POLYBROMINATED DIPHENYL ETHERS (PBDEs) IN AIR AND DUST FROM ELECTRONIC WASTE STORAGE FACILITIES AND HOUSES IN THAILAND: IMPLICATIONS FOR HUMAN EXPOSURE

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Abstract

This study is the first report of PBDE concentrations in indoor/outdoor air (using PUF disk passive air samplers) and dust samples collected from 5 electronic waste storage facilities and 33 homes in various locations across Thailand. Ten PBDE congeners present predominantly in the Penta-BDE formulation (BDE 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) were measured in a total of 18 air and 78 dust samples. Atmospheric concentrations of ΣPBDEs in outdoor air in the vicinity of electronic waste storage facilities ranged from 8 to 150 pg m^{-3}. Indoor air concentrations ranged from 46 to 350 pg m^{-3}, with highest concentrations found in a computer and printer waste storage room at a waste storage facility. ∑ PBDE concentrations in domestic indoor air ranged from 23 to 72 pg m^{-3}. The predominant congeners in both outdoor and indoor air samples were BDE 47 and 99. Concentrations in dust from electronic waste storage plants and houses were 36-12000 and 0.55-260 ng ∑ PBDE g^{-1} respectively, with the highest levels found in a room used to house computers and printers at a waste storage facility. The congener profile in all dust samples was dominated by BDE 99 and 47. While the concentrations in Thai domestic indoor air and dust appear at the low end of those reported elsewhere in the world, these data may still indicate indoor environments to be important sources of occupational and non-occupational exposure of the Thai population to PBDEs.

Introduction

Polybrominated diphenyl ethers (PBDEs) have been used extensively as flame retardants in consumer products, including electronic and electrical devices, plastics, building materials, and textiles. They are released into the environment through a variety of routes such as volatilization or dust formation during the use of treated products in homes, car interiors and workplaces, emissions during manufacture and ensuing waste disposal as well as during recycling of PBDE-containing products[1, 2, 3, 4]. Elevated levels of PBDEs have been detected in indoor air and dust owing to emissions from the in-use reservoir which is gradually releasing PBDEs into the outdoor environment[1]. In view of the fact that PBDEs have been used widely in indoor applications, their concentrations in indoor environments are significantly higher than in the outdoor environment[5]. The inhalation of indoor air and ingestion of indoor dust can be the most important exposure pathway for some individuals and age groups (primarily toddlers)[6]. In Thailand, the total electronic waste (televisions, refrigerators, washing machines, air conditioners, computer units, and CRT computer screens) produced in 2003 was approximately 58,000 tons[7]; a quantity that is estimated to increase at a rate of 12% each year[7]. Due to the lack of proper electronic waste handling facilities in Thailand, workers at electronic waste storage facilities face the high risk of exposure to PBDEs in the form of contaminated dust and air. This paper is the first report of PBDE concentrations in indoor/outdoor air and dust samples collected from electronic waste storage facilities and homes in various locations across Thailand.

Materials and methods

PUF (polyurethane foam) disk passive air samplers treated with 10 ng of sampling efficiency standard (SES) were deployed to take 10 outdoor air samples both upwind and downwind of 5 electronic waste storage facilities. In addition, one indoor air sample was taken at each of these facilities as well in 3 homes for a period of approximately 1.5 months. All samples were taken at locations in Thailand. As well as these air samples, dust samples were collected from 4 electronic waste storage plants and 33 homes in locations across Thailand using a vacuum cleaner via a previously reported methodology[8]. All samples were extracted, concentrated, purified and then analyzed for the PBDE concentration (BDE 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) by a Fisons' MD-

800 GC/MS system fitted with a 60 m VF5 MS column (0.25mm id, 0.25 μm film thickness). Standard solutions of PBDE congeners were used to evaluate the efficiency of the method[8, 9, 10].

Results and discussion

Ten PBDE congeners (BDE 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) were measured in a total of 18 air and 78 dust samples. Atmospheric concentrations of ∑ PBDE in outdoor air samples in the vicinity of electronic waste storage facilities ranged from 8 to 150 pg m^{-3}. Indoor air concentrations ranged from 46 to 350 pg m^{-3}, with the highest concentration found in a room storing personal computer and printer waste at a waste storage facility. ∑ PBDE concentrations in indoor air samples are significantly higher than those in outdoor air samples, consistent with an earlier study in Ottawa, Canada[5]. ∑ PBDE concentrations in domestic indoor air ranged from 23 to 72 pg m^{-3} and were higher than those reported previously in Kuwait[11]. The predominant congeners in both outdoor and indoor air samples were BDE 47 and 99.

