209 levels have been measured in the vicinity of industrial facilities (e.g. Zhang 2013d, Wang 2011d), and although VECAP estimates suggests otherwise (VECAP 2010a,b, 2012, 2014), the releases from industrial point sources to the surrounding environment can be considerable (ACAP 2007). For example, in 2003 the production of c-decaBDE in the United States released as much as 31 tonnes of c-decaBDE to the atmosphere alone (ACAP 2007).

35. Emissions of c-decaBDE during the service life and upon disposal of products are considered to be substantial. In the recent EU assessment it was found that service life is the main source of release, followed by production of articles and waste stage (RPA 2014). An earlier assessment by the UK Environment Agency indicated that the main source of emissions were from landfill and waste incineration, followed by releases of waste water and releases to air from articles during service-life. Polymers and textiles in articles and waste were the main contributors (UK EA 2009). Similar findings are reported also by others (ECHA 2012c, ACAP 2007, Sakai 2006, OSPAR 2009). In addition, recycling can also be an important source of environmental releases of BDE-209 (Yu 2008, Gao 2011, Tang 2014 and references therein).

36. Controlled product testing has indicated low or no emission of BDE-209 from synthetic, vulcanised rubber products (Kemmllein 2003). However, BDE-209 has been shown to be emitted to the surrounding environment from textiles and TV-casings (Kemmllein 2006, Kajiwara 2013a). Higher levels of BDE-209 are moreover typically reported in indoor environments with many c-decaBDE containing products such as office environments, airplane interiors etc. (Björklund 2012, Allen 2013). BDE-209 is also reported to be the most prevalent PBDE congener in house dust and indoor air (e.g. Harrad 2010, Fredriksen 2009a, Besis and Samara 2012, Fromme 2009, Coakley 2013, EFSA 2011). BDE-209 in indoor environments is also a significant source to BDE-209 pollution in urban outdoor air (Björklund 2012, Cousins 2014), and to human exposure (see Section 2.3.4). Based on measurements in sewage sludge the estimated releases of BDE-209 from the technosphere, in Europe, are  $16 \pm 8.6$  tonnes annually and  $41 \pm 22$  mg annually per person or 0.2% of annual c-decaBDE usage in Europe (Ricklund 2008). Hence, use of c-decaBDE in the production of textiles and electronics result in environmental releases of BDE-209 and other PBDEs, either during production or directly from articles or during disposal stage (RPA 2014 (in press), VECAP 2010) and thus contribute to environmental releases and transboundary air pollution. Physical abrasion, disintegration and weathering as well as photolysis, increased temperatures and thermal stress are all factors that contribute to release of c-decaBDE and lower brominated PBDEs from products (Earnshaw 2013, Chen 2013, Kajiwara 2008, 2013 a, b).

37. PBDEs are not removed during waste-water treatment (Danon-Schaffer 2007, Kim 2013b) and a substantial amount of c-decaBDE emitted from products during service life and as waste ends up in waste-water treatment plants (WWTP) through the disposal of wash water from contaminated indoor dust, leachate from landfilled PBDE-containing products and discharge from industrial sites processing PBDE containing material, and ultimately biosolids (Kim 2013a,b). In line with this, elevated levels of BDE-209 is reported in sediment near the outflow of WWTP and sludge (biosoil) is found to be an important pathway for BDE-209 emissions to soil when applied as an agricultural fertilizer (Sellström 2005, de Wit 2005).

38. Emission estimates are available for some countries (e.g. ECB 2002, Morf 2003, 2007, 2008, Palm 2002, Sakai 2006 as cited in Earnshaw 2013, Buser 2007a). A comparison of available European estimates shows large differences in predicted environmental emissions of BDE-209 to all environmental compartments and for air in particular (three orders of magnitude, Earnshaw 2013). The dissimilarities likely reflect country specific differences in production, use and waste disposal as well as uncertainties/ differences in emission estimates and overall suggest that release estimates should be viewed in light of environmental monitoring data.

39. With regards to time-trends, emission estimates for the period 1970 to 2020 calculated by Earnshaw (2013) using a dynamic substance flow analysis model and available consumption data indicate that BDE-209 atmospheric emissions in Europe increased steadily from the 1970s and reached a peak in 2004 at 10 tonnes/ year. Emissions to soil and the hydrosphere are lower but follow a similar trend of increase from the 1970s, peaking in the late 2000s and declining thereafter. Emissions to soil peaked at 4 tonnes/year in 2000 whilst those to the hydrosphere peaked in the 2010s at 3.5 tonnes/ year. In Switzerland maximum emissions is estimated to have occurred in the 1990's (Buser 2007b, Morf 2007). 31 tonnes of BDE-209 were released to air in 2003 alone according to the US EPA Toxic Release Inventory (TRI) Public Data Release (ACAP 2007), in 2011 the release to air was down to 3.1 tonnes (<http://www.epa.gov/tri/>).

40. Further information on potential emission sources and environmental levels resulting from releases of c-decaBDE to the environment is provided in Section 2.3.1. In general, as indicated by measured environmental levels, releases to the environment are higher in industrialized and urban areas than in rural and agricultural areas where there are fewer sources (see Section 2.3.1). Environmental levels are typically lowest in remote regions, such as the Arctic.

## 2.2 Environmental fate

41. The environmental fate properties of BDE-209 have been assessed in various reports published by the EU, Canada and the United Kingdom (ECB 2002, 2004, ECHA 2012a, ECA 2006, 2010, UK EA 2009). Fugacity modeling predicts that most of the BDE-209 (> 96%) in the environment partitions to sediment and soil (ECA 2010, ECHA 2013a). Less than 3.4% of BDE-209 is expected to be associated with bulk air or bulk water phases. Due to its intrinsic properties i.e. an organic carbon-water partition coefficient ( $K_{oc}$ ) in the range 150,900 to 149,000,000L/kg, BDE-209 is known to adsorb strongly to organic matter in suspended particles, sewage sludge, sediment and soil (ECHA 2013a). Given its low water solubility and strong particle affinity, its mobility in soils is also likely to be low (ECHA 2013a). Consequently, transfer to other environmental compartments, by soil erosion and run-off, will depend on particle bounded transport. In the environment BDE-209 is persistent and elevated levels is found in soil and sediments.

42. BDE-209 is also found to be a major PBDE congener in snow and ice in the Arctic (Hermanson 2010, Meyer 2012), showing that the detected air levels at lower latitudes contributes to long-range transport and pollution in remote areas. BDE-209 is also found in biota, sometimes at high levels, where it along with other PBDEs bioaccumulates and biomagnifies via the food chain (see Sections 2.2.4, 2.3.1. and 2.3.2). As further discussed in chapters 2.2.2 and 2.4.6 debromination of BDE-209 to lower brominated PBDEs in environmental matrices and biota has important implications for the risk from c-decaBDE imposed to the environment, due to the PBT, vPvB and POP properties of its metabolites.

### 2.2.1 Persistence

43. Photodegradation and biodegradation are the main mechanisms for transformation of BDE-209 in the environment (ECA 2006, 2010). Due to the lack of any functional groups that are readily susceptible to hydrolysis and a very low water solubility of BDE-209, < 0.1 µg/L at 25 °C (Stenzel and Markley 1997), hydrolysis is unlikely to be a relevant degradation process in the environment (ECHA 2012a). Photodegradation might, however, be a contributing factor for BDE-209 degradation in air and topsoil (see Section 2.2.2). Yet, in the atmospheric compartment, BDE-209 will almost exclusively be adsorbed to air-particles. As air-particles protect the BDE-209 molecule, degradation in air via photolysis is not substantial (see Section 2.2.2).

44. High persistency of BDE-209 in soil, sediment and air is demonstrated in several studies and appears to be dependent on slow biodegradation processes and the degree of exposure to light (ECHA 2012a, ECA 2010). The type of particle to which BDE-209 is bound may also influence the degradation rate. For example, studies of photolytic degradation on various solid matrices has revealed half-lives of 36 and 44 days for BDE-209 adsorbed to montmorillonite or kaolinite, respectively, with much slower degradation occurring when sorbed on organic carbon-rich natural sediment ( $t_{1/2} = 150$  days) (Ahn 2006). Half-life in sand was found to be only 35-37 hours while the corresponding half-lives in sediment and soil were estimated to be 100 and 200 hours, respectively (Söderström 2004 and Tysklind 2001 as cited in ECHA 2012a). In natural waters the presence of other organic substances such as humic substances can limit photodegradation by absorbing light or by hydrophobic interactions with the BDE-209 molecule (Leal 2013). Similarly, it has been shown that sand particles coated with humic acid may decrease degradation rates of BDE-209 when irradiated with UV light (Hua 2003). In addition the nature of dissolved organic matter, the amount of suspended particulates, the adsorption of BDE-209 to solid surfaces and the depth are of importance (Leal 2013). Increased adsorption to the soil or sediment matrix with ageing is an additional factor can contribute to longer environmental half-lives under natural conditions (ECHA 2013a).

45. Under conditions (e.g. deep sea sediments) where light attenuation and matrix shielding would affect overall exposure to sunlight and potential for photodegradation, the persistency of BDE-209 appears to be high (ECHA 2012a and references therein). Estimations of half-lives in water are generally complicated by the poor water solubility of BDE-209 and are highly dependent on the experimental conditions. Yet, when correcting for the use of solvents and taking into account natural light conditions, environmental half-lives ranging from a few hours up to 660 days in water have recently been suggested (Kuivikko 2007 in Leal 2013). The longest environmental half-life is reported by Tokarz (2008), who by conducting a laboratory microcosm experiment over a period of 3.5 years at 22°C under dark conditions found the half-life of BDE-209 in sediment to range between 6 and 50 years, with an average of around 14 years. The long half-lives found by Tokarz are underpinned by monitoring in the field. Kohler (2008) investigated concentrations and temporal trends of BDE-209 in the sediments of a small lake located in an urban area in Switzerland. BDE-209 first appeared in sediment layers corresponding to the mid 1970s and the levels increased steadily to 7.4 ng/g dry weight (dw) in 2001 with a doubling time of about 9 years. No evidence for sediment-related long-term transformation processes was found in this study covering almost 30 years.

46. Further evidence for the persistency of BDE-209 is provided by studies on sludge and soil. Liu (2011a) observed no degradation of BDE-209 after 180 days in soil samples spiked with BDE-209 in darkness. In another study on sludge-amended soil, the extrapolated primary degradation half-life under both aerobic and anaerobic conditions was found to be >360 days assuming exponential decay (Nyholm 2010, 2011, as cited in ECHA 2012a). In a controlled laboratory experiment at 37 °C under dark anaerobic conditions using digested sewage sludge spiked with BDE-209, the concentration of BDE-209 decreased by only 30% during the incubation time of 238 days (Gerecke 2005). These results are further strengthened by field studies. Eljarrat (2008) examined the fate of PBDEs in sewage sludge from five municipal WWTPs after agricultural application of sludge to the topsoil at six sludge application sites and one reference site. According to the authors, BDE-209 concentrations in soil remained high (71.7 ng/g dw) even at one site that had not received sludge applications for four years, illustrating the persistency of BDE-209 in soils. Similarly, Sellström (2005) measured PBDE levels in agricultural soil from sites that had received past sewage sludge amendments and found that levels in a farm soil between 0.015 to 22,000 ng/g dw even though contaminated sewage sludge had not been applied to the soil for many years. The highest levels were detected at a farm site that had not received amendments for 20 years.

### 2.2.2 Degradation and debromination

47. In spite of BDE-209's persistence and long environmental half-lives in sediment, soil and air, there is considerable evidence that BDE-209 is debrominated to lower brominated PBDEs in the abiotic environment, as well as in biota (ECHA 2012a,c, 2013a,b UK EA 2009, ECA 2010, POPRC 2010c, 2013a, NCP 2013). Observed debromination products detected range from mono- to nonaBDEs, and include listed POPs such as tetra- to heptaBDE and bromophenols, as well as recognized PBT/ vPvB substances such as brominated dioxins and furans (PBDD/ PBDF) and hexabromobenzene (Christiansson 2009, UK EA 2009, ECHA 2012a,c, ECA 2010, see Tables 3.1 to 3.4 UNEP/POPS/POPRC.10/INF5). The biotransformation of BDE-209 in biota, in particular, is considered to be of concern in a number of recent reports and published studies (ACHS 2010, ECHA 2012a,c, EFSA 2011, ECA 2010, POPRC 2010a,b,c, Ross 2009, McKinney 2011a).

48. Abiotic degradation studies have shown the formation of nona- to triBDEs (reviewed in ECHA 2012c). The most unequivocal evidence that photodebromination occur in soil, sediment, air and other matrices come from controlled laboratory studies with natural sunlight. While the identity of the degradation products is inconclusive in some studies (Örn 1997, Palm 2003, Gerecke 2006), other studies provide good evidence for the formation of hepta- and hexaBDE congeners in freshly spiked sediment, soil and sand following exposure to light under laboratory conditions (Sellström 1998a, Tysklind 2001, Söderström 2003, 2004, ECHA 2013a, Jafvert and Hua 2001a, Eriksson 2004). Ahn (2006) found that debromination of BDE-209 adsorbed to minerals was a stepwise reaction, initially forming nona-, then octa- and heptaBDE congeners after 14 days exposure to sunlight, but with increased exposure time, hexa- to triBDEs were also formed. A number of studies, while not necessarily being representative of environmental conditions, have shown that microorganisms can influence BDE-209 degradation in soil and sediments as they are capable of transforming deca-, nona- and octaBDEs to at least hepta- and hexaBDEs (Robrock 2008, Lee and He 2010, Deng 2011, Qiu 2012). Photodegradation and debromination of BDE-209 have also been studied in abiotic material such as dust, plastic and textile exposed to light, and degradation products have been identified from hexa- to nonaBDE (Stapleton and Dodder, 2008, Kajiwara 2008, 2013a,b). Other degradation products such as PBDD/ PBDF, pentabromophenol and hexabromobenzene can moreover be formed from BDE-209 during processing (recycling), plastics production, photolysis, food preparation (cooking of fish) and waste disposal (Vetter 2012, Kajiwara 2008, 2013a,b, Hamm 2001, Ebert and Bahadir 2003, Weber and Kuch 2003, POPRC 2010b, Thoma and Hutzinger 1987, Christiansson 2009). Formation is strongly dependent on conditions like temperature and purity of the flame retardant.

49. Monitoring data provide supporting evidence that degradation of BDE-209 occurs under environmental conditions (ECHA 2012c, Hermanson 2010, Xiao 2012). Results provide evidence of the formation of small amounts of nona- and octaBDEs over a period of 30 days in lake sediments (Orihel 2014 in press, see also ECHA 2012c). A few studies demonstrate degradation of BDE-209 (mainly to nona- and octaBDEs) in sewage sludge (Stiborova 2008, Gerecke 2006, ECHA 2012c), as well as in precipitation (Arinaitwe 2014). Change in the congener ratio in sludge compared to commercial formulations has also been observed (Knoth 2007). Although minimal debromination during WWT was reported in the past (Kim 2013a, Zennegg 2013), findings support the contention that BDE-209 in sewage sludge can be dehalogenated to less brominated congeners (Hale 2012). In soil, debromination of BDE-209 is assisted by the presence of plants (Du 2013, Huang 2010a, 2013, Lu 2013, Wang 2011a, 2014). The distribution pattern of lower brominated PBDEs in plant tissues was different from the soil spiked with BDE-209 suggesting that debromination of BDE-209 in the soil occurred and that further debromination within the plants may occur (Du 2013, Wang 2011a, 2014).

An overview of degradation products in abiotic matrices is given in UNEP/POPS/POPRC.10/INF5 Tables 3.3 and 3.4.

50. Debromination is also shown in studies with higher vertebrates, including birds, fish and rodents (ECHA 2012a, c, UK EA 2009, ECA 2010, POPRC 2013a). While most vertebrates appear to be able to degrade BDE-209 to lower brominated PBDEs, different species may have different ability to debrominate BDE-209, with debromination occurring more rapidly and to a greater extent in some species than in others (McKinney 2011a). However, the amount metabolised is limited by the amount absorbed and by the metabolic capacity.

51. Several laboratory experiments and field studies on fish have shown debromination of BDE-209 after dietary- or water exposure, or after injection of BDE-209 (Kierkegaard 1999, Stapleton 2004, 2006, Kuo 2010, Munschy 2011, Vigano 2011, Noyes 2011, 2013, Zeng 2012, Wan 2013, Feng 2010, 2012, Luo 2013, Bhavsar 2008, Orihel 2014 in press or as reviewed in ECHA 2012c). A number of apparent degradation products have been detected in terms of lower brominated PBDEs ranging from mono- to octaBDE. In several studies congeners (BDE-49, BDE-126, BDE-179, BDE-188, BDE-202) not present in any technical PBDE products have been detected and reported as evidence for biotransformation of BDE-209 (Munschy 2011, Wan 2013, Vigano 2011). The concentrations of BDE-209 and its degradation products varied between the different fish species which might be explained by species-specific differences in bioaccumulation capacity and metabolism between the fish species (Stapleton 2006, Luo 2013, Roberts 2011). Formation of hydroxy- and methoxyBDE degradation products have also been reported (Feng 2010, 2012, Zeng 2012).

52. A number of studies have also revealed debromination of BDE-209 in birds or bird eggs (reviewed by Chen and Hale 2010, Park 2009, Van den Steen 2007, Letcher 2014, Holden 2009, Munoz-Arnanz 2011, Mo 2012, Crosse 2012). In American kestrels exposed to BDE-209 via diet the half-life of BDE-209 was estimated to 14 days based on plasma concentrations measured during the uptake and elimination periods (Letcher 2014). In addition, debromination products from nona- to heptaBDE were observed. As observed in fish, BDE-202 along with other unidentified congeners not present in c-decaBDE was detected in bird eggs and seen as evidence for debromination (Park 2009, Holden 2009, Mo 2012). Furthermore, the ratio between nonaBDE/BDE-209 congeners in eggs or prey fish was higher than the ratio seen in the commercial mixture indicating biotransformation of BDE-209 in birds/bird eggs (Holden 2009, Mo 2013). The bird egg congener profiles differ markedly from what have been reported in marine and aquatic biota, where lower-brominated (tetra- and penta-BDE) congeners predominate. These differences in congener profiles may be due to lower bioavailability to BDE-209 compared to lower-brominated congeners, debromination- and depletion of BDE-209 in marine and aquatic biota (McKinney 2011a, Huwe 2008). Indication of BDE-209 biotransformation in the terrestrial environment was also shown by the high amounts of BDE-208 in earthworms following exposure to BDE-209 (Sellström 2005, Klosterhaus and Baker 2010). An overview of degradation products in biota are reported in UNEP/POPS/POPRC.10/INF5 Tables 3.1 and 3.2.

53. Mammalian data indicate that debromination (nona - hepta-BDE) is the first step in biotransformation of BDE-209, followed by hydroxylation to phenols and catechols (Riu 2008, Wang 2010a, Huwe 2007), and that debromination either occurs in the intestine via metabolism by intestinal microflora or by first-pass metabolism by cytochrome P450 enzymes in the intestinal wall following uptake (Mörck 2003, Sandholm 2003).

54. The toxicity of lower brominated congeners is well known, thus debromination of BDE-209 to lower brominated congeners contributes to the outcome of c-decaBDE toxicity (Kodavanti 2011). Environmental degradation and/or biotransformation of BDE-209 showing degradation/transformation to POP BDEs (BDE-47, 99, 153, 154 and 183) has been reported (Wan 2013, Letcher 2014, She 2013, Zhang 2014, Munschy 2011, Stapleton 2004, Feng 2010, Luo 2013, Lu 2013, Huang 2013, see UNEP/POPS/POPRC.10/INF5 Tables 3.1-3.4). Due to the wide distribution and high persistency organisms are continuously exposed, through their lifetime, to a complex mixture of BDE-209, lower brominated BDEs and other BDE-209 degradation products (ECHA 2012), increasing the likelihood for adverse effects (Ross 2009, McKinney 2011a, Kortenkamp 2014). A study by He (2011) showed that long-term chronic exposure to low doses of BDE-209 not only affects F0 growth and reproduction, but also elicits neurobehavioral alterations in F1 offspring. Bioaccumulation of BDE-209 and biotransformation to low concentrations of the congener's nona- to hexaBDE was observed and the risk of mixture toxicity was raised by the authors. Hence, uptake and bioaccumulation of BDE-209 together with its biotransformation to more bioaccumulative and toxic metabolites in organisms has the potential for significant adverse effects as a result of the combined exposures (see Section 2.4.6). Similar results have been reported by Noyes (2011) and Chen (2012a).

### 2.2.3 Bioavailability and tissue distribution

55. The bioavailability of BDE-209 is low due to its high molecular weight that affects its passive diffusion through biological membranes (Frouin 2013, Mizukawa 2009) and its strong affinity for particles i.e. sediment and soil (Tian and Zhu 2011, see also Section 2.2.1). In spite of that and as confirmed by monitoring data from across the world (see Section 2.3 and Tables 5.1 and 5.2 UNEP/POPS/POPRC.10/INF5) and available laboratory studies, detectable and sometimes high BDE-209 levels have been measured in a wide variety of tissues, species, food webs and top predators.

56. As discussed in Section 1.1 the water solubility of BDE-209 is low and bioavailability via direct exposure through aquatic media is reported to be very limited (Ciparis and Hale 2005, Klosterhaus and Baker 2010). However, some evidence for the bioavailability of BDE-209 in medaka following direct water exposure is shown (Luo 2013). Due to its propensity for particle binding BDE-209 is considered to be bioavailable via food and through ingestion of particles, such as dust, sediment, soil or sand (ECHA 2012c). Uptake of BDE-209 through diet was evaluated in fish (Kierkegaard 1999, Stapleton 2004, 2006) and shown to range between 0.02% and 3.2% dependent on the species and whether debromination products of BDE-209 were taken into account when estimating the total uptake. Evidence for bioavailability of BDE-209 in terrestrial species is shown by the many studies showing uptake of BDE-209 into birds (Letcher 2014, Sagerup 2009, reviewed by Chen and Hale 2010), and is underpinned by biomonitoring data evidencing uptake also in other wildlife species, as well as in humans (Section 2.3). In rats, oral absorption is reported to range from 1-26%, inhalation absorption is estimated to be negligible (El Dareer 1987, Mörk 2003, Sandholm 2003, Riu 2008), and in an in vitro experiment dermal absorption was less than 20% (Hughes 2001). Furthermore an in vitro assessment using a human gastrointestinal tract model showed that BDE-209 was bioaccessible (14%) after exposure to indoor dust samples (Abdallah 2012). In the rat and cow the majority of BDE-209 administered is recovered in feces as the original compound (Kierkegaard 2007, Huwe 2008, Riu 2008, Biesemeier 2010).

57. Studies have shown that BDE-209 preferentially sequesters to blood-rich tissues such as muscle, liver, intestine, gills (fish), and to lesser extent to adipose tissue (e.g. Shaw 2012, Wan 2013, EFSA 2011, ECB 2002, 2004). The sequestration to blood rich tissues may possibly be explained by BDE-209 binding to proteins (Hakk 2002, Mörck 2003). In Chinese sturgeons, lipids did not play an important role in the distribution of BDE-209 (Wan 2013). BDE-209 was detected at relatively high concentrations in organs participating in absorption, uptake and metabolism such as the liver, gills, and intestines with liver having the highest concentration of BDE-209 followed by gills. Furthermore, the estimated partition coefficients between tissues and blood were higher than those of less brominated BDEs suggesting that the low partition ratios from blood to tissues would lead to high bioaccumulation of BDE-209, especially in absorbing organs (Wan 2013). Since this organism almost stops feeding during the migration period in the Yangtze River it can be assumed that the sturgeon was in a depuration period. A similar pattern was observed in a bioaccumulation study on harbor seals (Shaw 2012). Average hepatic ΣPBDE (tri- to octa-BDE) concentrations were similar to those of the average seal blubber ΣPBDE (mono- to hexa-BDE) as reported in Shaw (2008). In contrast, BDE-209 concentrations in liver were up to five times higher than those in blubber, which is consistent with observations that BDE-209 migrates to perfused tissues such as the liver in biota. In rats, based on organ fresh weights, the highest concentrations were found in adrenals, kidney, heart, liver and ovaries (EFSA 2011, Seyer 2010, Riu 2008). In lactating cows fed naturally contaminated silage BDE-209 was the dominating congener in feed, organs, adipose tissue and feces, but not milk (Kierkegaard 2007). In dietary exposure of American kestrels, higher levels were observed in fat than liver on wet weight basis at the end of the depuration period (Letcher 2014).

58. Human data demonstrate that BDE-209 is absorbed and distributed to fat, blood, cord blood, placenta, fetuses and breast milk (Frederiksen 2009a, Zhao 2013; UNEP/POPS/POPRC.10/INF5, Table 4.1). Maternal transfer of BDE-209 to eggs and offspring has also been reported in fish, frogs, birds, rats and reindeer (Vorkamp 2005, Lindberg 2004, Johansson 2009, Garcia-Reyero 2014, Nyholm 2008, Rui 2008, Biesemeier 2010, Cai 2011, Holma-Suutari 2014, Liu 2011c).

### 2.2.4 Bioaccumulation

59. In the past, bioaccumulation of BDE-209 in biota was assumed to be low, mostly attributed to the large molecular size and extreme hydrophobicity and low bioavailability of BDE-209 (Hale 2003). However, low bioaccumulation can also be explained by factors such as low uptake and/or high ability to eliminate or metabolize BDE-209 through excretion and debromination of BDE-209 (Hale 2003, Arnot 2010). Furthermore, variable results for bioaccumulation can also be explained by analytical challenges to measure BDE-209 (Ross 2009, de Boer and Wells 2006, Covaci 2003, Kortenkamp 2014) and/or debromination to lower PBDEs. As noted by ECA (2010) a complete evaluation of a substance's bioaccumulation potential should consider the bioaccumulation potential of both the parent substance

and its metabolic product(s). Environmental monitoring studies show that BDE-209 is found to be present in a variety of species as well as humans all over the world, and provide supporting evidence for bioaccumulation (see section 2.3.1 and UNEP/POPS/POPRC.10/INF, Table 5.2). The octanol-water partition coefficient (log Kow) values for BDE-209 reported in the literature are highly variable ranging from 6.27 to 12.11 depending on the measurement or estimation method used (CMABFRIP 1997, Dinn 2012, ECA 2010, Kelly 2007, Tian 2012, US EPA 2010, Watanabe and Tatsukawa 1990). While compounds with a log Kow >5 are considered bioaccumulative, chemicals (like BDE-209) with a log Kow > 7.5 are thought to be less bioaccumulative because of predicted declines in dietary absorption potential (Arnot and Gobas 2003). However, results from food web studies show that BDE-209 bioaccumulates (BMF>1) in both aquatic and terrestrial species (Yu 2011, 2013, Wu 2009a, EC 2010 and references therein).

60. The BCF for BDE-209 in fish has been estimated to be <5000 with non-appreciable aqueous uptake predicted due to its large size and low water solubility (ECHA 2012 a, ECA 2010). However, BCF is not considered to be a good descriptor of the bioaccumulation capacity of strongly hydrophobic substances, such as BDE-209. BCFs represent processes of chemical absorption by an aquatic organism from the ambient aqueous environment through its respiratory and dermal surfaces with no dietary considerations (Arnot and Gobas 2006). According to the revised OECD guidelines for bioaccumulation studies, testing via aqueous exposure may become increasingly difficult with increasing hydrophobicity. Hence, for strongly hydrophobic substances (log KOW >5 and water solubility below ~ 0.01-0.1 mg/L) a dietary test is recommended (OECD 305, 2012).

61. For terrestrial organisms log KOW and BCF are not good predictors of biomagnification for chemicals with log KOA  $\geq$ 6 and log KOW>2 (Kelly 2007, 2009) and in terrestrial food chains chemicals with log KOW<5 and BCFs<5000 have been shown to biomagnify. As previously mentioned, the most important exposure route for BDE-209 in aquatic and terrestrial food webs is through the diet (Shaw 2009, Kelly 2007). The accumulated levels of BDE-209 in sediment-associated organisms and filter feeders (mussels, zoo plankton, crustacean, flat fishes, benthic invertebrates and aquatic worms) have been interpreted to be the result of uptake of particles containing adsorbed BDE-209 and not as evidence of bioaccumulation, however, uptake of particles is considered to be an exposure route for higher trophic levels in aquatic food webs (Shaw 2009 and references therein). In terrestrial ecosystems, BDE-209 adsorbs strongly to atmospheric particulates (i.e. aerosols) due to its high octanol-air partition coefficient (KOA), and will be deposited to terrestrial vegetation and soil through wet and dry deposition (Christensen 2005, ECA 2010, Mizukawa 2013, Yu 2011). This provides an exposure route for terrestrial organisms that ingest soil or plants as a food source. Therefore, when considering the bioaccumulative behaviour of BDE-209, calculated or measured BAFs, biomagnification factors (BMFs) and trophic magnification factors (TMFs) are believed to give more relevant information than calculated or measured BCFs (Shaw 2009, Kelly 2007, Powell 2013).

62. The BAF represents the bioaccumulation of chemicals in an organism by all routes of exposure, including by dietary and ambient sources. Historically, limited data have been available to allow for estimations of BAFs for BDE-209, as numerous studies measured BDE-209 concentration but did not compare these values with ambient levels. As a result, previous assessments found equivocal evidence concerning whether BDE-209 is bioaccumulative (ECHA 2012a,c, ECA 2010, US EPA 2010). Since this time, additional studies have measured BDE-209 BAFs in biota from regions captured by previous assessments, as well as from other areas. In particular in one study by Frouin (2013) the logBAF values based on lipid weight were higher than 6 for aquatic invertebrates thus exceeding logBAFs>3.7 corresponding to a BAF>5000 (He 2012, ECA 2010), fulfilling thereby the criteria on bioaccumulation in Annex D (BAF>5000). In the above mentioned studies the BDE-209 uptakes by aquatic organisms were measured and compared to water concentrations, and logBAFs were estimated.

