DIETARY INTAKE OF POLYBROMINATED DIPHENYLETHERS IN THE NETHERLANDS

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Introduction

Polybrominated diphenylethers (PBDEs) are widely used brominated flame retardants which are applied in all kinds of consumer products. These compounds are persistent and bioaccumulative[1]. Humans are exposed to PBDEs mainly via food consumption, the ingestion of house dust and inhalation[2,3].

In the present study, the dietary intake of PBDEs by the Dutch population is investigated. To this end, food products purchased in The Netherlands were analysed for PBDEs. The measured concentrations were used to calculate the dietary exposure. A risk assessment of the dietary exposure to PBDEs is discussed.

Materials and Methods

Food sampling

A sampling programme was designed to obtain representative data on concentrations of lipophilic compounds like PBDEs in foods in The Netherlands. The food categories were divided in four groups. Samples of Group 1 and 2 were collected (May-September 2004) and analysed by the National Institute of Public Health and the Environment (RIVM) (Table 1). Fish and crustaceans (Group 3) were collected in May-September 2003 by the Netherlands Institute for Fisheries Research (RIVO) and were analysed by the same institute. PBDE-concentrations in the remaining food categories (Group 4: vegetables, complex dishes, bakery products and sweets) were not measured but estimated with the Conversion model for Primary Agricultural Products (CPAP)[4] based on their composition.

Table 1. Sampling strategy for relevant food categories

Food categories	Number of samples within each composite sample[a]	Sampling date, institute and sampling method
Group 1: butter, cheese, eggs, vegetable oils and fats, industrial oils and fats, bread, fruit, canned tuna	11	June 2004, RIVM, purchase of set of food products covering 95% of fat intake, and 95% of product intake for cereals and fruit, in supermarkets
Group 2: beef, pork, poultry, mixed meat, milk	4	Sept 2004, RIVM, purchase of set of food products covering 95% of fat intake, in supermarkets
Group 3: fish, crustaceans	9-25[b]	May-Sept 2003, RIVO, samples from research vessel, fish auction, fisherman or wholesale

[a] For food groups 1 and 2 one composite sample was analysed, for group 3 more than one sample was available (wild eel: n = 13; herring: n = 4; mackerel and mussels: n = 3; farmed eel, plaice, sole, shrimp, salmon, flounder, pollack, cod: n = 2); [b] Every fish sample consisted of 9-25 individual fishes. The composite sample of mussels consisted of a homogenate of 100 g mussel meat (out of ca. 500 g mussels). Shrimps (500 g) were homogenised and analysed as whole organisms (uncooked and unpeeled).

Chemical analysis

The extraction and analysis procedures carried out by RIVM (Group 1 and 2, see Table 1) are described in De Mul et al. (2005)[5]. For the extraction and analysis method of RIVO (samples of Group 3) details can be found in De Boer et al. (2001)[6]. Accuracy and reproducibility of the data were established by regular quality control procedures of both institutes. The reproducibility of the PBDE-methods of all groups is good (relative standard deviation < 16 %).

Samples containing PBDE concentrations below the limit of detection (LOD) were assigned levels equal to 0.5 × LOD (upper bound estimates) or zero (lower bound estimates). LODs were reported for each analysis.

Dietary intake
The food consumption of the Dutch population was estimated using the data of the Dutch National Food Consumption Survey 1997/1998 (DNFCS 3)[7]. In short, the food consumption of 6250 individuals (2770 households) was assessed by a 2-day dietary record method, equally distributed over the seven days of the week and over a whole year. The PBDE-concentrations were assigned to consumed food products as recorded in DNFCS 3 by combining information from the chemical analyses of the food categories (group 1-3, Table 1) with the Conversion model of Primary Agricultural Products as described by Van Dooren et al.[4]. To calculate the observed, short-term, PBDE intake of the population, for each participant of the DNFCS the PBDE intake for the two consecutive days considered in the survey was computed. An estimation of long-term intake was made by statistical analysis of the short-term intake data applying the Statistical Exposure Model (STEM) developed by Slob[8].

