Human Exposure to Decabromodiphenyl Ether, Tetrabromobisphenol A, and Decabromodiphenyl Ethane in Indoor Dust

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Abstract

This paper explores efforts that have been made to quantify the intake of selected flame retardants (FRs) from indoor dust, focusing on decabromodiphenyl ether (BDE-209), tetrabromobisphenol A (TBBPA), and decabromodiphenyl ethane (DeBDethane). After reviewing approaches used to evaluate human exposures to FRs via indoor dust and available exposure estimates, we present quantitative estimates of human exposures to indoor dust via incidental ingestion and dermal contact in a residential setting based on a probabilistic exposure assessment framework. Average daily intake estimates for BDE-209 ranged from 2.2 to 451 ng/kg-day for young children and from 0.26 to 54 ng/kg-day for adults. Based on data from a single study each for TBBPA and DeBDethane, the average daily intake for TBBPA was estimated to be 0.26 ng/kg-day in children and 0.03 ng/kg-day in adults, while the corresponding estimates for DeBDethane were 0.99 ng/kg-day for children and 0.11 ng/kg-day in adults. These results support previous evaluations pointing to incidental soil/dust ingestion as the primary contributor to the total indoor dust exposures associated with the combined exposure pathways (constituting 60 to almost 90% of the combined exposures). This paper also reviews important sources of uncertainty in the exposure estimates and additional research needed to develop more rigorous exposure estimates, such as more accurate characterization of exposure parameters for indoor dust exposures, studies to address data gaps for specific FR compounds and exposure settings, and development of more standardized sampling and analysis protocols.

Keywords: PBDE, BDE-209, TBBPA, DeBDethane, flame retardants, exposure assessment, dust

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1. Introduction

Flame retardants (FRs) are chemicals that are used in a variety of products to delay or prevent the ignition or spread of a fire in combustible materials. Flame retardant chemicals differ in their chemical nature and in the ways that they act to reduce the potential for fire-related harm and damage [1]. In recent years, numerous studies and reports have examined the presence of FR chemicals in various environmental media (e.g., air and dust) and biological media (including human tissues), the sources of these chemicals, and the likely magnitude and relevance of potential pathways for human exposures (e.g., inhalation or incidental ingestion in food or dust). These studies vary in the sampling methodologies used to measure FRs and in the specific chemicals, environmental media, exposure pathways, and exposure locations included in these analyses. As a result, only preliminary conclusions can be drawn from these studies regarding the exposure sources, pathways, and chemicals that are the primary contributors to human exposure.

In a companion paper, Dodge et al. [2]. critically reviewed and analyzed available data regarding the presence of six selected FRs in indoor dust collected using variable sample collection methods (i.e., vacuum, wipe, and tweezer techniques), in different exposure settings [i.e., residences, workplaces (reflecting use of FR-containing products, not manufacturing processes), schools, automobiles, and hotels], and different geographical locations (i.e., North America, Europe, and elsewhere). The selected FRs examined by Dodge et al.

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[2] included compounds reflecting a range of FR characteristics, including their current role in FR uses (e.g., compounds representing a high proportion of current FR uses vs. compounds that have more limited, but potentially emerging, use), their chemical composition (e.g., halogenated vs. non-halogenated compounds), and their method of application in products (e.g., bound to vs. applied to product materials).

Based on a detailed literature search, Dodge et al. [2] found that the most extensive information regarding indoor dust concentrations and related exposure evaluations was available for decabromodiphenyl ether (decaBDE) – an FR compound that currently makes up a major portion of the brominated FR market. The commercial decaBDE belongs to the family of polybrominated diphenyl ethers (PBDEs) that have received intense scrutiny because several studies have reported increasing concentrations in the environment and in humans. DecaBDE is composed almost entirely of the PBDE congener decabromodiphenyl ether (BDE-209), and is used primarily as an additive in a range of hard plastics (i.e., TV casings) and secondarily in some upholstery textiles. More limited information was identified regarding tetrabromobisphenol A (TBBPA) – a high production FR mostly used as a reactive intermediate in printed circuit boards – and decabromodiphenyl ethane (DeBDethane) – another brominated FR being produced and marketed as a general-purpose, direct substitute for BDE-209. For three of the six FRs considered by Dodge et al. [2], no indoor dust data or exposure analyses were located in the scientific literature – resorcinol diphenyl phosphate (RDP), bisphenol A diphenyl phosphate (BDP), and 6H-dibenz(c,e)(1,2)oxaphosphorin, 6-oxide (DOPO). All three of these non-halogenated compounds have been used as alternatives to either decaBDE or TBBPA.