63. BMFs and TMFs from field data show that BDE-209 can biomagnify in several aquatic and terrestrial organisms and food webs (BMFs >1 and TMF>1; see UNEP/POPS/POPRC.10/INF5, Table 3.5 for details). BMFs range between 1-7 in terrestrial organisms and food webs as reported in the scientific literature (Yu 2011, Wu 2009a) and estimated from modeling (Kelly 2007). In a terrestrial food web study spanning several trophic levels BMFs ranging between 1.4 and 4.7 were reported (Yu 2011, 2013). In another field study on frog (influenced both by aquatic and terrestrial environments) focusing on biomagnification from insect to frog, BMFs ranged from 0.8-13.0 depending on gender (Wu 2009a). In aquatic organisms, BMFs ranged between 0.02 and 34. BMFs in seal blubber and blood have been found to be in the range 0.03-0.06 and 8.3-20.8, respectively (Thomas 2005 as reported in ECA 2010). Other studies report BMFs between 0.2 and 2.2 for harbor seals (Jenssen 2007), 1.5 for marine biota (Baron 2013), and 1.28 for rainbow trout (Stapleton 2006 as reported in ECA, 2010). Furthermore BMFs between 0.1 and 34 were reported in an aquatic food web study by Law (2006). In a number of other aquatic studies BMFs from 1.2 to 5.1 (Mo 2012), 0.67 to 1.3 (Shaw 2009), 0.4 to 1.3 (Poma 2014), 4.8 to 12.7, although there were some uncertainties regarding the

food web (Tomy 2009), and between 0.02 and 5 (Burreau 2004, 2006, reviewed in ECA 2010) have been reported. In aquatic food webs TMF values have been reported as 3.6 (Law 2006), 0.26 (Wu 2009b), 0.78 (Yu 2012, as reviewed in ECA 2010) and 0.3 (Tomy 2008). Most of the reported BMFs and TMFs for BDE-209 have all been calculated using muscle (fish, mammals, and birds), whole body (bivalves, zooplankton, and fish) or adipose tissues (fish and mammals). The differences between BMFs and TMFs reported may be species dependent and influenced by overall condition of the organism, diet, exposures and tissue analysed, metabolism, sex, and food web structure.

64. The trophic dilution (TMF<1) observed in some studies might be due to biotransformation of BDE-209 through the food webs, since TMFs>1 have been reported for BDE-209 biotransformation products (Wu 2009b, Poma 2014). Furthermore BMFs of known biotransformation products such as BDE-202, not present in any commercial available PBDE formulations, have been reported (Yu 2011, Mo 2012, Poma 2014). Hence, in some studies, bioaccumulation of degradation products, such as BDE-202, has been observed rather than bioaccumulation of BDE-209 itself.

65. The biota-sediment accumulation factor (BSAF) represents the steady state concentration ratio of a contaminant between an organism and sediment, and can provide further insights into bioaccumulation and biomagnification potential. Calculated sediment BSAF values for BDE-209 suggest low biomagnification potential (BSAF<1) in a number of studies (Klosterhaus and Baker 2010, He 2012, La Guardia 2012, Sellström 2005, Tian and Zhu 2011, Xiang 2007, reviewed in EC 2010). But some studies show higher sediment BSAFs > 3 suggestive of bioaccumulation potential in some shellfish species (deBruyn 2009, Wang 2009). In the study by deBruyn (2009), BDE-209 concentrations were either low (BSAF≤ 1.48) or below the limits of quantification for most samples except at one reference site where the sediment BSAFs was calculated as 3.53 (deBruyn 2009). However, in a recent study in a soil invertebrate food web BSAFs for BDE-209 ranged from 0.07 to 10.5 following land-application of biosolids. In the same study, BMFs ranged from 0.07 to 4.0, however, there was some uncertainties regarding the  $\Delta\delta N$  isotope analysis and the authors further concluded that soil contact is likely more important than trophic status in determination of PBDE accumulation in soil invertebrates inhabiting sludge-applied sites (Gaylor 2014) (see UNEP/POPS/POPRC.10/INF5, Table 3.5 for details). The interpretation of BSAF values for BDE-209 is complicated by the fact that BDE-209 metabolism varies widely across species, extremely high sediment levels in some of the field studies and problems of getting clean and sediment-free samples for sediment living organisms (ECHA 2012c, La Guardia 2012).

66. Some studies have observed higher biomagnification or increased accumulation potential of BDE-209 in terrestrial organisms compared to aquatic organisms (Christensen 2005, Chen and Hale 2010b, Jaspers 2006, Kelly 2007, Voorspoels 2006a). This is expected given the physico-chemical properties of BDE-209 and the differences in toxicokinetics between terrestrial and aquatic organisms as defined by Kelly (2007). Kelly (2007) calculated higher BMFs for BDE-209 among terrestrial carnivores and humans (BMF=8) than for marine mammals (BMF=3) with the lowest BDE-209 BMF values in terrestrial herbivores and aquatic organisms (BMFs=1). This study concluded that BMFs for very hydrophobic chemicals like BDE-209 were higher in air-breathing animals than water-breathing animals due to slower respiratory elimination and slow elimination via urine that was reflective of the compound's high  $K_{oa}$  and  $K_{ow}$  values, respectively. Conversely, other studies show that BDE-209 absorption in some teleost fish occurs at a slow rate, which may allow for lower bioaccumulation potential and greater metabolism (or debromination) and elimination of BDE-209 than seen in terrestrial species (Mörck 2003, Stapleton 2004, Kierkegaard 1999). Available data also suggests that there are additional variables influencing the bioaccumulation of BDE-209. For instance, BDE-209 partitions strongly to sediments and soils, is highly persistent, and is the dominant or one of the most predominant PBDEs detected in abiotic compartments of the global environment (see section 2.3.1). This ubiquitous abiotic contamination sometimes at high levels may allow BDE-209 to enter food webs and reach steady state levels in biota despite the large molecular size (MW=959) and high log  $K_{ow}$  (Stapleton 2004).

67. Little is known about the bioaccumulation of BDE-209 (or other PBDEs) in plants and in herbivores. BDE-209 was examined in a small herbivorous food chain (paddy soils, rice plants, and apple snails) from an electronic waste recycling site in South China. The BMFs for BDE-209 from the rice plant to snails ranged between 1.2 and 6.3 and clearly demonstrated that BDE-209 can bioaccumulate in the plant/herbivore food web (She 2013). On the other hand, bioaccumulation was not observed in a recent laboratory experiment where apple snails were dietary exposed to BDE-209 (reported BAF was <1) (Koch 2014). Hence from these two studies a clear conclusion of bioaccumulation in snails cannot be made. Many of the reported concentrations of BDE-209 in biota are given on a lipid-normalised basis. Although this is common practice when reporting the levels of bioaccumulative substances, in retrospect this might not be the best analytical approach for those substances that do not partition significantly to lipid (OECD 2012), as is possibly the case for BDE-209



(see section 2.2.3). Studies showing a lack of BDE-209 biomagnification in fish and mammals have been based on levels detected in muscles or adipose tissue and/or have been lipid normalised. As discussed in section 2.2.3 evidence shows that BDE-209 preferentially sequesters to blood-rich tissues, such as the liver, intestine, muscle and gills, hence some previous studies may have targeted the wrong tissue and underestimated the bioaccumulation and biomagnification potential of BDE-209 (Stapleton 2004, Voorspoels 2006a, Wan 2013). Recent experimental advances in isotopic ecology have shown that using a fixed  $\Delta^{15}\text{N}$  value is inappropriate and that escalated  $\Delta^{15}\text{N}$  value is more meaningful (Hussey 2014). Thus, correction for trophic levels introduces additional uncertainty, especially for well established food webs.

68. Debromination of BDE-209 to lower brominated and more bioaccumulative PBDEs after uptake of BDE-209 in organisms (see section 2.2.2) adds to the concern about the use and releases of BDE-209, since some PBDEs are already listed in Annex A of the Stockholm Convention for global elimination, and/or are vPvB and PBT substances in the EU (POPRC 2006, 2007, ECHA 2012a, ECA 2010). Studies of toxic effect and debromination to lower PBDEs have been paralleled by observations of bioconcentration and bioaccumulation of BDE-209 (Garcia-Reyero 2014, Noyes 2011, 2013, Kuo 2010). Furthermore the presence of lower brominated PBDEs in field studies can be due to both debromination of BDE-209 and as a result of direct exposure from c-pentaBDE or c-octaBDE.

### 2.2.5 Potential for long-range environmental transport

69. Along with other less brominated PBDEs, BDE-209 is found in various environmental compartments in the Arctic and Antarctic including air, sediment, snow, ice, soil, sediment and biota (UNEP/POPS/POPRC.10/INF, Tables 5.1 and 5.2).

70. Several studies have reported that BDE-209 is the predominant or one of the dominating PBDEs in Arctic air (Wang 2005, Su 2007, Hermanson 2010, Hung 2010, Möller 2011b, Meyer 2012, NEA 2014, Salamova 2014). The levels of BDE-209 in the Arctic atmosphere together with studies showing a significant deposition on Arctic ice (Hermanson 2010) and snow (Meyer 2012) underlines the potential of BDE-209 to undergo long-range environmental transport to remote regions. For example, in a study assessing a total of 19 different BFRs in ice core samples from the Norwegian Arctic, BDE-209 was found to provide the second greatest share of the deposition of BFRs from air to the Arctic ice. The deposition rate for BDE-209 was found to be 320 pg cm<sup>-2</sup> y<sup>-1</sup> in the period 1995-2005, surpassed only by HBCD, and substantially higher than for other PBDEs (Hermanson 2010). The detection of BDE-209 in Antarctic air and deposition samples provide further evidence of the long-range transport of this compound over remarkable long distances (Dickhut 2012).

71. BDE-209 deposited to the Arctic environment is bioavailable to the organisms living there and is widespread in Arctic food webs (de Wit 2006 and 2010, ECA 2010, NCP 2013). Arctic biota samples contaminated with BDE-209 include e.g. vegetation, birds of prey, seabirds and seabird eggs, marine and freshwater fish, different amphipods, zooplankton, shrimps and clams, terrestrial and marine mammals (de Wit 2006 and 2010, Letcher 2010, Tomy 2008). Typically Arctic biota is co-exposed to BDE-209 and a multitude of other PBDEs and POPs (de Wit 2006, 2010, Letcher 2010). Biomonitoring data have shown that BDE-209 contributes significantly to the total body burden of PBDEs in some Arctic species, accounting for >50% of total PBDE burden in detritus feeding ice-amphipods (Sørmo 2006), 60% in redfish and 75% in Arctic cod (Tomy 2008). BDE-209 is also the predominant congener in moss samples from remote sites in Norway (Mariussen 2008).

72. BDE-209 is also found in air in remote areas of Asia on the Tibetan Plateau (Xiao 2012, Xu 2011). Snow pack samples in the Tartra Mountains in Slovakia showed remarkably high levels of BDE-209 (Arellano 2011). Systematic monitoring at open sea from ships has also proved the abundance of BDE-209 in air samples from the Arctic, Atlantic, Indian, and Pacific oceans (Möller 2012, Möller 2011a,b, Lohmann 2013). Both oceanic and atmospheric processes contribute to the environmental transport of BDE-209 (Su 2007, Möller 2011a,b, Breivik 2006). Since BDE-209 has a very low vapor pressure, volatilization is unlikely to contribute significantly to the long-range environmental transport, rather the atmospheric long-range transport appears to be controlled by the atmospheric mobility of the particles to which it is attached (Breivik 2006, Wania and Dugani 2003). Finer particles (with a diameter around a few micrometres) might remain airborne for hours or days, provided that they are not removed by wet deposition (Wilford 2008, Meyer 2012). Furthermore particles can protect the BDE-209 molecule from photolysis and lengthen its life-time in the air to >200 days (Breivik 2006, Raff and Hites 2007 as cited in de Wit 2010). In the Arctic, the deposition of airborne particles is found to be higher during the Arctic haze season (Su 2007, AMAP 2009). In tropical Asia, long-range environmental transport of PBDEs including BDE-209 associated with gas and/or particles is assisted by the monsoon (Xu 2011).

73. Based on hydroxyl radical reaction BDE-209 has an estimated atmospheric half-life of 94 days in air according to calculations from the chemical structure using the Syracuse Research Corporation AOP program and assuming a hydroxyl radical concentration of  $5 \times 10^5$  molecule  $\text{cm}^{-3}$  and a reaction rate of  $1.7 \times 10^{-13}$   $\text{cm}^3$  molecule $^{-1}$  s $^{-1}$  (ECB 2002). Other applications such as EPISuite 4.1 (AOPwin module) and PBTProfiler estimate a different reaction rate ( $3.37 \times 10^{-14}$   $\text{cm}^3$  molecule $^{-1}$  s $^{-1}$ ) and therefore predict even longer half-lives of 317 days (12 h day,  $1.5 \times 10^6$  OH radicals  $\text{cm}^{-3}$ ) and 470 days (24 h day,  $5 \times 10^5$  molecules  $\text{cm}^{-3}$ ) respectively.

74. Although local sources of releases may be present (Hale 2008, Danon-Schaeffer 2007, Li 2012c), the available data from remote regions overall shows that BDE-209 is detected in these areas as a result of long-range environmental transport.

## 2.3 Exposure

### 2.3.1 Environmental levels and trends

75. BDE-209 is widely dispersed in the global environment and is found in biotic and abiotic matrices worldwide. An overview of environmental levels is reported in several reviews (de Wit 2006, 2010, ECA 2010, Letcher 2010, Law 2014) and in UNEP/POPS/POPRC.10/INF5 Table 5.1 and 5.2. In most environmental matrices BDE-209 co-exists with other PBDEs and is the main or one of the dominating PBDEs detected.

76. BDE-209 is detected in air in urban, rural and remote regions (UNEP/POPS/POPRC.10/INF5 Table 5.1), as well as in precipitation (Ma 2013, Robson 2013, Arinaitwe 2014 and references therein). In urban and rural environments detected levels range between 4.1 and 60  $\text{pg m}^{-3}$  (as reviewed by Syed 2013) while concentrations in Arctic air ranges from non-detectable to 41  $\text{pg m}^{-3}$  (reviewed by de Wit 2010). Levels in background locations outside the Arctic have been reported to range from non-detectable to 29  $\text{pg m}^{-3}$ , i.e. higher than the levels found in the Arctic and lower than the levels found in urban and rural environments (Xiao 2012, Möller 2011a,b, 2012). Recently, however, Lohman (2013) reported particle-bound and gas-phase BDE-209 concentrations in tropical Atlantic Ocean air as high as 43.89 and 260  $\text{pg m}^{-3}$ , respectively. Based on these measurements Lohman (2013) calculated the total deposition of BDE-209 to the Atlantic Ocean from air to be approximately 27.5 tonnes annually, 20 and 7.5 tonnes each for the gas- and particle phase, respectively. The findings indicate that air-levels and deposition over the global oceans may be higher than previously thought. As described above, both in the Arctic and the tropics, air-transport of BDE-209 is influenced by seasonal weather phenomena (Xu 2011, Su 2007, AMAP 2009). Air mass back trajectory analysis indicates that major potential source regions of BDE-209 are widely distributed in industrialized and urbanized areas in tropical Asia (Xu 2011).

77. Most available data reporting BDE-209 levels in soil are from affected areas. Reported levels in soil worldwide range from non-detectable up to 8600  $\text{pg g}^{-1}$  dw soil in polluted areas, but may possibly be even higher (reviewed by Wang 2010b). BDE-209 was detected in soil at landfill sites in Arctic Canada (Danon-Schaeffer 2007, Li 2012c), but PBDE soil levels outside the landfills were similar to levels measured in soil at background locations elsewhere in the Arctic (de Wit 2006, 2010), suggesting that emissions of BDE-209 and other PBDEs from these sources to the Arctic environment at present are small. Compared to remote sites, BDE-levels in urban and rural areas are significantly higher. In particular, the levels of BDE-209 in soil at e-waste sites such as recycling plants, dumping- and industrial sites in China are very high (Wang 2011b, reviewed by Wang 2010b, Gao 2011, Li 2012a). Sewage sludge from several countries is reported to contain BDE-209 and when soil is amended with sludge BDE-209 is transferred to soil and biota (de Wit 2005, NEA 2012, NERI 2003, Annex E Denmark, Ricklund 2008a,b, Earnshaw 2013). As shown by Sellström (2005) and de Wit (2005) levels of BDE-209 were 100-1000 fold higher at sites fertilized with sewage sludge compared to reference sites. In this study, BDE-209 was the dominant congener in soil and earthworms, with higher levels reported in the worms than in the soil (Sellström 2005).

78. Reported BDE-209 levels in sediments worldwide range from non-detectable to 16,000  $\text{ng/g dw}$  i.e. slightly higher than in soil (see Wang 2010b, Eljarrat 2007, Sellström 1998b; POPRC/ INF Table 5.1). High concentrations in sediment are typically found in the vicinity of industrial sites (Wang 2010b, Eljarrat 2004, 2005, 2007, Sellström 1998b). Similar to findings in soil, BDE-209 is the predominant congener reported in sediments contributing almost 100% to the total PBDE measured in some studies (Wang 2010b, Eljarrat 2005, Marvin 2013). Levels of BDE-209 in soil and sediment in remote regions are low (de Wit 2006, 2010, CPAN 2010, 2012b, Boitsov and Klungsoyr 2013, SFT 2008a,b), but have been found to be elevated at a few sites affected by local contamination such as at landfills and in the vicinity waste water outfalls (Hale 2008, Danon-Schaeffer 2007, Li 2012c). The doubling time for

BDE-209 in these sediments range between 5.3 and 8.4 years (Chen 2007b, Kwan 2014, Zhu and Hites, 2005, Zegers 2003; UNEP/POPS/POPRC.10/INF5 Table 5.1).

79. BDE-209 is also found in a variety of terrestrial and aquatic species globally (de Wit 2006, 2010, Letcher 2010, ECA 2010, Chen and Hale 2010, NCP 2013; see UNEP/POPS/POPRC.10/INF5 Table 5.2). Measurements include plants, seabirds such as eider, guillemot, glaucous- and herring gulls, different birds of prey, fish and marine invertebrates, marine crustaceans, insects and frogs, as well as marine and terrestrial mammals. BDE-209 is found in a variety of tissues in adults, as well as in eggs of oviparous organisms.

80. In the Arctic, reported biota levels range from non-detectable to 250 ng/g lw (UNEP/POPS/POPRC.10/INF5 Table 5.2). Extrapolation of lab-based effects data to field measurements suggests that the health of fish from the Canadian Arctic is likely being negatively impacted by current decaBDE exposure levels (Noyes 2013, Tomy 2008, 2009). The same applies for fish from south China where measured decaBDE concentrations exceed levels where effects have been observed (Noyes 2013, Mo 2012). In areas more affected by anthropogenic activities levels up to  $\geq 12000$  ng/g lw have been reported. High BDE-209 levels have often been shown in terrestrial environments, and likely reflect the low volatility of BDE-209 and its high affinity to organic matter in dust and soils (Chen and Hale 2010, Chen 2012d). In particular, BDE-209 levels in birds and bird eggs are extensively studied, and have in some instances reported to be very high. Common kestrels from China contain very high BDE-209 levels with concentrations of 2150 and 2870 ng/g lw, in muscle and liver, respectively (Chen 2007a). One specimen contained as much as 6220 ng/g lw in the muscle and 12 200 ng/g lw in the liver. These levels are among the highest BDE-209 levels reported in wildlife (Chen 2007a), and much higher than reported elsewhere (Bustnes 2007, Fliedner 2012, Johansson 2011, Sørmo 2011, Voorpoels 2006b, Gentes 2012, Chabot-Giguère 2013, Mo 2013, Chen 2010a, Chen and Hale 2010). High levels were also reported in kingfishers, Eurasian tree sparrows and common kestrels in China (Chen 2007a, Yu 2011, Mo 2012) and peregrine falcons in Sweden (Johansson 2011). BDE-209 is also detected in several species of Arctic birds (de Wit 2006, 2010). Red foxes in urban, rural areas in Belgium had liver levels opp to 760 ng/g lw, where BDE-209 typically contributed to ~70 % of the total PBDE load (Voorpoels 2006a). High levels were also found in Eurasian otters from the UK, with concentrations up to 6800 ng/g lw in the liver (Pountney 2014).

81. Limited data on temporal changes in environmental BDE-209 levels is available. In the few studies reporting temporal trend data from abiota in the Arctic, BDE-209 levels in Canadian Arctic air were found to increase from 2002-2005 (Su 2007, Hung 2010), while the same was not observed from 2007-2009 (NCP, 2013). For the period 2002-2005 doubling times in the range of 3.5-6.2 years were reported (Su 2007, Hung 2010). No temporal trends of BDE-209 in air for 2007-2013 can be seen at the Norwegian Arctic sites (i.e. Zeppelin and Andøya observatory) (NEA 2014). Instead the concentrations fluctuate from year to year. In contrast, levels in Antarctic ice are reported as stable and unchanged in the period 2001-2007 (Dickhut 2012). In urban and rural air and precipitation where levels are influenced by both diffuse and point sources, the pattern is more complex and suggests either no significant change (Ma 2013), an increase (Arinaitwe 2014) or a decline (Robson 2013) in BDE-209 levels over time. It should be noted that in most studies on air or precipitation no clear temporal or spatial trends in is reported. Although BDE-209 is stabilized by binding to air particles (de Wit 2010), the lack of any observable time-trends may in some cases possibly result from photolysis/debromination of BDE-209 to lower brominated PBDEs (Wang 2005, Xiao 2012, see also Meyer 2012, Robson 2013, Arinaitwe 2014). With regards to geographical trends, geographical comparisons of air monitoring data are generally hampered by the fact that most studies report episodic monitoring data.

82. Concentration- and time trends of BDE-209 in sediment have also been reported. In sediment cores from a remote lake in Switzerland BDE-209 levels increased steadily in the period from 1990s to 2001 with a doubling time of about 9 years (Kohler 2008). Sediment cores from urban/polluted areas show doubling times for BDE-209 between 5.3 and 8.4 years (Chen 2007b, Kwan 2014, Zhu and Hites, 2005, Zegers 2003; UNEP/POPS/POPRC.10/INF5 Table 5.1). Based on a study in the south of China, the time at which BDE-209 started to increase in sediments in China seems to be 10-20 years later than those in North America and Europe, which might reflect differences in historical patterns of production and use of BDE-209 in these continents (Chen 2007b). In dated sediment cores taken from lakes in Ontario, Quebec and northern New York State along a latitudinal transect in North America, BDE-209 was generally detected only in recent sediment horizons, and sedimentation fluxes were found to decline exponentially with latitude (Breivik 2006).

83. Paralleling the observation of increasing levels of BDE-209 in Arctic air, Vorkamp (2005) observed a significantly increasing temporal trend in BDE-209 concentration in eggs of peregrine falcon from southwestern Greenland collected from 1986 to 2003. The measured concentrations in this study ranged from 3.8 to 250 ng/g lw, with a median of 11 ng/g lw. An increase in BDE-209 was also observed in peregrine falcon eggs from Sweden collected from 1974 to 2007 from <4 to 190 ng/g lw

(Johansson 2011). BDE-209 levels in UK peregrine falcon eggs were found to increase from 1975 to 1995, and thereafter to decrease from 1995 to 2001 (Leslie 2011). Increasing temporal trends in BDE-209 concentrations were also reported in herring gull eggs from the Laurentian Great Lakes in North-America (Gauthier 2008). From 1982 to 2006 BDE-209 doubling times ranged from 2.1 to 3 years. In contrast, steady state levels were reported in eggs of coastal herring gulls in Germany (Fliedner 2012). In the same study, no significant temporal trend was observed between 1973 and 2001 for BDE-209 concentrations in sparrowhawk muscle tissue, although some samples with higher concentrations were seen in later years. In Norway, geographical trends in BDE-209 levels are observed in moss (Mariussen 2008). Following a transect from south to north BDE-209 levels in moss is observed to decline, indicating that BDE-209 originating in source regions south of Norway are transported towards the Arctic via atmospheric processes and deposited along the way, resulting in the observed decreasing geographical gradient. BDE-209 levels in moss in Norway also appear to have increased over time likely reflecting similar changes in air levels (SFT 2002, Mariussen 2008, CPAN 2012b).

### 2.3.2 Human exposure

84. Dust, indoor air and to a lesser extent food, are considered to be the most important sources and pathways for human exposure to PBDEs (US EPA 2010). In this assessment household consumer products were identified as the main source for the PBDEs in house dust. On the contrary a Canadian assessment identified food and dust as main sources for exposure in adults (HCA 2012). Detected BDE-209 concentrations in the indoor air range from <LOQ to 651 pg/m<sup>3</sup> (Harrad 2010) and from 63 to 10,000 ng/g in dust from Germany, Sweden and the UK (Fromme 2009). The BDE-209 concentrations in dust exceeded by far the sum of the lower brominated PBDEs that have been detected (Frederiksen 2009a, EFSA 2011, Besis and Samara 2012). The concentrations of BDE-209 in North American house dust were comparable to those in Europe (<500-2000 ng/g) (Fromme 2009). Further, the occupancy in cars and airplanes may be a significant source to PBDE exposure as reviewed by Besis and Samara (2012). The median levels of BDE-209 in dust from cars were about 20 times higher than in house dust, although the levels varied substantially between the studies. This is in line with a recent German study where the mean BDE-209 concentration in car, house, and office dust samples were 940, 45 and 120 ng/g, respectively (Brommer 2012). A correlation between BDE-209 in house dust and mother's milk is also reported, suggesting that BDE-209 levels in indoor environments have an impact on the exposure of breastfeeding children (Coakley 2013).

85. BDE-209 is widely present in food and is reported in concentrations ranging from ~2 to >50,000 pg/g ww as reviewed by Frederiksen (2009a). The highest concentrations of lower brominated PBDE were generally measured in fish, and shellfish, while BDE-209 was found in sausage and dairy products, but also food wrapping may contribute (Schecter 2011, EFSA 2011 and Riviere 2014). Contributions from drinking water and outdoor air to indirect BDE-209 exposure are low compared to intakes from food and often considered negligible.

86. The internal dose, e.g. assessed using human biomonitoring, reflects an integrated exposure over time comprising various sources and pathways. BDE-209 has been measured in placental samples in concentrations ranging from 0.05 to 8.4 ng/g lw in a Danish and Spanish study, the median were 1.14 and 1.0 ng/g lw, respectively (Frederiksen 2009b, Gomara 2007). Both studies reported BDE-209 to be the dominating PBDE, representing around 50% of the total PBDEs. A similar congener pattern was observed in a recent study from China, where prenatal placental concentrations were in the range of 1.33 to 8.84 ng/g lw (median 2.64 ng/g lw) (Zhao 2013). Biomonitoring studies on cord blood showed BDE-209 median concentrations to be in the range <1.2 to 27.1 ng/g lw (UNEP/POPS/POPRC.10/INF5, Table 4.1). BDE-209 was in general the largest contributor to the sum of the PBDEs. Exposures to BDE-209 continue in early infancy due to its presence in breast milk. The extensive review by Frederiksen (2009a) covered studies published until 2007 and showed that BDE-209 was reported in the concentration range of 0.1 to 2.9 ng/g lw. More recent studies report similar median concentrations (UNEP/POPS/POPRC.10/INF5, Table 4.1), while maximum values vary considerably within and between geographical regions. BDE-209 concentrations in serum or plasma of adult populations with no known occupational exposure were shown to range from 1 to 18.5 ng/g lw (Frederiksen 2009a). More recent studies show similar levels (UNEP/POPS/POPRC.10/INF5, 4.1), except from the strikingly high levels (mean 220 ng/g lw) reported from Laizhou in China, a previous production area of halogenated flame retardants (He 2013). One study from Sweden has assessed the concentration of BDE-209 in serum from first time mothers living in Uppsala sampled from 1996 to 2010 (Lignell 2011). The mean of the 36 serum pools was 1.3 ng/g lw and no significant temporal trend was seen. This is in accordance with the lack of time trend seen for breast milk collected at the Faroe Islands in 1987, 1994-5 and 1999 (Fängström 2005a). In summary, the biomonitoring data show widespread and ongoing exposures to BDE-209 throughout the world, and confirm fetal exposure and absorption in adults.

87. Studies on occupational exposure are mostly from Scandinavia and Asia, where high-exposure occupational groups like electronic dismantlers have been the main focus. In Sweden, the median BDE-209 blood level in electronic dismantling workers and computer technicians was reported to be 4.8 and 1.53 ng/g lw, respectively (Sjödin 1999, Jakobsson 2002), while a median of 35 ng/g lw were reported among rubber workers (Thuresson 2005). The widespread recycling and dismantling of e-waste under primitive conditions in China has received increasing attention. Median BDE-209 concentrations in Guiyu (Bi 2007) were 50-200 times higher than previously reported in the occupationally exposed populations in Sweden. The highest concentration of BDE-209 in human serum ever reported has been observed in a study by Qu (2007), i.e. 3,436 ng/g lw which is about 3,000 times higher than usually observed in general populations. In contrast, a recent study (Yang 2013) did not find significant difference between the residents in an e-waste recycling area and the reference group.

88. The estimated mean dietary intake of BDE-209 for average consumers in Europe ranged from 0.35 (minimum lower bound (LB))<sup>1</sup> to 2.82 ng/kg bw (maximum upper bound (UB)) per day (EFSA 2011). Based on a daily intake of 50 mg dust and a bw of 70 kg, EFSA estimated the exposure of adults to be 0.045 to 7 ng/kg bw per day. Lorber (2008) reviewed exposure to PBDEs in the US and showed that for BDE-209, soil/dust ingestion with 104.8 ng/day made the largest contribution to the exposure, followed by soil/dust through dermal contact (25.2 ng/day). The total exposure was estimated to 147.9 ng/day of which food and drinking water contributed only 16.3 and 0.09 ng/day, respectively. The total exposure corresponds to 2.11 ng/kg bw per day given a body weight of 70 kg as used by EFSA. Health Canada estimated the upper-bound total daily intake of BDE-209 to be 9.3 ng/kg bw for Canadian adults (20-59 years) (HCA 2012). Food and indoor dust were the dominant sources of exposure, contributing 51 and 45% to the total intake, respectively.

89. Breast milk concentrations measured in Europe, China/Taiwan, Ghana and India were recently used to estimate mean daily intakes for breastfed infants  $\leq 3$  months. The intakes were similar, ranging from 1.0 (LB) to 13.8 (UB) ng/kg bw/day (Kortenkamp 2013). Health Canada (HCA 2012) estimated the total intake of breast fed infants up to 6 months to be between 50-187 ng/kg bw per day, with dust contributing 40 ng/kg bw per day. A study from New Zealand estimated that BDE-209 intakes for infants aged 3 to 6 months was 11.7 ng/kg bw/day, while that in 6 to 12 months old children was estimated to 8.2 ng/kg bw/day (Coakley, 2013). Children 1 to 2 years old had the highest estimated intakes of BDE-209 with 13.2 ng/kg bw/day which likely reflects the high dust ingestion rate (60 mg/day) for this group. The daily intake of decaBDE and other PBDEs from dust and breast milk measured in this study was below US EPA Reference Dose values (7  $\mu$ g/kg bw d, US EPA 2008).

