Åke Bergman Curriculum vitae

Personal
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Education/Academic Training, Degrees and Academic Positions

1974-12-23	BS at Stockholm University
1980-05-27	Ph.D. in Organic Chemistry, Stockholm University
1983-09-15	Docent (Associate professor) in Organic Chemistry at Stockholm University
1993-11-01	Professor in Environmental Chemistry, Chair of Environmental Chemistry, Stockholm University

Appointments

750101-830930	Research. assistant at the Unit of Organic Chemistry, Wallenberg laboratory, SU.
810801-820731	Research associate, Dept. of Biochemistry, North Dakota, State University, Fargo, ND, USA.
831001-860630	Researcher at Unit of Organic Chemistry, Wallenberg laboratory, SU (40%).
860701-870630	Researcher at the Special Analytical Laboratory, Swedish EPA (60%).
870701-931101	University lecturer in miljökemisk syntes at the Unit of Environmental Chemistry, SU
900301-920630	Acting professor in Kemisk Miljöanalys at Unit of Environmental Chemistry, SU
900701-	Head of the Unit of Environmental Chemistry, SU, 940920.
920701-931030	Acting professor in Environmental Chemistry at the Unit of Environmental Chemistry, SU. Prefekt (Head of the unit)
931101-20091231	Professor in Environmental Chemistry at Stockholm University. Prefekt (Head of the department)#
20100101-	Deputy head of the Department of Materials and Environmental Chemistry, Head of the Environmental Chemistry Unit

Research orientation

My present research activities are best seen as presented at our website (www.miljokemi.su.se). In breif, my research projects in the field of organic environmental chemistry include *i:* synthesis of standard and test compounds of environmental concern, including metabolites of these compounds and radiolabelled substances; *ii:* development of analytical methods for and analysis of organic substances in environmental samples (primarily in biota); *iii:* exposure assessments in humans and wildlife; *iv:* metabolism studies (kinetics) of environmental pollutants; *v:* development of a new operational concept of persistency; and *vi:* contributions to risk assessment of chemicals.

The status of the Unit of Environmental Chemistry was changed to Department of Environmental Chemistry in September, 1994

International Committee/Board member
International Advisory Committee for the dioxin series of symposia, from 1996 – 2002
Editorial board of "Impact of Endocrine Disrupters on Human Health and Wildlife, 1996/1997, (EU, EEA, WHO, OECD and three national EPA, CEFIC/EMSG).Steering group on Endocrine disrupters, IPCS/OECD, WHO, Pan American Health Organisation/ AMRO 1998-
National representative in Federation of European Chemical Societies (FECS), Division on Chemistry and the Environment, 1998 – Name changed to EuCheMS 2004
EuCheMS Vice Chair of Division of Chemicals and the Environment, 2009 -
International Advisory Committee for BFR workshops 2003-
Albemarle Scientific Advisory Council, Albemarle 2008 – 2009
International Panel on Chemical Pollutants, Founding member and Board member, 2008 –
EFSA Working group member on Brominated flame retardants 2009 -

National Committee/Board member
Research committees at the Swedish EPA (1990-1998)
Institute of Applied Environmental Research (ITM), Stockholm University, 1992-; Chairman 1995-1998, 1999-2001.
The Swedish Chemicals Policy Committee 1996/1997, Expert group
Expert panel for STFI, 1997-
Expert panel for NCC, 1998- 2001
Expert board for the National Food Administration, 1998-
The Royal Swedish Academy of Sciences, The Environmental Committee, 2000-2002; 2003-2005.
Board Member of the Foundation for Strategic Environmental Research - MISTRA, 2000-2001; 2002-2003; 2004-2005
Member of the Scientific Advisory Board for the Swedish Society for Risk Sciences, 2000-
Chairman of the committee for environmentally related toxicology, KMRT, FORMAS, 2001-2003.
Appointed by the Swedish government as a member of the Environmental Advisory Council, 2002-2007
Appointed by the Swedish government as a member of the board of the Swedish Chemicals Agency, 2005 - 2008

Stockholm University Committee/Board member
Member of the Stockholm University Institute for Applied Environmental Research (ITM) board from 1992-2001, and as ITM board chairman 1996-2001.
Deputy member of the Natural Science Faculty board 1994-2002.
Chairman of the Environmental Science drafting committee 2002-2005; 2006-
Member of the "tjänsteförslagsnämnen" within the Chemistry section at Stockholm University

Other activities
Co-ordinator of the 4th framework EU programme "Risk of Endocrine Contaminants" 1996-1999.
Main co-organiser of the 18th Symposium on Halogenated Environmental Organic Pollutants in Stockholm, August 17-21, 1998 (>700 participants)
Government expert on brominated flame retardants on a one week tour to the US (Washington, Chicago and San Francisco together with the State Secretary of the Environment, Ministry of the Environment, Sweden (June 28-July 2, 1999).
Swedish participant in the start up of the STINT program for bilateral cooperation between Mexico and Sweden, 2000
Chairman of "The Second International Workshop on Brominated Flame Retardants", Stockholm May 14-16, 2001 (150-200 participants)
Chairman of12th EuCheMS International Conference of chemistry and the environment - ICCE 2009; Stockholm June 14-17, 2009 (>500 participants)

Reviewer of scientific articles for
Ambio; Analytical Chemistry; Chemosphere; Environment and Health Perspectives; Environmental Science and Technology; Journal of Chromatography; Rapid Communications in Mass Spectrometry; Science; Toxicological and Environmental Research; Environmental Pollution and occasionally other scientific journals.

Scientific Editor
Editor of Environmental Science and Pollution Research International (ESPR), 2009-

Professional Associations (International and National Societies)
American Chemical Society (ACS)
International panel on Chemical Pollutants (IPCP)
International Society for the Study of Xenobiotics (ISSX)
International Isotope Society (IIS)
Society of Environmental Toxicology and Chemistry (SETAC)
Swedish Chemical Society
Swedish Society for Toxicology
International Panel on Chemical Pollution (IPCP)

Awards
Stipend from The Swedish Union of Clerical and Technical Employees in Industry (SIF), 1997
Research Stipend from the King Carl XVI Gustafs jubileumsfond, 1998
Travel stipend from Stockholm University 1999
Awarded the *Honoris causa* degree at University of Latvia, 2002.
Award recognizing the contribution of A. Bergman and B. Jansson in the field of BFR research "The Ake Bergman & Bo Jansson BFR Student Presentation Award" ("Award recognizing the contribution of A. Bergman and B. Janssonin the field of BFR research") at the International BFR workshop 2004, Toronto.
Travel stipend from Stockholm University 2007
Excellence in Review Board 2008 (ACS; Environmental Science and Technology)
The Cancer and Allergy fund, Environmental Medicine Prize, 2009.

Teaching activities
Teacher of undergraduate courses
Environmental Chemistry and Organic Environmental Chemistry, respectively, at Stockholm University.
Regular lecturer at university courses at Uppsala University
Lecturer at post-graduate courses
In charge of a program for environmental science education (3 or 4 years of studies) at Stockholm University, Faculty of Natural Sciences, starting August 2004.
In charge of the department participation for the development of the master program "Swedish School of Environmental Chemistry" SSEC offered as a joint program between Department of Environmental Chemistry, Stockholm University and Department of Chemistry/Environmental Chemistry, Umeå University, starting August 2006 (www.mk.su.se).