Risk assessment
In the human body tetra-, hepta- and hexa-brominated PBDEs have persistent characteristics, with reported half-lives being in the range of several years. For such chemicals bioaccumulation, instead of the intake *per se*, should be used as the starting point for the risk assessment of these chemicals ("body burden approach")[9,10]. Basically this approach consists of the following steps: 1. The determination of the NOAEL/LOAEL and corresponding "body burden" in experimental animals and 2. The estimation of the daily human exposure ("maximal allowed intake level") which leads to the same body burden in humans using a one-compartment "steady state" kinetic analysis.

Results
Dietary exposure of the Dutch population to PBDEs
The life-long averaged dietary intakes for the individual PBDE congeners and for the ΣPBDEs calculated with STEM are given in Table 2. BDE 47 shows the highest contribution to the dietary exposure to the ΣPBDEs: about 60-80 % to the total. The most important food categories contributing to the mean intake of the ΣPBDEs were dairy, fish (herring) and meat (Figure 2).

Table 2. Life-long averaged (i.e. averaged for all age classes) long-term dietary intake (ng/kg bw/d) of PBDEs by the Dutch population.

Compound	Dietary intake <LOD=0.5LOD	
	Median	P97.5
BDE 47	0.40	1.09
BDE 99	0.11	0.21
BDE 100	0.08	0.14
BDE 153 + 154[1]	0.14	0.23
Sum of 5 PBDEs	0.79	1.62

[1] BDE 153 concentrations in fish estimated; [2] Could not be determined due to too few positive intakes; [3] Not determined

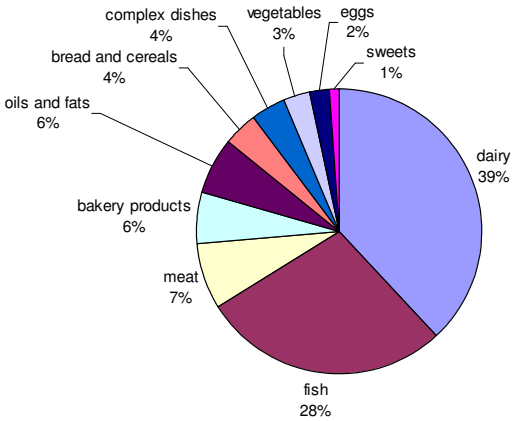

Figure 2. The contribution of different food categories to the intake of the sum of five PBDEs (upper bound estimates) by the Dutch population.

Risk assessment
It appears that reproductive toxicity, as measured by impaired spermatogenesis in offspring, is the hitherto most sensitive endpoint for BDE 99 toxicity in rodents (LOAEL: 60 µg/kg- bw, single dose, p.o. exposure of dams during Gestational Day 6 (GD6)[11]. Similarly a (preliminary) LOAEL of 140 µg/kg has been reported as the most sensitive effect for thyroid hormone disturbance by BDE 47 (p.o., single dose, GD6)[12].
For BDE 99 the risk assessment procedure resulted in a maximal allowed human daily intake level which lies just above the 99th percentile of the long-term daily intake from food in the Dutch population (0.24 ng/kg bw/day). In a similar way a maximal allowed intake level which is just lower than the 90th percentile of the daily intake of BDE 47 from food was calculated. It is concluded that the long-term exposure to BDE 99 and BDE 47 from food is close to the maximal allowed human intake levels. This finding is at odds with the earlier risk evaluations indicating a sufficient Margin of Exposure to preclude a concern of PBDEs for public health[10].

Discussion
Uncertainty
Although the congeners analysed represent a major part of the PBDEs present in the samples, they do not cover the total amount of PBDEs present. It should be kept in mind that the total PBDE concentration will be 10-30% higher than the sum of the PBDEs analysed in this study.
Exposure calculations inherently include sampling uncertainty. This type of uncertainty is related to the high variability of input data used in the exposure assessment, in this case food consumption data and PBDE-concentrations. The sampling uncertainty of the former is negligible in the present study, since the sample size is very large (6250 individuals × 2 days). As the relevant time frame for toxicity of PBDEs is the long-term, the average concentration of the PBDEs in the food categories was determined. To this end, the samples of the food categories were pooled into one composite sample (or at least two composite samples for the fish and crustaceans). This implies that there is no information from this study on the variation of PBDE concentrations within the food categories.