90. Several studies show that toddlers and young children have higher levels of PBDEs than adults (Frederiksen 2009a), which was also seen for BDE-209 (Fischer 2006, Lunder 2010, Sahlström 2014). Small children, as a result of their behavior receive considerable PBDE doses from house dust. Assuming a daily ingestion of 100 mg dust the exposure for 1-3 year old children in Europe were estimated to range from 0.53 to 83 ng/kg bw per day, which is higher than the corresponding calculated median dietary intake ranging between 2.59 and 6.4 ng/kg bw (EFSA 2011). Health Canada estimated the daily BDE-209 intake for the age group 0.5 to 4 years to be 89 ng/kg bw of which diet and dust contributed 24 and 64 ng/g kg bw, respectively. Children's toys, specifically hard plastic toys, have been identified as a potential source of exposure of young children to c-decaBDE (Chen 2009). This exposure was modelled in the assessment of oral intake of BDE-209 of Canadian children for the 0.5- to 4-year age group (HCA 2012). The upper-bound estimate was 120 ng/kg bw per day, which was twice the exposure estimate from soil (dust) for this age group. Congener-to-congener correlations within the mother or toddler cohorts in a Swedish study suggested diet as an important exposure pathway for tetra- to nonaBDEs for mothers (Sahlström 2014). For infants breastfeeding was the predominant exposure pathway for tetra- to hexaBDEs and dust the most important exposure pathway for octa- to decaBDEs for toddlers. Despite some geographic differences, all available intake estimates for BDE-209 point out the importance of dust exposure, particularly for small children.

## 2.4 Hazard assessment for endpoints of concern

91. National and regional assessments conducted by the EU, the United Kingdom, Canada and US have evaluated the potential for c-decaBDE/BDE-209 to induce adverse effects in wildlife and humans (e.g. ECB 2002, 2004, 2007, UK EA 2009, ECHA 2012a, HCA 2006, 2012, US EPA 2008, EFSA 2011). In addition, the toxicity of BDE-209 and other PBDEs has been the topic of several scientific papers and reviews (see e.g. Dingemans 2011, Chen and Hale 2010, Costa and Giordano 2011, Kortenkamp 2014). In the literature toxic effects are reported for soil organisms, plants, birds, fish, frog,

<sup>1</sup> Lower bound: values < LOD/Q has been assigned 0 concentration. Upper bound: values < LOD/Q has been assigned the LOQ/Q-concentration.

rat, mice and humans. Reported effects of BDE-209 range from changes at biochemical- and cellular level to effects which may have more direct implications at higher-levels of biological organization including survival, growth, behavior, immune function, reproduction, development, nervous system and endocrine modulating effects. In vertebrates, the liver, the thyroid hormone (TH) axis and the nervous system appear to be the main targets for BDE-209 toxicity (for review see Costa and Giordano 2011). In both wildlife and humans, early developmental stages appear more vulnerable to BDE-209 exposure than adults. In addition, debromination of PBDEs to more toxic PBDEs is a reason for concern in several assessments (UK EA 2009, ECHA 2012a,c, ECA 2010, Kortenkamp 2014). While some studies either report no effects or effects only at high doses, other studies suggest that BDE-209 may induce adverse effects at low and/or environmentally relevant concentrations.

#### 2.4.1 Toxicity to aquatic organisms

92. C-decaBDE and its main constituent BDE-209 has limited water solubility, and early hazard assessments suggested that significant acute or chronic toxic effects was not likely to occur in aquatic organisms at concentrations below water solubility (e.g. ECB 2002, 2004, 2007, UK EA 2009). However, the most recent EU assessment of BDE-209 raised a concern for adverse effects also to aquatic organisms based on new studies documenting effects on important biological endpoints including reproduction, development, nervous system, endocrine system, growth and fitness (ECHA 2012 a).

93. Aquatic toxicity studies have revealed a number of effects on aquatic organisms, mostly fish and amphibians. Through their influence on the TH system, PBDEs including nona- and BDE-209, was shown to have the potential to affect development and metamorphosis in amphibians (Schriks 2006, 2007, Balch 2006, Qin 2010). According to the available studies BDE-209 and BDE-206, which is one of the congeners present in c-decaBDE and a possible degradation product of BDE-209, can delay metamorphosis in African Clawed Frog tadpoles. In a study by Shricks (2006) a significantly reduced tail tip regression was observed following BDE-206 exposure of tails *ex vivo*. In a more recent *in vivo* study a c-decaBDE (DE-83R) consisting of 98.5% w/w BDE-209 was reported to affect metamorphosis in African Clawed Frog tadpoles by delaying the time to forelimb emergence (Qin 2010). The delayed forelimb emergence was accompanied by histological changes in the thyroid gland and reduced expression of the thyroid receptor in tail tissue. Based on this study an aquatic NOEC of around 0.001 mg/L (1 µg/L) for delayed metamorphosis in African Clawed Frog tadpoles was indicated (ECHA 2012a). Studies have also demonstrated that BDE-209, following flow-through exposure to 0 ppb, 0.1 ppb, 10 ppb, and 100 ppb for 12 weeks, can alter the anatomy and function of the African Clawed Frog vocal system by affecting the laryngeal motor neurons when animals are exposed during the androgen sensitive critical period of vocal system development and during adulthood when the tissues are utilizing androgens to vocalize (Ganser 2009). In this study BDE-209 also inhibited male-typical vocalization, a critical aspect of mating behavior by reducing the number of calls elicited as well as the average call amplitude. The data suggest that BDE-209 can alter anatomy and function, mediated through pathways that include blocking the androgens necessary for proper vocal system. These findings may be of concern given that wild frogs are exposed to BDE-209 already at the egg stage and that BDE-209 in frogs also is transferred to brain and testis (Liu 2011c, Wu 2009a).

94. In fish, controlled feeding studies with fathead minnows conducted at environmentally relevant concentrations have shown that BDE-209 either alone and/or in combination with its debromination products may interfere with the TH system in adult and juvenile fathead minnow (Noyes 2011, 2013). In the latter study, adult fish dietary exposed to a low dose of ~3 ng/g BDE-209 bw per day for 28 days showed a 53% and 46% decline in circulating total thyroxine (TT4) and 3,5,3'-triiodothyronine (TT3), respectively, compared to controls (Noyes 2013). In fish exposed to a high dose of 300 ng BDE-209/g bw, the levels of TT4 and TT3 were lowered to 62 and 59%, respectively. Both in high and low-dose exposed fish, TH levels remained suppressed after a 14-day depuration period. Both doses also reduced brain deiodinase activity (T4-ORD) with 65% compared to control. Similarly, the study by Chen (2012a) indicated that BDE-209 has the potential to cause adverse effects in zebrafish at early life stages with impacts on T3 and T4 concentrations. Li (2011) observed changes in expression of TH-associated genes in rare minnow larvae and adults following exposure to 0.01- 10 µg/L BDE-209 via water for 21 days. In contrast to these findings, Thienpont (2011) and Garcia-Reyero (2014) report no visible effect on thyroid function in exposed fish embryos. However, it should be noted that Thienpont (2011), who exposed 48 hours post fertilization embryos to 960 µg/L BDE-209 for three days conclude that the assay used, a T4 immunofluorescence quantitative disruption test, was not suitable for detecting effects of chemical pollutants such as BDE-209 that indirectly disrupt thyroid gland function. Garcia-Reyero (2014) speculated that the absence of effects on the TH-system in their study may be explained by shorter exposure and/or lower doses than those used by Noyes (2011) and Chen (2012a). Potential TH disruption in fish by several PBDEs was also investigated *in vitro* by Morgado (2007) with negative results. In this study neither BDE-209 nor BDE-206 showed any binding to sea bream transthyretin

(TTR), a TH binding protein in the blood. The result suggests that BDE-209 likely does not interfere with binding of TH to TTR.

95. Other effects, both chronic and acute, have also been observed in fish following exposure to BDE-209. In the above dietary study from 2013, Noyes observed a significant increase in percent cumulative mortality as well as a decline in gonadal-somatic index. Chen (2012a) observed significant decreases in body weight and survival rate of zebrafish larvae exposed to 1.92 mg/L BDE-209 via water for 14-days. Significant changes were not observed at any of the lower exposure doses tested (0, 0.08, 0.38 mg/L).

96. Based on measurements of otolith increment widths in juvenile lake whitefish (~5 months old) fed BDE-209-spiked diets (control, 0.1, 1, and 2 µg/g-diet) there were indications that BDE-209 may affect growth rates in fish at environmentally relevant levels of BDE-209 found in sediment (Kuo 2010, de Wit 2002).

97. He (2011) documented effects on overall fitness, reproductive parameters and behavior as well as motor neuron and skeletal muscle development in a low dose chronic toxicity study with zebrafish. Several of the effects reported by He (2011) were trans-generational i.e. they were observed in offspring of exposed parents and are according to the authors likely explained by maternal transfer of BDE-209. In male fish, indicators of sperm quality were significantly affected even at the lowest exposure dose (0.001 µM or 0.96 µg/L).

98. Potential reproductive toxicity of BDE-209 was also demonstrated in rare minnow (Li 2011). In this study, reduction of spermatocytes and inhibition of spermatogenesis was demonstrated in adult rare minnow exposed to 10 µg BDE-209/L via water. Changes in the expression of TH and spermatogenesis associated genes in rare minnow larvae and adults were observed following exposure to 0.1-10 µg BDE-209/L. In addition effects on body length and gonadosomatic index of adult females were observed at 10 µg/L, but no significant histological changes were found in the ovary at any of the concentrations tested. Furthermore, no change in mortality or body length of larvae and adult males was observed.

99. In the above mentioned study (Garcia-Reyero 2014) BDE-209 impacted expression of neurological pathways and altered the behavior of zebrafish larvae, although it had no visible effects on TH function or motor neuron and neuromast development. In this study fish were exposed to BDE-209 spiked sediment, at a concentration of 12.5 mg/kg. Concentrations in exposed larvae and solvent control measured after 8 days were 69.6±9.8 ng/g ww and 6.7±0.5 ng/g ww, respectively.

100. Besides the other effect reported above, BDE-209 was shown to induce oxidative stress in the liver of goldfish. A reduction in glutathione level and in the activity of antioxidant enzymes, (glutathione peroxidase, superoxide and catalase) was observed from 7-30 days after a single intraperitoneal injection of 10 mg/kg (Feng 2013a, b).

101. In several of the above fish studies BDE-209 was reported to debrominate to lower brominated PBDEs (Noyes 2011, 2013 Chen 2012c, Kuo 2010, He, 2011), thus it is possible that other PBDE congeners besides BDE-209 contributed to the effects reported in these studies. Reported debromination products included nona-, octa-, hepta-, hexa- and pentaBDEs.

102. In summary, the lowest aquatic NOEC for exposure via water reported appears to be below 0.001 mg/L (1 µg/L) and was observed for delayed metamorphosis in amphibians. Based on Noyes (2013) a LOEL of ~3 ng/g BDE-209 bw/day or 0.41 ng/g ww food can be derived for TH disruptive effects and mortality in fish. Overall the aquatic toxicity data suggest that BDE-209 can have adverse effects on critical endpoints such as survival, growth, fitness, reproduction, development, somatic maintenance, thyroid hormone homeostasis and neurological function. The data, moreover, add to the concern regarding the bioaccumulation potential of BDE-209 and debromination in organisms in the environment, since they show that the accumulation of BDE-209 can lead to adverse effects in vulnerable life stages of mammals, fish and amphibians (Chen 2012a, He 2011, Noyes 2011). The levels used in some of the experiments were comparable to levels in more polluted areas (Zhang 2010a, Wang 2011b).

#### 2.4.2 Toxicity in soil organisms and plants

103. Toxicity data are available for soil microorganisms, plants and earthworms. Most of the published data is new and was not reviewed in any of the previous risk assessments and evaluations (e.g. ECHA 2012a, UK EPA 2009, ECA 2006). Based on a plant toxicity study by (Porch and Krueger, 2001) and two 28- and 56-day toxicity studies with earthworms, ECB (2002) reported that no effects were seen on plants at concentrations up to 5,349 mg/kg dry weight. and that a NOEC ≥ 4,910 could be

derived for earthworms. Based on these results and using an assessment factor of 50 PNEC values for soil of 98 mg/kg dry and 87 mg/kg wet weight were estimated.

104. Xie (2011) observed a significant increase in hydroxyl radical levels in earthworms at 0.01-10 mg/kg of BDE-209, which is within the range of environmental levels reported in soil (Syed 2013). The effect was paralleled by oxidative damage to protein and lipids and a reduction in antioxidant capacity. In this study oxidative stress and oxidative lipid damages were observed at concentrations as low as 0.01 mg/kg (Xie 2011). In a more recent acute earthworm study by the same authors, effects on behavior, survival, growth and reproductive parameters were investigated following exposure to 0.1-100 mg/kg BDE-209 for 48 hours and 28 days. Except for a significant decrease in the number of juveniles per hatched cocoon and non-significant changes in avoidance response at 1000 mg/kg BDE-209, no other effects were reported suggesting that adult earthworms have a strong tolerance for BDE-209 in soils, but that a potential toxicity exist for earthworm embryos or juveniles (Xie 2013b).

105. In ryegrass seedlings exposed to 100 mg/kg BDE-209 Xie (2013a) observed a 35% inhibition of root growth and 30% decrease of the chlorophyll b and carotenoid contents of leaves. No other visual signs of toxicity were observed, but BDE-209 exposure induced oxidative stress and damage, altered the activity of several antioxidant enzymes and reduced the non-enzymatic antioxidant capacity at concentrations starting from 1 mg/kg. Sverdrup (2006) did not observe effects on nitrifying bacteria, red clover seedling emergence or survival and reproduction of soil invertebrates at concentrations up to 1,000 mg BDE-209/kg spiked soil and speculated that the absence of toxicity could be due to the low water solubility of BDE-209.

106. In summary, BDE-209 appears not to be acutely toxic to plants and soil organisms and adverse effects are generally observed at high doses (ECB 2002, Sverdrup 2006, Xie 2013 a,b). However, new data suggests that toxic effects of BDE-209 in some instances may occur at lower doses (0.01-1 mg BDE-209/kg) than previously shown (Zhu 2010, Liu 2011a, Zhang 2012, 2013c, Xie 2011, 2013a).

### 2.4.3 Toxicity in birds

107. As highlighted by Chen and Hale (2010), birds exhibit some of the highest concentrations of BDE-209 reported in wildlife and may be at risk for experiencing adverse effects (ECHA 2012a, see also UNEP/POPS/POPRC.10/INF5, Table 5.2). However, a limited number of studies examining adverse effects of BDE-209 exposure to birds are available.

108. In a study on swallows nesting at a WWTP, a positive relationship between egg size and BDE-209 levels were found, however, no significant correlation were found for reproductive parameters (Gilchrist 2014). BDE-209 concentrations were not reported.

109. Sifleet (2009) observed a mortality of up to 98% in embryos of captive chicken injected with a single dose of 80 µg BDE-209 /egg and exposed for 20-days via the yolk sac. The reported LD50 from this study was 44 µg/egg (740 µg kg ww). An assessment undertaken by the EU, revealed that the BDE-209 concentrations typically found in wild bird eggs are around 2-10 times lower than the concentrations that according to Sifleet (2009) induce mortality (ECHA 2012 a). Reported concentrations in bird eggs typically range between 1-100 µg/kg ww, but up to 420 µg/kg ww have been reported (ECHA 2012a). In spite of important study limitations, the EU risk assessment indicated that the margin between exposure levels in wild birds and observed effect levels is not high, especially considering that Sifleet (2009) did not take into account potential sub-lethal effects, and that additional BDE-209 would likely have been assimilated following hatching and desorption of the remaining yolk thereby further increasing exposure.

110. A reduction in body mass was observed in European starlings exposed to BDE-209 by silica implants (van den Steen 2007).

111. Birds are reported to metabolize BDE-209 to lower brominated PBDEs, including some POP-BDEs (BDE-183) (Letcher 2014 ) and exposure to lower brominated PBDEs have been associated with immunomodulatory changes, developmental toxicity, altered reproductive behavior, reduced fertility and reproductive success (for overview see Chen and Hale 2010, Gilchrist 2014, POPRC 2007). In a study on captive American kestrels exposed to DE-71, a commercial penta-PBDE mixture, at environmentally relevant levels in ovo, the low BDE-209 levels present (<2.5 %) was found to be associated with an increase in flight behavior of male kestrels both in the courtship period as well as during brood rearing later in life (Marteinsson 2010). The BDE-209 concentrations measured in this study were not reported. These findings suggest that BDE-209 like other PBDEs may affect behavior in birds and is consistent with research on laboratory rodents where some studies report that BDE-209 causes changes in spontaneous behaviour. For a comprehensive discussion on behavioral effects in rodents see chapter 2.4.4 below.



#### 2.4.4 Toxicity in terrestrial mammals

112. The toxicity of c-decaBDE to terrestrial mammals has mainly been investigated in rodents. Although several effects are reported including reproductive toxicity, data in particular point to neurodevelopmental toxicity and effects on the TH-system. In addition available scientific evidence suggests that BDE-209 either alone or in concert with other PBDEs could act as a developmental neurotoxicant in terrestrial mammals and humans (Dingemans 2011, Messer 2010, Kicinski 2012, Costa and Giordano 2011, HCA 2006, 2012, Gascon 2012, Chao 2011, Kortenkamp 2014).

113. Developmental neurotoxicity is the reported critical endpoint of several PBDEs (Blanco 2013, Branchi 2002, Eriksson 2001, Kuriyama 2005, Rice 2007, 2009, Suvorov 2009, Viberg 2003, 2004, 2007, Xing 2009, Zhang 2013a, UNEP/POPS/POPRC.10/INF5, Table 6.1). Several mechanisms for developmental neurotox effects are proposed, for instance impaired thyroid homeostasis, direct toxicity to neuronal and stem cells, and disturbing neurotransmitter systems (Costa 2014). Developmental neurotoxicity has also been reported for BDE-209 in some studies (Johansson 2008, Viberg 2003, 2007, Rice 2007, 2009, Fujimoto 2011, Heredia 2012, Chen 2014, Reverte 2013, 2014, Buratovic 2014, Mariani 2014) but not by others (Biesemeier 2011). Mariani (2014) reports neurodevelopmental effects of BDE-209 in mice at dose levels relevant for pregnant women. Neurobehavioral effects of BDE-209 in rodents during juvenile development or adulthood have also been reported more recently (Buratovic 2014, Heredia 2012, Chen 2014, Reverte 2013, 2014). For example, long-lasting effects in spatial learning and memory were observed in transgenic mice after postnatal exposure to BDE-209 and reduction in anxiety levels and delayed learning in spatial memory tasks were found in wild type mice (Reverte 2013, Heredia 2012). In another study a single dose of BDE-209, administered orally at post natal day 10, was also observed to cause long-lasting effects on emotional learning and TH-levels in mice carrying two variants of apolipoprotein E, apoE2 and E3 (Reverte 2014). Moreover, Chen (2014) reported that prenatal BDE-209 exposure in rats impaired learning acquisition in a dose dependent manner, and *in vitro* data suggested that this impairment in rat learning acquisition may be linked to effects on brain neurogenesis.

114. The majority of developmental studies with BDE-209 used oral administration, but only a few were designed according to the OECD 426 guideline “Developmental Neurotoxicity Studies” (OECD 2007). In mice and rats administered a single dose of BDE-209 during the “brain growth spurt” period consistent and persistent alterations in behavior, habituation and memory were observed by Viberg (2003, 2007) and Johansson (2008). Other researchers (e.g. Hardy 2008, 2009, Goodman 2009, William and DeSesso 2010) have noted limitations with the former studies, in particular for not using the litter as a basis for the statistical evaluation. Despite this, the US EPA used the studies from Eriksson and Viberg in their derivation of oral reference doses for BDE-209 (as reviewed in US EPA 2008). A study conducted by Rice (2007) did not show a consistent depression in motor activity over time in mice, however their follow-up study showed neurobehavioral long-lasting deficits when tested at 16 months (Rice 2009). Similar to the findings of Viberg (2003, 2007) and Johansson (2008), behavioral effects from developmental BDE-209 exposure appeared to get worse with age. Additional evidence for neurodevelopmental effects of BDE-209 come from several publications that indicate that PBDEs affect the cholinergic system in both mouse and rat brain which could lead to disturbed cognition (learning and memory) (Fischer 2008a, Viberg 2003, 2007, Liang 2010, Buratovic 2014). In further support of findings indicating that BDE-209 can act as a neurotoxicant in mammals, Fujimoto (2011) showed that BDE-209 exposure resulted in reductions in the neural connections between the left and right brain hemispheres (the corpus callosum area) and that it caused irreversible white matter hypoplasia targeting oligodendrocytes in rats. This effect was accompanied by developmental hypothyroidism. In contrast, no clinical signs, or any neurobehavioral changes, effects on startle response, or learning behavior were reported at any dose level by Biesemeier (2011), where motor activity and behavior of BDE-209 exposed rats was assessed at two, four, and six months of age. The Biesemeier study has, however, since been critically evaluated by Shibusaki (2011) who noted the omission of measurement of thyroid-related effects, histopathological parameters on neuronal migration, oligodendroglial development, discussions of the significant decreases in the hemisphere height and decrease in the pons and cortex vertical thicknesses. The Biesemeier study has also been discussed in the Health Canada (HCA 2012) report, where lower LOAEL and NOAEL values have been suggested instead of the value reported in the original study.

115. In line with the findings of Chen (2014), other studies show that BDE-209 can exert direct toxic effects on neuronal cells (reviewed by Dingemans 2011, UNEP/POPS/POPRC.10/INF5 Table 6.2) and interfere with neuronal signalling, neuronal development and induce oxidative stress and apoptosis (Chen 2010b, Huang 2010b, Al-Mousa and Michelangeli 2012, Hendriks 2012, Liang 2010, Xing 2010, Mariani 2014) effects that may lead to neurotoxicity and interfere with learning and memory by affecting long-term potentiation as shown by Viberg (2008) and Xing (2009). BDE-209 is further shown to cause changes in gene expression, intracellular protein levels, and disturbance of

synaptogenesis and cell differentiation (Pacyniak 2007, Viberg 2008, 2009, Zhang 2010b, Song 2013, Mariani 2014).

116. In addition to neurotoxic effects available data point to BDE-209 and lower brominated PBDEs as potential endocrine disruptors. PBDEs structurally resemble THs, and as indicated earlier, effects on the TH system (TH: T4 and T3), along with the above mentioned and more direct toxic effects to neuronal cells is suggested as underlying mechanisms of BDE-209 and PBDE neurotoxicity (Ahmed 2008, Gilbert 2012, Dingemans 2011). In vitro (Hamers 2006, Ibhazehiebo 2011, Ren 2013b) and in vivo studies assessing TH/TSH effects due to BDE-209 administration (UNEP/POPS/POPRC.10/INF5 Table 6.3) show that BDE-209 and other PBDEs interfere with the TH-system, but the results on BDE-209 or c-decaBDE mixtures are not consistent in terms of what effects are observed. For instance, whereas most animal studies report decreased T3 levels following high BDE-209 exposures (Lee 2010b, Chi 2011, Fujimoto 2011), also no change (Wang 2010a, Zhou 2001), and increase in T3 levels has been reported (Van der Ven 2008, Wang 2011c). For T4, animal studies report both decreases in T4 levels at high dose (Rice 2007, Kim 2009, Chi 2011, Fujimoto 2011) as well as no change in T4 level (Tseng 2008, Van der Ven 2008, Wang 2010a, 2011c, Lee 2010b, Zhou 2001). For TSH, two animal studies performed with BDE-209 (Kim 2009, Lee 2010b) both report increased TSH levels at the highest BDE-209 exposures while no effects were reported in adult rats dosed with commercial c-decaBDE mixture DE-83R at doses of 0.3-300 mg/kg/day for four days. Repeated dietary administration of BDE-209 (at a high dose) induced thyroid follicular cell hyperplasia in male mice but not in female mice or in either sex of rats (NTP 1986). Studies reporting significant changes in TH/TSH levels in rats and mice have often administered BDE-209 at doses that are orders of magnitude higher than human exposures. However, studies on rodent offsprings have indicated that low doses of BDE-209 may adversely affect the developing thyroid organ (Kim 2009, Lee 2010b, Fujimoto 2011). The recent WHO/UNEP report (2013) concluded that endocrine disruptors can cause adverse effects at low environmental levels, may display non-monotonic dose-responses, and that the timing of exposure can be more critical than the level of exposure. Thus the observed inconsistencies in reported TH/TSH effects may possibly, at least in part, be explained by differences in the experimental conditions used in these studies.

117. Studies suggest that in utero exposure to BDE-209 at high parental doses may cause reproductive toxicity and lead to developmental abnormalities such as decreased anogenital distance and testicular histopathological changes, sperm-head abnormality, and sperm chromatin DNA damage (Tseng 2006, 2013, van der Ven 2008). Effects on testicular development has also been reported following exposure at post natal days 1-5 at low doses (Miyaso 2012). Reported low-dose effects (0.025 mg/kg, subcutaneously) included reduction in testicular weight, sperm count, elongated spermatid and sertoli cell numbers as well as changes in protein expression and phosphorylation status. Also possible modulation of sex steroids in the male (van der Ven 2008) and female (Hamers 2006, Gregoraszcuk 2008) genital system cannot be entirely ruled out. In contrast, no reproductive toxicity was observed in Sprague-Dawley pregnant female rats exposed to BDE-209 from gestational day 0-19 (Hardy 2002). Similarly, Ernest (2012) reported that a mixture composed of three commercial BDEs (52.1% DE-71, 0.4% DE-79, and 44.2% decaBDE-209) affected liver and thyroid physiology but not male reproductive parameters in exposed rats. Yet, in female mice adrenals, decreased activity in the dehydroepiandrosteron synthesis assay was observed indicating reduced CYP17 enzyme activity and potential effects on steroid hormone production (van der Ven 2008). Further, BDE-209 can inhibit estradiol-sulfotransferase in vitro (Hamers 2006), which could implicate a (local) increase of endogenous estradiol in vivo. In another in vitro study Gregoraszcuk (2008) found that BDE-209 exposure led to increased testosterone-, progesterone- and estradiol secretion in porcine ovary cells, a finding that suggests that BDE-209 can induce preterm luteinization in antral follicles followed by the disruption of ovulation.

118. Oxidative stress and impaired glucose homeostasis has been reported in rats exposed to BDE-209. Dose-related fasting hyperglycemia was observed in adult rats exposed to BDE-209 (0.05 mg/kg) for 8 weeks (Zhang 2013e). Reduced insulin levels and increased levels of tumor necrosis factor- (TNF-alpha) were observed in plasma followed by reduction in the oxidative stress markers glutathione and superoxide dismutase. Dose-dependent morphological changes such as blurring boundaries among pancreatic islet cells were observed (Zhang 2013e). Van der Ven (2008) also observed insulinitis in male rats in a 28-days exposure study however, no differences were observed between the exposure groups. Similar to the reported effects on the steroid and TH systems the observed effects on glucose homeostasis/ insulin levels are suggestive of the endocrine disruptive potential of BDE-209.

119. Immunotoxic effects of BDE-209 have been reported in some studies (Teshima 2008, Watanabe 2008, 2010, Zeng 2014), although immunotoxicity is not regarded as a critical toxic endpoint of PBDEs in general. In the most recent of the studies showing that BDE-209 can act as an

immunotoxicant, reduced qualitative and quantitative CD8 T-cell response was observed in mice after long-term BDE-209 exposure (Zeng 2014). In contrast to these studies, van der Ven (2008) reported no immunotoxic effects on the T cells in rats.

120. Gene mutations are suggested not to occur after exposure to BDE-209 or other PBDEs (Anderson 1990, EFSA 2011, HCA 2012, JETOC 2000, Kirkland 2005, NTP 1986), although recent studies have indicated that BDE-209 may cause DNA damage through the induction of oxidative stress *in vitro* (Ji 2011, Tseng 2011). There is limited evidence for carcinogenicity of BDE-209 in experimental animals (EFSA 2011, HCA 2012). According to the NTP report (1986) there is some evidence at high dose levels for an increase in liver adenoma in rats and liver adenoma and carcinoma in mice, but this may be related to a secondary mode of action (EFSA 2011).

#### 2.4.5 Human toxicity

121. A number of studies have assessed the risk of BDE-209 and other PBDEs to humans. The primary focus has been on assessing the risk for developmental neurotoxicity, which is generally considered as the most critical effect in mammals.

122. The observation, as outlined in section 2.3.4, that exposure takes place already during the early phases of human development i.e. *in utero* via placental transfer and postnatal via mothers milk (e.g. Gómara 2007, Kawashiro 2008, Wu 2010, Miller 2012, Mannetje 2013, Coakley 2013), support the notion that the developmental neurotoxicity observed in mammalian models could have implications also for humans. The risk for implications to human health is further underpinned by epidemiological data. Although having a limited number of individuals, studies have shown an association between BDE-209 levels in cholestrol and lower mental development scores in children 12-18 months of age (Gascon 2012), and that human prenatal or postnatal exposure to BDE-209 delays cognitions and potentially affects neurological development (Chao 2011). Furthermore, several epidemiological studies support that exposure to PBDEs may result in human neurodevelopmental toxicity (Harley 2011, Hoffman 2012, Herbstman 2008, Chevrier 2010, 2011, Gascon 2011, Roze 2009, Eskenazi 2013, Schreiber 2010). Some human studies also observed associations between TH/TSH levels and exposure to BDE-209 or other high congeners such as BDE $\geq$ 183 (Huang 2014, Zota 2011, Wang 2010c, see UNEP/POPS/POPRC.10/INF5 Table 6.4).

123. A risk characterization and a hazard and dose-response assessment of BDE-209 suggested that the daily intake of BDE-209 in the USA and Canada was not likely to result in neurodevelopmental toxicity for infants (Health Canada, 2012, US EPA 2008, 2010). EFSA also concluded that current dietary exposure or the intake of BDE-209 by breast-fed infants does not constitute a health concern in the EU (EFSA 2011). Among the four PBDEs (BDE-47, BDE-99, BDE-153 and BDE-209) investigated by EFSA, a potential health concern with respect to current dietary exposure was only identified for BDE-99 (EFSA 2011). A recent PBDE risk assessment based on oral, dermal, and inhalation exposure of infants 0-5 years of age, indicates no risk for adverse health effects in infants that are restrained in a car seat (Fowles and Margott 2013). However, these assessments do not consider the possibility that several PBDEs could act in concert, inducing additive or synergistic effects as suggested by the available *in vitro* data, or that there may be multiple sources of exposure (e.g. Pellacani 2012, Tagliaferri 2010, Llabjani 2010, Karpeta and Gregoraszczyk 2010, Hallgren and Darnerud 2002, He 2009).