Degrees completed under my supervision
Main supervisor for 20 doctorate degrees: Eva Jakobsson (1994); Anders Olsson (1999); Andreas Sjödin (2000), Karlis Valters (2001), Maria Söderström (2002), Christina Larsson (2002), Göran Marsh (2003), Maria Athanasiadou (2003), Johan Eriksson (2004), Sara Rahm (2004), Tina Malmberg (2004), Kaj Thuresson (2005), Britta Fängström (2005); Lotta Hofvader (2006); Karin Norström (2006); Jana Weiss (2006), Anna Christiansson (2008); Hrönn Jörundsdottir (2009), Patricia Moreira Bastos (2009), Tatiana Cantillana (2009)

Assistant supervisor for the doctorate degree of: Eva Klasson Wehler (1989); Lillemor Asplund (1994), Henrik Kylin (1994), Daiva Guvenius-Meironyté (2002), Anna Malmvärn (2007); Daniel Teclchiel (2008)

Opponent for doctoral degree/External reviewer outside Sweden (Respondent names given below)
Ulrika Nilsson, Stockholm University (1992)
Martine Lans, Wageningen Agricultural University, Wageningen, The Netherlands (1995)
Lars-Ove Kjeller, Umeå University (1998)
Hermes Licea Pérez, Stockholm University (2000)
Ilonka Meerts, Wageningen University, Wageningen, The Netherlands (2001).
Monica Waldebäck, Uppsala University (2005)
Leisa Toms, University of Queensland, Brisbane, Australia (2009)
Craig Butt, University of Toronto, Toronto, Canada (2009)

Doctoral degree committees
Frequently appointed; Not specified.

Post doctoral collaborators: Koichi Haraguchi, Japan (1990/91); Hiroaki Kuroki, Japan (1991/92); Nicholas Green, UK (2003/04); Kerri Hornbuckle, USA (2007); Belen Gomara, Spain (2007); Yanling Qiu, China (2007/08); Mohammad Shoeb, Bangladesh (2008)

Publications (please see www.miljokemi.su.se under my name)
Hirsch factor: 49. Up till now I have published >250 original scientific articles in peer reviewed international journals and approx. 110 peer reviewed extended abstracts (4-6 pages) for presentations at international symposia, preferentially the Dioxin symposium series. I have published an additional number of short abstracts (1 page or less) for presentations at national and international symposia. The latter have not been listed among the "Publications".
Book chapters, popular scientific publications, compendium for teaching, scientific policy documents and debate articles have also been written by me.
Part of several newspaper, radio and television interviews and/or discussions.

Invited speaker and session organizer
List available upon request.

Research grants
List available upon request.
Financial support for the research I am doing is coming from Sweden (the Research Council Formas, MISTRA, SEPA), Nordic Council of Ministers, EU R&D and US granting bodies.

Stockholm 2010-03-06
Åke Bergman
Professor, Ph.D.

The Abysmal Failure of Preventing Human and Environmental Exposure to Persistent Brominated Flame Retardants: A Brief Historical Review of BFRs

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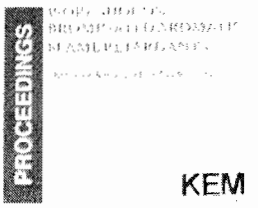
SE-10691 Stockholm, Sweden

Introduction

In 1973, only seven years after the discovery of polychlorinated biphenyls (PCBs) as an environmental contaminant, and five years after the PCB intoxication in Japan, the Yusho tragedy, polybrominated biphenyls (PBBs) were accidentally distributed to farm animals in Michigan[1]. This incident instantly lead to some in-depth studies of this class of brominated flame retardants (BFRs). A few foresighted scientists tried to enlighten the world about the polybrominated diphenyl ethers (PBDEs)[2-4] and pentabromotoluene (PBT)5 as potential environmental issues of concern during the 1970's, but with poor success. The health hazard of tris(2,3-dibromopropyl)phosphate (known as Tris and as TBPP) was identified[6,7] and the compound was phased out. Actually these authors brought forward most of the brominated flame retardants (BFRs) that we still discuss. In the early 1980's came an article reporting on high concentrations of PBDEs in pike from a textile manufacturing area in the southwestern part of Sweden that sparked the issue of PBDEs, at least in Sweden[8].

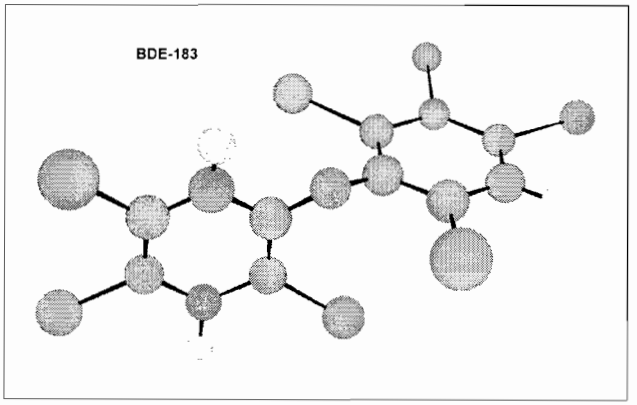
During the next decade, the 1980's, when dioxin was the main environmental contaminant of concern, a few articles from Japan and Sweden put the PBDEs on the agenda. A picture of the BFRs started to emerge, and in 1989 the First International Workshop on Brominated Flame Retardants was held in Skokloster, Sweden[9]. This was an important meeting since data were shared showing the potential impact and volume of environmental problems that BFRs could cause. The time trend of PBDEs in human milk, as presented at the Dioxin '98 symposium in Stockholm, came to be an important scientific contribution showing this class of persistent organic pollutants (POPs) being redoubled every fifth year in Swedish women[10]. Another important discovery was that PBDEs cause developmental neurotoxicity in mice[11-19]. Over the last five years a huge number of scientific articles have been published dealing with PBDEs in particular but also of several other BFRs. In 2004 two types of PBDEs were banned for future use within EU20 and the production was ceased in the U.S. of PentaBDE and OctaBDE. But this did not happen until PBDE concentrations in the most exposed humans were well above the levels of individual PCB and DDT compounds. The concentrations of several persistent PBRs have been allowed to increase in the environment without proper action being taken by countries around the world.



The 1970's

The literature on BFRs can hardly be dated back to years before the 1970's. Still there were a few publications describing synthesis and characteristics of brominated compounds, later to be applied as BFRs. Much more interesting are the articles published during the 1970's that can

only be characterised as foresighted. Those articles were authored by e.g. Bruce Ames[6], Vincent DeCarlo[21], Otto Hutzinger[2] and Åke Norström[3], excluding what was done on the PBBs since that literature was driven by the Michigan incident. The initial publications were dealing with properties of flame retardants and less focussing on the actual chemicals. Blum and Ames published a Science article in 1977 which they end by the sentence *"While waiting for the effects of the large scale human exposure to halogenated carcinogens – polychlorinated biphenyls (PCBs), vinyl chloride, Strobane-toxaphene, aldrin-dieldrin, DDT, trichloroethylene, dibromochloropropane, chloroform, ethylene dibromide, kepone-mirex, heptachlor-chlordane, pentachloronitrobenzene; and so forth – we might think about the avoidance of a similar situation with flame retardants"*[6]. This is one of the articles pointing out the hazards with the BFRs at a very early stage. Others were those dealing with characterisation of major products in PBBs[22-27], PBDEs[3,4,28] and identification of PBT in sewage sludge5. In the second half of this decade photochemical methodology proved useful for synthesis of polychlorinated dibenzofurans (PCDFs)[29,30], and simultaneously photodegradation of PBBs and of polychlorinated diphenyl ethers (PCDEs) were studied[24,31]. The PBB congeners were shown to debrominate to lower PBB congeners and PCDEs to lower chlorinated congeners, as well. The PCDEs formed PCDFs as minor products. Interestingly others did not reflect over similar uncontrolled reaction of e.g. the PBDEs. Even though hexachlorobenzene (HCB) and hexabromobenzene (HBB) were discussed as environmental contaminants, the latter was not in focus as a BFR.



