HUMAN EXPUSURE TO NOVEL FLAME RETARDANTS – FROM MATERIALS TO HUMANS

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Introduction

Indoor spaces are important environments for exposure to a variety of chemical compounds. Flame retardants are among these compounds and they are often semi-volatile organic compounds (SVOCs), which make them behave very differently from volatile organic compounds (VOCs) in the indoor environment. They evaporate from products, but are adsorbed onto other surfaces e.g. airborne particles, walls, human skin, food items etc. Consequently, they can be found both in the gas phase and bound to airborne particles as well as on surfaces of materials where they were not initially added. Moreover, the equilibration time is often very long, which makes them more difficult to study. Furthermore, other processes such as abrasion from products have been shown to be an important mechanism for spreading of chemicals from materials to the indoor environment[1].

The phase-out of polybrominated diphenyl ethers (PBDEs) in many parts of the world has led to a shift in the compounds used for flame retardation towards novel brominated flame retardants (NBFRs) and organophosphate flame retardants (OPFRs). NBFRs is a pragmatic abbreviation for the group of chemically diverse non-PBDE BFRs including (among others) decabromodiphenyl ethane (DBDPE), 1,2-bis(4,2,4-tribromophenoxy) ethane (BTBPE), 2,3-dibromopropyl-2,4,6-tribromophenyl ether (DPTE), 2-ethylhehexyl-2,3,4,5-tetrabromobenzoate (EH-TBB also known as TBB), bis(2-ethylhexyl)-3,4,5,6-tetrabromophthalate (BEH-TEBP also known as TBPH). Of these, EH-TBB/BEH-TEBP, BTBPE and DBDPE have been described among others as replacements of Penta-, Octa- and DecaBDE, respectively[2,3]. Other NBFRs, along with hexabromocyclododecane (HBCD), can be expected to be increasingly used as replacements for the banned/phased out PBDEs[4]. These compounds have been found in the environment including the Arctic[2,5]. They have also been found in the indoor environment including in house dust[3,6] where levels of BEH-TEBP and DBDPE, in some places, were found to exceed the levels of PBDEs[7].

The literature on human exposure and possible health effects of these compounds is scarce. Limited published literature is available on human internal exposure to these compounds, e.g. DBDPE and BTBPE were below limits of detection (LOD) in serum from China[8]. Some of these compounds (e.g. DBDPE and BTBPE) structurally resemble PBDEs while BEH-TEBP is brominated DEHP (di(2-ethylhexyl) phthalate), which causes concern considering the toxicity of these compounds. Toxicological data on the NBFRs are limited, but DBDPE affects the hatching success of zebra fish[9] while endocrine disrupting potential has been shown for EB-TBB and BEH-TEBP, and the metabolite mono(2-ethylhexyl)tetrabromophthalate exhibited toxicity in rodents[10-12].

The evaporation of NBFRs from construction materials and consumer products is largely unexplored. In addition to the new focus on these compounds, some of the obstacles of performing chamber experiments are the long equilibration times and the re-adsorption to surfaces. Experiments over months are necessary for complete emission testing.

Currently no data exist on the levels of NBFRs in Denmark and the exposure to NBFRs in the indoor environment, but dust has been shown to be an important indicator of exposure to PBDEs[13]. The role of dust as a

vector for NBFRs is not fully understood, but one of the exposure pathways, on addition to ingestion, could be contact to skin, possibly resulting in dermal absorption of NBFRs. However, generally the importance of dermal absorption of flame retardants is poorly understood.

Therefore, in the current project, we will investigate the NBFRs' way from materials to the resulting internal human exposure. This includes:

a) emissions from flame retardant materials
b) levels in house dust
c) levels in human breast milk
d) dermal absorption, using a human skin model

Materials and methods

Emission tests:

The materials for the emission testing were selected based on XRF screening to ensure emission potential. The screening was performed using a Thermo Scientific Nitron XL2 handheld XRF. LOD was between 5 and 500 ppm, depending on material. Seven suppliers of construction materials, furniture and textiles were chosen in the larger Copenhagen area for initial XRF screening of their products. The screening included more than 300 items. Eleven emission experiments has been initiated using 50l CLIMPAQ glass chambers, allowing emission tests at constant temperatures and air velocities, using filtered (F7 and carbon filters) and conditioned air. The flow was adjusted to mimic the situation in a model room, as described in the Nordtest method[14]. This set-up has previously been used successfully for emission estimates of PCBs from construction materials[15]. Air samples will be collected over 24 hrs using XAD-2 sorbent tubes (flow of 1,9l/min). At present, the emission experiment has been started and is going to run for the next 6 months with samples taken regularly. At the end of the experiment, the surfaces of the chambers will be sampled using isopropanol wipes to estimate the fraction left in the surface film of the chambers.

House dust:

House dust was sampled using vacuum cleaner bags from the private homes of new mothers. The dust was sieved and only the size fraction <75µm has been used. The majority of samples (n=37) were collected in 2007 and were originally used for analysis of PBDEs[16]; in brief, vacuum cleaner bags were, sampled 3 months after birth along with a sample of breast milk (see below). In addition to the samples from 2007, 5 new sample sets were collected in 2014.