#### 2.4.6 Mixture toxicity and combined effects of multiple stressors

124. In the environment, the exposure and response to toxic compounds as well as the likelihood for adverse effects is influenced by a number of factors besides the inherent properties of the compound. Such effects include environmental temperature, salinity and pH, the physiological status of the organisms, toxicokinetic processes, food web or trophic structure, environmental transport, partitioning, transfer mechanisms and deposition (for overview see Letcher 2010, Schiedek 2007, AMAP 2011, POPRC 2013b). Climate change impact on ecosystems may also have an effect on several of these factors and hazardous chemicals can affect the ability of organisms to adapt to climate changes and endure their physical environments (AMAP 2003, POPRC 2013b, UNEP/AMAP 2011, NCP 2013). In addition, wildlife and humans are typically not only exposed to BDE-209 alone but rather to a complex mixture of multiple PBDEs as well as other POPs (de Wit 2006, 2010, Kortenkamp 2014, EFSA 2011, NCP 2013). Thus when considering the likelihood for adverse effects to humans and wildlife all these factors need to be considered and may provide additional reasons for concern.

125. While the mixture toxicity of BDE-209 and other PBDEs have not been studied experimentally to a large extent, a combination of BDE-47 and -99 was observed to induce synergistic cytotoxic effects in neuronal cells (Tagliaferri 2010). Furthermore, a mixture of PBDE congeners (BDE-47, -99, -100 and -209) at levels detected in human blood had irreversible effect on hormone secretion in ovarian follicles

(Karpeta 2010). The results from this study suggest that combined effects of PBDEs may be much larger than indicated by the sum of the effects of the individual congeners. The presence of other POPs may also affect the toxicity of PBDEs. In an *in vitro* study with binary mixtures of PCBs and PBDEs (BDE-47, -153, -183, or 209), Ljabljani (2010) found that PCB-126 and PBDEs could mutually inhibit each other while PCB-153 and PBDEs jointly could exacerbate the observed biochemical alterations. PBDEs are considered to be potential endocrine disruptors which may act additively at low concentrations UNEP/WHO (2013).

126. Further indications for possible mixture toxicity between PBDEs is provided by Kortenkamp (2014), who evaluated the likelihood and type of combined effects between BDE-209 and other PBDEs to humans and wildlife based on concentration addition using the hazard index approach. The common modes of action are not yet fully established; however, common adverse outcomes are established. The study finds that it can be expected that BDE-209 and other PBDEs may produce combined developmental neurotoxicity both in humans and wildlife (Kortenkamp 2014). For humans, the study shows that by taking into account the combined exposure to PBDEs the tolerable combined exposures are exceeded for all age groups, particularly for small children. Though the authors indicate that further research is necessary, the mixture risk assessment nonetheless indicates that combined exposures to BDE-209 and other PBDE likely pose significant health concerns, especially for young children of age 6 months to 3 years which bear the highest PBDE exposures of all age groups. The study also indicates a risk from combined PBDE exposure to wildlife, including Arctic top predators such as the polar bear. Relative to the other PBDEs BDE-209 was found not to make a significant contribution to the overall risk to wildlife. Overall, the study shows that a consideration of BDE-209 in isolation, without taking into account co-exposure to other BDEs, would underestimate the risk. A similar concern was also indicated by Villanger (2011a,b, 2013) who demonstrated that organohalogen contaminant mixtures including several PBDEs (BDE-28, -47,-99,-100 and -153) may influence the thyroid homeostasis in Arctic marine mammals. Though the impact of BDE-209 was not assessed in these studies and only correlations were reported, the study, similar to the findings of Kortenkamp (2014), raises concerns that PBDEs due to a similar mode of action may act in concert and induce adverse toxic effects and thereby pose a threat to Arctic marine top predators and other wildlife.

127. Available studies also suggest a risk to birds arising from exposure to a combination of different PBDEs and other environmental pollutants. In a field study Plourde (2013) observed that concentrations of the hexa-, hepta-, octa- and BDE-209 congeners (BDE-154, -183, -201 and -209) in liver and BDE-209 in plasma of male ring-billed gulls breeding in the urbanized Montreal region were negatively correlated with trabecular and cortical bone mineral density of the tarsus. The finding suggests that the PBDEs at the levels reported in these birds (i.e. liver BDE-209 2.74-283 ng/g ww and  $\Sigma$ PBDE 26.2-680 ng/g ww, plasma BDE-209 0.70-19.1 ng/g ww and  $\Sigma$ PBDE 3.55-89.2 ng/g ww) can negatively affect bone tissue structure and metabolism in birds. In another study, the combined effects of several organochlorine pesticides, PCBs and PBDEs including BDE-209 and several nonaBDEs were postulated to have contributed to the death of weakened individuals of glaucous gull found in the breeding seasons 2003-2005 on Bjørnøya in the Barents Sea (Sagerup 2009). However, BDE-209 was only detected at very low concentrations in liver and brain (<MDL-2.6 and <MDL-0.01  $\mu$ g/g lipid, in liver and brain respectively), along with other PBDEs, POPs and mercury. In relation to the study by Plourde (2013) which shows effects on bone tissue it is worth noting that common kestrels in urban areas in China were reported to have mean liver concentration of  $2870 \pm 1040$  ng/g lw of BDE-209 (Chen, 2007a) and levels ranging from 4.46 to as high as 1710 ng/g lw have been reported in house sparrows from Helgeland, a remote/ rural site in Norway (Ciesielski 2008). However, as these studies report BDE-209 concentration on a ng/g lw basis they are not directly comparable to the findings of Plourde (2013) who reported BDE-209 concentrations in ng/g ww .

128. Additional concerns relate to multiple stressor effects i.e. possible combined effects between toxic chemicals and other factors. Iodine deficiency, a common condition worldwide (reviewed by Walker 2007), can increase the sensitivity to adverse effects from thyroid-disrupting chemicals such as BDE-209 (see Dingemans 2011). Second, exposures to thyroid-disrupting chemicals, including BDE-209 and other PBDEs, may also impair the ability of vertebrates to adequately respond to the climate change impact on their environment (Hooper 2013, POPRC 2013b). Third, climate change and elevated temperatures may increase degradation, and long-range environmental transport of BDE-209 (POPRC 2013b, IPCC 2007, NCP 2013, Xu 2011, Christensen 2014).

### 3. Synthesis of information

129. C-decaBDE is still produced and used as a flame retardant in many countries. BDE-209, the main component of c-decaBDE, is ubiquitous in the global environment, including biota. Monitoring data provide evidence for environmental emission from a wide range of sources, as well as long-range environmental transport over great distances.

130. High persistency of BDE-209 in soil and sediment is demonstrated in several studies. Reported half-lives in sediment and soil are high and range from >180 days to 50 years, depending on the environmental conditions.

131. Although BDE-209 is persistent in soil, sediment and air, it is known to debrominate to lower brominated PBDEs in the environment and biota. Debromination is indicated as a major concern in a number of assessments as some of the lower brominated PBDEs that are formed are known to be more bioaccumulative, toxic and persistent and to have a greater tendency to undergo long-range environmental transport than the fully brominated BDE-209. Some of the PBDEs formed are also listed POPs. Studies have shown debromination in biota and in environmental matrices. Several PBDE congeners that are not part of c-decaBDE have been identified and are considered to provide evidence for debromination. C-decaBDE and BDE-209 are also a source to highly toxic PBDD/PBDF and hexabromobenzene. PBDD/PBDF are found as impurities in c-decaBDE and may be formed unintentionally during e.g. UV-exposure, industrial-, waste- and recycling operations.

132. Both oceanic and atmospheric processes contribute to the long-range environmental transport of BDE-209, but atmospheric particle transport is believed to be the main mechanism. The estimated atmospheric half-life in air is 94 days, but the life-time can exceed 200 days. In the Arctic and other remote regions BDE-209 is found in various environmental compartments including air, sediment, snow, ice and biota.

133. BDE-209 released to the environment is bioavailable and taken up by organisms, including humans. BDE-209 is widely distributed in the global environment and high body burdens have been demonstrated in some species. Common kestrels in China contained some of the highest BDE-209 levels ever reported in wildlife, while increasing levels have been observed in peregrine falcons from Greenland, North-America and Sweden. Temporal trends indicate that the levels of BDE-209 were increasing in the Arctic atmosphere from 2002-2005 with a doubling time in the range of 3.5-6.2 years. In the period 2009-2013 no temporal trends of BDE-209 in air have been observed.

134. BDE-209 can transfer from mother to off-spring and exposure takes place during early development. Maternal transfer to eggs and offspring has been reported in fish, amphibians, birds and reindeer. In humans, exposure to BDE-209 takes place in the early phases of development in utero via placental transfer and postnatally via mother's milk. In addition infants and toddlers are reported to have higher body burdens of BDE-209 and other PBDEs than adults due to a higher exposure to dust. In humans elevated levels have been reported in electronic dismantler workers, computer technicians, injection workers at electrical application factories and people residing near production and recycling facilities.

135. The equivocity in the available bioaccumulation data largely reflects species differences in uptake, metabolism and elimination, differences in exposure regimes and analytical challenges in measuring BDE-209. The BCF for BDE-209 in fish has been estimated to be <5000 with non-appreciable aqueous uptake predicted due to its large molecular size and low water solubility (<0.1 µg/L at 24 °C). However, the most important exposure route for BDE-209 in aquatic and terrestrial food webs is through the diet, and when considering the bioaccumulative behaviour of BDE-209, calculated or measured BAFs, BMFs and TMFs are believed to give more relevant information than calculated or measured BCFs. Although some studies do not demonstrate BDE-209 bioaccumulation and trophic dilution has been observed (TMF<1), bioaccumulation has been reported for a number of aquatic and terrestrial organisms (BAFs>5000, BMFs>1 and TMF>1).

136. There is evidence that BDE-209 can result in adverse effects to reproductive health and output in fish, earthworm, mouse and rats as well as developmental- and neurotoxic effects in amphibians, rodents and humans. For some organisms such as frogs, mammals, fish and birds adverse effects levels reported for BDE-209 are close to or within the range of reported environmental levels. Measured body burden levels in the mammals and Arctic fish are in the range or above the low dose effects found in laboratory, such as neurodevelopmental effects in fish and mammals and reproductive effects in fish at vulnerable life stages. Due to debromination, organisms are moreover co-exposed to a complex mixture of PBDEs, including the already listed POPs BDEs. On the basis of the established common adverse outcomes, there is a concern that BDE-209 and other PBDEs combined may cause developmental neurotoxicity in both humans and wildlife at environmentally relevant concentrations.

137. There is an increasing concern about endocrine disruptive chemicals since they can cause adverse effects at low environmental levels and the timing of exposure can be more critical than the level of exposure (UNEP/WHO 2013). Available toxicity data shows that BDE-209, similarly to other PBDEs, may act as an endocrine disruptor, and interfere with TH homeostasis in fish, amphibians, rat, mice and humans, and possibly with steroid hormone homeostasis. This fact, combined with debromination and co-exposure to BDE-209 and other similarly acting PBDEs, some of which are listed

POPs, as well as the high persistency of BDE-209 in sediments and soils, increases the likelihood for chronic long-term adverse effects.

**Table 3. POP characteristics of BDE-209, the main component of c-decaBDE**

Criterion	Meets the criterion (Yes/No)	Remark
Persistence	Yes	<p>Dated sediment cores indicate no degradation over a period of almost 30 years (Kohler 2008). Reported half-life in sediment range between 6 and 50 years, with an average of around 14 years at 22°C and under dark conditions (Tokarz 2008).</p> <p>Degradation half-life in sludge-amended soil under aerobic and anaerobic conditions &gt;360 days (Nyholm 2010, 2011, as cited in ECHA 2012 a).</p> <p>No degradation of decaBDE after 180 days in soil samples spiked with BDE-209 (Liu 2011a)</p> <p>Temporally increasing concentrations is observed in some organisms and support the picture of BDE-209 as a persistent substance (e.g. Vorkamp 2005).</p> <p>Debrominates to lower brominated PBDEs with PBT/vPvB and POP properties that are known to be persistent (ECHA 2012a, POPRC 2013a)</p>
Bio-accumulation	Yes	<p>Found in elevated concentrations in top predators (Shaw 2008, 2009, 2012, Voorspoels 2006a, Jenssen 2007, Sørmø 2006, Verreault 2005, Pountney 2014).</p> <p>Log <math>K_{ow}</math> ranging between 6.27 to 12.11 (CMABFRIP 1997, Dinn 2012, ECA 2010, Kelly 2007, Tian 2012, US EPA 2010, Watanabe and Tatsukawa 1990).</p> <p>().</p> <p>BAF&gt;5000 and BMFs&gt;1 in aquatic organisms (Baron 2013, Law 2006, Jenssen 2007, Mo 2012, Shaw 2009, Tomy 2009, Frouin 2013)</p> <p>BMFs &gt;1 in terrestrial organisms (Yu 2011, 2013, She 2013, Wu 2009a).</p> <p>TMFs &gt; 1 in Arctic aquatic organisms (Law 2006).</p> <p>Debrominates to lower brominated PBDEs with PBT/vPvB and POP properties that are known to bioaccumulate (ECHA 2012a, POPRC 2013A)</p> <p>Toxic effects are observed at low and/ or environmentally relevant concentrations in birds, fish and frog (ECHA 2012a, Plourde 2013, Kuo 2010, Qin 2010, Wu 2009a, Liu 2011c)</p>
Potential for Long-Range Environmental Transport	Yes	<p>Widespread in the Arctic environment and biota (de Wit 2006, 2010, ECA 2010, NCP 2013).</p> <p>Monitoring data on BDE-209 levels in moss from Norway show that levels decrease from southern to northern Norway (Mariussen 2008)</p> <p>When bound to fine air particles BDE-209 can remain airborne for hours or days, provided it is not removed by wet deposition (Wilford 2008, Meyer 2012).</p> <p>The estimated atmospheric half-life in air is 94 days in air, but the life-time can be &gt; 200 days (Breivik 2006, Raff and Hites 2007).</p> <p>DecaBDE debrominates to lower brominated PBDEs with PBT/vPvB and POP properties that are known to undergo long-range environmental transport (ECHA 2012a, POPRC 2013a)</p>
Adverse effects	Yes	<p>BDE-209 exerts reproductive, developmental, endocrine and neurotoxic effects in aquatic organisms, mammals and birds. Effects on growth, survival and mortality are also reported. Key data include:</p> <ul style="list-style-type: none"> <li>▪ Delayed metamorphosis in tadpoles with a tentative NOEC below 1 µg/L (Qin 2010 in ECHA 2012a).</li> <li>▪ TH disruptive effects and mortality in fathead minnow chronic 28 d-LOEL of ~3 ng/g BDE-209 bw/day or 0.41 ng/g ww food (Noyes 2013).</li> <li>▪ Mortality of up to 98% in chicken embryos after 20 days following a single egg injection with BDE-209 (LD<sub>50</sub> of 44 µg/ egg or 740 µg/ kg ww, Sifleet 2009 in ECHA 2012a).</li> <li>▪ Developmental neurotoxicity in rodents (e.g. Johansson 2008, Viberg 2003, 2007, Rice 2009, Fujimoto 2011, Heredia 2012, Reverte 2013, 2014, Buratovic 2014).</li> </ul> <p>Epidemiological association for cognitive developmental effects in humans with decaBDE exposure (Gascon 2012, Chao 2011).</p> <ul style="list-style-type: none"> <li>▪ Several studies suggest that adverse effects may occur at BDE-209 concentrations at or close to environmentally relevant levels in fish, frogs, birds and mammals (Kuo 2010, Wu 2009a, Liu 2011c, Qin 2010, Noyes 2013, Sifleet 2009, ECHA 2012a, Pountney 2014, Tomy 2008, 2009).</li> <li>▪ Debromination to lower brominated PBDEs with PBT/vPvB and POP properties that are known to have significant adverse effects (ECHA 2012a, POPRC 2013a, POPRC6 and POPRC7).</li> <li>▪ Potential risk to humans and wildlife resulting from combined effects between BDE-209 and other PBDEs at environmentally relevant concentrations (e.g. Kortenkamp 2014, Plourde 2013).</li> </ul>

		<ul style="list-style-type: none"> <li>▪ Potential risk for low-dose effects during sensitive developmental periods as a result of endocrine disruption (UNEP/WHO 2012, Johansson 2008, Viberg 2003, 2007, Rice 2009, Fujimoto 2011, Heredia 2012, Reverte 2013, 2014, Buratovic 2014, Noyes 2013).</li> </ul>
--	--	--

#### 4. Concluding statement

138. C-decaBDE is a synthetic substance with no known natural occurrence that is used as a flame retardant in many applications worldwide. Releases of c-decaBDE to the environment are continuing in all regions investigated. BDE-209 (or decaBDE), the main constituent of c-decaBDE is persistent in the environment and bioaccumulates and biomagnifies in several species of fish, birds and mammals as well as in food webs. There is evidence for adverse effects to critical endpoints including reproduction, survival, nerve- and endocrine systems. C decaBDE is also degraded to lower brominated PBDEs, with known PBT/vPvB and POP properties. Lower brominated congeners contribute in the outcome of BDE-209 toxicity. Due to debromination and historical reservoirs of c-penta- and c-octaBDE congeners in the environment, organisms are exposed to a complex mixture of PBDEs that in combination pose a higher risk than BDE-209 alone. Measured BDE-209 levels in some species of biota, including higher trophic levels such as birds and mammals in source and remote regions are close to reported effect concentrations and indicate that BDE-209 together with other PBDEs pose a significant concern for human health and the environment. C-decaBDE with its main constituent BDE-209 is likely, therefore, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted.

## References

- Abdallah MA, Tilston E, Harrad S, Collins C (2012). In vitro assessment of the bioaccessibility of brominated flame retardants in indoor dust using a colon extended model of the human gastrointestinal tract. *J Environ Monit.* 14(12):3276-83.
- ACAP, Arctic Contaminants Action Programme (2007). Final Report of Phase I of the ACAP Project on Brominated Flame Retardants (BFRs) Phase I: Inventory of sources and identification of BFR alternatives and management strategies. AMAP Report 2007:6, SFT Report TA-2440/2008.
- ACHS, Advisory Committee on Hazardous Substances 2010. ACHS opinion on decabrominated diphenyl ether (decaBDE). Final Version (23rd September 2010). Department for Environment, Food and Rural Affairs, United Kingdom, p.1-63.
- Ahn MY, Filley TR, Jafvert CT, Nies L, Hua I, Bezares-Cruz J (2006). Photodegradation of decabromodiphenyl ether adsorbed onto clay minerals, metal oxides, and sediment. *Environ Sci Technol.* 40(1):215-20.
- Ahmed, O. M., A. W. El-Gareib, A. M. El-Bakry, S. M. Abd El-Tawab and R. G. Ahmed (2008). "Thyroid hormones states and brain development interactions." *Int J Dev Neurosci* 26(2): 147-209.
- Allan, I., Aas, W., Langford, K., Christensen, G., Green, N. W., Breivik, K., Bæk, K., and Ranneklev, S. (2012). Passive air and water sampling at Andøya, Bjørnøya og Jan Mayen. Klima og forurensningsdirektoratet (Klif).  
[http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Overvaking\\_av\\_miljogifter\\_og\\_beregning\\_av\\_tilforsler\\_til\\_norske\\_kyst\\_og\\_havomrader\\_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet\\_2011\\_Passive\\_air\\_and\\_water\\_sampling\\_at\\_Andoya\\_Bjornoya\\_and\\_Jan\\_Mayen/](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Overvaking_av_miljogifter_og_beregning_av_tilforsler_til_norske_kyst_og_havomrader_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet_2011_Passive_air_and_water_sampling_at_Andoya_Bjornoya_and_Jan_Mayen/)
- Allen JG, Sumner AL, Nishioka MG, Vallarino J, Turner DJ, Saltman HK, Spengler JD (2013). Air concentrations of PBDEs on in-flight airplanes and assessment of flight crew inhalation exposure. *J Expo Sci Environ Epidemiol.* 23(4):337-42.
- Al-Mousa, F. and F. Michelangeli (2012). "Some commonly used brominated flame retardants cause Ca<sup>2+</sup>-ATPase inhibition, beta-amyloid peptide release and apoptosis in SH-SY5Y neuronal cells." *PLoS one* 7: e33059.
- AMAP. Arctic Monitoring and Assessment Programme (2009). Arctic Pollution 2009, Oslo. 83 pp.
- Anderson, B. E., E. Zeiger, M. D. Shelby, M. A. Resnick, D. K. Gulati, J. L. Ivett and K. S. Loveday (1990). Chromosome aberration and sister chromatid exchange test results with 42 chemicals." *Environmental and molecular mutagenesis* 16 Suppl 1: 55-137.
- Arinaitwe K, Muir DCG, Kiremire BT, Fellin P, Li H, Teixeira C (2014). Polybrominated diphenyl ethers and alternative flame retardants in air and precipitation samples from the northern Lake Victoria region, East Africa. *Environ Sci Technol.* 48: 1458-16-44.
- Arellano L, Fernández P, Tatosova J, Stuchlik E, Grimalt JO (2011). Long-range transported atmospheric pollutants in snowpacks accumulated at different altitudes in the Tatra Mountains (Slovakia). *Environ Sci Technol.* 45(21): 9268-75.
- Arnot JA, MacKay D, Parkerton TF, Zaleski RT, Warren CS (2010). Multimedia modeling of human exposure to chemical substances; The roles of food web biomagnification and biotransformation. *Environmental Toxicology and Chemistry*, Vol. 29, No. 1, pp. 45–55
- Arnot JA, Gobas F (2006). A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environ Rev* 14(4):257-297.
- Arnot JA, Gobas F (2003). A generic QSAR for assessing the bioaccumulation potential of organic chemicals in aquatic food webs. *Qsar Comb Sci* 22(3):337-345.
- Balch, G. C., L. A. Velez-Espino (2006). "Inhibition of metamorphosis in tadpoles of *Xenopus laevis* exposed to polybrominated diphenyl ethers (PBDEs)." *Chemosphere* 64(2): 328-338.
- Baron E, Rudolph I, Chiang G, Barra R, Eljarrat E, Barcelo D (2013). Occurrence and behavior of natural and anthropogenic (emerging and historical) halogenated compounds in marine biota from the Coast of Concepcion (Chile). *Sci Total Environ* 461:258-264.
- Besis A, Samara C (2012). Polybrominated diphenyl ethers (PBDEs) in the indoor and outdoor environments - A review on occurrence and human exposure. *Environ Pollut* 169:217-229.
- Bhavsar SP, Gandhi N, Gewurtz SB, Tomy GT (2008). Fate of PBDEs in juvenile lake trout estimated using a dynamic multichemical fish model. *Environ Sci Technol* 42:3724–31.



- Bi XH, Thomas GO, Jones KC, Qu WY, Sheng GY, Martin FL, (2007). Exposure of electronics dismantling workers to polybrominated diphenyl ethers, polychlorinated biphenyls, and organochlorine pesticides in South China. *Environ Sci Technol* 41(16):5647-5653.
- Biesemeier, J. a., M. J. Beck, H. Silberberg, N. R. Myers, J. M. Ariano, A. Radovsky, L. Freshwater, D. W. Sved, S. Jacobi, D. G. Stump, M. L. Hardy and T. Stedeford (2011). "An oral developmental neurotoxicity study of decabromodiphenyl ether (DecaBDE) in rats." *Birth defects research. Part B, Developmental and reproductive toxicology* 92: 17-35.
- Biesemeier, J. A., M. J. Beck, H. Silberberg, N. R. Myers, J. M. Ariano, E. S. Bodle, D. W. Sved, S. Jacobi, D. G. Stump, M. Hardy and T. Stedeford (2010). "Effects of dose, administration route, and/or vehicle on decabromodiphenyl ether concentrations in plasma of maternal, fetal, and neonatal rats and in milk of maternal rats." *Drug Metabolism and Disposition* 38: 1648-1654.
- Björklund, J. A., K. Thuresson, (2012). "Indoor Air Is a Significant Source of Tri-decabrominated Diphenyl Ethers to Outdoor Air via Ventilation Systems." *Environmental Science & Technology* 46(11): 5876-5884.
- Blanco, J., M. Mulero, L. Heredia, A. Pujol, J. L. Domingo and D. J. Sánchez (2013). "Perinatal exposure to BDE-99 causes learning disorders and decreases serum thyroid hormone levels and BDNF gene expression in hippocampus in rat offspring." *Toxicology* 308: 122-128.
- Boitsov, S. and Klungsøyr, J. (2013). Undersøkelser av organiske miljøgifter i sedimenter fra MAREANO-området 2011. Bergen Havforskningsinstituttet. p. 1-40.  
[http://www.imr.no/filarkiv/2013/04/rapport\\_1\\_13.pdf/nb-no](http://www.imr.no/filarkiv/2013/04/rapport_1_13.pdf/nb-no)
- Borgå K, Kidd KA, Muir DC, Berglund O, Conder JM, Gobas FA, Kucklick J, Malm O, Powell DE (2012). Trophic magnification factors: considerations of ecology, ecosystems, and study design. *Integr Environ Assess Manag.* 8(1): 64-84.
- Branchi, I., E. Alleva and L. G. Costa (2002). "Effects of perinatal exposure to a polybrominated diphenyl ether (PBDE 99) on mouse neurobehavioural development." *Neurotoxicology* 23: 375-384
- Breivik K, Wania F, Muir DC, Alaee M, Backus S (2006). Pacepavicius G. Empirical and modeling evidence of the long-range atmospheric transport of decabromodiphenyl ether. *Environ Sci Technol.* 40(15):4612-8.
- Breivik K, Sweetman A, Pacyna J, Jones K (2002). Towards a global historical emission inventory for selected PCB congeners – a mass balance approach: 1. Global production and consumption. *Sci Total Environ* 290:181-198
- BSEF, Bromine Science and Environmental Forum (2013). About decabromo diphenyl ether (decaBDE), <http://www.bsef.com/our-substances/deca-bde/about-deca-bde> (accessed in April 2013)
- BSEF, Bromine Science and Environmental Forum (2012). Brominated flame retardant: decabromodiphenyl ether fact sheet. 2012; 2010.
- Brommer S, Harrad S, van den Eede N, Covaci A (2012). Concentrations of organophosphate esters and brominated flame retardants in German indoor dust samples. *J Environ Monit*;14:2482-2487.
- Bureau S, Zebühr Y, Broman D, Ishaq R. (2006). Biomagnification of PBDEs and PCBs in food webs from the Baltic Sea and northern Atlantic Ocean. *Sci Total Environ* 366:659-672.
- Bureau S, Zebühr Y, Broman D, Ishaq R. (2004). Biomagnification of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) studied in pike (*Esox lucius*), perch (*perca fluviatilis*) and roach (*Rutilus rutilus*) from the Baltic Sea. *Chemosphere* 55:1043-1052.
- Buratovic S, Viberg H, Fredriksson A, Eriksson P. (2014). Developmental exposure to the polybrominated diphenyl ether PBDE 209: Neurobehavioural and neuroprotein analysis in adult male and female mice. *Environ Toxicol Pharmacol.* 38, 570-85.
- Buser AM, Morf LS, Taverna R, Bader HP, Scheidegger R (2007a). Temporal behaviour of the anthropogenic metabolism of selected brominated flame retardants: Emissions to the environment. BFR 2007, 4th International Workshop on Brominated Flame Retardants, Amsterdam, The Netherlands, 24-27 April, 2007.
- Buser AM, Morf LS, Taverna R, Bader HP, Scheidegger R (2007b). Comparison of BDE-209 concentrations modelled in a dynamic substance flow analysis for Switzerland and field data B. *Organohalogen Compounds*, 69, 2748-2751.