The world became alerted to the risks of BFRs in 1973 when symptoms of intoxication were reported in farm animals in Michigan[32,33]. The cause of the poisoning was not resolved until the spring, 1974. After some major detective work – and with the aid of a little serendipity – scientists were able to identify PBBs as the cause of the intoxication[1]. The problem was that the analytical chemists were not yet used to any chemicals eluting as slowly from a gas chromatograph as the PBBs. The commercial brand name of the PBB was Firemaster BP-6. Symptoms observed among farm animals were loss of weight, decreased milk production, excessive salivation, diarrhea and lowered heart rates among many other symptoms[34]. The intoxication and contamination of farm animals made it necessary to slaughter almost 10.000 cattle, 2000 pigs, 400 sheep and 2 million chickens. The reason behind the intoxication was an accidental mix up of magnesium oxide and PBB at a plant handling both products due to a paper bag shortage at the plant. This led to the distribution of up to 500 kg of PBBs to farmers in Michigan that had ordered the magnesium oxide product. The time lag between distribution of the PBBs to the farmers and the observation of symptoms of intoxication was long enough to cause PBB contamination of a large number of dairy products. This led to a significant exposure of people, particularly of humans living in the state of Michigan, but also others. An early work by Wolff and coworkers[35] reports ppm concentrations of PBBs in workers (median serum levels were 15 ppm on lipid weight basis) at the PBB manufacturing plant.

Technical PBBs were investigated in the 1970's and shown to be much simpler mixtures than the corresponding chlorinated products, the PCBs. The major constituent in PBB products was identified as 2,2',4,4',5,5'-hexabromobiphenyl (BB-153). The compound was responsible for 54-68% of the total BB congener content. BB-153 is still found in biota, and not only from Michigan. The contaminant is frequently detected in European biota as well. It is not clear how the general use of PBBs and decaBB may have influenced the occurrence and distribution of BB-153 in the environment and in humans.

The PBB tragedy in Michigan lead to the cessation of their production and consequently the exposure of population in general has been limited. Still, the major hexaBB congener is frequently determined in both environmental and human samples today. DecaBB was produced for

many years afterward and the manufacturing of this BFR in France was not stopped until 2001. The PBB incident also initiated research on these chemicals and a slow but continuous production of articles and reviews have been presented ever since the accident occurred. Far less has been done in regard of the decaBB.

The other well known BFR from the 1970's is the tris(2,3-dibromopropyl) phosphate, the TBPP. The application of TBPP to impregnated cloths like children's pyjamas made the headlines and lead to the removal of this BFR from the market for this type of application quite rapidly (Blum-ref). Even known for so long there seem to be major data gaps also in the knowledge of TBPP as expressed in the review of the compound as done by IPCS[36]. The mutagenic and carcinogenic characteristics of TBPP were drivers for its elimination from at least part of the market[6;7;36]. However, the toxicological effects are not only limited to those just mentioned as evident from more recent reviews[36;37]. On the other hand the distribution of TBPP in the environment and its exposure to humans and wildlife are not yet well understood. TBPP is metabolised to at least six products, bis(dibromopropyl) phosphate being the major metabolite[36;38].

1980 TO 1995

The first phase of BFR concern, the 1970's, was mainly directed to accidental and obvious exposure to a couple of BFRs. However the basis for future development of BFR research was indeed made over this period. The second phase of BFR research starts around 1980 and includes the next fifteen years, approximately. PBB articles continue to emerge but the difference is that the PBDEs are slowly becoming an issue of environmental concern. In the first half of the 1990's an easily accessible document dealing with BFRs in general was published by IPCS[39] as well as more specific IPCS reviews on PBDEs and tetrabromobisphenol A (TBBPA)[40;41]. Several governmental reports and assessments emerged as well, and media became alerted to PBDEs in electronics. In 1989 the Swedish Chemicals Inspectorate organised the first international workshop on brominated flame retardants[9]. These actions were all initiated by the slowly developing reports of PBDEs and PBBs in the environment, i.e. their occurrence in sediments and wildlife. Very few reports emerged on PBDEs, or any other BFRs, and humans.

Even though the PBDEs were discussed to some extent earlier, the detection of PBDEs in pike downstream from some textile manufacturing plants in southwestern Sweden had specific impact[8]. This BFR made it to the environment and fish were contaminated; the levels were in the ppm range, on a lipid weight basis. A less well known report also came from Wolf and Rimkus that identified PBDEs in the German environment[42]. Stafford possibly found PBDEs in US and Canadian avian tissue in 1983[43], while PBDEs were reported with certainty in Japanese fish, shellfish and sediments from both fresh and marine waters in 1987[44]. In Europe, a report appeared simultaneously presenting data on PBB and PBDE contamination in seals, guillemot and white-tailed sea eagle from the Baltic Sea, in marine waters west of Sweden and in ringed seal from Spitzbergen[45]. A couple of years later additional data were presented on PBDEs in the livers of cod sampled in the North Sea[46]. The number of articles on PBDEs in biota increased in the first part of the 1990's; with e.g. the following European papers[47-50]. The first confirmed PBDE identifications of PBDEs reported from North American wildlife, on dolphins and carp, came in the early 1990's[51;52]. In 1991 Stanley et al report PBDEs in human adipose tissue but no concentrations were determined due to the lack of standards[53]. This is still not the first time decaBDE is mentioned as a contaminant in humans since it was mentioned as early as in 1979[21].

Thermal degradation of PBDEs was performed, by several scientists, in a series of studies during the latter part of the 1980's[54-61]. Some of the studies were performed in the presence of polymeric materials and the common BFR additive antimony(III) oxide. The studies showed that both polybrominated dibenzo-p-dioxins (PBDDs) and PBDFs were formed. These results were confirmed in large-scale combustion experiments conducted in the early 2000's[62;63]. In the latter case the studies included incineration experiments with TBBPA and hexabromocyclododecane (HBCDD), which was also shown to contribute to the formation of PBDFs. Abiotic formation of PBDFs was first reported to occur through photodegradation[64]. Several additional studies have been performed thereafter as presented below.

The toxicologically oriented research on BFRs was mainly concentrated on PBBs and this literature has been reviewed[1;65] and more recently by IPCS66 and ATSDR (http://www.atsdr.cdc.gov). Very little was done on any of the other BFRs. A study on uptake, distribution and elimination of decaBDe was performed by El Dareer et al[67], leading the authors to the conclusion that the compound was so rapidly excreted that it may be a useful BFR. A NTP study was performed reporting on some evidence of carcinogenicity of decaBDE[68] but this result has been largely overlooked since the dose of exposure was high, omitting the fact that only a very minor proportion of the dose was taken up. An example of another toxicologically oriented study was the aryl hydrocarbon hydroxylase induction response to thermally degraded PBDEs[69]. An early ecotoxicologically relevant study was performed dosing three-spined stickleback with organohalogens, including PBDEs[70;71]. The PBDEs caused a decrease in successful spawns.

The availability of pure reference standards and test PBDE compounds was a limiting factor at the time. From early 1990's a program was initiated for synthesis of PBDE congeners. The results from this work have been published in a series of articles over the last ten years[72-75].

