Occupational Exposure to Hexabromocyclododecane in Workers at an Industrial Plant

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Introduction

Hexabromocyclododecane (HBCD), the third most produced brominated flame retardant (BFR), is used as an additive BFR mainly in polystyrene thermal insulations and packaging, but also in upholstery textiles and electrical household equipment (Alaee et al. 2003, BSEF 2006). The technical HBCD product consists mainly of three diastereomers; α-, β-, and γ-HBCD, with the γ-isomer being the major constituent (>70%). HBCD has been identified by the U.K. Chemical Stakeholders Forum as a persistent, bioaccumulative and toxic chemical and has been included in the OSPAR list of chemicals for priority action (KEMI 2005). Even though HBCD has been found to be widespread in the environment (de Wit 2002, Remberger et al. 2004, Law et al. 2005, Covaci et al. 2006,), data on levels in humans are scarce (Covaci et al. 2006). The aim of this study was to investigate the HBCD exposure of workers at an industrial plant producing expandable polystyrene flame retarded with HBCD by measuring HBCD concentrations in the workplace atmosphere and in the workers' serum. A control group was constituted from subjects expected to have a background exposure to HBCD.

Materials and Methods

Study subjects

Ten persons working at an industrial plant producing expandable polystyrene were recruited for this study and informed consent was obtained from all subjects. Products containing HBCD have been produced periodically. The ten workers were either working in the so called "reactor" or "mixer" area. Dust protection masks and other personal protection equipment were used on a voluntary basis. The workers were all men, aged 27 to 60 years (mean 43 years). Ten persons from the general Norwegian population were also included in the study in order to compare the serum concentrations of HBCD in the workers at the plant with serum concentrations found in persons expected to have a background exposure to HBCD. This control group comprised five men and five women, their mean age being 65 and 51 years, respectively.

Samples and sampling

Airborne particles were sampled within one of the production periods when HBCD was used. All together 30 samples were obtained. Personal sampling equipment was used, sampling near the breathing zone of the workers throughout the eight hour shift. Each of the ten workers was carrying the sampling equipment during three shifts, as presented in Table 1. Portable battery operated pumps sampling 2 L air per minute were used. As information regarding the particle distribution of the HBCD dust was unavailable, a filter sampling the total dust fraction was used. Thus the measured concentration does not necessarily represent the inhalable fraction. This methodology has been validated and is in routine use at the National Institute of Occupational Health for exposure characterization of aerosols of other low volatile compounds.

Blood samples from the ten workers were collected twice; the first sampling was done between the fourth and ninth day of the production period when air particulate was sampled, and the second blood sampling was performed about six weeks after the end of the production period.

Analysis

Native standards of individual HBCD diastereoisomers were from Cambridge Isotope Laboratories (Andover, MA, USA). The filters were extracted twice in an ultrasonic bath (30 min) using 3 ml dichloromethane. Determination of total HBCD in the extracts was performed at the National Institute of Occupational Health using GC-MS with electron impact ionization. External quantification was used and the extraction efficiency corrected for. The serum samples were added 30 µl of an internal standard solution containing 75 pg 2,3,3',4,4',5-polybrominated diphenyl ether (BDE-156) (Wellington Laboratories, Guelph, Ontario, Canada). The samples were kept overnight in a refrigerator and subsequently extracted according to a previously described method using automated solid phase extraction (Thomsen et al. 2006). The lipids were determined enzymatically and the total lipid content of the samples calculated according to the method described by Grimvall et al. (1997). The total HBCD concentrations in the serum extracts were determined at the Norwegian Institute of Public Health using GC-MS in electron capture negative ionization mode. Internal standard calibration with matrix matched standards of horse serum was used for quantification.

Results and Discussion

Table 1. Concentration of HBCD in airborne particulate samples. Person D and J worked in the mixer area, all the others in the reactor area.

Person	Sampling day	Shift	Conc. in air (µg/m^3)
A	Day 1	Day	1.5
B	Day 1	Day	2.2
C	Day 1	Afternoon	2.1
J	Day 1	Afternoon	0.24
A	Day 2	Day	2.6
B	Day 2	Day	5.6
C	Day 2	Afternoon	1.1
J	Day 2	Afternoon	0.31
A	Day 3	Day	33
B	Day 3	Day	1.9
C	Day 3	Afternoon	1.2
J	Day 3	Afternoon	0.36
G	Day 5	Day	8.8
H	Day 5	Day	2.0
I	Day 5	Afternoon	1.5
E	Day 5	Night	23
F	Day 5	Night	4.0
D	Day 5	Night	0.86
G	Day 6	Day	8.4
H	Day 6	Day	150
I	Day 6	Afternoon	2.7
E	Day 6	Night	2.1
F	Day 6	Night	76
D	Day 6	Night	0.67
G	Day 7	Day	1.0
H	Day 7	Day	8.0
I	Day 7	Afternoon	8.6
E	Day 7	Night	15
F	Day 7	Night	1.5
D	Day 7	Night	0.75

The total HBCD concentration (in µg/m^3) found in the individual samples of airborne particles (n=30) are presented in Table 1 together with information on the work area, sampling day and shift. The HBCD concentration varied from 0.24 µg/m^3 to 150 µg/m^3, with a mean of 12 µg/m^3 and a median of 2.1 µg/m^3. The individual concentrations represent an average during the eight hour shift. The concentrations found in the samples from the mixer area (mean 0.5 µg/m^3, median 0.5 µg/m^3) were significantly lower than those measured in the reactor area (mean 15 µg/m^3, median 2.7 µg/m^3), and the variability was much lower. The HBCD compositions in all the airborne particulate samples closely resembled the technical HBCD mixture used at the factory (results not shown).