- Byun GH, Moon HB, Choi JH, Hwang J, Kang CK. (2013). Biomagnification of persistent chlorinated and brominated contaminants in food web components of the Yellow Sea. *Mar Pollut Bull* 73(1):210-219.
- Cai, Y., W. Zhang, J. Hu, G. Sheng, D. Chen and J. Fu (2011). "Characterization of maternal transfer of decabromodiphenyl ether (BDE-209) administered to pregnant Sprague-Dawley rats." *Reprod Toxicol* 31: 106-110.
- Chabot-Giguere, B., R. J. Letcher, and J. Verreault. (2013). In vitro biotransformation of decabromodiphenyl ether (BDE-209) and Dechlorane Plus flame retardants: a case study of ring-billed gull breeding in a pollution hotspot in the St. Lawrence River, Canada. *Environ Int* 55:101-108.
- Chao, H.-R., T.-C. Tsou, H.-L. Huang and G.-P. Chang-Chien (2011). Levels of breast milk PBDEs from southern Taiwan and their potential impact on neurodevelopment. *Pediatric research* 70: 596-600.
- Chao HR, Shy CG, Wang SL, Chen SCC, Koh TW, Chen FA et al (2010). Impact of non-occupational exposure to polybrominated diphenyl ethers on menstruation characteristics of reproductive-age females. *Environ Int*;36:728–735.
- Chen YH, Li ZH, Tan Y, Zhang CF, Chen JS, He F, Yu YH, Chen DJ (2014). Prenatal exposure to decabrominated diphenyl ether impairs learning ability by altering neural stem cell viability, apoptosis, and differentiation in rat hippocampus. *Hum Exp Toxicol* Feb 24 [Epub ahead of print] PubMed PMID: 24567298 .
- Chen J, Chen LL, Liu DY, Zhang GS (2013a). Polybrominated Diphenyl Ethers Contamination in Marine Organisms of Yantai Coast, Northern Yellow Sea of China. *B Environ Contam Tox* 90(6):679-683.
- Chen D, Martin P, Burgess NM, Champoux L, Elliott JE, Forsyth DJ, (2013b). European Starlings (*Sturnus vulgaris*) Suggest That Landfills Are an Important Source of Bioaccumulative Flame Retardants to Canadian Terrestrial Ecosystems. *Environ Sci Technol* 47(21):12238-12247.
- Chen Q, Yu LQ, Yang LH, Zhou BS (2012a). Bioconcentration and metabolism of decabromodiphenyl ether (BDE-209) result in thyroid endocrine disruption in zebrafish larvae. *Aquat Toxicol* 110(141-148).
- Chen D, Letcher RJ, Martin P (2012b). Flame retardants in eggs of American kestrels and European starlings from southern Lake Ontario region (North America). *J Environ Monitor* 14(11):2870-2876.
- Chen D, Letcher RJ, Burgess NM, Champoux L, Elliott JE, Hebert CE, Martin P, Wayland M, Chip Weseloh DV, Wilson L (2012d). Flame retardants in eggs of four gull species (*Laridae*) from breeding sites spanning Atlantic to Pacific Canada. *Environ Pollut*. 168: 1-9.
- Chen, D. and Hale, R. C (2010). A global review of polybrominated diphenyl ether flame retardant contamination in birds. *Environment International*, 36, 800–811.
- Chen D, Hale RC, Watts BD, La Guardia MJ, Harvey E, Mojica EK (2010a). Species-specific accumulation of polybrominated diphenyl ether flame retardants in birds of prey from the Chesapeake Bay region, USA. *Environ Pollut* 158(5):1883-1889.
- Chen, J., C. Liufu, W. Sun, X. Sun and D. Chen (2010b). Assessment of the neurotoxic mechanisms of decabrominated diphenyl ether (PBDE-209) in primary cultured neonatal rat hippocampal neurons includes alterations in second messenger signaling and oxidative stress. *Toxicology Letters* 192: 431-439.
- Chen S, Ma YJ, Wang J, Chen D, Luo XJ, Mai BX (2009). Brominated flame retardants in children's toys: Concentration, composition, and children's exposure and risk assessment. *Environ Sci Technol*; 43:4200–4206.
- Chen D, La Guardia MJ, Harvey E, Amaral M, Wohlfort K, Hale RC (2008). Polybrominated Diphenyl Ethers in Peregrine Falcon (*Falco peregrinus*) Eggs from the Northeastern US. *Environ Sci Technol* 42(20):7594-7600.
- Chen D, Mai B, Song J, Sun Q, Luo Y, Luo X, ( 2007a). Polybrominated Diphenyl Ethers in Birds of Prey from Northern China. *Environ Sci Technol* 41(6):1828-1833.
- Chen SJ, Luo XJ, Lin Z, Luo Y, Li KC, Peng XZ, Mai BX, Ran Y, Zeng EY (2007b). Time trends of polybrominated diphenyl ethers in sediment cores from the Pearl River Estuary, South China. *Environ Sci Technol* 41(16): 5595-5600.
- Chevrier, J., K. G. Harley, A. Bradman, A. Sjödin and B. Eskenazi (2011). "Prenatal exposure to polybrominated

- diphenyl ether flame retardants and neonatal thyroid-stimulating hormone levels in the CHAMACOS study." *American journal of epidemiology* 174: 1166-1174.
- Chevrier, J., K. G. Harley, A. Bradman, M. Gharbi, A. Sjödin and B. Eskenazi (2010). "Polybrominated diphenyl ether (PBDE) flame retardants and thyroid hormone during pregnancy." *Environmental health perspectives* 118: 1444-1449.
- Chi, Y., H. Xia, M. Su, P. Song, X. Qi, Y. Cui, Y. Cao, T. Chen, Y. Qiu, A. Zhao, X. Ma, X. Zheng and W. Jia (2011). "Metabonomic phenotyping reveals an embryotoxicity of deca-brominated diphenyl ether in mice." *Chemical research in toxicology* 24: 1976-1983.
- Christiansson A, Eriksson J, Teelechiel D, Bergman A. (2009). Identification and quantification of products formed via photolysis of decabromodiphenyl ether. *Environ Sci Pollut Res Int* 16(3):312-21.
- Christensen JH, et al. (2014) Climate phenomena and their relevance for future regional climate change. *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Stocker TF, et al. (Cambridge University Press, Cambridge, UK)
- Christensen JR, Macduffee M, Macdonald RW, Whiticar M, Ross PS (2005). Persistent organic pollutants in British Columbia grizzly bears: Consequence of divergent diets. *Environ Sci Technol* 39(18):6952-6960.
- Christensen JH, Groth BS, Vikelsøe J., Vorkamp K. Polybrominated diphenyl ethers (PBDEs) in sewage sludge and wastewater. NERI Technical Report No. 481, (2003). 28 pp. (Annex E submission by Denmark).
- Ciesielski T, Jenssen BM, Pedersen HC, Bæk K, Skaare JU, Ringsby TH (2008). Decabrominated diphenyl ether in ptarmigans and sparrows in Norway. *Organohalogen Compounds*, 70;001181-001184.
- Ciparis S and Hale, R.C., (2005). Bioavailability of polybrominated diphenyl ether flame retardants in biosolids and spiked sediment to the aquatic oligochaete, *lumbriculus variegatus* *Environ. Tox. Chem.*, 24 (4): 916–925.
- CPAN, Climate and Pollution Agency, Norway (2012a). Forbidden brominated flame retardand in work wear. Information and update from the Climate and Pollution Agency TA-2971/2012 (in Norwegian only). <http://www.miljodirektoratet.no/old/klif/publikasjoner/2971/ta2971.pdf>
- CPAN, Climate and Pollution Agency, Norway (2012b). Tilførselsprogrammet 2011. Overvåking av tilførsler og miljøtilstand i Norskehavet. p. 1-227. [http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Overvaking\\_av\\_miljogifter\\_og\\_beregning\\_av\\_tilforsler\\_til\\_norske\\_kyst\\_og\\_havomrader\\_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet\\_2011\\_Overvaking\\_av\\_tilforsler\\_og\\_miljotilstand\\_i\\_Norskehavet/](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Overvaking_av_miljogifter_og_beregning_av_tilforsler_til_norske_kyst_og_havomrader_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet_2011_Overvaking_av_tilforsler_og_miljotilstand_i_Norskehavet/) Authors: Green, Normann W., Heldal, H. E., Måge, Amund, Aas, Wenche, Gafvert, T., Schrum, C., Boitsov, S., Breivik Knut, Iosjpe, M., Yakushev, E., Skogen, M., Høgåsen, T., Eckhardt, S., Christiansen, A. B., Daae, K. L., Durand, D., Ledang, A. B., and Jaccard, P. F.
- CPAN, Climate and Pollution Agency, Norway (2010). Overvåking av tilførsler og miljøtilstand i Barentshavet og Lofotenområdet. Oslo Klima- og forurensningsdirektoratet (Klif). p. 1-246. [http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Overvaking\\_av\\_miljogifter\\_og\\_beregning\\_av\\_tilforsler\\_til\\_norske\\_kyst\\_og\\_havomrader\\_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet\\_2009\\_Overvaking\\_av\\_tilforsler\\_og/](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Overvaking_av_miljogifter_og_beregning_av_tilforsler_til_norske_kyst_og_havomrader_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet_2009_Overvaking_av_tilforsler_og/) Authors: Green, Norman W., Molvær, J., Kaste, Ø., Schrum, C., Yakushev, E., Sørensen, K., Allan, I., Høgåsen, T., Christiansen, A. B., Heldal, H. E., Klungsoyr, Jarle, Boitsov, Stepa, Børsheim, K. Y., Måge, Amund, Julshamn, Kaare, Aas, Wenche, Braathen, Ole-Anders, Breivik, Knut, Eckhardt, S., Rudjord, A. L., Iosjpe, M., and Brungot, A. L. 2010. Tilførselsprogrammet 2009.
- CMABFRIP, Chemical Manufacturers Association Brominated Flame Retardant Industry Panel (1997). Decabromodiphenyl oxide (DBDPO): determination of n-octanol/water partition coefficient. Chemical Manufacturers Association Brominated Flame Retardant Panel. Wildlife International Ltd. Project Number 439C-101.
- Coakley JD, Harrad SJ, Goosey E, Ali N, Dirtu AC, Van den Eede N, Covaci A, Douwes J, Mannetje A' (2013). Concentrations of polybrominated diphenyl ethers in matched samples of indoor dust and breast milk in New Zealand. *Environ Int.*;59:255-61.
- Costa LG, Giordano G (2011). Is decabromodiphenyl ether (BDE-209) a developmental neurotoxicant? *Neurotoxicology*; 32:9–24.

- Costa LG, de Laat R, Tagliaferri S, Pellacani C (2014). A mechanistic view of polybrominated diphenyl ether (PBDE) developmental neurotoxicity. *Toxicol Lett*. Oct 15;230(2):282-94.
- Cousins AP, Holmgren T, Remberger M.(2014) Emissions of two phthalate esters and BDE 209 to indoor air and their impact on urban air quality. *Sci Total Environ*. 470-471:527-35.
- Covaci, A.; Voorspoels, S.; de Boer, J (2003). Determination of brominated flame retardants, with emphasis on polybrominated diphenyl ethers (PBDEs) in environmental and human samples: A review. *Environ. Int.*, 29, 735–756
- Crosse, JD, Shore RF, Wadsworth RA, Jones KC, and Pereira MGR. (2012). Long-term trends in PBDEs in sparrowhawk (*Accipiter nisus*) eggs indicate sustained contamination of UK terrestrial ecosystems. *Environ Sci. Technol*. 46:13504-13511.
- Danon-Schaffer MN, Gorgy T, Li L, Grace JR. Determination of PBDEs in Canadian North landfill leachate and soils. Final Report – September 2007. Vancouver, BC, Canada: Environmental Damages Fund, Environment Canada, University of British Columbia; 2007. 139 pp.
- de Boer, J.; Wells, D. E (2006). Pitfalls in the analysis of brominated flame retardants in environmental, human and food samples, including results of three international interlaboratory studies. *Trends Anal. Chem.*, 25, 364–372.
- De Bruyn AMH, Meloche LM, Lowe CJ (2009). Patterns of Bioaccumulation of Polybrominated Diphenyl Ether and Polychlorinated Biphenyl Congeners in Marine Mussels. *Environmental Science & Technology* 43(10):3700-3704.
- Deng, D., J. Guo, G. Sun, X. Chen, M. Qiu, and M. Xu. 2011. Aerobic debromination of deca-BDE: Isolation and characterization of an indigenous isolate from a PBDE contaminated sediment. *International Biodeterioration & Biodegradation* 65:465-469.
- De Wit CA, Herzke D, Vorkamp K. (2010). Brominated flame retardants in the Arctic environment — trends and new candidates. *Sci Total Environ* 408(15):2885-2918.
- De Wit, C. A., M. Alae (2006). "Levels and trends of brominated flame retardants in the Arctic." *Chemosphere* 64(2): 209-233.
- de Wit CA (2002) An overview of brominated flame retardants in the environment. *Chemosphere* 46:583–624
- De Wit C, Ulla Sellström U, Nadja Lundgren N, Mats Tysklind M (2005). Higher brominated diphenyl ethers in earthworms and reference and sewage-sludge amended soils. *Organohalogen Compounds - Volume 67*
- Dickhut RM, Cincinelli A, Cochran M, Kylin H (2012). Aerosol-mediated transport and deposition of brominated diphenyl ethers to Antarctica. *Environ Sci Technol*. 46(6):3135-40.
- Dingemans, M. M., M. van den Berg, et. al. (2011). "Neurotoxicity of brominated flame retardants: (in) direct effects of parent and hydroxylated polybrominated diphenyl ethers on the (developing) nervous system." *Environ Health Perspect* 119(7): 900-907.
- Dinn PM, Johannessen SC, Ross PS, Macdonald RW, Whitarcar MJ, Lowe CJ, van Roodselaar A (2012). PBDE and PCB accumulation in benthos near marine wastewater outfalls: The role of sediment organic carbon. *Environ Pollut* 171: 241-248.
- Du W, Ji R, Sun Y, et. al. (2013). Fate and Ecological Effects of Decabromodiphenyl Ether in a Field Lysimeter. *Environmental Science & Technology* 47:9167-9174.
- Earnshaw, M. R., K. C. Jones, (2013). Estimating European historical production, consumption and atmospheric emissions of decabromodiphenyl ether. *Sci Total Environ* 447: 133-142.
- ECA, Environment Canada (2013). Risk Management of DecaBDE: Commitment to Voluntary Phase-Out Exports to Canada. <http://www.ec.gc.ca/toxiques-toxics/default.asp?lang=En&n=F64D6E3B-1&xml=F64D6E3B-0328-4C11-A9E4-790D053E42A1>
- ECA, Environment Canada (2011). Environmental Monitoring and Surveillance in Support of the Chemicals Management Plan. PBDEs in the Canadian Environment. Fact sheet.p. 1-10.
- ECA, Environment Canada (2010). Ecological State of the Science Report on Decabromodiphenyl Ether (decaBDE). Bioaccumulation and Transformation. Available at: [http://www.ec.gc.ca/lcpe-cepa/documents/substances/decabde/ess\\_report\\_decabde-eng.pdf](http://www.ec.gc.ca/lcpe-cepa/documents/substances/decabde/ess_report_decabde-eng.pdf)
- ECA, Environment Canada (2008). The Polybrominated Diphenyl Ethers Regulations (SOR/2008-218) under the Canadian Environmental Protection Act, 1999.

- ECA, Environment Canada (2006). Canadian Environmental Protection Act, 1999. Ecological Screening Assessment Report on polybrominated diphenyl ethers (PBDEs).
- ECA, Environment Canada. (2003). Polybrominated Diphenyl Ether (PBDE) Brominated Flame Retardant (BFR) Report of Section 71 (CEPA, 1999) Notice with Respect to Certain Substances on the Domestic Substances List (DSL).
- Ebert, J. and M. Bahadir (2003). "Formation of PBDD/F from flame-retarded plastic materials under thermal stress." *Environment International* 29(6): 711-716.
- European Commission (2007). Update of the risk assessment of bis(pentabromophenyl) ether. Final Draft of October 2007. European Chemicals Bureau.
- ECB, European Chemicals Bureau (2004). Update of the Risk assessment of bis(pentabromophenyl) ether (decabromodiphenyl ether) CAS Number. 1163-19-5, EINECS Number. 214-604-9, Final Environmental Draft of May 2004, 294 pp.
- ECB, European Chemicals Bureau (2002). European Union Risk Assessment Report: Bis(pentabromophenyl) ether. 1st priority list, Volume 17, Luxemburg: European Communities.
- ECHA, European Chemicals Agency, (2013a). Draft background document for Bis(pentabromophenyl)ether (decabromodiphenyl ether; decaBDE). Document developed in the context of ECHA's fifth Recommendation for the inclusion of substances in Annex XIV. 24 June 2013
- ECHA, European Chemicals Agency (2013b). ECHA dissemination portal. [Online] Available at: <http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances> [Accessed 12 November 2013].
- ECHA European Chemicals Agency (2012a). Support Document Bis(pentabromophenyl) ether [decabromodiphenyl ether] (Member State Committee, 29 November 2012).
- ECHA, European Chemicals Agency (2012b). Agreement of the member state committee On the identification of bis(pentabromophenyl) ether [decabromodiphenyl ether], (Member State Committee, 29 November 2012).
- ECHA, European Chemicals Agency (2012c). Annex XV dossier. Proposal for Identification of a PBT/vPvB Substance. Bis(pentabromophenyl)ether (decabromodiphenyl ether; decaBDE). July 2012-final. Submitted by the United Kingdom, August 2012.  
[http://echa.europa.eu/documents/10162/13638/SVHC\\_AXVREP\\_pub\\_EC\\_214\\_604\\_9\\_decabromodiphenylether\\_en.pdf](http://echa.europa.eu/documents/10162/13638/SVHC_AXVREP_pub_EC_214_604_9_decabromodiphenylether_en.pdf)
- ECHA (2012d) – "Responses to comments" documents. Document compiled by UK from the commenting period 03/09/2012 - 18/10/2012 on the proposal to identify the substance Bis(pentabromophenyl)ether [decabromodiphenyl ether; decaBDE] as a Substance of Very High Concern. [http://echa.europa.eu/identification-of-svhc-/substance/2403/search/+/del/20/col/ADOPTIONDATEMSCA\\_A/type/desc/pre/2/view](http://echa.europa.eu/identification-of-svhc-/substance/2403/search/+/del/20/col/ADOPTIONDATEMSCA_A/type/desc/pre/2/view)
- EFSA, European Food Safety Authority Panel(2011). European Food Safety Authority Panel on Contaminants in the Food Chain (CONTAM). Scientific Opinion on Polybrominated Diphenyl Ethers (PBDEs) in Food. *EFSA Journal*, 9 (5), 2156. doi.10.2903/j.efsa.2011.2156. Available online: <http://www.efsa.europa.eu/en/efsajournal/doc/2156.pdf>
- El Dareer, S. M., J. R. Kalin, K. F. Tillery and D. L. Hill (1987). Disposition of decabromobiphenyl ether in rats dosed intravenously or by feeding. *Journal of Toxicology and Environmental Health*. 22: 405-415.
- Eljarrat E, Marsh G, Labandeira A, Barcelo D, (2008). Effect of sewage sludges contaminated with polybrominated diphenylethers on agricultural soils. *Chemosphere* 71: 1079–1086
- Eljarrat E, Labandeira A, Marsh G, Raldua D, Barcelo´ D (2007). Decabrominated diphenyl ether in river fish and sediment samples collected downstream an industrial park. *Chemosphere* 69: 1278–1286
- Eljarrat, E., de la Cal, A., Lazzazabal, D., Fabrellas, B., Fernandez-Alba, A. R., Borrull, F., Marce, R. M. and Barcelo, D. (2005). "Occurrence of polybrominated diphenyl ethers, polychlorinated dibenzo-p-dioxins, dibenzofurans and biphenyls in coastal sediments from Spain." *Environmental Pollution*, 136, 493-501.
- Eljarrat, E., de la Cal, A., Raldua, D., Duran, C. and Barcelo, D. (2004). "Occurrence and bioavailability of polybrominated diphenyl ethers and hexabromocyclododecane in sediment and fish from the Cinca River, a Tributary of the Ebro River (Spain)." *Environmental Science and Technology*, 38, 2603-2608.

- Eriksson J, Green N, Marsh G, Bergman A (2004). Photochemical decomposition of 15 polybrominated diphenyl ether congeners in methanol/water. *Environ Sci Technol.*38(11):3119-25
- Eriksson, P., E. Jakobsson and A. Fredriksson (2001). Brominated flame retardants: A novel class of developmental neurotoxicants in our environment? *Environmental Health Perspectives.* 109: 903-908.
- Ernest, S. R., M. G. Wade, C. Lalancette, Y. Q. Ma, R. G. Berger, B. Robaire and B. F. Hales (2012). "Effects of chronic exposure to an environmentally relevant mixture of brominated flame retardants on the reproductive and thyroid system in adult male rats." *Toxicol Sci* 127(2): 496-507.
- Eskenazi, B., J. Chevrier, S. A. Rauch, K. Kogut, K. G. Harley, C. Johnson, C. Trujillo, A. Sjödin and A. Bradman (2013). "In utero and childhood polybrominated diphenyl ether (PBDE) exposures and neurodevelopment in the CHAMACOS study." *Environmental health perspectives* 121: 257-262.
- Feng M, Li Y, Qu R, Wang L, Wang Z (2013a). Oxidative stress biomarkers in freshwater fish *Carassius auratus* exposed to decabromodiphenyl ether and ethane, or their mixture. *Ecotoxicology*; 22(7):1101–10. <http://dx.doi.org/10.1007/s10646-013-1097-2>.
- Feng M, Qu R, Wang C, Wang L, Wang Z (2013b). Comparative antioxidant status in freshwater fish *Carassius auratus* exposed to six current-use brominated flame retardants: a combined experimental and theoretical study. *Aquat Toxicol*; 140–141: 314–23.
- Feng C, Xu Y, Zhao G, Zha J, Wu F, Wang Z. (2012). Relationship between BDE 209 metabolites and thyroid hormone levels in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology* 122–123:28-35.
- Feng C, Xu Y, He Y, Luo Q, Zha J, Wang Z (2010). Debrominated and methoxylated polybrominated diphenyl ether metabolites in rainbow trout (*Oncorhynchus mykiss*) after exposure to decabromodiphenyl ether. *J Environ Sci (China)*. 22(9):1425-34.
- Fischer, C., A. Fredriksson and P. Eriksson (2008a). "Coexposure of neonatal mice to a flame retardant PBDE 99 (2,2',4,4',5-pentabromodiphenyl ether) and methyl mercury enhances developmental neurotoxic defects." *Toxicological sciences : an official journal of the Society of Toxicology* 101: 275-285.
- Fischer, C., A. Fredriksson and P. Eriksson (2008b). "Neonatal co-exposure to low doses of an ortho-PCB (PCB 153) and methyl mercury exacerbate defective developmental neurobehavior in mice." *Toxicology* 244: 157-165.
- Fischer D, Hooper K, Athanasiadou M, Athanassiadis I, Bergman A. (2006). Children show highest levels of polybrominated diphenyl ethers in a California family of four: A case study. *Environ Health Perspect* 114(10):1581-1584.
- Fliedner A, Heinz Rüdell, Heinrich Jüring, Josef Müller, Frank Neugebauer and Christa Schröter-Kermani (2012). Levels and trends of industrial chemicals (PCBs, PFCs, PBDEs) in archived herring gull eggs from German coastal regions. *Environmental Sciences Europe*, 24:7
- Fowles, J. and D. Morgott (2013). Infant/toddler health risks from exposure to polybrominated diphenyl ethers (pbdes) in car seats and automotive upholstery. Christchurch, New Zealand, Institute of Environmental Science and Research, Ltd. Report FW13051: 78pp
- Frederiksen M, Vorkamp K, Thomsen M, Knudsen LE (2009a). Human internal and external exposure to PBDEs - a review of levels and sources. *Int J Hyg Environ Health*; 212:109-134.
- Frederiksen M, Thomsen M, Vorkamp K, Knudsen LE (2009b). Patterns and concentration levels of polybrominated diphenyl ethers (PBDEs) in placental tissue of women in Denmark. *Chemosphere*;76:1464–1469.
- Fromme H, Korner W, Shahin N, Wanner A, Albrecht M, Boehmer S, Parlar H, Mayer R, Liebl B and Bolte G (2009). Human exposure to polybrominated diphenyl ethers (PBDE), as evidenced by data from a duplicate diet study, indoor air, house dust, and biomonitoring in Germany. *Environ Int*; 35:1125-1135.
- Frouin H, Dangerfield N, Macdonald RW, Galbraith M, Crewe N, Shaw P, (2013). Partitioning and bioaccumulation of PCBs and PBDEs in marine plankton from the Strait of Georgia, British Columbia, Canada. *Prog Oceanogr* 115(SI):65-75.
- Fujimoto, H., G. H. Woo, K. Inoue, M. Takahashi, M. Hirose, A. Nishikawa and M. Shibutani (2011). "Impaired oligodendroglial development by decabromodiphenyl ether in rat offspring after maternal exposure from mid-gestation through lactation." *Reprod Toxicol* 31(1): 86-94.
- Fängström B, Hovander L, Bignert A, Athanassiadis I, Linderholm L, Grandjean P, Weihe P, Bergman A (2005a). Concentrations of polybrominated diphenyl ethers, polychlorinated biphenyls, and

- polychlorobiphenyls in serum from pregnant Faroese women and their children 7 years later. *Environ Sci Technol.*;39:9457-9463.
- Fängstrom B, Athanasiadou M, Athanassiadis I, Bignert A, Grandjean P, Weihe P, (2005b). Polybrominated diphenyl ethers and traditional organochlorine pollutants in fulmars (*Fulmarus glacialis*) from the Faroe Islands. *Chemosphere*; 60:836-43.
- Ganser, Lisa Rania, "Anatomy and Function of the African Clawed Frog Vocal System is Altered by the Brominated Flame Retardant, PBDE-209" (2009). Open Access Dissertations. Paper 245. [http://scholarlyrepository.miami.edu/oa\\_dissertations](http://scholarlyrepository.miami.edu/oa_dissertations)
- Gao S, Hong J, Yu Z, Wang J, Yang G, Sheng G, Fu J (2011). Polybrominated diphenyl ethers in surface soils from e-waste recycling areas and industrial areas in South China: concentration levels, congener profile, and inventory. *Environ Toxicol Chem.* 30(12):2688-96
- Gao F, Luo XJ, Yang ZF, Wang XM, Mai BX. (2009). Brominated Flame Retardants, Polychlorinated Biphenyls, and Organochlorine Pesticides in Bird Eggs from the Yellow River Delta, North China. *Environ Sci Technol* 43(18):6956-6962.
- Garcia-Reyero N, Escalon BL, Prats E, Stanley JK, Thienpont B, Melby NL, Barón E, Eljarrat E, Barceló D, Jordi Mestres e, Patrick J. Babin, Perkins E J, Raldúa D (2014). "Effects of BDE-209 contaminated sediments on zebrafish development and potential implications to human health." *Environ Int* 5: 216-223.
- Gascon, M., M. Fort, D. Martinez, A. E. Carsin, J. Forns, J. O. Grimalt, L. Santa Marina, N. Lertxundi, J. Sunyer and M. Vrijheid (2012). "Polybrominated diphenyl ethers (PBDEs) in breast milk and neuropsychological development in infants." *Environ Health Perspect* 120(12): 1760-1765.
- Gascon, M., M. Vrijheid, D. Martinez, J. Forns, J. O. Grimalt, M. Torrent and J. Sunyer (2011). "Effects of pre and postnatal exposure to low levels of polybromodiphenyl ethers on neurodevelopment and thyroid hormone levels at 4 years of age." *Environ Int* 37: 605-611.
- Gauthier LT, Hebert CE, Weseloh DVC, Letcher RJ. (2008). Dramatic changes in the temporal trends of polybrominated diphenyl ethers (PBDEs) in herring gull eggs from the Laurentian Great Lakes: 1982-2006. *Environ Sci Technol* 42(5):1524-1530.
- Gaylor MO, Mears GL, Harvey E, La Guardia MJ, Hale RC (2014). Polybrominated diphenyl ether accumulation in an agricultural soil ecosystem receiving wastewater sludge amendments. *Environ Sci Technol.* 48(12):7034-43.
- Gentes ML, Robert J. Letcher RJ, Caron-Beaudoin E, Jonathan Verreault J (2012). Novel Flame Retardants in Urban-Feeding Ring-Billed Gulls from the St. Lawrence River, Canada. *Environ. Sci. Technol.*, 46, 9735-9744
- Gerecke AC, Giger W, Hartmann PC, Heeb NV, Kohler H-P E, Schmid P, Zennegg M, Kohler M (2006). Anaerobic degradation of brominated flame retardants in sewage sludge. *Chemosphere*, 64, 311-317.
- Gerecke AC, Hartmann PC, Heeb NV, Kohler H-P E, Giger W, Schmid P, Zennegg M, Kohler M (2005). Anaerobic degradation of decabromodiphenyl ether. *Environmental Science and Technology*, 39, 1078-1083.
- Gilbert, M. E., J. Rovet, Z. Chen and N. Koibuchi (2012). "Developmental thyroid hormone disruption: prevalence, environmental contaminants and neurodevelopmental consequences." *Neurotoxicology* 33: 842-852.
- Gilchrist TT, Letcher RJ, Thomas P, Fernie KJ (2014). Polybrominated diphenyl ethers and multiple stressors influence the reproduction of free-ranging tree swallows (*Tachycineta bicolor*) nesting at wastewater treatment plants. *Sci Total Environ.* 472:63-71.
- Gómara B, Herrero L, Pacepavicius G, Ohta S, Alaee M, González MJ (2011). Occurrence of co-planar polybrominated/chlorinated biphenyls (PXBs), polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in breast milk of women from Spain. *Chemosphere*;83:799-805.
- Gómara, B., L. Herrero, J. J. Ramos, J. R. Mateo, M. A. Fernández, J. F. García and M. J. González (2007). Distribution of polybrominated diphenyl ethers in human umbilical cord serum, paternal serum, maternal serum, placentas, and breast milk from Madrid population, Spain. *Environmental Science and Technology* 41: 6961-6968.
- Goodman, J. E. (2009). "Neurodevelopmental effects of decabromodiphenyl ether (BDE-209) and implications for the reference dose." *Regul Toxicol Pharmacol* 54(1): 91-104. Goutte A, Chevreuil M,

- Alliot F, Chastel O, Cherel Y, Eléaume M, 2013. Persistent organic pollutants in benthic and pelagic organisms off Adélie Land, Antarctica. *Mar Pollut Bull* 77(1–2):82-89.
- Gregoraszczyk EŁ, Rak A, Kawalec K, Ropstad E (2008). Steroid secretion following exposure of ovarian follicular cells to single congeners and defined mixture of polybrominated dibenzoethers (PBDEs), p,p'-DDT and its metabolite p,p'-DDE. *Toxicol Lett* 178(2): 103-9. doi: 10.1016/j.toxlet.2008.02.011.
- Hakk, H., Larsen G, Bergman Å, Örn U (2002). "Binding of brominated diphenyl ethers to male rat carrier proteins." *Xenobiotica* 32(12): 1079-1091.
- Hale, R. C., M. J. La Guardia, E. Harvey, D. Chen, T. M. Mainor, D. R. Luellen, and L. S. Hundal. (2012). Polybrominated Diphenyl Ethers in U.S. Sewage Sludges and Biosolids: Temporal and Geographical Trends and Uptake by Corn Following Land Application. *Environmental Science & Technology* 46:2055-2063.
- Hale RC, Kim SL (2008). "Antarctic research bases: local sources of polybrominated diphenyl ether (PBDE) flame retardants." *Environ Sci Technol* 42(5): 1452-1457.
- Hale RC, Alace M, Manchester-Neesvig JB, Stapleton HM, Ikonomou MG (2003). Polybrominated diphenyl ether flame retardants in the North American environment. *Environ. Int.* 29: 771–779.
- Hallgren, S. and P. O. Darnerud (2002). "Polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and chlorinated paraffins (CPs) in rats-testing interactions and mechanisms for thyroid hormone effects." *Toxicology* 177: 227-243.
- Hamers, T., J. H. Kamstra, E. Sonneveld, A. J. Murk, M. H. a. Kester, P. L. Andersson, J. Legler and A. Brouwer (2006). "In vitro profiling of the endocrine-disrupting potency of brominated flame retardants." *Toxicological sciences : an official journal of the Society of Toxicology* 92: 157-173.
- Hamm S, Strickeling M, Ranken PF, Rothenbacher KP (2001). Determination of polybrominated diphenyl ethers and PBDD/Fs during the recycling of high impact polystyrene containing decabromodiphenyl ether and antimony oxide. *Chemosphere* 44(6):1353-60
- Hardy, M. L., M. Banasik and T. Stedeford (2009). "Toxicology and human health assessment of decabromodiphenyl ether BDE-209 human health assessment " *Critical Reviews in Toxicology* 39: 1-44.
- Hardy, M. and T. Stedeford (2008). "Developmental neurotoxicity: when research succeeds through inappropriate statistics." *Neurotoxicology* 29(3): 476.
- Hardy, M. L., R. Schroeder, J. Biesemeier and O. Manor (2002). "Prenatal oral (gavage) developmental toxicity study of decabromodiphenyl oxide in rats." *Int J Toxicol* 21(2): 83-91.
- Harley, K. G., J. Chevrier, R. Aguilar Schall, A. Sjödin, A. Bradman and B. Eskenazi (2011). "Association of prenatal exposure to polybrominated diphenyl ethers and infant birth weight." *American journal of epidemiology* 174: 885-892.
- Harrad S, de Wit CA, Abdallah MA, Bergh C, Bjorklund JA, Covaci A, et al (2010). Indoor contamination with hexabromocyclododecanes, polybrominated diphenyl ethers, and perfluoroalkyl compounds: an important exposure pathway for people? *Environ Sci Technol* 44:3221-3231.
- He S, Li M, Jin J, Wang Y, Bu Y, Xu M et al (2013). Concentrations and trends of halogenated flame retardants in the pooled serum of residents of Laizhou bay, China. *Environ Toxicol Chem* 32:1242-1247.
- He MJ, Luo XJ, Chen MY, Sun YX, Chen SJ, Mai BX. (2012). Bioaccumulation of polybrominated diphenyl ethers and decabromodiphenyl ethane in fish from a river system in a highly industrialized area, South China. *Sci Total Environ* 419: 109-115.
- He J, Yang D, (2011). Chronic zebrafish low dose decabrominated diphenyl ether (BDE-209) exposure affected parental gonad development and locomotion in F1 offspring. *Ecotoxicology* 20(8): 1813-1822.
- He P, Wang AG, Xia T, Gao P, Niu Q, Guo LJ, Xu BY, Chen XM (2009). "Mechanism of the neurotoxic effect of PBDE-47 and interaction of PBDE-47 and PCB153 in enhancing toxicity in SH-SY5Y cells." *Neurotoxicology* 30: 10-15.
- Hendriks HS, van Kleef RG, Westerink RH (2012). Modulation of human  $\alpha 4\beta 2$  nicotinic acetylcholine receptors by brominated and halogen-free flame retardants as a measure for in vitro neurotoxicity. *Toxicol Lett.* 213(2):266-74.
- HCA, Health Canada. Human (2012). Health - State of the science report on decabromodiphenyl ether (decaBDE). Ottawa, Canada.