The BFR issue was somewhat extended by the introduction of a few articles on TBBPA. The occurrence of this compound and its methylated counterpart were reported in sediment and mussels in Japan[76]. Later on TBBPA and TBBPA methyl ether were reported in Swedish sediment and sewage sludge[77]. The presence of TBBPA in the environment was related to its use in printed circuit boards. A few additional articles were published on HBB as a flame retardant[78] and relating to its metabolism[78-81]. Interestingly HBB is still in use as a BFR, at least in Japan according to production figures[82].

The Swedish interest for BFRs was sparked by the first international workshop on brominated flame retardants held in 1989[9]. The highlights from this workshop included chemistry, production and use of BFRs, their occurrence and (eco)toxicity. The workshop attempted to approach the complexity and several BFRs not previously really discussed were presented at the meeting. A review on PBBs and PBDEs was published in 1995[83].

THE LAST TEN YEARS, 1995-2005

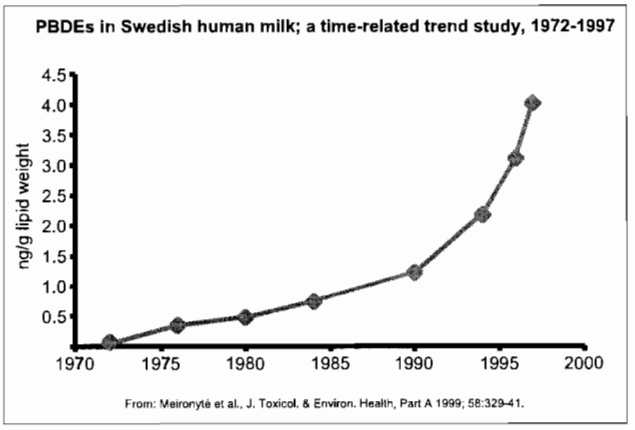
The interest in BFRs, mirrored e.g. by the number of articles in the scientific literature, abstracts to the Dioxin Symposium series and the special workshops, held in Stockholm 2001 and in Toronto 2004, follows an exponential curve. Risk assessment work has been in progress for PBDEs, TBBPA and also HBCDD. This has led to a ban of PentaBDE and OctaBDE within EU and a voluntary change in the production in the U.S.[84;85] while none of the others have yet been brought to a final decision. Over these ten years almost all aspects of abiotic sources, transformations, transportation, wildlife and human exposure, ecotoxicological and toxicological testing have been addressed for the PBDEs. Also HBCDD has entered the arena of interest, at least if we look into the last five years. However, (eco)toxicological testing of HBCDD is still limited. Bis(2,4,6-tribomophenoxy)ethane (BTBPE) and decabromodiphenyl ethane (DBDPEt) have also been found in indoor and outdoor environments[86;87].

I like to highlight a few of the results from the science performed over the last ten years, science that has had particular impact on the field of BFR research and on society. There are still a large number of interesting articles that unfortunately will not be referred to. Unquestionably, the BFRs have become an environmental and health issue for individual countries, as well as the EU, OECD and UNEP. The media attention is more obvious than ever. For those interested to learn more about the state of the science of BFRs, as reviewed at different time points over the last five years, are suggested to consult the articles indicated here[88-96]. OECD is at present finalising a document on PBDEs. To get a view of BFRs not really yet discussed as environmental contaminants may look into a summary presented at the third international workshop on brominated flame retardants in Toronto, 2004[97].

Geographical distribution and abiotic degradation: PBDEs, including decaBDE, have been reported to occur in gradient concentrations from urban to rural areas[98]. They are transported long distances and present in the Arctic region as determined in lake sediments[99], in air[98;100-103] and in biota at high trophic levels[104-106]. Different wildlife concentrations of BFRs in different Arctic regions have just been

discussed[107]. The PBDEs are reported in wildlife from all over the world and are accordingly recognised as POPs. Environmental contamination of PBDEs have been reviewed by several authors[94;108;109]. Now that a number of photodegradation studies have confirmed the UV degradation results of decaBDE in 1987[64], it is clear to all that the highest brominated diphenyl ethers are indeed undergoing debromination and also forming PBDFs[110-112]. Reductive debromination of decaBDE has been shown to occur as well[113;114].

Human levels and trends: There are geographical distribution differences in the concentrations of PBDEs in humans, with the highest concentrations reported so far in the US and Canada[109;115-117] but a very recent study also shows high concentrations among people in Nicaragua (Fäldt et al., Dioxin 2005). In the latter case the decaBDE concentration is high compared to levels in humans subjected to background exposure. PBDE concentrations in humans are in general rather low in Europe[109;118-123] and Japan[124;125] but recently reports of about one fourth the US median levels were reported in women and children from the Faroe Islands[126]. Australians seem to have intermediate levels of PBDEs, somewhere between European and North American concentrations[127]. A most important result on PBDE concentrations was presented at the "Dioxin symposium" in Stockholm, 1998, when a redoubling of the PBDE levels were shown to happen every fifth year[10], a result in direct contrast to the development of DDT and PCB concentrations. This became to be one of the most important studies in the PBDE research since this was something that made risk assessors concerned. Time trend studies from the U.S. and from the Faroe Islands are still indicating increasing trends while levels in Sweden (Stockholm area) seem to be decreasing[128]. Most recently there seem to be a PBDE congener pattern shift, at least in certain populations. The BDE-153 is becoming a more important congener[122;126], a fact that can not yet be explained.



Uptake, distribution and metabolism: Even a molecule with as high a molecular mass as decaBDE is bioavailable and accumulating in the body. So far there are no indications of tissue specificity of the PBDEs. They are retained in adipose tissue, human milk and in e.g. blood lipids. The PBDEs are metabolised as reviewed by Hakk and Letcher[38]. More recently it was shown that decaBDE seems to generate lower brominated diphenyl ethers in humans exposed to the compound[122]. The OH-PBDEs, formed from PBDE congeners, are retained in the blood compartment of experimental animals[129].

Developmental neurotoxicity: A series of studies have revealed similar developmental neurotoxicity of the PBDEs as of PCB congeners[11-19]. This is a most important result as it is shown as an effect in vivo and at doses low enough to have an impact on humans if we prove to be similarly sensitive to the exposure. Only exposure at a certain window is leading to the observed effects. As the PBDEs are persistent they will be continuously present in most humans.

HBCDD: Research on HBCDD, analysis, environmental concentrations and effects has taken off very recently. Analytical methodological issues have been much in focus since this BFR forms, in practise, three isomers (_-, _- and _-HBCDD) among which there are several optically active forms[130]. Some environmental data have been reviewed by Remberger et al96 and other recent data are also available[131-134]. HBCDD concentrations in humans have been reported from a Dutch population and in Mexican women[135]. Wildlife levels of HBCDD are still scarce and so is (eco)toxicological data.

Personal remarks on the history of BFRs

The present brief review of the BFR history shows that we have for long been aware of the problems of both persistent and semi-persistent BFRs. We had a chance to

show that humans are intelligent and capable of handling environmental problems in the late 1970's, but we failed to recognize the grave seriousness of the risk that brominated flame retardants pose to the environment and health. Instead scientists, in increasing numbers, have for a quarter of a century, added data to establish a very good database for the PBDEs but less on other BFRs even though lots of data are available, particularly on PBBs. It must be stressed that we really cannot discuss the overall BFR situation because research has really only dealt with PBBs and PBDEs; to some extent also with TBBPA, HBCDD, HBB and TBPP. This is indeed part of the failure. On the other hand, society did not comprehend the serious threat that the persistent and reactive BFRs pose to life.