We hypothesise that PBDE levels in indoor air at electronic waste storage plants exceed that in outdoor air because of the volatilization of PBDEs from the indoor stored electronic wastes. Additionally, the downwind concentrations at 2 e-waste storage facilities (facility 1 and 3) are higher than upwind suggesting that these facilities represent a source of PBDEs to the outdoor environment. Interestingly, the PBDE levels at the other 3 plants are lower at the downwind sites than the upwind sites. Possible reasons for this are: (a) the upwind sampling location for plant 4 is the drop off point where all used electronic and electrical device donations arrive, and is located close to a fridge and washing machine waste storage room; and (b) the upwind sampling locations for plants 2 and 5 are near electrical waste piles.

Concentrations in dust from electronic waste storage facilities and homes were 36-12000 and 0.55-260 ng ∑ PBDE g^{-1} respectively. The congener profile in all dust samples was dominated by BDE 99 and 47. Levels of all BDE congeners detected in household dust in this study were lower than the levels reported in many countries around the world including United Kingdom, United States, Canada, Germany, Australia, New Zealand, Kuwait and Singapore[10, 12, 13, 14]. The reasons for the low PBDE concentrations in house dust in this study are most likely due to greater use of BFRs like TBBP-A in Thailand as well as differences in use patterns and household characteristics such as furnishings, non-carpeted rooms/floor and the small number of electronic and electrical items (especially personal computers and laptops) in rural Thai homes that account for 89% of our total dust sampling sites.

In contrast to the situation in Thai homes, the concentrations detected in dust samples from inside electronic waste storage facilities are typically at least an order of magnitude higher than those detected in UK homes[8]. Within the facilities studied, the highest levels in dust were found in a room used to house personal computers and printers. Figure 1 illustrates how concentrations of ∑ PBDEs in dust samples from an electronic waste storage facility vary with the different waste types stored in the rooms from which dust was sampled. The highest concentration of ∑ PBDEs (12000 ng g^{-1}) was found in dust collected from a room used to store personal computers and printers, whereas the lowest concentration (360 ng g^{-1}) was found in dust sampled from a room used to store waste TVs and fans. Although concentrations of PBDEs in indoor air and dust from electronic waste storage facilities were lower than those in Swedish and Chinese electronic waste recycling facilities[15, 16], the presence of relatively high levels of ∑ PBDEs in indoor air and dust from a Thai electronic waste storage plant suggests that workplace environments have the potential to cause detrimental effects on worker and environmental health. Despite the fact that no *dismantling* of e-waste occurs at these waste storage facilities, the elevated concentrations detected, raise concerns that concentrations at e-waste dismantling facilities may be much higher. While concentrations of PBDEs in Thai domestic indoor air and dust appear at the low end of those reported elsewhere in the world, the data on e-waste storage facilities may still indicate such environments to be important sources of occupational exposure to PBDEs.

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Table1: Σ PBDE concentrations (pg m^{-3}) in 18 outdoor/indoor air samples from different environment categories in this study

Congener/ Location	17	28	47	49	66	85	99	100	153	154	ΣBDE
Plant 1, Indoor air	0.80	2.6	13	1.4	0.34	<dl	11	0.60	14	3.0	46
Plant 1, Outdoor air, Upwind	0.93	1.4	12	0.13	1.6	<dl	4.9	2.2	0.71	0.52	24
Plant 1, Outdoor air, Downwind	0.59	3.8	20	3.4	1.3	3.9	11	5.5	20	5.0	75
Plant 2, Indoor air	0.55	1.8	9.8	0.26	0.71	0.22	15	4.3	9.9	9.3	52
Plant 2, Outdoor air, Upwind	0.29	0.74	5.0	0.21	0.47	0.80	3.5	0.70	0.32	<dl	12
Plant 2, Outdoor air, Downwind	0.29	1.1	2.9	0.19	0.29	0.12	1.4	0.17	1.0	0.59	8
Plant 3, Indoor air	2.2	8.9	49	4.6	3.3	2.6	31	8.5	18	13	140
Plant 3, Outdoor air, Upwind	0.82	3.1	17	3.8	1.9	0.70	23	9.4	0.93	0.77	61
Plant 3, Outdoor air, Downwind	0.86	5.8	46	5.9	3.1	2.3	29	1.1	8.1	5.3	107
Plant 4, Indoor air	0.99	5.3	84	6.2	4.4	7.2	169	30	20	18	345
Plant 4, Outdoor air, Upwind	0.66	2.8	40	3.2	2.1	4.2	73	12	7.2	6.6	152
Plant 4, Outdoor air, Downwind	0.41	1.5	13	1.7	0.87	2.4	27	4.7	2.9	2.5	57
Plant 5, Indoor air	2.4	9.5	14	3.7	2.6	3.9	5.2	1.8	1.8	1.5	46
Plant 5, Outdoor air, Upwind	0.36	1.2	9.6	0.71	1.1	0.25	6.8	8.5	3.1	1.7	33
Plant 5, Outdoor air, Downwind	0.25	0.93	3.8	0.82	0.66	0.71	8.8	3.8	1.6	1.3	23
House in Phuket Province	1.7	6.1	5.9	1.4	0.52	0.85	4.5	0.36	1.3	0.96	23
House in Yala Province	0.54	1.3	17	<dl	<dl	0.72	3.0	0.63	0.22	0.22	23
House in Surin Province	1.8	6.1	29	3.4	2.1	8.5	15	6.0	0.50	0.25	72