- HCA, Health Canada (2006). State of the Science Report for a Screening Health Assessment Polybrominated Diphenyl Ethers (PBDEs)[Tetra-, Penta-, Hexa-, Hepta-, Octa-, Nona- and Deca-Congeners][CAS Nos. 40088-47-9, 32534-81-9, 36483-60-0, 68928-80-3, 32536-52-0, 63936-56-1, 1163-19-5]. 39.
- Herbstman, J. B., A. Sjödin, B. J. Apelberg, F. R. Witter, R. U. Haiden, D. G. Patterson Jr., S. R. Panny, L. L. Needham and L. R. Goldman (2008). Birth delivery mode modifies the associations between prenatal polychlorinated biphenyl (PCB) and polybrominated diphenyl ether (PBDE) and neonatal thyroid hormone levels. *Environmental Health Perspectives*. 116: 1376-1382.
- Heredia, L., M. Torrente, M. T. Colomina and J. L. Domingo (2012). "Behavioral effects of oral subacute exposure to BDE-209 in young adult mice: a preliminary study." *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 50: 707-712.
- Hermanson, M. H., E. Isaksson, (2010). "Deposition history of brominated flame retardant compounds in an ice core from Holtedahlfonna, Svalbard, Norway." *Environ Sci Technol* 44(19): 7405-7410.
- Hoffman, K., M. Adgent, B. D. Goldman, A. Sjödin and J. L. Daniels (2012). "Lactational Exposure to Polybrominated Diphenyl Ethers and Its Relation to Social and Emotional Development among Toddlers." 1438: 1438-1442.
- Holden A, Park JS, Chu V, Kim M, Choi G, Shi Y, Chin, T, Chun C, Linthicum J, Walton BJ, Hooper K, (2009). Unusual hepta- and octa-brominated diphenyl ethers and nona-brominated diphenyl ether profile in California, USA, peregrine falcons (*Falco peregrinus*): More evidence for brominated diphenyl ether-209 debromination. *Environmental Toxicology and Chemistry*, 28 (9), 1906-11.
- Holma-Suutari, P. Ruokojärvi, S. Laaksonen, H. Kiviranta, M. Nieminen, M. Viluksela, A (2014). Hallikainen. Persistent organic pollutant levels in semi-domesticated reindeer (*Rangifer tarandus tarandus* L.), feed, lichen, blood, milk, placenta, foetus and calf. *Science of the Total Environment* 476-477: 125-135
- Hong SK, Sohn KH, Kim IY, Lee JK, Ju JH, Kim JH, Lim CH, Han BS, Jung HC, Lee JY, Park KL (2010). Polybrominated Diphenyl Ethers Orally Administration to Mice Were Transferred to Offspring during Gestation and Lactation with Disruptions on the Immune System. *Immune Netw*. 2010 10(2):64-74.
- Hooper MJ, Ankley GT, Cristol DA, Maryoung LA, Noyes PD, Pinkerton KE. Interactions between chemical and climate stressors: a role for mechanistic toxicology in assessing climate change risks. *Environ Toxicol Chem*. 2013 Jan (1):32-48.
- Hu XZ, Xu Y, Hu DC, Hui Y, Yang FX. (2007). Apoptosis induction on human hepatoma cells Hep G2 of decabrominated diphenyl ether (PBDE-209). *Toxicol Lett* 171:19-28.
- Hua, I., Kang, N., Jafvert, C.T. and Fabrega-Duque, J.R., (2003). Heterogeneous photochemical reactions of decabromodiphenyl ether. *Environmental Toxicology and Chemistry*, 22 (4), 798-804.
- Huang, F., S. Wen, J. Li, Y. Zhong, Y. Zhao and Y. Wu (2014). "The human body burden of polybrominated diphenyl ethers and their relationships with thyroid hormones in the general population in Northern China." *The Science of the total environment* 466-467: 609-615.
- Huang, H., Zhang, S., Wang, S. & Lv, J., (2013). In vitro biotransformation of PBDEs by root crude enzyme extracts: Potential role of nitrate reductase (NaR) and glutathione S-transferase (GST) in their debromination. *Chemosphere*, 90(6), pp.1885-1892.
- Huang, H., S. Zhang, P. Christie, S. Wang, and M. Xie. (2010a). Behavior of decabromodiphenyl ether (BDE-209) in the soil-plant system: uptake, translocation, and metabolism in plants and dissipation in soil. *Environmental Science & Technology* 44:663.
- Huang SC, Giordano G, Costa LG (2010b). "Comparative cytotoxicity and intracellular accumulation of five polybrominated diphenyl ether congeners in mouse cerebellar granule neurons." *Toxicological sciences : an official journal of the Society of Toxicology* 114: 124-132.
- Hughes, M. F., B. C. Edwards, C. T. Mitchell and B. Bhooshan (2001). "In vitro dermal absorption of flame retardant chemicals." *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 39: 1263-1270.
- Hung H, Kallenborn R, Breivik K, Su Y, Brorström-Lundén E, Olafsdottir K, Thorlacius JM, Leppänen S, Bossi R, Skov H, Manø S, Patton GW, Stern G, Sverko E, Fellin P (2010). Atmospheric monitoring

- of organic pollutants in the Arctic under the Arctic Monitoring and Assessment Programme (AMAP): 1993-2006. *Sci Total Environ.* 408(15): 2854-73.
- Hussey NE, Macneil MA, McMeans BC, Olin JA, Dudley SF, Cliff G, Wintner SP, Fennessy ST, Fisk AT. Rescaling the trophic structure of marine food webs. *Ecol Lett.* 2014 Feb;17(2):239-50. doi: 10.1111/ele.12226.
- Huwe JK, Hakk H, Smith DJ, Diliberto JJ, Richardson V, Stapleton HM, Birnbaum LS (2008). Comparative absorption and bioaccumulation of polybrominated diphenyl ethers following ingestion via dust and oil in male rats. *Environ Sci Technol.* 42(7):2694-700.
- Huwe, J. K. and D. J. Smith. 2007. Accumulation, whole-body depletion, and debromination of decabromodiphenyl ether in male sprague-dawley rats following dietary exposure. *Environmental Science & Technology* 41:2371-2377.
- Ibhazehiebo, K., T. Iwasaki, J. Kimura-Kuroda, W. Miyazaki, N. Shimokawa and N. Koibuchi (2011). "Disruption of thyroid hormone receptor-mediated transcription and thyroid hormone-induced Purkinje cell dendrite arborization by polybrominated diphenyl ethers." *Environmental health perspectives* 119: 168-175.
- IPCC, Intergovernmental Panel on Climate Change (2007). IPCC Fourth Assessment Report (AR4): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Available at: <http://www.ipcc.ch/ipccreports/assessments-reports.htm>. ISO, 2005. Soil quality-avoidance test for testing the quality of soils and toxicity of chemicals-test with earthworms (*Eisenia andrei*). International Organization for Standardization, Geneva.
- Jafvert C, Hua I. (2001a). Photochemical Reactions of Decabromodiphenyl Oxide and 2,2',4,4'-Tetrabromodiphenyl Oxide. Final Report. School of Civil Engineering, Purdue University, West Lafayette, Indiana, U.S.A
- Jafvert, C. and Hua, I., 2001b. Letter to Wendy Sherman, American Chemical Council Brominated Flame Retardant Industry Panel, 20 October 2001.
- Jakobsson K, Fang J, Athanasiadou M, Rignell-Hydbom A, Bergman Å (2012). Polybrominated diphenyl ethers in maternal serum, umbilical cord serum, colostrum and mature breast milk. Insights from a pilot study and the literature. *Environ Int* 47:121-130.
- Jakobsson, K., Thuresson, K., Höglund, P., Sjödin, A., & Hagmar, L. (2003). A summary of exposures to polybrominated diphenyl ethers (PBDEs) in Swedish workers, and determination of half-lives of PBDEs. 61, 17-20.
- Jakobsson K, Thuresson K, Rylander L, Sjödin A, Hagmar L, Bergman Å, (2002). Exposure to polybrominated diphenyl ethers and tetrabromobisphenol A among computer technicians. *Chemosphere* 46:709-716.
- Jaspers VLB, Covaci A, Voorspoels S, Dauwe T, Eens M, Schepens P (2006). Brominated flame retardants and organochlorine pollutants in aquatic and terrestrial predatory birds of Belgium. Levels, patterns, tissue distribution and condition factors. *Environ Pollut* 139:340-52.
- Jenssen BM, Sørmo E, Bæk K, Bytingsvik J, Gaustad H, Ruus A, Skaare JU (2007). Brominated flame retardants in north-east Atlantic marine ecosystems. *Environmental Health Perspectives* vol 115, Sup 1.
- JETOC (2000). Mutagenicity Test Data Of Existing Chemical Substances Based On The Toxicity Investigation Of The Industrial Safety And Health Law; (Suppl. 2), Japan Chemical Industry Ecology-Toxicology & Information Center.
- Ji, K., K. Choi, J. P. Giesy, J. Musarrat and S. Takeda (2011). "Genotoxicity of several polybrominated diphenyl ethers (PBDEs) and hydroxylated PBDEs, and their mechanisms of toxicity." *Environmental science & technology* 45: 5003-5008.
- Johansson A-K, Sellström U, Lindberg P, Bignert A, de Wit C (2011). Temporal trends of polybrominated diphenyl ethers and hexabromocyclododecane in Swedish Peregrine Falcon (*Falco peregrinus peregrinus*) eggs. *Environment International* 37: 678-686.
- Johansson AK, Sellström U, Lindberg P, Bignert A, de Wit C (2009). Polybrominated diphenyl ethers congener patterns, hexabromocyclododecane, and brominated biphenyl 153 in eggs of peregrine falcons (*Falco peregrinus*) breeding in Sweden. *Environmental Toxicology and Chemistry*, Vol. 28, No. 1, pp. 9-17.

- Johansson, N., H. Viberg, a. Fredriksson and P. Eriksson (2008). "Neonatal exposure to deca-brominated diphenyl ether (PBDE 209) causes dose-response changes in spontaneous behaviour and cholinergic susceptibility in adult mice." *Neurotoxicology* 29: 911-919.
- Kajiwara, N., J. Desborough, S. Harrad, and H. Takigami. (2013a). Photolysis of brominated flame retardants in textiles exposed to natural sunlight *ENVIRONMENTAL SCIENCE-PROCESSES & IMPACT* 15:653-660.
- Kajiwara N, Takigami H (2013b). Emission behavior of hexabromocyclododecanes and polybrominated diphenyl ethers from flame-retardant-treated textiles. *Environ Sci Process Impacts*.15(10):1957-63.
- Kajiwara, N., Y. Noma, and H. Takigami. (2008). Photolysis studies of technical decabromodiphenyl ether (DecaBDE) and ethane (DeBDethane) in plastics under natural sunlight. *Environmental Science & Technology* 42:4404-4409.
- Kagaku Kogyo Nenkan, Flame Retardants, Kagaku Kogyo Nippo, Tokyo, Japan, (2001), pp. 367–369.
- Karpeta, A. and E. Gregoraszczyk (2010). "Mixture of dominant PBDE congeners (BDE-47, -99, -100 and -209) at levels noted in human blood dramatically enhances progesterone secretion by ovarian follicles." *Endocrine regulations* 44: 49-55.
- Kawashiro, Y., H. Fukata, M. Omori-Inoue, K. Kubonoya, T. Jotaki, H. Takigami, S.-i. Sakai and C. Mori (2008). "Perinatal exposure to brominated flame retardants and polychlorinated biphenyls in Japan." *Endocrine journal* 55: 1071-1084.
- Kelly, B. C., M. G. Ikonou, (2009). "Perfluoroalkyl contaminants in an Arctic marine food web: trophic magnification and wildlife exposure." *Environ Sci Technol* 43(11): 4037-4043.
- Kelly BC, Ikonou MG, Blair JD, Morin AE, Gobas F. (2007). Food web-specific biomagnification of persistent organic pollutants. *Science* 317(5835):236-239.
- KemI (1994). Risk Assessment of Polybrominated Diphenyl Ethers, Solna: The Swedish National Chemicals Inspectorate.
- Kemmlin (2006). Emission test chamber study: Specific emission rates of PBDE from selected materials under various conditions. *DIOXIN 2006*, Oslo, Norway, August 21-24, 2006.
- Kemmlin, (2003). "Emission of Flame Retardants from Consumer Products and Building Materials", Federal Environment Agency publication
- Kicinski, M., M. K. Viaene, E. Den Hond, G. Schoeters, A. Covaci, A. C. Dirtu, V. Nelen, L. Bruckers, K. Croes, I. Sioen, W. Baeyens, N. Van Larebeke and T. S. Nawrot (2012). "Neurobehavioral function and low-level exposure to brominated flame retardants in adolescents: a cross-sectional study." *Environ Health* 11: 86.
- Kim M, Guerra P, Theocharides M, Barclay K, Smyth SA, Alae M (2013a). Polybrominated diphenyl ethers in sewage sludge and treated biosolids: effect factors and mass balance. *Water Res*. Nov 1;47(17):6496-505.
- Kim, M., et al. (2013b). "Parameters affecting the occurrence and removal of polybrominated diphenyl ethers in twenty Canadian wastewater treatment plants." *Water Res* 47(7): 2213-2221.
- Kim, TH., Lee YJ, Lee E, Kim MS, Kwack S J, Kim KB, Chung KK, Kang TS, Han SY, Lee J, Lee BM and Kim HS (2009). "Effects of gestational exposure to decabromodiphenyl ether on reproductive parameters, thyroid hormone levels, and neuronal development in Sprague-Dawley rats offspring." *J Toxicol Environ Health A* 72(21-22): 1296-1303.
- Kierkegaard, A., L. Asplund, (2007). "Fate of higher brominated PBDEs in lactating cows." *Environ Sci Technol* 41(2): 417-423.
- Kierkegaard A, Balk L, Tjarnlund U, De Wit CA, Jansson, B. (1999). Dietary uptake and biological effects of decabromodiphenyl ether in rainbow trout (*Oncorhynchus mykiss*). *Environ. Sci. Technol.* 1999, 33 (10), 1612–1617.
- Kirkland, D., M. Aardema, L. Henderson and L. Müller (2005). "Evaluation of the ability of a battery of three in vitro genotoxicity tests to discriminate rodent carcinogens and non-carcinogens I. Sensitivity, specificity and relative predictivity." *Mutation research* 584: 1-256.
- Klif, Klima- og forurensningsdirektoratet (2011). Tilførselsprogrammet 2011. Overvåking av tilførsler og miljøtilstand i Norskehavet. Oslo TA-2935/ 2011. Oslo. p. 1-227.  
[http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Overvaking\\_av\\_miljogifter\\_og\\_beregning\\_av\\_tilforsler\\_til\\_norske\\_kyst\\_og\\_havomrader\\_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet\\_2011\\_Overvaking\\_av\\_tilforsler\\_og\\_miljotilstand\\_i\\_Norskehavet/](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Overvaking_av_miljogifter_og_beregning_av_tilforsler_til_norske_kyst_og_havomrader_Tilforselsprogrammet/Rapporter/TilforseIsprogrammet_2011_Overvaking_av_tilforsler_og_miljotilstand_i_Norskehavet/)

- Klif, Klima- og forurensningsdirektoratet (2010). Tilførselsprogrammet 2009. Overvåking av tilførsler og miljøtilstand i Barentshavet og Lofotenområdet. TA-2660/ 2010. Oslo p. 1-246.  
[http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Overvaking\\_av\\_miljogifter\\_og\\_beregning\\_av\\_tilforsler\\_til\\_norske\\_kyst\\_og\\_havomrader\\_Tilforselsprogrammet/Rapporter/Tilforse lsprogrammet\\_2009\\_Overvaking\\_av\\_tilforsler\\_og/](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Overvaking_av_miljogifter_og_beregning_av_tilforsler_til_norske_kyst_og_havomrader_Tilforselsprogrammet/Rapporter/Tilforse lsprogrammet_2009_Overvaking_av_tilforsler_og/)
- Klosterhaus, S. L. and J. E. Baker (2010). "Bioavailability of decabromodiphenyl ether to the marine polychaete *Nereis virens*." *Environ Toxicol Chem* 29(4): 860-868.
- Knoth W, Winfried Mann W, Meyer R, Nebhuth J (2007). Polybrominated diphenyl ether in sewage sludge in Germany. *Chemosphere* 67: 1831-1837
- Koch E & J C Altamirano & A Covaci & N B Lana & N F Ciocco (2014). Should apple snail *Pomacea canaliculata* (Caenogastropoda, Ampullariidae) be used as bioindicator for BDE-209? *Environ Sci Pollut Res* 21:761-765
- Kodavanti, P.R.S., Szabo, D.T., Stoker, T.E., and Fenton, S.E. (2011). Brominated flame retardants. In: *Reproductive and Developmental Toxicology*, ed by Ramesh C. Gupta, Elsevier Inc., pp523-541.
- Kohler, M., M. Zennegg, (2008). "Temporal trends, congener patterns, and sources of octa-, nona-, and decabromodiphenyl ethers (PBDE) and hexabromocyclododecanes (HBCD) in Swiss lake sediments." *Environ Sci Technol* 42(17): 6378-6384.
- Kortenkamp, A., O. Martin, R. Evans, M. Faust and T. Backhaus (2014). Risk of combination effects between decabromodiphenyl ether and other polybrominated diphenyl ethers, Norwegian Environmental Protection Agency, Oslo, Norway.: 152pp. Available at:  
<http://www.miljodirektoratet.no/no/Publikasjoner/2014/Juli-2014/Risk-of-Combination-Effects-Between-Decabromodiphenyl-Ether-and-Other-Polybrominated-Diphenyl-Ethers/>
- Kuivikko M, Kotiaho T, Hartonen K, Tanskanen A, Vahatalo AV (2007). Modeled direct photolytic decomposition of Polybrominated diphenyl ethers in the Baltic sea and the Atlantic ocean. *Environ. Sci. Technol.* 41 (20), 7016-7021.
- Kuo YM, Sepulveda MS (2010). Bioaccumulation and biotransformation of decabromodiphenyl ether and effects on daily growth in juvenile lake whitefish (*Coregonus clupeaformis*). *Ecotoxicology* 19(4). 751-760
- Kuriyama, S. N., C. E. Talsness, K. Grote and I. Chahoud (2005). "Developmental exposure to low dose PBDE 99: effects on male fertility and neurobehavior in rat offspring." *Environmental health perspectives* 113: 149-154.
- Kwan C, Hideshige Takada, Ruchaya Boonyatumanond, Yoshihisa Kato, Kaoruko Mizukawa, Maki Ito, Le Quang Dung, Mohamad Pauzi Zakaria, Evangeline C. Santiago (2014). Historical occurrences of polybrominated diphenyl ethers and polychlorinated biphenyls in Manila Bay, Philippines, and in the upper Gulf of Thailand. *Science of the Total Environment* 470-471: 427-437
- Kwan C, & Hideshige Takada & Kaoruko Mizukawa & Maiko Torii & Tatsuya Koike & Rei Yamashita & Rinawati & Mahua Saha & Evangeline C (2013). Santiago. PBDEs in leachates from municipal solid waste dumping sites in tropical Asian countries: phase distribution and debromination. *Environ Sci Pollut Res* 20:4188-4204
- La Guardia MJ, Hale RC, Harvey E, Mainor TM, Ciparis S. (2012). In Situ Accumulation of HBCD, PBDEs, and Several Alternative Flame-Retardants in the Bivalve (*Corbicula fluminea*) and Gastropod (*Elimia proxima*). *Environ Sci Technol* 46(11):5798-5805.
- Law RJ, Covaci A, Harrad S, Herzke D, Abdallah MA, Fernie K, Toms LM, Takigami H (2014). Levels and trends of PBDEs and HBCDs in the global environment: status at the end of 2012. *Environ Int.* 65:147-58.
- Law K, Halldorson T, Danell R, Stern G, Gewurtz S, Alae M, (2006). Bioaccumulation and trophic transfer of some brominated flame retardants in a Lake Winnipeg (Canada) food web. *Environ Toxicol Chem* 25(8):2177-2186.
- Leal, J.F., Esteves, V.I. and Santos, E.B.H. (2013) BDE-209: Kinetic Studies and Effect of Humic Substances on Photodegradation in Water. *Environmental Science & Technology*, 47, 14010-14017
- Lee LK, He J (2010a). Reductive debromination of polybrominated diphenyl ethers by anaerobic bacteria from soils and sediments. *Applied and Environmental Microbiology*, 76(3), 794-802.
- Lee ETHK, Jae Seok Choi, Patra Nabanata, Na Young Kim, Mee Young Ahn, Ki Kyung Jung, Il Hyun Kang, Tae Sung Kim, Seung Jun Kwack, Kui Lea Park, Seung Hee Kim, Tae Seok Kang, Jaewon Lee, Byung Mu Lee and Hyung Sik Kim (2010b). "Evaluation of liver and thyroid toxicity in Sprague-

- Dawley rats after exposure to polybrominated diphenyl ether BDE-209." *The Journal of Toxicological Sciences* 35(4): 535-545.
- Leslie, H. A., et al. (2011). "Decabromodiphenylether and hexabromocyclododecane in wild birds from the United Kingdom, Sweden and The Netherlands: Screening and time trends." *Chemosphere* 82(1): 88-95.
- Letcher, R. J., S. C. Martenson, (2014). "Dietary exposure of American kestrels (*Falco sparverius*) to decabromodiphenyl ether (BDE-209) flame retardant: Uptake, distribution, debromination and cytochrome P450 enzyme induction." *Environ Int* 63: 182-190.
- Letcher, R. J., J. O. Bustnes (2010). "Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish." *Sci Total Environ* 408(15): 2995-3043.
- Li Y, Duan YP, Huang F, Yang J, Xiang N, Meng XZ, Chen L (2013). Polybrominated diphenyl ethers in e-waste: Level and transfer in a typical e-waste recycling site in Shanghai, Eastern China. *Waste Manag.* S0956-053X(13)00409-1
- Li Y, Lin T, Chen Y, Hu L, Guo Z, Zhang G (2012a). Polybrominated diphenyl ethers (PBDEs) in sediments of the coastal East China Sea: occurrence, distribution and mass inventory. *Environ Pollut.* 171:155-61.
- Li ZH, Liu XY, Wang N, Chen JS, Chen YH, Huang JT (2012b). Effects of Decabrominated Diphenyl Ether (PBDE-209) in Regulation of Growth and Apoptosis of Breast, Ovarian, and Cervical Cancer Cells. *Environ Health Perspect* 120(4):541-546.
- Li, B., et al. (2012c). "Occurrence of PFCs and PBDEs in Landfill Leachates from Across Canada." *Water, Air, & Soil Pollution* 223(6): 3365-3372.
- Li W, Zhu L (2011). "Effects of decabromodiphenyl ether (BDE-209) on mRNA transcription of thyroid hormone pathway and spermatogenesis associated genes in Chinese rare minnow (*Gobiocypris rarus*)." *Environ Toxicol.*
- Li QZ, Yan CZ, Luo ZX, Zhang X. (2010). Occurrence and levels of polybrominated diphenyl ethers (PBDEs) in recent sediments and marine organisms from Xiamen offshore areas, China. *Mar Pollut Bull* 60(3):464-469.
- Li, Y.F., Bidleman, T.F., (2003). Correlation between global emission of  $\alpha$ -hexachlorocyclohexane and its concentrations in the Arctic air. *Journal of Environmental Informatics* 1, 52-57.
- Liang, S.-X. X., H.-X. X. Gao, Y.-Y. Y. Zhao, X.-M. M. Ma and H.-W. W. Sun (2010). "Effects of repeated exposure to decabrominated diphenyl ether (BDE-209) on mice nervous system and its self repair." *Environmental toxicology and pharmacology* 29: 297-301.
- Lignell S, Aune M, Isaksson M, Redeby J, Darnerud PO, Glynn A (2011). BDE-209 in blood serum from first-time mothers in Uppsala – temporal trend 1996-2010. National Food Agency, Uppsala, Sweden,
- Lin, Y.-M., et al. (2012). "Emissions of Polybrominated Diphenyl Ethers during the Thermal Treatment for Electric Arc Furnace Fly Ash." *Aerosol and Air Quality Research* 12: 237-250.
- Lindberg, P., Sellstrom, U., Haggberg, L. and De Wit, C. A., (2004). Higher brominated PBDEs and hexabromocyclododecane found in eggs of peregrine falcon (*Falco peregrinus*) breeding in Sweden. *Environmental Science & Technology*, 38(1), 93-96.
- Liu X, Zhan H, (2012). The PBDE-209 exposure during pregnancy and lactation impairs immune function in rats. *Mediators Inflamm* 692467(10). 15.
- Liu L, Zhu W, (2011a). Effect of decabromodiphenyl ether (BDE 209) and dibromodiphenyl ether (BDE 15) on soil microbial activity and bacterial community composition. *J Hazard Mater* 186(1). 883-890.
- Liu Y, Li J, Zhao Y, Wen S, Huang F, Wu Y. (2011b). Polybrominated diphenyl ethers (PBDEs) and indicator polychlorinated biphenyls (PCBs) in marine fish from four areas of China. *Chemosphere* 83(2):168-174.
- Liu PY, Du GD, Zhao YX, Mu YS, Zhang AQ, Qin ZF, Zhang XY, Yan SS, Li Y, Wei RG, Qin XF, Yang YJ (2011c). Bioaccumulation, maternal transfer and elimination of polybrominated diphenyl ethers in wild frogs. *Chemosphere.* 2011;84(7):972-8.

- Llabjani, V., J. Trevisan, K. C. Jones, R. F. Shore and F. L. Martin (2010). "Binary mixture effects by PBDE congeners (47, 153, 183, or 209) and PCB congeners (126 or 153) in MCF-7 cells: biochemical alterations assessed by IR spectroscopy and multivariate analysis." *Environmental science & technology* 44: 3992-3998.
- Lohmann, R., J. Klanova (2013). "Concentrations, Fluxes, and Residence Time of PBDEs Across the Tropical Atlantic Ocean." *Environ Sci Technol* 27: 27.
- Lorber M (2008). Exposure of Americans to polybrominated diphenyl ethers. *J Exp Sci Environ Epidemiol* 18:2-19.
- Lu, M., Zhang, Z.-Z., Su, X.-L., Xu, Y.-X., Wu, X.-J. & Zhang, M., 2013. Effect of copper on in vivo fate of BDE-209 in pumpkin. *Journal of hazardous materials*, 262, pp.311–7.
- Lunder S, Hovander L, Athanassiadis I, Bergman A. (2010). Significantly Higher Polybrominated Diphenyl Ether Levels in Young US Children than in Their Mothers. *Environ Sci Technol* 44(13):5256-5262.
- Luo Q, Zha JM, Wang ZJ, Wong MH, Cai ZW. (2013). Bioaccumulation and debromination of BDE-209 in Japanese medaka (*Oryzias Latipes*) when continuously exposed to environmental relevant concentrations. *J Environ Sci Heal A* 48(11):1349-1355.
- Ma Y, Salamova A, Venier M, Hites RA (2013). Has the Phase-Out of PBDEs Affected Their Atmospheric Levels? Trends of PBDEs and Their Replacements in the Great Lakes Atmosphere. *Environmental Science & Technology* 47 (20), 11457-11464
- MacGregor JA and Nixon WB (1997). Decabromodiphenyl oxide (DBDPO): Determination of n-octanol/water partition coefficient. *Wildlife International Ltd*, 1997.
- Mannetje A, Coakley J, Bridgen P, Brooks C, Harrad S, Smith AH, Pearce N, Douwes J (2013). Current concentrations, temporal trends and determinants of persistent organic pollutants in breast milk of New Zealand women. *Sci Total Environ* 458-460:399-407.
- Mansouri K, Consonni V, Durjava MK, Kolar B, Oberg T, Todeschini R. (2012). Assessing bioaccumulation of polybrominated diphenyl ethers for aquatic species by QSAR modeling. *Chemosphere* 89(4):433-444.
- Mariani A, Fanelli R, Re Depaolini A, De Paola M. (2014) Decabrominated diphenyl ether and methylmercury impair fetal nervous system development in mice at documented human exposure levels. *Dev Neurobiol*. 2014 Jul 9. doi: 10.1002/dneu.22208.
- Mariussen E, Steinnes E, Breivik K, Nygaard T, Schlabach M, Kalas JA (2008). Spatial patterns of polybrominated diphenyl ethers (PBDEs) in mosses, herbivores and a carnivore from the Norwegian terrestrial biota. *Sci Total Environ* 404:162–70.
- Marteinson SC, Bird DM, Shutt JL, Letcher RJ, Ritchie IJ, Fernie K (2010). Multi-generational effects of polybrominated diphenylethers exposure: Embryonic exposure of male American kestrels (*Falco sparverius*) to DE-71 alters reproductive success and behaviors. *Environ Toxicol Chem* 28:1740–7.
- Marvin C, Jasmine Waltho, Julia Jia, Debbie Burniston (2013). Spatial distributions and temporal trends in polybrominated diphenyl ethers in Detroit River suspended sediments. *Chemosphere* 91: 778–783
- McKinney, M. A., Dietz, R., Sonne, C., de Guise, S., Skirnisson, K., Karlsson, K., Steingrimsson, E., & Letcher, R. J. (2011a). Comparative Hepatic Microsomal Biotransformation of Selected PBDEs, Including Decabromodiphenyl Ether, and Decabromodiphenyl Ethane Flame Retardants in Arctic Marine-Feeding Mammals, *Environmental Toxicology and Chemistry*, vol. 30, no. 7, pp. 1506-1514.
- Messer A (2010). Mini-review: polybrominated diphenyl ether (PBDE) flame retardants as potential autism risk factors. *Physiol Behav*. 100(3):245-9.
- Meyer, T., D. C. Muir, (2012). "Deposition of brominated flame retardants to the Devon Ice Cap, Nunavut, Canada." *Environ Sci Technol* 46(2): 826-833.
- Miyaso, H., et al. (2012). "Postnatal exposure to low-dose decabromodiphenyl ether adversely affects mouse testes by increasing tyrosine phosphorylation level of cortactin." *J Toxicol Sci* 37(5): 987-999.
- Miller, M. F., S. M. Chernyak, S. E. Domino, S. a. Batterman and R. Loch-Caruso (2012). "Concentrations and speciation of polybrominated diphenyl ethers in human amniotic fluid." *The Science of the total environment* 417-418: 294-298.
- Mizukawa H, Nomiyama K, Nakatsu S, Yachimori S, Hayashi T, Tashiro Y, (2013). Species-specific differences in the accumulation features of organohalogen contaminants and their metabolites in the blood of Japanese terrestrial mammals. *Environ Pollut* 174(28-37).