Independent of the *corpus* that all chemicals are toxic if the dose is high enough, as first presented by Paracelsus almost 500 years ago, only accidents with severe human symptoms or casualties make societies able to act. What did we then learn from the PCBs, DDT, HCB, PBBs, PCDDs, PCDFs, the "drins", toxaphen, mirex, chlordane, heptachlor...?

References

1. Fries GF. The PBB episode in Michigan. an overall appraisal. Crit.Rev.Toxicol. 1985;16:105-56.
2. Hutzinger, O., Sundstrom, G., and Safe, S. Environmental chemistry of flame retardants. Part I. Introduction and principles. Chemosphere 1976; 5:3-10.
3. Norström Å, Andersson K, Rappe C. Major components of some brominated aromatics used as flame retardants. Chemosphere 1976;5:255-61.
4. Sundström G, Hutzinger O. Environmental chemistry of flame retardants V. The composition of Bromkal 70-5 DE - a pentabromodiphenyl ether preparation. Chemosphere 1976;5:187-90.
5. Mattsson PE, Norström Å, Rappe C. Identification of the flame retardant pentabromotoluene in sewage sludge. J.Chromatogr. 1975;111:209-13.
6. Blum, A. and Ames, B. N. Flame-retardant additives as possible cancer hazards. Science 1977;195:17-23.
7. Blum A, Gold MD, Ames BN et al. Children adsorb tris-BP flame retardant from sleepwear: urine contains the mutagenic metabolite, 2,3-dibromopropanol. Science 1978;201:1020-1023.
8. Andersson Ö, Blomkvist G. Polybrominated aromatic pollutants found in fish in Sweden. Chemosphere 1981;10:1051-60.
9. BFR 1989. Workshop on brominated aromatic flame retardants - Proceedings. Stockholm, Sweden: 1990.
10. Meironyté D, Norén K, Bergman Å. Analysis of polybrominated diphenyl ethers in Swedish human milk. A time-related trend study, 1972-1997. Journal of Toxicology and Environmental Health, Part A 1999;58:329-41.
11. Branchi I, Alleva E, Costa LG. Effects of perinatal exposure to polybrominated diphenyl ether (PBDE 99) on mouse neurobehavioural development. NeuroToxicology 2002;23:375-84.
12. Branchi I, Capone F, Alleva E, Costa LG. Polybrominated diphenyl ethers: Neurobehavioral effects following developmental exposure. NeuroToxicology 2003;24:449-62.
13. Eriksson P, Jakobsson E, Fredriksson A. Brominated flame retardants: A novel class of developmental neurotoxicants in our environment. Environ.Health Perspect. 2001;109:903-8.
14. Eriksson P, Viberg H, Jakobsson E, Örn U, Fredriksson A. A brominated flame retardant, 2,2',4,4',5-pentabromodiphenyl ether: Uptake, retention, and induction of neurobehavioral alterations in mice during a critical phase of neonatal brain development. Toxicol.Sci. 2002;67:98-103.
15. Viberg H, Fredriksson A, Eriksson P. Neonatal exposure to the brominated flame retardant 2,2',4,4',5-pentabromodiphenyl ether causes atered susceptibility in the cholinergic transmittoer system in the adult mouse. Toxicol.Sci. 2002;67:104-7.
16. Viberg H, Fredriksson A, Eriksson P. Neonatal exposure to polybrominated diphenyl ether (PBDE 153) disrupts spontaneous behavior, impairs learning and memory, and decreases hippocampal cholinergic receptors in adult mice. Toxicol.Appl.Pharmacol. 2003;192:95-106.
17. Viberg H, Fredriksson A, Jakobsson E, Örn U, Eriksson P. Neurobehavioral derangements in adult mice recieving decabrominated diphenyl ether (PBDE 209) during a defined period of neonatal brain develpment. Toxicol.Sci. 2003;76:112-20.
18. Viberg H, Fredriksson A, Eriksson P. Investigations of Strain and/or Gender Differences in Developmental Neurotoxic Effects of Polybrominated Diphenyl Ethers in Mice. Toxicol.Sci. 2004;81:344-53.
19. Viberg H, Fredriksson A, Eriksson P. Neonatal exposure to the brominated flame-retardant, 2,2',4,4',5-pentabromodiphenyl ether, decreases cholinergic nicotinic receptors in hippocampus and affects spontaneous behaviour in the adult mouse. Environ.Toxicol.Pharmacol. 2004;17:61-65.
20. Cox P, Efthymiou P. Directive 2003/11/EC of the European parliament and of the council of February 6 2003 amending for the 24th time Council Directive 76/669/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations (pentabromodiphenyl ether, octabromodiphenyl ether). Official Journal of the European Union 2003;OJ L 42(15.2.2003):45-46.
21. DeCarlo, Vincent J. Studies on brominated chemicals in the environment. Annals of the New York Academy of Sciences 320, 678-81:1979.
22. de Kok JJ, de Kok A, Brinkman UA, Kok RM. Analysis of polybrominated biphenyls. J.Chromatogr. 1977;142:367-83.
23. Robertson, Larry W., Safe, Stephen H., Parkinson, Andrew, Pellizzari, Edo, Pochini, Carol, and Mullin, Michael D. Synthesis and identification of highly toxic polybrominated biphenyls in the fire retardant Firemaster BP-6. Journal of Agricultural and Food Chemistry 1984;32:1107-1111.
24. Ruzo, L. O., Sundstrom, G., Hutzinger, O., and Safe, S. Photodegradation of polybromobiphenyls (PBB). Journal of Agricultural and Food Chemistry 1976;24:1062-1065.
25. Safe, S., Kohli, J., and Crawford, A. Firemaster BP-6: fractionation, metabolic and enzyme induction studies. Environ.Health Perspects 1978;23:147-152.
26. Sundstrom, G., Hutzinger, O., Safe, S., and Zitko, V. Environmental chemistry of flame retardants. III. The synthesis and gas chromatographic properties of bromobiphenyls. Stevens Report, Stevens Institute of Technology 1976(1);15-29.
27. Sundström G, Hutzinger O, Safe S. Identification of 2,2',4,4',5,5'-hexabromobiphenyl as the major component of flame retardant FireMaster® BP-6. Chemosphere 1976;5:11-14.
28. de Kok JJ, de Kok A, Brinkman UA. Analysis of polybrominated aromatic ethers. J.Chromatogr. 1979;171:269-78.
29. Choudhry GG, Sundstrom G, van der Wielen FWM, Hutzinger O. Synthesis of chlorinated dibenzofurans by photolysis of chlorinated diphenyl ethers in acetone solution. Chemosphere 1977;6:327-32.
30. Norstrom A, Andersson K, Rappe C. Formation of chlorodibenzofurans by irradiation of chlorinated diphenyl ethers. Chemosphere 1976;5:21-24.

31. Choudhry GG, Sundstrom G, Ruzo LO, Hutzinger O. Photochemistry of chlorinated diphenyl ethers. J.Agric.Food Chem. 1977;25:1371-76.

32. Jackson, T. F. and Halbert, F. L. A toxic syndrome associated with the feeding of polybrominated biphenyl-contaminated protein concentrate to dairy cattle. Journal of the American Veterinary Medical Association 1974;165:437-439.

33. Kay, K. Polybrominated biphenyls (PBB) environmental contamination in Michigan, 1973-1976. Environmental Research 1977;13:74-93.

34. Durst, H. I., Willett, L. B., Brumm, C. J., and Mercer, H. D. Effects of polybrominated biphenyls on health and performance of pregnant Holstein heifers. Journal of Dairy Science 1977;60:1294-1300.