In this paper, we build upon the Dodge et al. [2] analysis to develop estimates of human intake associated with residential exposures to BDE-209, TBBPA, and DeBDethane in indoor dust. First, we review the approaches that have been used to estimate human intake of FRs via indoor dust and present the available intake estimates that have been derived. Then, we present an assessment of human exposures to FRs in indoor dust based on a probabilistic exposure assessment framework. Data compiled by Dodge et al. [2] are applied in this framework to derive intake estimates for BDE-209, TBBPA, and DeBDethane. In contrast to most previous evaluations of potential exposures to FRs via indoor dust, which have been conducted using simplified, deterministic calculations, the use of a probabilistic approach allows for more explicit consideration and examination of the distribution of available dust concentration data and the inherent variability and uncertainty in the exposure parameters used in the analysis. Finally, we review important sources of uncertainty in the exposure estimates and additional research that is needed to support development of more rigorous exposure estimates.

2. Exposure Assessment Literature Review

Dodge et al. [2] conducted an extensive literature search to identify published articles and other reports presenting indoor dust data for selected FRs. This literature search also identified materials discussing approaches for developing quantitative exposure estimates for FRs in indoor dust and closely-related issues, which were the focus of the analysis presented in this paper. Table 1 briefly summarizes the articles identified in the literature search that present approaches for quantifying human intake of FRs.

Almost all of the identified reports that provided exposure estimates for FRs focused on PBDEs, with most of the reports providing specific information regarding BDE-209. One recent article provided exposure estimates for DeBDethane [3], while another report presented quantitative exposure estimates for TBBPA [4]. This review also identified one study which examined exposure issues for phosphororganic FR compounds [5].

Almost all of the reports that provided quantitative exposure estimates – including the report identified for DeBDethane – examined intake associated with incidental ingestion of indoor dust, although one report only included air data and inhalation exposures [6] and several reports evaluating PBDEs did not provide intake estimates specifically for BDE-209 [7, 8] The report that presented intake estimates for TBBPA assessed exposures via dust ingestion, inhalation, and dietary sources [4]. Of the studies that provided estimates for BDE-209, only a few provided intake estimates for exposure pathways other than soil and dust ingestion. For example, several studies also provided quantitative estimates of intake via inhalation and/or diet [9-11]. Hays and Pyatt [12] evaluated potential exposures to decaBDE in a variety of scenarios, including ingestion of breast milk from mothers with workplace exposures, mouthing of decaBDE-containing products, inhalation of decaBDE particulates released from products, and overall intake (estimated based on measured body burden levels). The Hays and Pyatt study, however, did not develop estimates of decaBDE intake associated specifically with incidental ingestion of soil and dust. Lorber [13] conducted an extensive multipathway assessment of potential exposures to PBDEs (including BDE-209), including consideration of exposures via inhalation; dermal contact with soil and dust; and ingestion of water, soil, dust, and a variety of food types.

In most cases, only highly simplified exposure algorithms were used to estimate FR intake associated with dust exposures. For example, the primary focus of many of the studies was collection of concentration data from

Table 1
Exposure Assessment Study Elements

Study	Flame Retardants	Exposure Setting	Exposure Data	Exposed Population	Exposure Routes	Exposure Assessment Type	Location
Abdallah et al., 2008[4]	TBBPA and hexabromocyclo-dodecanes	R, W, A	Collected medium measurements - ID, IA, OA; used estimated dietary intakes from another study	Receptors in ~160 homes, offices, and public microenvironments (e.g., restaurants and pubs); 5 outdoor sampling locations; and 5 cars.	ING - S/D, ING - FD, INH	MOD - INTK (simple algorithms)	UK (West Midlands)
Harrad et al., 2008a[3]	PBDEs (8 congeners, including BDE-209), DeBDethane, and 12 other brominated FRs	R, W, A	Collected medium measurements - ID	Adults and toddlers contacting 30 homes, 18 offices, and 20 cars	ING - S/D	MOD - INTK (simple algorithms)	UK (West Midlands)
Harrad et al., 2008b[58]	PBDEs (tri-deca congeners, including BDE-209)	R	Collected medium measurements - ID	Adults and toddlers contacting ~80 homes	ING - S/D	MOD - INTK (simple algorithms)	NA (TX; Toronto); UK (Birmingham); W (NZ)
Lorber, 2008[13]	PBDEs (primary focus on 9 congeners)	R, W	Used measured medium data from various individual studies - for WTR, OS, ID, IA, OA, fish, meat, dairy; also BLD, MLK	General population - analyses for adults; children (1-5, 6-11, 12-19 years old)	ING - S/D, WTR, FD (dairy, meat, fish); DERM - S/D; INH	MOD - INTK (simple algorithms); MOD - BB/PK (one-compartment; adults only)	primarily NA; some references for E, O
Sjodin et al., 2008[15]	PBDEs (7 congeners, including BDE-209)	R	Collected medium measurements - ID	Adults in 40 residences in 4 countries	ING - S/D	MOD - INTK (simple algorithms)	NA (US); E (Germany, Great Britain); O (Australia)
Stapleton et al., 2008[14]	PBDEs (32 congeners, including BDE-209)	R	Collected medium measurements - OTHER (hand wipes)	32 receptors in Durham, NC	ING - S/D	MOD – INTK (simple algorithm for hand-to-mouth contact)	NA (US)
Allen et al., 2007[9]	PBDEs	R	Collected medium measurements (using personal and air samplers) - IA; used measured FD and S/D data from other studies	20 Boston-area residents	ING - S/D, FD (dairy, meat, fish); INH	MOD - INTK (simple algorithms)	NA (MA)
Tan et al., 2007[10]	PBDEs (8 congeners)	R	Collected medium measurements - ID (from fans and air conditioner filters); used FD and INH intake estimates from other studies	Residents of 31 Singapore homes	ING - S/D, FD (dairy, meat, fish); INH	MOD - INTK (simple algorithms)	primarily O (Singapore); some info for NA, E
Fischer et al., 2006[11]	PBDEs (6 congeners)	R	Collected medium measurements - BLD; used measured S/D and MLK data from other studies	4 members of a CA family	ING - S/D, MLK	MOD - INTK (simple algorithms)	NA (CA)
Harrad et al., 2006[8]	PBDEs	R, W, A, O	Collected medium measurements - IA, some ID; used FD intake estimates from other studies	Receptors at 31 homes, 33 offices, 25 cars, and 3 public microenvironments in Birmingham, UK	ING - S/D, FD; INH	MOD- INTK (simple algorithms)	E (UK)