- Mizukawa K, Takada H, Takeuchi I, Ikemoto T, Omori K, Tsuchiya K. (2009). Bioconcentration and biomagnification of polybrominated diphenyl ethers (PBDEs) through lower-trophic-level coastal marine food web. *Marine Pollution Bulletin* 58(8):1217-1224.
- Mo L, Wu JP, Luo XJ, Li KL, Peng Y, Feng AH, (2013). Using the kingfisher (*Alcedo atthis*) as a bioindicator of PCBs and PBDEs in the dinghushan biosphere reserve, China. *Environ Toxicol Chem* 32(7):1655-1662.
- Mo L, Wu JP, Luo XJ, Zou FS, Mai BX. (2012). Bioaccumulation of polybrominated diphenyl ethers, decabromodiphenyl ethane, and 1,2-bis(2,4,6-tribromophenoxy) ethane flame retardants in kingfishers (*Alcedo atthis*) from an electronic waste-recycling site in South China. *Environ Toxicol Chem*. 31(9):2153-8.
- Morf LS, Buser AM, Taverna R, Bader H-P, Scheidegger R (2008). Dynamic substance flow analysis as a valuable risk evaluation tool a case study for brominated flame retardants as an example of potential endocrine disrupters. *CHIMIA Int J Chem*62:424-31.
- Morf, LS, Buser AM, Taverna R, Bader HP, Scheidegger R. (2007). Efficient measures in waste management as a key factor to reduce emissions of BFRs: Case study results for DecaBDE in Switzerland and global implications. *Organohalogen Compounds*, 69, 916-919.
- Morf L, Smutny R, Taverna R, Daxbeck H. Selected polybrominated flame retardants, PBDEs and TBBPA—substance flow analysis. Berne: Swiss Agency for the Environment, Forests and Landscape; 2003.
- Morgado I, Hamers T, Van der Ven L, Power DM (2007). Disruption of thyroid hormone binding to sea bream recombinant transthyretin by ioxinyl and polybrominated diphenyl ethers. *Chemosphere*. 69(1): 155-63
- Muñoz-Arnanz J, Sáez M, Aguirre JI, Hiraldo F, Baos R, Pácepavicius G, (2011). Predominance of BDE-209 and other higher brominated diphenyl ethers in eggs of white stork (*Ciconia ciconia*) colonies from Spain. *Environ Int* 37(3):572-576.
- Munsch C, K. Héas-Moisan, C. Tixier, N. Olivier, O. Gastineau, N. Le Bayon, V. Buchet (2011). Dietary exposure of juvenile common sole (*Solea solea* L.) to polybrominated diphenyl ethers (PBDEs): Part 1. Bioaccumulation and elimination kinetics of individual congeners and their debrominated metabolites. *Environmental Pollution* 159: 229-237
- Möller, A., Z. Y. Xie, (2012). "Occurrence and air-seawater exchange of brominated flame retardants and Dechlorane Plus in the North Sea." *Atmospheric Environment* 46: 346-353.
- Möller, A., Z. Xie, (2011a). "Polybrominated diphenyl ethers vs alternate brominated flame retardants and Dechloranes from East Asia to the Arctic." *Environ Sci Technol* 45(16): 6793-6799.
- Möller, A., Z. Xie, (2011b). "Polybrominated diphenyl ethers (PBDEs) and alternative brominated flame retardants in air and seawater of the European Arctic." *Environ Pollut* 159(6): 1577-1583.
- Mörck, A., H. Hakk, U. Örn, E. K. Wehler, A. Morck, U. Orn and E. Klasson Wehler (2003). "Decabromodiphenyl Ether In The Rat : Absorption , Distribution , Metabolism , And Excretion." *Drug metabolism and disposition: the biological fate of chemicals* 31:7: 900-907.
- NCP, Northern Contaminants Program 2013. Canadian Arctic Contaminants Assessment Report On Persistent Organic Pollutants – 2013.
- NERI Technical Report No. 481 2003. Polybrominated Diphenyl Ethers (PBDEs) in Sewage Sludge and Wastewater
- Method Development and Validation. National Environmental Research Institute Ministry of the Environment. Denmark. p-1-34.
- Ni K, Lu Y(2013). "Polybrominated diphenyl ethers (PBDEs) in China: Policies and recommendations for sound management of plastics from electronic wastes." *J Environ Manage* 115(0): 114-123.
- Norway 2013. Proposal to list decabromodiphenyl ether (commercial mixture, c-decaBDE) in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants. UNEP/POPS/POP/RC.9/2
- NEA, Norwegian Environment Agency (2014). Monitoring of environmental contaminants in air and precipitation, annual report 2013. Report M-202/2014. p. 1-70. Authors: Nizzetto PB, Aas W, Krogseth IS.
- Noyes PD, Lema SC, Macaulay LJ, Douglas NK, Stapleton HM. (2013). Low Level Exposure to the Flame Retardant BDE-209 Reduces Thyroid Hormone Levels and Disrupts Thyroid Signaling in Fathead Minnows. *Environ Sci Technol* 47(17):10012-10021.

- Noyes PD, Hinton DE (2011). Accumulation and debromination of decabromodiphenyl ether (BDE-209) in juvenile fathead minnows (*Pimephra promelas*) induces thyroid disruption and liver alterations. *Toxicol Sci* 122(2). 265-274.
- NTP (1986). Toxicology and carcinogenesis studies of decabromodiphenyl oxide (CAS no. 1163-19-5) in F344/N and B 6c3F1 mice (fed studies). National Toxicology Program, National Institute of Environmental Health and Safety. Available on-line at: [ntp.niehs.nih.gov/ntp/htdocs/lt\\_rpts/tr309.pdf](http://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr309.pdf). NTP:National Toxicology Program. NTP TR 309.
- Nyholm JR (2011). Email from Jenny Nyholm to Stephen Dungey, Environment Agency, 21 August 2011.
- Nyholm JR, Lundberg C and Andersson PL (2010). Biodegradation kinetics of selected brominated flame retardants in aerobic and anaerobic soil. *Environmental Pollution*, 158 (6), 2235-2240.
- Nyholm JR, Norman A, Norrgren L, Haglund P, Andersson PL (2008). Maternal transfer of brominated flame retardants in zebrafish (*Danio rerio*). *Chemosphere*.73(2):203-8.
- Odabasi M, Bayram A, Elbir T, Seyfioglu R, Dumanoglu Y, Bozlaker A, Demircioglu H, Altioek H, Yatkin S, Cetin B. Electric arc furnaces for steel-making: hot spots for persistent organic pollutants. *Environ Sci Technol*. 2009 Jul 15;43(14):5205-11.
- OECD, Organisation for Economic Co-operation and Development (2014): Risk management of installations and chemicals. Brominated Flame Retardants. <http://www.oecd.org/env/ehs/risk-management/brominatedflameretardants.htm> (Accessed; 27.02.2014).
- OECD, Organisation for Economic Co-operation and Development (2012). OECD Guidelines for testing of chemicals; Bioaccumulation in Fish: Aqueous and Dietary Exposure. 305 Adopted: 2 October 2012.
- OECD, Organisation for Economic Co-operation and Development (2008). Brominated Flame Retardants (BFRs). Hazard/Risk Information Sheets, October 2008. <http://www.oecd.org/dataoecd/3/6/42073463.pdf>
- OECD, Organisation for Economic Co-operation and Development (2007). OECD Guideline For The Testing Of Chemicals. Developmental Neurotoxicity Study. 426.
- OECD, Organisation for Economic Co-operation and Development (1998). Waste Management Policy Group 1998. Report on incineration of products containing brominated flame retardants. p. 1-11
- Orihel DM., Bisbicos T, Dupuis AP., Paterson MJ., and Muir DCG. (2014). Debromination of the flame retardant decabromodiphenyl ether in lake sediments. Paper submitted to Environmental Science and Technology.
- Orihel D, Bisbicos T, Dupuis A, Paterson M, Tomy G, and Muir D. (2011) Debromination of 13C-labelled Decabromodiphenyl Ether in Lake Sediments. Poster. ATW.
- OSPAR, The Convention for the Protection of the marine Environment of the North-East Atlantic (2009). OSPAR Background Document on certain brominated flame retardants – Polybrominated Diphenylethers, Polybrominated Biphenyls, Hexabromo Cyclododecane, Update 2009. Hazardous Substances Series. OSPAR Commission.
- Pacyniak, E. K., X. Cheng, M. L. Cunningham, K. Crofton, C. D. Klaassen and G. L. Guo (2007). "The flame retardants, polybrominated diphenyl ethers, are pregnane X receptor activators." *Toxicological sciences* : an official journal of the Society of Toxicology 97: 94-102.
- Palm W-U, Kopetzky R, Sossinka W, Kruger H-U, Lin Q, Barcellos da Rosa ST, Zetzsch C. 2003. Environmental photochemistry of decabromodiphenyl ethers in organic solvents and adsorbed on particles in air and in aqueous suspension (including a feasibility study on OH reactivities in an aerosol smog chamber facility). Report for the Bromine Science and Environmental Forum [cited in United Kingdom 2004].
- Palm A, Cousins IT, Mackay D, Tysklind M, Metcalfe C, Alaee M (2002). Assessing the environmental fate of chemicals of emerging concern: a case study of the polybrominated diphenyl ethers. *Environ Pollut* 117:195–213.
- Park JS, Holden A, Chu V, Kim M, Rhee A, Patel P, (2009). Time-Trends and Congener Profiles of PBDEs and PCBs in California Peregrine Falcons (*Falco peregrinus*). *Environ Sci Technol* 43(23):8744-8751.
- Pellacani, C., S. Tagliaferri, A. Caglieri, M. Goldoni, G. Giordano, A. Mutti and L. G. Costa (2012). "Synergistic interactions between PBDEs and PCBs in human neuroblastoma cells." *Environ Toxicol*.



- Plourde, S. P., R. Moreau, (2013). "Is the bone tissue of ring-billed gulls breeding in a pollution hotspot in the St. Lawrence River, Canada, impacted by halogenated flame retardant exposure?" *Chemosphere* 93(10): 2333-2340.
- Poma G., Pietro Volta, Claudio Roscioli. (2014) Novel brominated flameand fish from LakeBettinetti c, Licia GuzzellaConcentrations and trophic interactions ofretardants, HBCD, and PBDEs in zooplanktMaggiore (Northern Italy). *Science of the Total Environment* 481 (2014) 401–408.
- Pountney Angela a, Amy L. Filby a, Gareth O. Thomas b, Vic R. Simpson c, Elizabeth A. Chadwick d, Jamie R. Stevens a, Charles R. Tyler. High liver content of polybrominated dip(Lutra lutra) from England and Walesenyl ether (PBDE) in otters. *Chemosphere* 118 (2014) 81–86.
- POPRC, Persistent Organic Review Committee (2013a). Debromination of decabromodiphenyl ether (BDE-209) in the environment; Stockholm Convention Persistent Organic Pollutants Review Committee, Ninth Meeting, Rome 14-18 October, 2013. UNEP/POPS/POPRC.9/INF/19.
- POPRC, Persistent Organic Review Committee (2013b), Revised draft guidance on how to assess the possible impact of climate change on the work of the Persistent Organic Pollutants Review Committee. UNEP/POPS/POPRC.9/INF/15.
- POPRC, Persistent Organic Review Committee (2010a). Work programmes on new persistent organic pollutants as adopted by the Conference of the Parties. Stockholm Convention on Persistent Organic Pollutants: Persistent Organic Pollutants Review Committee, Sixth Meeting, Geneva 11-15 October, 2010. UNEP/POPS/POPRC.6/2/Rev.1. United Nations Environment Programme.
- POPRC, Persistent Organic Review Committee (2010b) Supporting Document for Technical review of the implications of recycling commercial penta and octabromodiphenyl ethers. Stockholm Convention on Persistent Organic Pollutants: Persistent Organic Pollutants Review Committee, Sixth Meeting, Geneva 11-15 October, 2010. (UNEP/POPS/POPRC.6/INF/6).
- POPRC Persistent Organic Review Committee (2010c) Debromination of brominated flame retardants. Stockholm Convention on Persistent Organic Pollutants: Persistent Organic Pollutants Review Committee, Sixth Meeting, Geneva 11-15 October, 2010.(UNEP/POPS/POPRC.6/INF/20/Rev.1).
- POPRC, Persistent Organic Review Committee (2006). Risk profile on commercial pentabromodiphenyl ether. UNEP/POPS/POPRC.2/17/Add.1
- POPRC, Persistent Organic Review Committee 2007. Risk profile on commercial octabromodiphenyl ether. UNEP/POPS/POPRC.3/20/Add.6
- Porch JR and Krueger HO (2001). Decabromodiphenyl oxide (DBDPO): a toxicity test to determine the effects of the substance on seedling emergence of six species of plants. Wildlife International Ltd Project Number: 439-101. Wildlife International Ltd, Maryland, United States.
- Powell DE, Sesten RM, Woodburn KE, Gerhards R. (2013). Trophic magnification factors (TMF). Interrelationship with other measures used to interpret bioaccumulation in aquatic environments. Scientific advancements in bioaccumulation assessment. Helsinki Workshop, 11 mars 2013.
- Qiu, M., X. Chen, D. Deng, J. Guo, G. Sun, B. Mai, and M. Xu. (2012). Effects of electron donors on anaerobic microbial debromination of polybrominated diphenyl ethers (PBDEs). *Biodegradation* 23:351-361.
- Qin, X., X. Xia, (2010). Thyroid disruption by technical decabromodiphenyl ether (DE-83R) at low concentrations in *Xenopus laevis*. *J Environ Sci* 22(5): 744-751.
- Qu WY, Bi XH, Sheng GY, Lu SY, Fu H, Yuan J, (2007). Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. *Environ Int* 33(8):1029-1034.
- Raff JD, Hites RA (2007). Deposition versus photochemical removal of PBDEs from Lake Superior air. *Environ Sci Technol* 41:6725–31.
- Ren, G., Z. Wang, Z. Yu, Y. Wang, S. Ma, M. Wu, G. Sheng, and J. Fu. (2013a). Primary investigation on contamination pattern of legacy and emerging halogenated organic pollutions in freshwater fish from Liaohe River, Northeast China. *Environmental Pollution* 172:94-99.
- Ren, X. M., L. H. Guo, Y. Gao, B. T. Zhang and B. Wan (2013b). "Hydroxylated polybrominated diphenyl ethers exhibit different activities on thyroid hormone receptors depending on their degree of bromination." *Toxicol Appl Pharmacol* 268(3): 256-263.

- Ren Z, Xiao X, Chen D, Bi X, Huang B, Liu M, Hu J, Peng P, Sheng G, Fu J. (2014). Halogenated organic pollutants in particulate matters emitted during recycling of waste printed circuit boards in a typical e-waste workshop of Southern China. *Chemosphere*. 2014;94:143-150.
- Ren, M., P. a. Peng, (2011). "PBDD/F impurities in some commercial deca-BDE." *Environmental Pollution* 159(5): 1375-1380.
- Reverte, I., et al. (2014). "Thyroid hormones and fear learning but not anxiety are affected in adult apoE transgenic mice exposed postnatally to decabromodiphenyl ether (BDE-209)." *Physiol Behav* 133C: 81-91.
- Reverte, I., A. B. Klein, J. L. Domingo and M. T. Colomina (2013). "Long term effects of murine postnatal exposure to decabromodiphenyl ether (BDE-209) on learning and memory are dependent upon APOE polymorphism and age." *Neurotoxicol Teratol* 40C: 17-27.
- Rice, D. C., W. D. Thompson, E. A. Reeve, K. D. Onos, M. Assadollahzadeh and V. P. Markowski (2009). "Behavioral changes in aging but not young mice after neonatal exposure to the polybrominated flame retardant decaBDE." *Environ Health Perspect* 117(12): 1903-1911.
- Rice, D. C., E. a. Reeve, A. Herlihy, R. T. Zoeller, W. D. Thompson and V. P. Markowski (2007). "Developmental delays and locomotor activity in the C57BL6/J mouse following neonatal exposure to the fully-brominated PBDE, decabromodiphenyl ether." *Neurotoxicol Teratol* 29: 511-520.
- Ricklund N, Kierkegaard A, McLachlan MS, Wahlberg C (2008a). Mass balance of decabromodiphenyl ethane and decabromodiphenyl ether in a WWTP. *Chemosphere* 74: 389–394
- Ricklund, N., A. Kierkegaard, (2008b). "An international survey of decabromodiphenyl ethane (deBDethane) and decabromodiphenyl ether (decaBDE) in sewage sludge samples." *Chemosphere* 73(11): 1799-1804.
- Riu, A., J.-p. Cravedi, L. Debrauwer, A. Garcia, C. Canlet, I. Jouanin and D. Zalko (2008). "Disposition and metabolic profiling of [14C]-decabromodiphenyl ether in pregnant Wistar rats." *Environment international* 34: 318-329.
- Rivière G, Sirot V, Tard A, Jean J, Marchand P, Veyrand B, Le Bizec B, Leblanc JC (2014). Food risk assessment for perfluoroalkyl acids and brominated flame retardants in the French population: Results from the second French total diet study. *Sci Total Environ*. Feb 12. pii: S0048-9697(14)00133-8. doi: 10.1016/j.scitotenv.2014.01.104
- Roberts SC, Noyes PD, Gallagher EP, Stapleton HM (2011). Species-specific differences and structure-activity relationships in the debromination of PBDE congeners in three fish species. *Environ Sci Technol*. ;45(5):1999-2005.
- Robrock KR, Korytár P, Alvarez-Cohen L(2008). Pathways for the anaerobic microbial debromination of polybrominated diphenyl ethers. *Environ Sci Technol*. 42(8):2845-52.
- Robson, M., et al. (2013). "Wet deposition of brominated flame retardants to the Great Lakes basin--status and trends." *Environ Pollut* 182: 299-306
- Ross PS 2009. Large and growing environmental reservoirs of Deca-BDE present an emerging health risk for fish and marine mammals. *Marine Pollution Bulletin* 58:7-10.
- Roze, E., L. Meijer, A. Bakker, K. N. J. A. Van Braeckel, P. J. J. Sauer and A. F. Bos (2009). "Prenatal exposure to organohalogenes, including brominated flame retardants, influences motor, cognitive, and behavioral performance at school age." *Environmental health perspectives* 117: 1953-1958.
- RPA, Risk&Policy Analysts .Georgalas B, Sanchez A, Zarogiannis P (2014). Multiple Framework Contract with Re-opening of competition for Scientific Services for ECHA. Reference: ECHA/2011/01 Service Request SR 14:Support to an Annex XV Dossier on Bis-(pentabromophenyl) ether (DecaBDE) (manuscript in press).
- Sagerup, K., L. B. Helgason, (2009). "Persistent organic pollutants and mercury in dead and dying glaucous gulls (*Larus hyperboreus*) at Bjornoya (Svalbard)." *Sci Total Environ* 407(23): 6009-6016.
- Sandholm, A., B.-M. Emanuelsson and E. K. Wehler (2003). "Bioavailability and half-life of decabromodiphenyl ether (BDE-209) in rat." *Xenobiotica; the fate of foreign compounds in biological systems* 33: 1149-1158.
- Samsonek J, Puype F (2013). Occurrence of brominated flame retardants in black thermo cups and selected kitchen utensils purchased on the European market. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess* 30:1976-86. doi: 10.1080/19440049.2013.829246

- Sakai S-i, Hirai Y, Aizawa H, Ota S, Muroishi Y (2006). Emission inventory of deca-brominated diphenyl ether (DBDE) in Japan. *J. Mater. Cycles Waste Manage.* 8:56–62.
- Salamova A, Hermanson MH, Hites RA (2014). Organophosphate and halogenated flame retardants in atmospheric particles from a European arctic site. *Environ Sci Technol.* 48(11):6133-40.
- Schechter A, Smith S, Colacino J, Malik N, Opel M, Paepke O, Birnbaum L (2011). Contamination of U.S. butter with polybrominated diphenyl ethers from wrapping paper. *Environ Health Perspect.* 119(2):151-4.
- Schiedek D, Sundelin B, Readman JW, Macdonald RW (2007). Interactions between climate change and contaminants. *Mar Pollut Bull.* 54(12):1845-56.
- Schlabach, M., Mariussen, E., Borgen, A., Dye, C., Enge, E.-K., Steinnes, E., Green, N., Mohn, H., (2002). Kartlegging av bromerte flammehemmere og klorerte parafiner. Norsk institutt for luftforskning (NILU), Kjeller, Norway, Rapport 62/2002, p. 71 (in Norwegian). Available from: [http://www.nilu.no/index.cfm?ac=publications&folder\\_id=4309&publication\\_id=3221&view=rep](http://www.nilu.no/index.cfm?ac=publications&folder_id=4309&publication_id=3221&view=rep)
- Schriks, M., J. M. Roessig, (2007). "Thyroid hormone receptor isoform selectivity of thyroid hormone disrupting compounds quantified with an in vitro reporter gene assay." *Environ Toxicol Pharmacol* 23(3): 302-307.
- Schriks M, Zvinavashe E, Furlow JD, Murk AJ (2006). Disruption of thyroid hormone-mediated *Xenopus laevis* tadpole tail tip regression by hexabromocyclododecane (HBCD) and 2,2',3,3',4,4',5,5',6-nona brominated diphenyl ether (BDE206). *Chemosphere* 65(10):1904-8.
- Schreiber, T., K. Gassmann, C. Götz, U. Hübenthal, M. Moors, G. Krause, H. F. Merk, N.-H. Nguyen, T. S. Scanlan, J. Abel, C. R. Rose and E. Fritsche (2010). "Polybrominated diphenyl ethers induce developmental neurotoxicity in a human in vitro model: evidence for endocrine disruption." *Environmental health perspectives* 118: 572-578.
- Sahlström LM, Sellström U, de Wit CA, Lignell S, Darnerud PO (2014). Brominated Flame Retardants in Matched Serum Samples from Swedish First-Time Mothers and Their Toddlers. *Environ Sci Technol.* Jun 19. [Epub ahead of print] PubMed PMID: 24927135.
- Sellström, U., G. Söderström, C. De Wit, and M. Tysklind. (1998a). Photolytic debromination of decabromodiphenyl ether (DeBDE). *Organohalogen Compounds* 35:447-450.
- Sellström U, Kierkegaard A, de Wit C, and Jansson B (1998b). Polybrominated diphenyl ethers and hexabromocyclododecane in sediment and fish from a Swedish river. *Environ. Toxicol. Chem.*, 17, 1065-1072.
- Sellstrom U, C. De Wit, N. Lundgren, and M. Tysklind (2005). Effect of Sewage-Sludge Application on Concentrations of Higher-Brominated Diphenyl Ethers in Soils and Earthworms. *Environ. Sci. Technol.*, 39: 9064-9070
- Seyer A, Riu A, Debrauwer L, Bourgès-Abella N, Brunelle A, Laprèvote O, Zalko D (2010). Time-of-flight secondary ion mass spectrometry imaging demonstrates the specific localization of deca-bromo-diphenyl-ether residues in the ovaries and adrenal glands of exposed rats. *J Am Soc Mass Spectrom.* 11:1836-45.
- SFT, Norwegian Pollution Control Authority (2008a). Mapping selected organic contaminants in the Barents Sea 2007. Report 1021/2008. Oslo, Norway. p.1-137. Available at: [http://www.miljodirektoratet.no/no/Publikasjoner/Statlig\\_miljoovervakning/Kartlegging\\_av\\_nye\\_miljogifter/Rapporter/Mapping\\_selected\\_organic\\_contaminants\\_in\\_the\\_Barents\\_Sea\\_2007/Authors: Bakke T, Boiisov S, Green N, Brevik EM.](http://www.miljodirektoratet.no/no/Publikasjoner/Statlig_miljoovervakning/Kartlegging_av_nye_miljogifter/Rapporter/Mapping_selected_organic_contaminants_in_the_Barents_Sea_2007/Authors: Bakke T, Boiisov S, Green N, Brevik EM.)
- SFT, Norwegian Pollution Control Authority (2008b). National Lake Survey 2004–2006, Part III. AMAP. Status of metals and environmental pollutants in lakes and fish from the Norwegian part of the AMAP region. Report TA-2363/2008. p.1-170 pp. <http://www.sft.no/publikasjoner/2363/ta2363.pdf>.
- SFT, Norwegian Pollution Control Authority (2004). New and established organohalogen contaminants and their metabolites in plasma and eggs of glaucous gulls from Bear Island. TA-2057/2004. Oslo, Norway, p. 1-26. Available from: <http://www.miljodirektoratet.no/old/klif/publikasjoner/overvaking/2057/ta2057.pdf>
- SFT, Norwegian Pollution Control Authority (2004). (2004). Kartlegging av utvalgte nye organiske miljøgifter – bromerte flammehemmere, klorerte parafiner, bisfenol A og triclosan. SFT rapport TA-2006/2004 (Niva rapport nr. 4809-2004), 117p. Available from: [http://www.nilu.no/index.cfm?ac=publications &folder\\_id=4309&publication\\_id=5203&view=rep](http://www.nilu.no/index.cfm?ac=publications &folder_id=4309&publication_id=5203&view=rep) .

- Authors: Fjeld E, Schlabach M, Berge JA, Eggen T, Snilsberg P, Källberg G, Rognerud S, Enge EK, Borgen A and Gundersen H,
- Shaw SD, Berger ML, Weijs L, Covaci A. (2012). Tissue-specific accumulation of polybrominated diphenyl ethers (PBDEs) including Deca-BDE and hexabromocyclododecanes (HBCDs) in harbor seals from the northwest Atlantic. *Environ Int* 44(1-6).
- Shaw SD, Berger ML, (2009). Bioaccumulation of polybrominated diphenyl ethers and hexabromocyclododecane in the northwest Atlantic marine food web. *Sci Total Environ* 407(10). 3323-3329.
- Shaw SD, Brenner D, Berger ML, Fang F, Hong CS, Addink R, Hilker D (2008). Bioaccumulation of polybrominated diphenyl ethers in harbor seals from the northwest Atlantic. *Chemosphere* 73(11):1773-80.
- She Y-Z, Wu J-P, Zhang Y, Peng Y, Mo L, Luo X-J (2013). Bioaccumulation of polybrominated diphenyl ethers and several alternative halogenated flame retardants in a small herbivorous food chain. *Environ Pollut* 174(0):164-170.
- Shibutani, M., H. Fujimoto, G.-H. Woo, K. Inoue, M. Takahashi and A. Nishikawa (2011). "Reply to Comment on "Impaired oligodendroglial development by decabromodiphenyl ether in rat offspring after maternal exposure from mid-gestation through lactation" [Reprod. Toxicol. 31(1) (2011) 86–94]." *Reproductive Toxicology* 32: 375-378.
- Shi S & Yeru Huang & Li Zhou & Wenlong Yang & Liang Dong & Lifei Zhang & Xiulan Zhang (2013a). A preliminary investigation of BDE-209, OCPs, and PAHs in urban road dust from Yangtze River Delta, China. *Environ Monit Assess* 185:4887–4896
- Shi Z, Jiao Y, Hu Y, Sun Z, Zhou X, Feng J et al (2013b). Levels of tetrabromobisphenol A, Hexabromocyclododecanes and polybrominated diphenyl ethers in human milk from the general population in Beijing, China. *Sci Tot Environ* 452–453:10–18.
- Sifleet SD. (2009). Toxicology of Decabromodiphenyl Ether in Avian Embryos: Disposition of the Flame Retardant BDE-209 in Yolk-injected Chicken Embryos (*Gallus gallus*). Thesis presented to the Faculty of the School of Marine Science, The College of William and Mary in Virginia, USA.
- Sjödin A, Hagmar L, Klasson-Wehler E, Kronholm-Diab K, Jakobsson E and Bergman A (1999). Flame retardant exposure: polybrominated diphenyl ethers in blood from Swedish workers. *Environmental Health Perspectives*, 107,8, 643-648.
- Song, J., Z.-H. Li, Y.-T. He, C.-X. Liu, B. Sun, C.-F. Zhang, J. Zeng, P.-L. Du, H.-L. Zhang, Y.-H. Yu and D.-J. Chen (2013). "Decabrominated diphenyl ether (BDE-209) and/or BDE-47 exposure alters protein expression in purified neural stem/progenitor cells determined by proteomics analysis." *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience* 33C: 8-14.
- Solaris Chemtech 2008. <http://www.solarischemtech.com/products-flame.asp?links=flame>
- Stapleton, H. M. and N. G. Dodder. (2008). Photodegradation of decabromodiphenyl ether in house dust by natural sunlight. *Environmental Toxicology and Chemistry* 27:306-312.
- Stapleton HM, Brazil B, Holbrook RD, Mitchelmore CL, Benedict R, Konstantinov A, Potter D. (2006). *In vivo* and *in vitro* debromination of decabromodiphenyl ether (BDE 209) by juvenile rainbow trout and common carp. *Environ Sci Technol* 40:4653-4658.
- Stapleton HM, Alae M, Letcher RJ, Baker JE. (2004). Debromination of the flame retardant decabromodiphenyl ether by juvenile carp (*Cyprinus carpio*) following dietary exposure. *Environ Sci Technol* 38(1):112-119.
- Stenzel JI and Markley BJ (1997). Decabromodiphenyl oxide (DBDPO): Determination of the Water Solubility. *Wildlife International Ltd.*, 1997.
- Stiborova, H., Zlamalikova, J., Pulkrabova, J., Hradkova, P., Napravnikova, M., Hajšlova, J., Mackova, M. and Demnerova, K., (2008). Aerobic and anaerobic degradation of polybrominated diphenyl ethers in sewage sludge. *Organohalogen Compounds*, 70, 197- 200.
- Su, Y., Hung, H., Sverko, E., Fellin, P., Li, H (2007). Multi-year measurements of polybrominated diphenyl ethers (PBDEs) in the Arctic atmosphere. *Atmos. Environ.*, 41, 8725–8735.
- Suvorov, A., Girard, S., Lachapelle, S., Abdelouahab, N., Sebire, G., and Takser, L. (2009). "Perinatal exposure to low-dose BDE-47, an emergent environmental contaminant, causes hyperactivity in rat offspring." *Neonatology* 95: 203-209.