35. Wolff, Mary Snow, Anderson, Henry A., Camper, Francie, Nikaido, Madelene N., Daum, Susan M., Haymes, Neil, and Selikoff, Irving J. Analysis of adipose tissue and serum from PBB (polybrominated biphenyl)-exposed workers. Journal of Environmental Pathology and Toxicology 1979;2:1397-1411.

36. WHO. Environmental Health Criteria 173. Tris(2,3-dibromopropyl) phosphate and Bis(2,3-dibromopropyl) phosphate. Geneva, Switzerland: International Program on Chemical Safety, World Health Organization, 1995.

37. Dybing, Erik, Omichinski, James G., Soederlund, Erik J., Brunborg, Gunnar, Laag, Marit, Holme, Joern A., and Nelson, Sidney D. Mutagenicity and organ damage of 1,2-dibromo-3-chloropropane (DBCP) and tris(2,3-dibromopropyl) phosphate (Tris-BP): role of metabolic activation. Reviews in Biochemical Toxicology 1989;10:139-186.

38. Hakk H, Letcher RJ. Metabolism in the toxicokinetics and fate of brominated flame retardants - a review. Environ.Int. 2003;29:801-28.

39. WHO. Environmental Health Criteria 192. Flame retardants: A general introduction. Geneva, Switzerland: International Program on Chemical Safety, World Health Organization, 1997.

40. WHO. Environmental Health Criteria 162. Brominated diphenyl ethers. Geneva, Switzerland: International Program on Chemical Safety, World Health Organization, 1994.

41. WHO. Environmental Health Criteria 172. Tetrabromobisphenol A and derivatives. Geneva, Switzerland: International Program on Chemical Safety, World Health Organization, 1995.

42. Wolf M, Rimkus G. Chemishe Untersuchungen zu einem Fischsterben mit Hilfe Gaschromatograpie/Massenspectrometrie. Dtsch.tierärztl.Wschr. 1985;92:165-204.

43. Stafford, Charles J. Halogenated diphenyl ethers identified in avian tissues and eggs by GC/MS. Chemosphere 1983;12:1487-95.

44. Watanabe I, Kashimoto T, Tatsukawa R. Polybrominated biphenyl ethers in marine fish, shellfish and river and marine sediments in Japan. Chemosphere 1987;16:2389-96.

45. Jansson B, Asplund L. Brominated flame retardants - Ubiquitous environmental pollutants? Chemosphere 1987;16:2343-49.

46. de Boer J. Organochlorine compounds and bromodiphenylethers in livers of atlantic cod (Gadus morhua) from the North Sea, 1977-1987. Chemosphere 1989;18:2131-40.

47. de Boer, J. Brominated diphenyl ethers in Dutch freshwater and marine fish. Organohalogen Compounds 1990;2:315-18.

48. Jansson B, Andersson R, Asplund L et al. Chlorinated and brominated persistent organic compounds in biological samples from the environment. Environ.Toxicol.Chem. 1993;12:1163-74.

49. Nylund K, Asplund L, Jansson B, Jonsson P, Litzén K, Sellström U. Analysis of some polyhalogenated organic pollutants in sediment and sewage sludge. Chemosphere 1992;24:1721-30.

50. Sellström U, Jansson B, Kierkegaard A, de Wit C, Odsjö T, Olsson M. Polybrominated diphenyl ethers (PBDE) in biological samples from the Swedish environment. Chemosphere 1993;26:1703-18.

51. Kuehl DW, Haebler R, Potter C. Chemical residues in dolphins from the U.S. atlantic coast including atlantic bottlenose obtained during the 1987/88 mass mortality. Chemosphere 1991;22:1071-84.

52. Loganathan BG, Kannan K, Watanabe I et al. Isomer-specific determination and toxic evaluation of polychlorinated biphenyls, polychlorinated/brominated dibenzo-p-dioxins and dibenzofurans, polybrominated biphenyl ethers, and extractable organic halogen in carp from the Buffalo river, New York. Environ.Sci.Technol. 1995;29:1832-38.

53. Stanley JS, Cramer PH, Thornburg KR, Remmers JC, Breen JJ, Schwemberger J. Mass spectral confirmation of chlorinated and brominated biphenylethers in human adipose tissues. Chemosphere 1991;23:1185-95.

54. Buser, H. R. Polybrominated dibenzofurans and dibenzo-p-dioxins: thermal reaction products of poly-brominated diphenyl ether flame retardants. Environ.Sci.Technol. 1986;20:404-08.

55. Dumler, R., Thoma, H., Lenoir, D., and Hutzinger, O. PBDF and PBDD from the combustion of bromine-containing flame retarded polymers: a survey. Chemosphere 1989;19:2023-31.

56. Hutzinger, O., Dumler, R., Lenoir, D., Teufl, C., and Thoma, H. PBDD and PBDF from brominated flame retardants: combustion equipment, analytical methodology, and synthesis of standards. Chemosphere 1989;18:1235-42.

57. Luijk, R., Govers, H. A. J., Eijkel, G. B., and Boon, J. J. Thermal degradation characteristics of high-impact polystyrene/decabromodiphenyl ether/antimony oxide studied by derivative thermogravimetry and temperature resolved pyrolysis-mass spectrometry: formation of polybrominated dibenzofurans, antimony (oxy)bromides and brominated styrene oligomers. Journal of Analytical and Applied Pyrolysis 1991;20, 303-19.

58. Luijk R, Govers HAJ, Nellssen L. Formation of polybrominated dibenzofurans during extrusion of high-impact polystyrene/decabromodiphenyl ether/Antimony(III) oxide. Environ.Sci.Technol. 1992;26:2191-98.

59. Luijk, R. and Govers, H. A. J. The formation of polybrominated dibenzo-p-dioxins (PBDDs) and dibenzofurans (PBDFs) during pyrolysis of polymer blends containing brominated flame retardants. Chemosphere 1992;25:361-74.

60. Thoma, H., Rist, S., Hauschulz, G., and Hutzinger, O. Polybrominated dibenzodioxins and -furans from the pyrolysis of some flame retardants. Chemosphere 1986;15:649-52.

61. Thoma, H. and Hutzinger, O. Pyrolysis and GC/MS-analysis of brominated flame retardants in on-line operation. Chemosphere 1989;18:1047-50.

62. Soederstroem, G. and Marklund, S. PBCDD and PBCDF from Incineration of Waste-Containing Brominated Flame Retardants. Environ.Sci.Technol. 2002;36:1959-64.

63. Soederstroem, G. and Marklund, S. Formation of PBCDD and PBCDF during Flue Gas Cooling. Environ.Sci.Technol. 2004;38:825-30.

64. Watanabe I, Tatsukawa R. Formation of brominated dibenzofurans from the photolysis of flame retardant decabromobiphenyl ether in hexane solution by UV and sun light. Bull. Environ. Contam. Toxicol. 1987;39:953-59.

65. Kimbrough, Renate D. Human health effects of polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs). Annual Review of Pharmacology and Toxicology 1987;27:87-111.

66. WHO. Environmental Health Criteria 152. Polybrominated Biphenyls. Geneva, Switzerland: International Program on Chemical Safety, World Health Organization, 1994.

67. El Dareer SM, Kalin JR, Tillery KF, Hill DL. Disposition of decabromobiphenyl ether in rats dosed intravenously or by feeding. J.Toxicol.Environ.Health 1987;22:405-15.