It is in general difficult to see any exposure trends regarding different persons, shifts and days. The generally high variation in air concentrations in the breathable zone found in the reactor area might be due to the workers' alternation among different work operations. The HBCD air concentrations were measured only for 3 consecutive shifts, and it is thus not possible to estimate the average HBCD exposure of the individual workers for the whole production period.

To our knowledge, concentrations of HBCD in airborne particulates in occupational settings have not previously been presented. However, HBCD concentrations about one to seven orders of magnitude lower than the mean air concentrations observed at the plant, have been found in outdoor air near potential point sources in Sweden (0.013 ng/m^3 to 1070 ng/m^3) (Remberger et al. 2004).

Two blood samples were taken from each worker; the first during one of the production periods, the second about six weeks after the manufacturing of HBCD containing products ended. The total HBCD concentrations in these two sets of serum samples are presented in Figure 1. The mean serum concentrations were 162 ng/g lipids and 218 ng/g lipids, respectively, the medians were 92 ng/g lipids and 117 ng/g lipids. HBCD was not detected above the limit of detection (LOD = 0.5 ng/g lipid) in any of the serum samples from the subjects in the control group. A large variation in the HBCD serum concentrations in the workers was observed, ranging from 6 ng/g lipids to 856 ng/g lipids, with a tendency to increasing concentration with age (R^2=0.39).

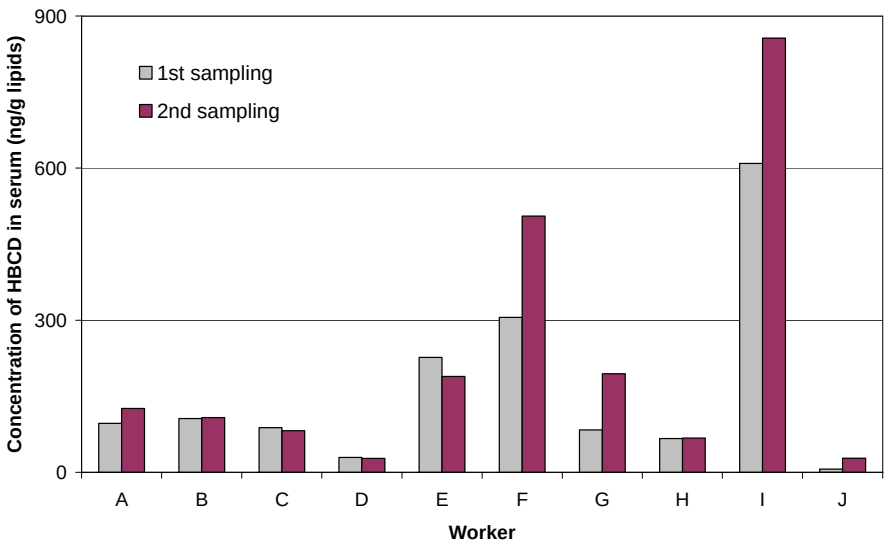

Figure 1. The total concentration of HBCD (ng/g lipids) in the workers' serum sampled in two periods.

Serum concentrations of HBCD were below the LOD for the entire control group. A few studies have presented detectable HBCD levels in general populations. In breast milk from Norwegian mothers, HBCD was detected in 49 out of 85 analyzed samples in the concentration range 0.4 ng/g lipids to 20 ng/g lipids (median 0.62 ng/g lipids) (Thomsen et al. 2005). Similarly, the median HBCD concentrations were reported to be 1.3 ng/g lipids in serum from the Netherlands (Weiss et al. 2004) and 0.5 ng/g lipids and 1.6 ng/g lipids in breast milk from the USA and Canada (Ryan et al. 2006). The serum HBCD levels observed in the workers in the present study are thus about 10 to 1000 times higher compared to background exposed persons.

There was no correlation of serum HBCD levels with average HBCD concentrations in the corresponding particulate air samples, except that considerably lower levels were found in the serum from the two subjects working in the low contaminated mixer area, but they were also the only ones that had used personal protection equipment.

HBCD concentrations in the two sets of the serum samples were closely related in about half of the cases (Figure 1). However, in five out of ten workers considerably increased HBCD levels were found in the second sampling, even though HBCD had not been applied in the production process for six weeks before this sampling. To explain this observed increase, we assume that inhalation of particulate HBCD is an important exposure route; HBCD particles which have penetrated into the deeper parts of the lung might slowly dissolve and enter the blood stream. Thus a peak of HBCD concentration in blood might be delayed with respect to the exposure peak. To our knowledge, no data on toxicokinetics and metabolism in humans exist for HBCD, but the half life in humans has been estimated to be about 64 days (Geyer et al. 2003).

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