Monitoring of brominated flame retardants
Studies on the PBDE-concentrations in the environment show that, in Europe, an increase since 1970s is followed by a decrease or levelling off of the PBDEs present in the technical pentaBDE product. This decrease/leveling off started in the period from the late 1980s to the early 2000s[13,14]. This is the result of the voluntary production stop and later ban of the technical pentaBDE product in the European Union during the last 10 years. The rate of decline depends on the amount of PBDEs used, as well as on the local and regional PBDE emission sources. Due to the official EU ban of pentaBDE since August 2004, the decreasing PBDE-trend in Europe will likely continue. However, because of their widespread presence in the environment and their persistent character it is expected that PBDEs will continue to be present at relative high levels in food and food products for several years to come. Hence, the European population will be exposed to these substances via food for a long period of time. Since PBDEs accumulate in the body, the body burden of PBDEs will lag behind a decreasing trend in the environment at least a decade and therefore may still increase over time in the coming years. Therefore, it is recommended to maintain a regular monitoring of PBDEs in food products and/or human milk.

Risk assessment
Some of the critical toxic effects which were used in the risk evaluation of PBDEs are described for dioxins as well. For example, impaired spermatogenesis in offspring has also been reported as induced by intrauterine exposure to 2,3,7,8-TCDD[9]. As mentioned before, similar effects were found at with BDE 99. The latter finding, however, was induced by BDE 99 of 98% purity. When assuming this impurity to arise from 2,3,7,8-TCDD this would have led to an exposure of 584 ng/kg 2,3,7,8-TCDD, an exposure level well above the LOAEL of 2,3,7,8-TCDD for this effect[9]. Nevertheless the risk assessment procedure presented here, i.e. leading to upper estimates of the maximal allowed intake levels of PBDEs, seems a reasonable, though ”worst case”, approach.

References

1. Darnerud PO, Eriksen GS, Johannesson T, Larsen PB, Viluksela M. *Environ Health Perspect* 2001; 109: 49
2. Harrad S, Wijesekera R, Hunter S, Halliwell C, Baker R. *Environ Sci Technol* 2004; 38: 2345.
3. Jones-Otazo HA, Clarke JP, Diamond ML, Archbold JA, Ferguson G, Harner T, Richardson GM, Ryan JJ, Wilford B. *Environ Sci Technol* 2005; 39: 5121.
4. Van Dooren MMH, Boeijen I, Van Klaveren JD, Van Donkersgoed G. *Conversie van consumeerbare voedingsmiddelen naar primaire agrarisch producten.* RIKILT Institute of Food Safety, report nr 95.17, Wageningen (In Dutch), 1995.

5. De Mul A, Van Donkersgoed G, Boon P, Bakker M, De Winter-Sorkina R. *Dietary intake of polybrominated diphenyl ethers by the Dutch population.* RIKILT report 2005.006/ RIVM Report 310305001, Bilthoven, the Netherlands, 2005 (available at www.rikilt.wur.nl).
6. De Boer J, Allchin C, Law R, Zegers B, Boon JP. *Trends in Anal Chem* 2001; 20: 591.
7. Kistemaker C, Bouman M, Hulshof KFAM. *Consumption of separate products by Dutch population groups - Dutch National Food Consumption Survey 1997 – 1998* (in Dutch)., TNO-Nutrition and Food Research Institute, TNO-report V98.812, Zeist, the Netherlands, 1998.
8. Slob W. *Risk Anal* 1993; 13: 525.
9. Joint FAO/WHO Expert Committee on Food Additives (JECFA). *Safety evaluation of certain food additives and contaminants*, WHO Food Additives Series 48, World Health Organisation, Geneva, 2002.
10. Joint FAO/WHO Expert Committee on Food Additives (JECFA) *Summary nd Conclusions of the sixty-fourth meeting, Rome, Italy*, 2005.
11. Kuriyama SN, Talsness CE, Grote K, Chahoud I. *Environ Health Perspect* 2005; 113: 149.
12. Andrade AJM, Kuriyama SN, Akkoc Z, Talsness CE, Chahoud I. Organohal Comp 2004; 66: 3907.
13. Kierkegaard A, Bignert A, Sellström U, Olsson M, Asplund M, Jansson B, De Wit C. *Environ Poll* 2004; 130: 187.
14. Sellström U, Bignert A, Kierkegaard A, Häggberg L, De Wit CA, Olsson M, Jansson B. *Environ Sci Technol* 2003; 37: 5496.