68. NTP. Toxicology and carcinogenesis studies of decabromodiphenyl oxide (CAS no 1163-19-5) in F344/N and B6C3F1 mice (feed studies). NTP TR 309. 1986.

69. Zacharewski, T., Harris, M., Safe, S., Thoma, H., Hauschulz, G., Knorr, E., and Hutzinger, O. Applications of the in vitro AHH induction bioassay for determining 2,3,7,8-TCDD equivalents: pyrolyzed flame retardant mixtures. Chemosphere 1989;18:383-87.

70. Holm G, Norrgren L, Andersson T, Thurén A. Effects of exposure to food contaminated with PBDE, PCN or PCB on reproduction, liver morphology and cytochrome P450 activity in the three-spined stickleback, Gasterosteus aculeatus. Aquat.Toxicol. 1993;27:33-50.

71. Holm, G., Lundstroem, J., Andersson, T., and Norrgren, L. Influences of halogenated organic substances on ovarian development and hepatic EROD activity in the three-spined stickleback, Gasterosteus aculeatus, and rainbow trout, Oncorhynchus mykiss. Aquatic Toxicology 1994;29:241-56.

72. Chen G, Konstantinov AD, Chittim BG, Joyce EM, Bols NC, Bunce NJ. Synthesis of polybrominated diphenyl ethers and their capacity to induce CYP1A by the Ah receptor mediated pathway. Environ.Sci.Technol. 2001;35:3749-56.

73. Marsh G, Hu J, Jakobsson E, Rahm S, Bergman Å. Synthesis and characterization of 32 polybrominated diphenyl ethers. Environ.Sci.Technol. 1999;33:3033-37.

74. Marsh G. Polybrominated diphenyl ethers and their hydroxy and methoxy derivatives. Congener specific synthesis and analysis [dissertation].Department of Environmental Chemistry, Stockholm University, 2003.

75. Örn U, Eriksson L, Jakobsson E, Bergman Å. Synthesis and characterization of polybrominated diphenyl ethers - unlabelled and radiolabelled tetra-, penta- and hexa-bromodiphenyl ethers. Acta Chem.Scand. 1996;50:802-7.

76. Watanabe I, Kashimoto T, Tatsukawa R. Identification of the flame retardant tetrabromobisphenol-A in the river sediment and mussel collected in Osaka. Bull.Environ.Contam.Toxicol. 1983;31:48-52.

77. Sellström U, Jansson B. Analysis of tetrabromobisphenol A in a product and environmental samples. Chemosphere 1995;31:3085-92.

78. Yamaguchi, Y., Kawano, M., and Tatsukawa, R. Tissue distribution and excretion of hexabromobenzene and its debrominated metabolites in the rat. Archives of Environmental Contamination and Toxicology 1988;17:807-812.

79. Koss G, Döring H, Würminghausen B, Koransky W. Metabolic fate of hexabromobenzene in rats. Toxicol.Lett. 1982;14:69-77.

80. Yamaguchi Y, Kawano M, Tatsukawa R. Tissue distribution and excretion of hexabromobenzene (HBB) and hexachlorobenzene (HCB) administered to rats. Chemosphere 1986;15:453-59.

81. Yamaguchi Y, Kawano M, Tatsukawa R, Moriwaki S. Hexabromobenzene and its debrominated compounds in human tissues of Japan. Chemosphere 1988;17:703-07.

82. Watanabe I, Sakai S-I. Environmetal release and behavior of brominated flame retardants. Environ.Int. 2003;29:665-82.

83. Pijnenburg AMCM, Everts JW, de Boer J, Boon JP. Polybrominated biphenyl and diphenylether flame retardants: analysis, toxicity, and environmental occurrence. Reviews of Environmental Contamination and Toxicology. New York, USA: Springer-Verlag, 1995.

84. BSEF. US legislation. http://www.bsef-site.com/regulation/regulator_ov_usa/. 11-16-2004. Bromine Science and Environmental Forum.

85. Cox JR, Ramsay OB. Mechanisms of nucleophilic substitution in phosphate esters. Chemical Reviews 1964;64:317-52.

86. Kierkegaard A, Björklund J, Friden U. Identification of the Flame Retardant Decabromodiphenyl Ethane in the Environment. Environ.Sci.Technol. 2004;38:3247-53.

87. Sjödin A, Carlsson H, Thuresson K, Sjölin S, Bergman Å, Östman C. Flame retardants in indoor air at an electronics recycling plant and at other work environments. Environ.Sci.Technol. 2001;35:448-54.

88. Birnbaum LS, Staskal DF. Brominated flame retardants: Cause for concern? Environ.Health Perspect. 2004;112:9-17.

89. Darnerud PO, Eriksen G, Jóhannesson T, Larsen P, Viluksela M. Polybrominated diphenyl ethers: occurrence, dietary exposure, and toxicology. Environ.Health Perspect. 2001;109:49-68.

90. Darnerud PO. Toxic effects of brominated flame retardants in man and in wildlife. Environ.Int. 2003;29:841-53.

91. de Boer J, de Boer K, Boon JP. Polybrominated biphenyls and diphenylethers. In: Paasivirta J, editor. The Handbook of Environmental Chemistry Vol. 3 Part K New types of persistent halogenated compounds. Berlin Heidelberg: Springer-Verlag, 2000:61-95.

92. de Wit C. An overview of brominated flame retardants in the environment. Chemosphere 2002;46:583-624.

93. Gill U, Chu I, Ryan JJ, Feeley M. Polybrominated diphenyl ethers: Human tissue levels and toxicology. Rev. Environ. Contam. Toxicol. 2004;182:55-96.

94. Law RJ, Alaee M, Allchin CR et al. Levels and trends of polybrominated diphenylethers and other brominated flame retardants in wildlife. Environ.Int. 2003;29:757-70.

95. McDonald TA. A perspective on the potential health risks of PBDEs. Chemosphere 2002;46:745-55.

96. Remberger M, Sternbeck J, Palm A, Kaj L, Strömberg K, Brorström-Lundén E. The environmental occurrence of hexabromocyclododecane in Sweden. Chemosphere 2004;54:9-21.

97. Örn U, Bergman Å. An attempt to assess the present commercial production of brominated flame retardants. Toronto, Canada: 2004.

98. Harner, Tom, Ikonomou, Michael, Shoeib, Mahiba, Stern, Gary, and Diamond, Miriam. Passive air sampling results for polybrominated diphenyl ethers along an urban-rural transect. Organohalogen Compounds 2002;57:33-36.

99. Muir, Derek, Teixeira, Camilla, Chigak, Maxim, Yang, Fan, D'Sa, Ivy, Cannon, Christina, Pacepavicius, Grazina, and Alaee, Mehran. Current deposition and historical profiles of decabromodiphenyl ether in sediment cores. Organohalogen Compounds 2003;61:77-80.

100. Alaee M, Cannon C, Muir D, Blanchard P, Brice K, Fellin P. Spatial distribution and seasonal variation of PBDEs in Arctic and Great Lakes air. 2001.

101. Butt CM, Diamond ML, Truong J, Ikonomou MG, ter Schure AFH. Spatial Distribution of Polybrominated Diphenyl Ethers in Southern Ontario As Measured in Indoor and Outdoor Window Organic Films. Environ.Sci.Technol. 2004;38:724-31.

102. Hale RC, Alaee M, Manchester-Neesvig JB, Stapleton HM, Ikonomou MG. Polybrominated diphenyl ether flame retardants in the North American environment. Environ.Int. 2003;29:771-79.