Table 2: Summary of Σ PBDE concentrations (ng g^{-1}) in dust samples from different indoor microenvironment categories in this and in Singapore homes[13]

Location	Congener/ Parameter	17	28	47	49	66	85	99	100	153	154	ΣBDE
Thailand, this study, 4 e-waste storage facilities, n = 25	Average	1.1	8.3	410	20	14	36	870	130	380	160	2000
	σ_n	0.90	8.1	500	29	28	45	1200	180	690	270	2900
	Median	0.93	6.8	160	19	1.2	20	380	52	130	49	840
	Minimum	0.07	0.26	6.9	<dl	<dl	0.75	10	2.4	2.6	0.24	36
	Maximum	4.3	33	1800	150	140	180	4600	680	3300	1100	12000
	Percentile 5	0.14	0.49	9.0	0.03	<dl	0.87	15	4.3	4.7	0.93	48
	Percentile 25	0.51	1.5	27	0.31	<dl	4.9	30	12	11	9.6	87
	Percentile 50	0.93	6.8	160	19	1.2	20	380	52	130	49	840
	Percentile 75	1.3	10	600	21	18	44	1100	160	460	160	2600
	Percentile 90	1.9	17	760	31	24	75	1400	200	700	260	3000
	Percentile 95	2.4	23	1600	51	46	130	3900	590	1400	820	8300
Thailand, this study, 33 homes, n=53	Average	0.05	0.14	3.7	0.73	0.40	0.85	6.7	1.4	1.9	1.3	17
	σ_n	0.07	0.14	8.3	1.2	0.76	1.2	19	2.9	3.3	2.9	36
	Median	0.01	0.10	1.9	0.20	0.13	0.38	3.4	0.72	0.91	0.48	10
	Minimum	<dl	<dl	0.12	<dl	<dl	<dl	0.19	<dl	<dl	<dl	0.55
	Maximum	0.32	0.55	59	6.0	5.0	5.3	138	21	17	18	257
	Percentile 5	<dl	<dl	0.22	<dl	<dl	0.01	0.40	0.05	<dl	<dl	1.3
	Percentile 25	<dl	0.04	0.92	0.09	0.06	0.15	1.8	0.26	0.23	0.07	4.0
	Percentile 50	0.01	0.10	1.9	0.20	0.13	0.38	3.4	0.72	0.91	0.48	10
	Percentile 75	0.06	0.20	3.8	0.64	0.39	1.0	5.7	1.3	1.9	1.1	16
	Percentile 90	0.14	0.31	6.8	2.2	0.88	2.3	8.9	2.8	4.5	2.9	25
	Percentile 95	0.18	0.43	9.1	3.3	1.3	3.1	13	3.8	7.3	4.7	43
Singapore 31 homes, n = 31	Average	-	1.2	110	-	-	-	340	65	76	43	660
	σ_n	-	1.3	290	-	-	-	1200	230	260	170	2200
	Median	-	0.6	20	-	-	-	24	4.2	6.9	3.5	86
	Minimum	-	<dl	<dl	-	-	-	<dl	<dl	<dl	<dl	5.5
	Maximum	-	5.8	1500	-	-	-	6300	1200	1400	960	12000

Figure 1: Variation of concentrations of Σ PBDEs (ng g^{-1}) in dust samples from areas of an electronic waste storage facility housing different waste categories