Hays and Pyatt, 2006[12]	BDE-209	R	Used data collected and compiled in scientific literature, agency reports, and manufacturer information	General population - analyses focused on children (0-2 years old); also some analyses of adults	ING - S/D, FD; INH; also MLK, OTHER	MOD - INTK (simple algorithms for certain scenarios); MOD-BB/PK (for general environmental exposures)	NA
Wenning et al., 2006[59]	PBDEs (17 congeners, including BDE-209)	R, W	Collected media measurements – ID (from vacuum cleaners and air conditioner filters)	Receptors at approximately 10 homes and 1 business	ING - S/D	MOD - INTK (simple algorithms)	NA (Northern CA), O (New Zealand)
Jones-Otazo et al., 2005[7]	PBDEs (excluding BDE-209)	R	Used measured and modeled concentrations from various sources - IA, OA, ID, OS, FD (including fruit, vegetables, grain, fish)	General population (adults 20+ years old; children: 0-0.5, 0.5-4, 5-11, and 12-19 years old); also workers in computer recycling facility	ING - S/D, FD, INH; also MLK	MOD - INTK (using Canadian multimedia risk assessment model - MUM-FAMrisk), OTHER	NA (Toronto, Canada)
Stapleton et al., 2005[60]	PBDEs (22 congeners, including BDE-209)	R	Used measured concentrations - ID (from floor vacuuming and clothes dryer lint)	General population in 17 residences (young children [1-4 years old], adults)	ING - S/D	MOD - INTK (simple algorithm)	NA (Washington, DC; SC)
Wensing et al., 2005[5]	8 phosphororganic FR compounds	R	Used measured data from several other studies	Young children (1-3 years old)	ING - S/D, INH	MOD - INTK (simple algorithm)	E (including Germany); NA (including US, Canada)
Luksemburg et al., 2004[41]	PBDEs (17 congeners, including BDE-209; and mono through non homologues)	R, W	Collected medium measurements - ID	Adults and children in 15 residences	ING - S/D	MOD - INTK (simple algorithm)	NA (MI, CA, NC, WA); O (New Zealand)
Sharp and Lunder, 2004[16]	PBDEs (13 congeners, including BDE-209)	R	Collected medium measurements - ID	Young children (1-4 years old) in 10 residences	ING - S/D	MOD - INTK (simple algorithm)	NA (10 locations throughout the US)
Wilford et al., 2004[6]	PBDEs (10 congeners detected, not including BDE-209)	R, O	Collected medium measurements - IA, OA	Adults in 74 residences	INH	MOD - INTK (simple algorithm)	NA (Ottawa, Canada)

Notes:	***Exposure Data:***	***Exposure Routes:***	***Exposure Assessment Type:***	***Location:***
Flame Retardants:	*BLD - blood*	*ING-S/D - incidental ingestion of soil and/or dust*	*BB - body burden*	*NA - North America*
FR - flame retardant	*IA - indoor air*	*ING - WTR - ingestion of water*	*INTK - intake*	*E - Europe*
PBDEs - polybrominated diphenyl ethers	*ID - indoor dust*	*ING - FD - ingestion of food*	*MOD - modeled (estimated) exposure*	*O - Other*
Exposure Environment:	*MLK - human milk*	*DERM - dermal contact with soil and/or dust*	*MSMT - measured exposure*	
A - automobile	*OA - outdoor air*	*INH - inhalation*	*OTHER*	*Jones-Otazo* et al., *2005 includes modeling of emissions and fate*
R - residential	*OS - outdoor soil*		*PK - pharmacokinetic model*	
S - school/daycare	*WTR - water*			
W - workplace	*OTHER*	*Hays and Pyatt, 2006[12] includes mouthing of BDE-209-containing consumer products.*		
O - other (shops, post office, backyards)				

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