103. ter Schure AFH, Larsson P, Agrell C, Boon JP. Atmospheric Transport of Polybrominated Diphenyl Ethers and Polychlorinated Biphenyls to the Baltic Sea. Environ.Sci.Technol. 2004;38:1282-87.

104. Ikonomou MG, Rayne S, Addison RF. Exponential increases of the brominated flame retardants, polybrominated diphenyl ethers, in the Canadian arctic from 1981 to 2000. Environ.Sci.Technol. 2002;36:1886-92.

105. Lebeuf M, Gouteux B, Measures L, Trottier S. Levels and Temporal Trends (1988-1999) of Polybrominated Diphenyl Ethers in Beluga Whales (Delphinapterus leucas) from the St. Lawrence Estuary, Canada. Environ.Sci.Technol. 2004;38:2971-77.

106. Wolkers H, van Bavel B, Derocher AE et al. Congener-specific accumulation and food chain transfer of polybrominated diphenyl ethers in two arctic food chains. Environ.Sci.Technol. 2004;38:1667-74.

107. Borg, Katrine, Gabrielsen, Geir Wing, Skaare, Janneche Utne, Kleivane, Lars, Norstrom, Ross J., and Fisk, Aaron T. Why Do Organochlorine Differences between Arctic Regions Vary among Trophic Levels? Environ.Sci.Technol. , ACS.

108. Hites R, Foran J, Schwager S, Knuth B, Hamilton C, Carpenter D. Global assessment of polybrominated diphenyl ethers in farmed and wild salmon. Berlin, Germany: 2004.

109. Hites RA. Polybrominated Diphenyl Ethers in the Environment and in People: A Meta-Analysis of Concentrations. Environ.Sci.Technol. 2004;38:945-56.

110. Bezares-Cruz J, Jafvert CT, Hua I. Solar Photodecomposition of Decabromodiphenyl Ether: Products and Quantum Yield. Environ.Sci.Technol. 2004;38:4149-56.

111. Peterman PH, Orazio CE, Feltz KP. Sunlight photolysis of 39 mono-hepta PBDE congeners in lipid. Boston, MA, USA: 2003.

112. Söderström G, Sellström U, de Wit CA, Tysklind M. Photolytic debromination of decabromodiphenyl ether (BDE 209). Environ.Sci.Technol. 2004;38:127-32.

113. Gerecke AC, Hartmann PC, Heeb NV et al. Anaerobic Degradation of Decabromodiphenyl Ether. Environ.Sci.Technol. 2005;39:1078-83.

114. Parsons J, Zegers B, Skoczynska E, de Voogt P. Reductive debromination of decabromodiphenyl ether (BDE-209) by anaerobic sediment microorganism. 04; Berlin, Germany: 2004.

115. Schecter A, Paepke O, Tung KC, Joseph J, Harris TR, Dahlgren J. Polybrominated Diphenyl Ether Flame Retardants in the U.S. Population: Current Levels, Temporal Trends, and Comparison With Dioxins, Dibenzofurans, and Polychlorinated Biphenyls. JOEM 2005;47:199-211.

116. Sjödin A, Patterson DGJr, Bergman Å. A review on human exposure to brominated flame retardants (BFRs) - particularly polybrominated diphenyl ethers (PBDEs). Environ.Int. 2003;29:829-39.

117. Sjödin A, Jones RS, Focant J-F et al. Retrospective time-trend study of polybrominated diphenyl ether and polybrominated and polychlorinated biphenyl levels in human serum from the United States. Environ.Health Perspect. 2004;112:654-58.

118. Kalantzi OI, Martin FL, Thomas GO et al. Different levels of polybrominated diphenyl ethers (PBDEs) and chlorinated compounds in breast milk from two U.K. Regions. Environ.Health Perspect. 2004;112:1085-91.

119. Lind Y, Darnerud PO, Atuma S et al. Polybrominated diphenyl ethers in breast milk from Uppsala county, Sweden. Environ.Res. 2003;93:186-94.

120. Strandman T, Koistinen J, Vartiainen T. Polybrominated diphenyl ethers (PBDEs) in placenta and human milk. Organohalogen Compounds 47;2000:61-64.

121. Thomsen C, Lundanes E, Becher G. Brominated flame retardants in archived serum samples from Norway: a study on temporal trends and the role of age. Environ.Sci.Technol. 2002;36:1414-18.

122. Thuresson K, Bergman Å, Jakobsson K. Occupational exposure to commercial decabromodiphenyl ether in workers manufacturing or handling flame retarded rubber. Environ.Sci.Technol. 2005;39:1980-86.

123. Weber, Heinz and Heseker, Helmut. Analysis of polybrominated diphenyl ethers in breast milk of German mothers - results of a pilot study. Fresenius Environmental Bulletin 2004;13,356-60.

124. Choi J, Fujimaki S, Kitamura K et al. Polybrominated dibenzo-p-dioxins, dibenzofurans, and diphenyl ethers in Japanese human adipose tissue. Environ.Sci.Technol. 2003;35:817-21.

125. Ohta S, Ishizuka D, Nishimura H et al. Comparison of polybrominated diphenyl ethers in fish, vegetables, and meats and levels in human milk of nursing women in Japan. Chemosphere 2002;46:689-96.

126. Fängström B. Human exposure to organohalogen compounds at the Faroe Islands [dissertation].Department of Environemtal Chemistry, Stockholm University, 2005.

127. Harden FA, Toms LL, Ryan JJ, Muller JF. Determination of the levels of polybrominated diphenylethers (PBDEs) in pooled blood sera obtained from Australians aged 31-45 years. Toronto, Canada: 2004.

128. Meironyté Guvenius D, Norén K. Polybrominared diphenyl ethers in Swedish human milk. The follow-up study. BFR 2001:303-05; Stockholm, Sweden: 2001.

129. Malmberg T, Athanasiadou M, Marsh G, Brandt I, Bergman Å. Identification of hydroxylated PBDE metabolites in blood plasma from PBDE exposed rats. Environ.Sci.Technol. 2005;In Press.

130. Becher G. The stereochemistry of 1,2,5,6,9,10-hexabromocyclododecane and its graphic representation. Chemosphere 2005;58:989-91.

131. Janak K, Covaci A, Voorspoels S, Becher G. Hexabromocyclododecane in Marine Species from the Western Scheldt Estuary: Diastereoisomer- and Enantiomer-Specific Accumulation. Environ.Sci.Technol. 2005;39:1987-94.

132. Tomy GT, Budakowski W, Halldorson T et al. Biomagnification of a- and g-Hexabromocyclododecane Isomers in a Lake Ontario Food Web. Environ.Sci.Technol. 2004;38:2298-303.

133. Zegers BN, Mets A, van Bommel R et al. Stereo-isomer specific bioaccumulation of hexabromocyclododecane (HBCD) in marine mammals. BFR 2004:411-14. Canada, Toronto: 2004.

134. Zegers, Bart N., Mets, Anchelique, Van Bommel, Ronald, Minkenberg, Chris, Hamers, Timo, Kamstra, Jorke H., Pierce, Graham J., and Boon, Jan P. Levels of Hexabromocyclododecane in Harbor Porpoises and Common Dolphins from Western European Seas, with Evidence for Stereoisomer-Specific Biotransformation by Cytochrome P450. Environ.Sci.Technol. 2005;39, 2095-2100.

135. Lopez D, Athanasiadou M, Athanassiadis I, Estrade LY, Diaz-Barriga F, Bergman Å. A preliminary study on PBDEs and HBCDD in blood and milk from Mexican women. BFR 2004:483-87. Toronto, Canada: 2004.