Breast milk:

As described above, human breast milk samples (n=37) were collected along with matching house dust samples in 2007. The participants were instructed to collect approximately 10-20 ml a week over a 3-month period. The samples were collected approximately 3 months after birth along with the dust samples. As for the dust samples, an additional 5 samples were collected in 2014 approximately 8 month after birth. The study was approved by the Regional Ethics Committee of the Capital Region of Denmark (H-KF-01-327603) as well as the Danish Data Protection Agency.

Dermal uptake model:

Subsequently, dermal absorption and transport across the dermal membrane will be estimated using static diffusion cells. The cells consist of a receptor chamber on top of which a piece of human skin (4x4cm) is placed; on top of the skin a donor chamber is mounted into which the test compounds are added (dissolved in ethanol). The receptor chamber contains a NaCl-buffer solution to which human serum albumin and hexamycin are added. The method is described in detail by Nielsen et al[17,18]. The experiments run for up to 72h after application of the test compounds. After the end of the experiments, the following compartments will be analysed: residual in donor chamber, top layer of skin (stratum corneum and top of epidermis), dermis and receptor fluid.

Chemical analyses

All matrices have been or will be analysed for DBDPE, BTBPE, EH-TBB, BEH-TEBP, DPTE as well as α-, β- and γ-HBCD. Depending on the matrix to be analysed, the extraction methods included Soxhlet extraction, pressurised liquid extraction and ultra-sonication, followed by clean-up by adsorption chromatography. Extracts were divided for separate analysis of NBFRs (GC-MS-ECNI) and HBCDs (LC-MS-MS)[19]. Detection limits for

NBFRs and HBCD isomers in dust ranged from 0.11 to 0.48 ng/g. Minor blanks occurred for HBCDs in the preliminary analyses, i.e. accounting for a maximum of 1% of the concentration in the samples.

Results and discussion

In the XRF screening, fewer items than expected were found to contain bromine at %-levels to indicate the addition of NBFRs. Only 20 of more than 300 items were found to have substantial Br-signal (>100 ppm), and among these only 7 items exceeded 1000 ppm Br. Bromine was not detected above 1000 ppm in any of the textiles or furniture tested (n=95), and only few of these products exceeded 100 ppm. The XRF was used as a screening tool for selection of materials and primarily used as an indicator of presence. The uncertainty of the measurements is unknown, thus the results should not be interpreted as exact bromine content, however others have found XRF to be in good agreement with later GC-MS analysis of the bromine content[20].

Table 1. Materials selected for emission testing and the interval of the bromine reading in ppm.

Material/Item	**Interval of XRF reading for bromine (ppm)**
Halogen spotlight casing	>10000
XPS construction board	>10000
Wall paper	10-100
Parquet underlay, XPS	500-1000
Drain pipes	5000-10000
Floor mat	10-100
Vapour barrier	>10000
PU foam (pressurised bottle)	1000-10000
PU foam, fire retardant (pressurised bottle)	*Not available*
Vinyl flooring	<LOD
Fire retardant carpet	<LOD

Preliminary data on house dust showed that all the NBFRs included in this study could be detected in the samples. DBDPE was often the dominating NBFR with levels clearly higher than the others. The samples had previously been analysed for PBDEs[21,22], and the preliminary results suggested that NBFRs occurred in comparable concentrations The compound distribution in the dust samples from Denmark was different from that in NIST Standard Reference Material 2585, which apparently contains relatively less DBDPE and more EH-TBB and BEH-TBPH than the Danish dust analysed so far[3,23]. This could indicate geographical differences in the use of NBFRs. Considerable geographical differences have been reported in NBFR levels and profiles in dust[24]. Varying DBDPE concentrations were also found nationally, in a UK study of offices, classrooms and homes, possibly an effect of the products in these rooms[25].

HBCD was widely detected in the house dust samples. In the preliminary data γ-HBCD was the dominating isomer among the HBCDs, however, with a varying γ-HBCD/α-HBCD ratio. The proximity to sources could suggest the same isomer pattern as that of the technical mixture, which predominantly consists of γ-HBCD (~78%). However, high temperatures during the incorporation of HBCD in the polymer can change the isomer pattern towards more α-HBCD[26]. Thus, the authors observed a higher percentage of α-HBCD in dust than the percentage in the technical HBCD mixture.

The NBFRs selected in the current project are very lipophilic with log K_{ow} values ranging from approximately 5.6 to 11[5]. The main challenge of the dermal transport model is therefore whether they are too lipophilic to go through the skin, and instead will be absorbed in the top layer of the skin only. Initial results from the dermal absorption model and breast milk analyses will be presented at the conference.

The screening of new materials indicated that there might have been a shift not only from PBDEs to NBFRs but also to some extent from NBFRs to other non-BFRs, since bromine was detected in only few items. However, the results from the dust samples demonstrate that they have been used at some point, and in significant amounts

or in other products that were not covered well by the screening, like electronics. It will be very interesting to see to what extent they can be dermally absorbed and what the resulting internal exposure is.

Since it seems that OPFRs have been widely applied in recent years, it would be highly relevant to investigate these, in particular regarding the dermal absorption. Since they are less lipophilic, their log K_{ow} (appr. 1-5) is closer to the range where transport across the dermal membrane is usually observed ($-2 < \log K_{ow} < 2$). Recent investigations of house dust have shown that they are often present at levels exceeding both PBDEs and NBFRs[27].

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