- Sverdrup LE, Hartnik T, Mariussen E, Jensen J (2006). Toxicity of three halogenated flame retardants to nitrifying bacteria, red clover (*Trifolium pratense*), and a soil invertebrate (*Enchytraeus crypticus*). *Chemosphere* 64(1):96-103.
- Syed JH, Malik RN, Li J, Wang Y, Xu Y, Zhang G, Jones KC (2013). Levels, profile and distribution of Decachloran Plus (DP) and Polybrominated Diphenyl Ethers (PBDEs) in the environment of Pakistan. *Chemosphere* 93(8):1646-53.
- Söderström, G., Sellström, U., De Wit, C.A., Tysklind, M., (2004). Photolytic debromination of decabromodiphenyl ether (BDE-209). *Environmental Science & Technology* 38, 127–132.
- Söderström G (2003). On the combustion and photolytic degradation products of some brominated flame retardants. Department of Chemistry, Environmental Chemistry, University of Umea, Sweden.
- Sørmo G, Lie E, Ruus A, Gaustad H, Skaare JU, Jenssen BM (2011). Trophic level determines levels of brominated flame-retardants in coastal herring gulls. *Ecotoxicology and Environmental Safety* 74: 2091-2098
- Sørmo EG, Salmer MP, Jenssen BM, Hop H, Baek K, Kovacs KM, et al (2006). Biomagnification of polybrominated diphenyl ether and hexabromocyclododecane flame retardants in the polar bear food chain in Svalbard, Norway. *Environ Toxicol Chem* 25: 2502–11.
- Tagliaferri, S., A. Caglieri, M. Goldoni, S. Pinelli, R. Alinovi, D. Poli, C. Pellacani, G. Giordano, A. Mutti and L. G. Costa (2010). "Low concentrations of the brominated flame retardants BDE-47 and BDE-99 induce synergistic oxidative stress-mediated neurotoxicity in human neuroblastoma cells." *Toxicology in vitro : an international journal published in association with BIBRA* 24: 116-122.
- Tang, Z., et al. (2014). "Polybrominated Diphenyl Ethers in Soils, Sediments, and Human Hair in a Plastic Waste Recycling Area: A Neglected Heavily Polluted Area." *Environmental Science & Technology* 48(3): 1508-1516.
- Tasaki, T., T. Takasuga, (2004). "Substance flow analysis of brominated flame retardants and related compounds in waste TV sets in Japan." *Waste Manag* 24(6): 571-580.
- Teshima, R., R. R. Nakamura, A. Hachisuka, J.-i. Sawada and M. Shibutani (2008). "Effects of Exposure to Decabromodiphenyl Ether on the Development of the Immune System in Rats." *Journal of Health Science* 54: 382-389.
- Thienpont, B., A. Tingaud-Sequeira, (2011). "Zebrafish *Eleutheroembryos* Provide a Suitable Vertebrate Model for Screening Chemicals that Impair Thyroid Hormone Synthesis." *Environmental Science & Technology* 45(17): 7525-7532.
- Thomas, G. O., Moss, S. E. W., Asplund, L. and Hall, A. J., (2005). Absorption of decabromodiphenyl ether and other organohalogen chemicals by grey seals (*Halichoerus grypus*). *Environmental Pollution*, 133, 581-586.
- Thoma H, Hutzinger O, 1987. Pyrolysis and GC/MS-analysis of brominated flame 602 retardants in on-line operation. *Chemosphere* 16, 1353–1360.
- Thuresson K, Bergman Å, Jakobsson K. (2005) Occupational exposure to commercial decabromodiphenyl ether in workers manufacturing or handling flame-retarded rubber. *Environ Sci Technol.* 39:1980-1986.
- Tian SY, Zhu LY, Bian JN, Fang SH. (2012). Bioaccumulation and Metabolism of Polybrominated Diphenyl Ethers in Carp (*Cyprinus carpio*) in a Water/Sediment Microcosm: Important Role of Particulate Matter Exposure. *Environ Sci Technol* 46(5):2951-2958.
- Tian SY, Zhu LY. (2011). Bioaccumulation kinetics of sediment-associated DE-83 in benthic invertebrates (*Nereis succinea*, polychaete). *Chemosphere* 84(1):160-165.
- Tian SY, Zhu LY, Liu M. (2010). Bioaccumulation and distribution of polybrominated diphenyl ethers in marine species from Bohai, Bay, China. *Environ Toxicol Chem* 29(10):2278-2285.
- Tokarz III JA, Ahn M-Y, Leng J, Filley T.R., Nies L, (2008). Reductive debromination of polybrominated diphenyl ethers in anaerobic sediment and a biomimetic system. *Environmental Science and Technology*, 42 (4), 1157-1164.
- Tomy GT, Pleskach K, Ferguson SH, Hare J, Stern G, MacInnis G, Marvin CH, Loseto L. (2009). Trophodynamics of some PFCs and BFRs in a western Canadian Arctic marine food web. *Environ Sci Technol* 43:4076-4081.

Tomy GT, Pleskach K, Oswald T, Halldorson T, Helm PA, MacInnis G, et al (2008b). Enantioselective bioaccumulation of hexabromocyclododecane and congener specific accumulation of brominated diphenyl ethers in an eastern Canadian Arctic marine food web. *Environ Sci Technol* 42:3634–9.

Tosoh Japan 2013. <http://www.tosoh.com/our-products/organic-chemicals/flame-retardants>

Tseng, L. H., P. C. Hsu, C. W. Lee, S. S. Tsai, M. H. Pan and M. H. Li (2013). "Developmental exposure to decabrominated diphenyl ether (BDE-209): effects on sperm oxidative stress and chromatin DNA damage in mouse offspring." *Environ Toxicol* 28(7): 380-389.

Tseng, L. (2011). Developmental Exposure to Decabrominated Diphenyl Ether ( BDE-209 ): Effects on Sperm Oxidative Stress and Chromatin DNA Damage in Mouse Offspring. *Environmental Toxicology*, (May), pp.380–389.

Tseng, L.-H. H., M.-H. H. Li, S.-S. S. Tsai, C.-W. W. Lee, M.-H. H. Pan, W.-J. J. Yao and P.-C. C. Hsu (2008). "Developmental exposure to decabromodiphenyl ether (PBDE 209): effects on thyroid hormone and hepatic enzyme activity in male mouse offspring." *Chemosphere* 70: 640-647.

Tseng, L. H., C. W. Lee, (2006). Postnatal exposure of the male mouse to 2,2',3,3',4,4',5,5',6,6' decabrominated diphenyl ether decreased epididymal sperm functions without alterations in DNA content and histology in testis. *Toxicology* 224(1-2). 33-43.

Tysklind M, Sellström U, Söderström G and de Wit C (2001). Abiotic transformation of polybrominated diphenyl ethers (PBDEs): Photolytic debromination of decabromo diphenyl ether. The Second International Workshop on Brominated Flame Retardants, BFR 2001, May 14-16, Stockholm

Ungherese G, Cincinelli A, Martellini T, Ugolini A. (2012). PBDEs in the supralittoral environment: The sandhopper *Talitrus saltator* (Montagu) as biomonitor? *Chemosphere* 86(3):223-227

UK EA, United Kingdom Environment Agency (2009). Environmental risk evaluation report. Decabromodiphenyl ether (CAS no. 1163-19-5). Authors Brooke, D.N., Burns, J., Crookes, M.J. and Dungey, S.M Report to the. 290 pp.

US EPA, U.S. Environmental Protection Agency (2014). An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE) Executive Summary. Final Report. January 2014. Final Report January 2014. p. 1-901. US EPA, U.S. Environmental Protection Agency (2012). DecaBDE Phase-out Initiative <http://www.epa.gov/oppt/existingchemicals/pubs/actionplans/deccadbe.html>. Accessed in January 2014.

US EPA, U.S. Environmental Protection Agency (2010). An Exposure Assessment of Polybrominated Diphenyl Ethers. National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington DC; EPA/600/R-08/086F. Available from the National Technical Information Service, Springfield, VA and on-line at: <http://www.epa.gov/ncea>.

US EPA, U.S. Environmental Protection Agency (2008). Toxicological Review Of Decabromodiphenyl Ether (BDE-209) (CAS No. 1163-19-5). In Support of Summary Information on the Integrated Risk Information System (IRIS). pp. 126. U.S. Environmental Protection Agency (EPA National Center for Environmental Assessment, Washington, DC; EPA/600/R-08/086F. Available from the National Technical Information Service, Springfield).

Van den Steen E, Covaci A, Jaspers VLB, Dauwe T, Voorspoels S, Eens M, (2007). Accumulation, tissue-specific distribution and debromination of decabromodiphenyl ether (BDE 209) in European starlings (*Sturnus vulgaris*). *Environ Pollut* 148(2):648-653.

Van der Ven LTM, van de Kuil T, Leonards PEG, Slob W, Cantón RF, Germer S, et al., (2008). "A 28-day oral dose toxicity study in Wistar rats enhanced to detect endocrine effects of decabromodiphenyl ether (decaBDE)." *Toxicology letters* 179: 6-14.

VECAP, The Voluntary Emissions Control Action Programme (2014). Sound results from a proactive industry. European annual progress report 2013.

VECAP, The Voluntary Emissions Control Action Programme (2012). Maintaining Momentum - European Annual Progress Report 2012, Brussels: VECAP.

VECAP, The Voluntary Emissions Control Action Programme (2010a). The Voluntary Emissions Control Action Programme. Annual progress report 2010a.

VECAP, The Voluntary Emissions Control Action Programme (2010b). Benchmarking for success. North American annual progress report 2010.

- Verreault J, Gabrielsen GW, Chu S, Muir DC, Andersen M, Hamaed A, Letcher RJ. (2005). Flame retardants and methoxylated and hydroxylated polybrominated diphenyl ethers in two Norwegian Arctic top predators: glaucous gulls and polar bears. *Environ Sci Technol.* 15;39(16):6021-8.
- Vetter W, Bendig P, Blumenstein M, Hägele F (2012). Cooking processes with food; The heating of the flame retardant BDE-209 in fish generated toxic polybrominated dibenzofurans. *Organohalogen Compounds* 74, 620-623 (2012)
- Viberg H. (2009). Neonatal ontogeny and neurotoxic effect of decabrominated diphenyl ether (PBDE 209) on levels of synaptophysin and tau. *Int J Dev Neurosci.* 27, 423-9.
- Viberg, H., W. Mundy and P. Eriksson (2008). "Neonatal exposure to decabrominated diphenyl ether (PBDE 209) results in changes in BDNF, CaMKII and GAP-43, biochemical substrates of neuronal survival, growth, and synaptogenesis." *Neurotoxicology* 29: 152-159.
- Viberg, H., A. Fredriksson and P. Eriksson (2007). "Changes in spontaneous behaviour and altered response to nicotine in the adult rat, after neonatal exposure to the brominated flame retardant, decabrominated diphenyl ether (PBDE 209)." *Neurotoxicology* 28(1): 136-142.
- Viberg, H., A. Fredriksson and P. Eriksson (2004). "Investigations of strain and/or gender differences in developmental neurotoxic effects of polybrominated diphenyl ethers in mice." *Toxicological sciences : an official journal of the Society of Toxicology* 81: 344-353.
- Viberg, H., A. Fredriksson, E. Jakobsson, U. Orn and P. Eriksson (2003). "Neurobehavioral derangements in adult mice receiving decabrominated diphenyl ether (PBDE 209) during a defined period of neonatal brain development." *Toxicol Sci* 76(1): 112-120.
- Vigano L, Roscioli C, Guzzella L. (2011). Decabromodiphenyl ether (BDE-209) enters the food web of the River Po and is metabolically debrominated in resident cyprinid fishes. *Sci Total Environ* 409(23):4966-4972.
- Villanger, G. D., K. M. Gabrielsen, (2013). "Effects of complex organohalogen contaminant mixtures on thyroid homeostasis in hooded seal (*Cystophora cristata*) mother-pup pairs." *Chemosphere* 92(7): 828-842.
- Villanger GD, Jenssen BM (2011a). "Exposure to mixtures of organohalogen contaminants and associative interactions with thyroid hormones in East Greenland polar bears (*Ursus maritimus*)." *Environment International* 37(4): 694-708.
- Villanger, G. D., C. Lydersen, (2011b). "Disruptive effects of persistent organohalogen contaminants on thyroid function in white whales (*Delphinapterus leucas*) from Svalbard." *Sci Total Environ* 409(13): 2511-2524.
- Voorspoels S, Covaci A, Lepom P, Escutenaire S, Schepens P. (2006a). Remarkable findings concerning PBDEs in the terrestrial top-predator red fox (*Vulpes vulpes*). *Environ Sci Technol* 40(9):2937-2943.
- Voorspoels S, Covaci A, Lepom P, Jaspers VLB, Schepens P. (2006b). Levels and distribution of polybrominated diphenyl ethers in various tissues of birds of prey. *Environ Pollut* 144(1):218-227.
- Vorkamp K, Thomsen M, Falk K, lie H, Møller S, Sørensen PB. (2005). Temporal development of brominated flame retardants in peregrine falcon (*Falco peregrinus*) eggs from South Greenland (1986-2003). *Environ Sci Technol* 39:8199-8206
- Walker SP, Wachs TD, Gardner JM, Lozoff B, Wasserman GA, Pollitt E, Carter JA (2007); International Child Development Steering Group. Child development: risk factors for adverse outcomes in developing countries. *Lancet.* 369 (9556): 145-57.
- Wan Y, Zhang K, Dong ZM, Hu JY. (2013). Distribution is a Major Factor Affecting Bioaccumulation of Decabrominated Diphenyl Ether: Chinese Sturgeon (*Acipenser sinensis*) as an Example. *Environ Sci Technol* 47(5): 2279-2286.
- Wang S, Zhang S., Huang, H., Niu, Z. & Han, W., 2014. Characterization of polybrominated diphenyl ethers (PBDEs) and hydroxylated and methoxylated PBDEs in soils and plants from an e-waste area, China. *Environmental Pollution*, 184, pp.405-413.
- Wang S, Zhang S, Huang H, Christie P (2011a). Behaviour of decabromodiphenyl ether (BDE-209) in soil. Effects of rhizosphere and mycorrhizal colonization of ryegrass roots. *Environmental Pollution*, 159, 749-753.
- Wang Y, Luo C, Li J, Yin H, Li X, Zhang G (2011b). Characterization of PBDEs in soils and vegetations near an e-waste recycling site in South China. *Environ Pollut.* Oct;159(10):2443-8

- Wang F, Wang J, Hu G, Luo X, Mai B, Dail J. (2011c). Tissue distribution and associated toxicological effects of decabrominated diphenyl ether in subchronically exposed male rats. *International Scholarly Research Network ISRN Toxicology*, Volume 2011, Article ID 989251, 8 pages.
- Wang, J., et al. (2011d). "Polybrominated diphenyl ethers in water, sediment, soil, and biological samples from different industrial areas in Zhejiang, China." *J Hazard Mater* 197: 211-219.
- Wang F, Wang J, Dai J, Hu G, Wang J, Luo X & Mai B (2010a). Comparative Tissue Distribution, Biotransformation and Associated Biological Effects by Decabromodiphenyl Ethane and Decabrominated Diphenyl Ether in Male Rats after a 90-Day Oral Exposure Study. *Environ. Sci. Technol.* 44: 5655–5660.
- Wang Bin, Fukuya Iino, Gang Yu, Jun Huang, and Masatoshi Morita (2010b). The Pollution Status of Emerging Persistent Organic Pollutants in China. *ENVIRONMENTAL ENGINEERING SCIENCE* Volume 27, Number 3,
- Wang, H., Y. Zhang, Q. Liu, F. Wang, J. Nie and Y. Qian (2010c). "Examining the relationship between brominated flame retardants (BFR) exposure and changes of thyroid hormone levels around e-waste dismantling sites." *International journal of hygiene and environmental health* 213: 369-380.
- Wang, L.-C., et al. (2010d). "Characterizing the Emissions of Polybrominated Diphenyl Ethers (PBDEs) and Polybrominated Dibenzo-p-dioxins and Dibenzofurans (PBDD/Fs) from Metallurgical Processes." *Environmental Science & Technology* 44(4): 1240-1246.
- Wang Z, Ma X, Lin Z, Na G, Yao Z. (2009). Congener specific distributions of polybrominated diphenyl ethers (PBDEs) in sediment and mussel (*Mytilus edulis*) of the Bo Sea, China. *Chemosphere* 74(7):896-901.
- Wang, X. M., X. Ding. (2005). Polybrominated diphenyl ethers in airborne particulates collected during a research expedition from the Bohai Sea to the Arctic. *Environmental Science & Technology* 39(20): 7803-7809.
- Wania F, Dugani CB (2003). Assessing the long-range transport potential of polybrominated diphenyl ethers: a comparison of four multimedia models. *Environ Toxicol Chem.* 22(6):1252-61
- Watanabe, W., T. Shimizu, R. Sawamura, A. Hino and K. Konno (2010). "Functional Disorder of Primary Immunity Responding to Respiratory Syncytial Virus Infection in Offspring Mice Exposed to a Flame Retardant, Decabrominated Diphenyl Ether, Perinatally." *J Med Virol.* 82(6):1075-82. doi: 10.1002/jmv.21770.
- Watanabe, W., T. Shimizu, A. Hino and M. Kurokawa (2008). "Effects of decabrominated diphenyl ether (DBDE) on developmental immunotoxicity in offspring mice." *Environmental toxicology and pharmacology* 26: 315-319.
- Watanabe I, Tatsukawa R. (1990). Anthropogenic brominated aromatics in the Japanese environment. In: *Proceedings of Workshop on Brominated Aromatic Flame Retardants*, Skokloster, Sweden, 24-26 October 1989. Swedish National Chemicals Inspectorate, KEMI, Solna, Sweden, 1990, p. 63-71
- Weber R and Kuch B (2003) Relevance of BFRs and thermal conditions on the formation pathways of brominated and brominated-chlorinated dibenzodioxins and dibenzofurans. *Environment International*, 29:699-710
- WHO/UNEP, World Health Organization and the United Nations Environment Programme (2013). *State of the Science of Endocrine Disrupting Chemicals-2012. An assessment of the state of the science of endocrine disruptors prepared by a group of experts for the United Nations Environment Programme and World Health Organization.* p1- 296. Eds: Bergman Å, Heindel JJ, Jobling S, Kidd KA and Zoeller T. IOMC (Inter-organizational program for the sound management of chemicals). Available at: <http://www.who.int/ceh/publications/endocrine/en/>
- Wilford BH, Thomas GO, Jones KC, Davison B, Hurst DK (2008). Decabromodiphenyl ether (deca-BDE) commercial mixture components, and other PBDEs, in airborne particles at a UK site. *Environ Int.* 34(3):412-9.
- Williams, A. L. and J. M. DeSesso (2010). "The potential of selected brominated flame retardants to affect neurological development." *J Toxicol Environ Health B Crit Rev* 13(5): 411-448.
- Wu, K., X. Xu, J. Liu, Y. Guo, Y. Li and X. Huo (2010). Polybrominated diphenyl ethers in umbilical cord blood and relevant factors in neonates from Guiyu, China. *Environmental science & technology* 44: 813-819.



- Wu J, Luo X, Zhang Y, Chen S, Mai B, Guan Y, Yang, Z (2009a). Residues of polybrominated diphenyl ethers in Frogs (*Rana limnocharis*) from a contaminated site, South China. Tissue distribution, biomagnification, and maternal transfer. *Environ. Sci. Technol.* 2009, 43, 5212–5217.
- Wu JP, Luo XJ, (2009b). Biomagnification of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls in a highly contaminated freshwater food web from South China. *Environmental Pollution* 157(3). 904-909.
- Xia J, Wang L. & Luo H (2005). Present status and developing tendency of flame retardant. *Applied Chemical Industry*, Volume 34, pp. 1-4.
- Xiao, H., L. Shen (2012). Atmospheric concentrations of halogenated flame retardants at two remote locations: the Canadian High Arctic and the Tibetan Plateau. *Environ Pollut* 161: 154-161.
- Xiang CH, Luo XJ, Chen SJ, Yu M, Mai BX, Zeng EY. (2007). Polybrominated diphenyl ethers in biota and sediments of the Pearl River Estuary, South China. *Environmental Toxicology and Chemistry* 26(4):616-62
- Xie X, Qian Y, Xue Y, He H, Wei D. (2013a). Plant uptake and phytotoxicity of decabromodiphenyl ether (BDE-209) in ryegrass (*Lolium perenne* L). *Environ Sci Process Impacts.* 15(10):1904-12. doi: 10.1039/c3em00252g.
- Xie, X., Y. Qian, (2013b). "Effects of decabromodiphenyl ether (BDE-209) on the avoidance response, survival, growth and reproduction of earthworms (*Eisenia fetida*)." *Ecotoxicol Environ Saf* 8(12): 00462-00469.
- Xie X, Wu Y, (2011). Hydroxyl radical generation and oxidative stress in earthworms (*Eisenia fetida*) exposed to decabromodiphenyl ether (BDE-209). *Ecotoxicology* 20(5). 993-999.
- Xing, T. R., W. Yong, L. Chen, M. L. Tang, M. Wang, J. T. Chen and D. Y. Ruan (2010). Effects of decabrominated diphenyl ether (PBDE 209) on voltage-gated sodium channels in primary cultured rat hippocampal neurons. *Environ Toxicol* 25(4): 400-408.
- Xing, T., L. Chen, Y. Tao, M. Wang, J. Chen and D.-Y. Y. Ruan (2009). "Effects of decabrominated diphenyl ether (PBDE 209) exposure at different developmental periods on synaptic plasticity in the dentate gyrus of adult rats *In vivo*." *Toxicological sciences : an official journal of the Society of Toxicology* 110: 401-410.
- Xu Y, Zhang G, Li J, Liu X, Li X. (2011) Atmospheric polybrominated diphenyl ethers (PBDEs) and Pb isotopes at a remote site in Southwestern China: Implications for monsoon-associated transport. *Science of total environment* Vol 409, 2011, Pages 4564-4571
- Yu L, Luo X, Zheng X, Zeng Y, Chen D, Wu J, (2013). Occurrence and biomagnification of organohalogen pollutants in two terrestrial predatory food chains. *Chemosphere* 93(3):506-511.
- Yu Y, Zhang S, Huang N, Li J, Pang Y, Zhang X, Yu Z, Xu Z. (2012). Polybrominated diphenyl ethers and polychlorinated biphenyls in freshwater fish from Taihu Lake, China. Their levels and the factors that influence biomagnification. *Environ Tox Chem*, 31(3):542-
- Yu L-H, Luo X-J, Wu J-P, Liu L-Y, Song J, Sun Q-H, (2011). Biomagnification of Higher Brominated PBDE Congeners in an Urban Terrestrial Food Web in North China Based on Field Observation of Prey Deliveries. *Environ Sci Technol* 45(12): 5125-5131.
- Yu X, Zennegg M, Engwall M, Rotander A, Larsson M, Ming Hung W, Weber R (2008) E-waste recycling heavily contaminates a Chinese city with chlorinated, brominated and mixed halogenated dioxins. *Organohalogen Compounds* 70:813-816
- Yang Q, Qiu X, Li R, Liu S, Li K, Wang F (2013). Exposure to typical persistent organic pollutants from an electronic waste recycling site in Northern China. *Chemosphere* 91:205–211.
- Zegers BN, Lewis WE, Booij K, Smittenberg RH, Boer W, de Boer J, Boon JP (2003). Levels of polybrominated diphenyl ether flame retardants in sediment cores from Western Europe. *Environ Sci Technol.* Sep 1;37(17):3803-7.
- Zeng W, Wang Y, Liu Z, Khanniche A, Hu Q, Feng Y, Ye W, Yang J, Wang S, Zhou L, Shen H, Wang Y (2014). Long-term exposure to decabrominated diphenyl ether impairs CD8 T-cell function in adult mice. *Cell Mol Immunol.* Apr 7. doi: 10.1038/cmi.2014.16.
- Zeng Y-H, Luo X-J, Chen Y, Yu Y, Chen Y, and Mai B-X (2012). Gastrointestinal absorption, metabolic debromination, and hydroxylation of three commercial polybrominated diphenyl ether mixtures by common carp *Environ Tox and Chem*, 31, (4): 731–738.

- Zennegg M, Munoz M, Schmid P, Gerecke AC (2013). Temporal trends of persistent organic pollutants in digested sewage sludge (1993-2012). *Environ Int.* 60:202-8.
- Zhang, W., Chen, L., Liu, K., Lin, K., Chen, Y. & Yan, Z., 2014. Bioaccumulation of decabromodiphenyl ether (BDE209) in earthworms in the presence of lead (Pb). *Chemosphere.* 106:57-64.
- Zhang, H., X. Li, J. Nie and Q. Niu (2013a). "Lactation exposure to BDE-153 damages learning and memory, disrupts spontaneous behavior and induces hippocampus neuron death in adult rats." *Brain Res* 1517: 44-56.
- Zhang BZ, Li HZ, Wei YL, You J. (2013b). Bioaccumulation kinetics of polybrominated diphenyl ethers and decabromodiphenyl ethane from field-collected sediment in teh Oligochaete, *Lumbriculus variegatus*. *Environmental Toxicology and Chemistry* 32(12):2711-2718.
- Zhang, W., L. Chen, (2013c). Lead accumulations and toxic effects in earthworms (*Eisenia fetida*) in the presence of decabromodiphenyl ether." *Environmental Science and Pollution Research:* 1-7.
- Zhang, Y., et al. (2013d). "Polybrominated diphenyl ethers in soil from three typical industrial areas in Beijing, China." *J Environ Sci (China)* 25(12): 2443-2450.
- Zhang Z, Sun ZZ, Xiao X, Zhou S, Wang XC, Gu J, Qiu LL, Zhang XH, Xu Q, Zhen B, Wang X, Wang SL (2013e). Mechanism of BDE209-induced impaired glucose homeostasis based on gene microarray analysis of adult rat liver. *Arch Toxicol.* 87(8):1557-67. doi: 10.1007/s00204-013-1059-8.
- Zhang, W., (2012). "The combined effect of decabromodiphenyl ether (BDE-209) and copper (Cu) on soil enzyme activities and microbial community structure." *Environ Toxicol Pharmacol* 34(2): 358-369.
- Zhang W, Cai Y, Sheng G, Chen D, Fu J. (2011 a). Tissue distribution of decabrominated diphenyl ether (BDE-209) and its metabolites in sucking rat pups after prenatal and/or postnatal exposure. *Toxicology.* 28;283(1).49-54.
- Zhang X, Ruan X, Yan M, Zhao Y, Wei W, Qin Z (2011b). Polybrominated diphenyl ether (PBDE) in blood from children (age 9–12) in Taizhou, China. *J Environ Sci.* 23:1199–1204.
- Zhang BZ, Ni HG, Guan YF, Zeng EY. (2010a). Occurrence, bioaccumulation and potential sources of polybrominated diphenyl ethers in typical freshwater cultured fish ponds of South China. *Environ Pollut* 158(5):1876-1882.
- Zhang, C., X. Liu and D. Chen (2010b). "Role of brominated diphenly ether-209 in the differentiation of neural stem cells in vitro." *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience* 28: 497-502.
- Zhao Y, Xianli R, Li Y, Yan M, Qin Z (2013). Polybrominated Diphenyl Ethers (PBDEs) in Aborted Human Fetuses and Placental Transfer during the First Trimester of Pregnancy. *Environ Sci Technol*47:5939–5946.
- Zhou, T., Ross, D.G., DeVito, M. J. & Crofton, K. M. (2001). Effects of short-term in vivo exposure to polybrominated diphenyl ethers on thyroid hormones and hepatic enzyme activities in weanling rats. *Toxicol. Sci.*, 61, 76-82.
- Zhu W, Liu L, (2010). Effect of decabromodiphenyl ether (BDE 209) on soil microbial activity and bacterial community composition. *World Journal of Microbiology and Biotechnology* 26(10). 1891-1899.
- Zhu LY, Hites RA (2005). Brominated flame retardants in sediment cores from Lakes Michigan and Erie. *Environ Sci Technol.*39(10):3488-94. (Erratum in: *Environ Sci Technol.* 2005 39(15):5904).
- Zota, A. R., J. S. Park, Y. Wang, M. Petreas, R. T. Zoeller and T. J. Woodruff (2011). "Polybrominated diphenyl ethers, hydroxylated polybrominated diphenyl ethers, and measures of thyroid function in second trimester pregnant women in California." *Environ Sci Technol* 45(18): 7896-7905.
- Zou, M., Ran, Y. & Gong, J., 2007. Polybrominated diphenyl ethers on watershed soils of the Pearl river delta, China, occurrence, inventory, and fate. *Environmental Science and Technology*, Volume 41, pp. 8262-8267.
- Örn U. (1997). Synthesis of polybrominated diphenyl ethers and metabolism of 2,2',4,4'-tetrabromo[14C]diphenyl ether. Licentiate Thesis, Department of Environmental Chemistry, Stockholm University.