THE USE OF FLAME RATARDANT CHEMICALS IN HEALTHCARE SETTINGS AND POTENTIAL EXPOSURE

by

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Abstract

While increased attention has focused on human exposure to flame retardant chemical additives in residential settings, little attention has focused on exposure and health risks in health care settings. More stringent flammability standards in these settings may result in increased use and exposure to these potentially toxic compounds in vulnerable populations including sick patients, the elderly, children and pregnant women. The goal of this project was to collect more information on the use and potential exposure to flame retardant chemicals in health care environments. To accomplish this goal, manufacturers of health care products were surveyed for information about the construction of their products and application of flame retardant chemicals. In addition, chemical analyses were conducted on both samples of furniture foam and indoor dust samples collected from hospitals as a means of estimating potential exposure and risks to hazardous flame retardants. Very few companies responded to the survey, resulting in limited responses, therefore, more focus was placed on chemical analyses in samples of healthcare products and hospital dust particles. Flame retardant chemicals were detected and quantified in 7 furniture products including a hospital sofa, patient beds and a baby bed. Several different flame retardant chemicals were also detected and quantified in 22 dust samples from 15 different hospitals. The range of total polybrominated diphenyl ether (PBDE) concentrations in dust samples was 1,080 to 75,800 ng/g dry dust and the total organophosphate flame retardants (OPFR) concentrations ranged from 2,290 to 108,000 ng/g dry dust. On average, the levels of OPFR in hospital dust were equivalent to reported levels in residential dust samples while the levels of PBDEs and a newer-use

flame retardant commercial mixture, Firemaster® 550 (FM 550), in hospital dust was higher than reported in residential environments. Estimates of exposure were made based on these measured concentrations and US EPA human dust ingestion data. Based on these findings, exposure to flame retardant chemicals in health care settings could be higher for vulnerable and sick populations, and suggests further research may be needed to assess potential health risks.

Introduction

Flame retardant chemical additives are widely applied to various polymers and textiles found in electrical and electronic equipment, furniture, and even construction materials to meet flammability standards (WHO,1994). These chemicals typically work by significantly reducing the time it takes for a material to combust, or delaying the rate at which a product will burn. Despite the potential benefits in delaying fire propagation and saving lives, these chemical additives are known to leach into the environment and accumulate both in the ecosystem and in human tissues (Soechitram, 2004) (Schecter, 2004). Several research studies have found increasing levels of flame retardants in human tissues over the past few decades, and levels in the United States population are considerably higher compared to levels measured in the European Union (EU) (Hites, 2004) (Hale, 2003). Furthermore, human and animal studies have observed the association of adverse health effects to flame retardant exposure, increasing public health concerns about flame retardants applications in consumer products (Sjödin, 2004) (Ikonomou, 2002) (Norstrom, 2002).

Flame retardants application

The more than 100 types of flame retardant chemicals can be generally divided into four classes: halogenated organic, organo-phosphorus, nitrogen-based and inorganic flame retardants. Brominated flame retardants (BFR), especially PBDE, have had a large market proportion of the halogenated organic market. They are additive chemicals, implying that they are not chemically bonded to the raw material in the products, and

they can continuously leach into the environment during the product lifetime. In addition, their persistence and bioaccumulation behavior contribute to their ubiquitous presence in the environment (Birnbaum, 2004). The measured PBDE concentrations in human tissue are 17 times higher in the United States than levels in Europe. For example, concentrations in people from Europe were about 2ng/g lipid and concentrations in people from United States were about 35 ng/g lipid (Hites, 2004). The higher levels in the US than in EU could be attributed to the stricter flammability standards for residential furniture, in which California's Home Furnishings Technical Bulletin 117 is the major standard (Phil Brown, 2011). Reported adverse effects of some flame retardants include endocrine disruption, neurotoxicity, suspect carcinogenicity and developmental effects. However, different flame retardants have different effects based on their respective structures and properties (Birnbaum, 2004) (Stapleton, Sharma, Getzinger, & Ferguson, 2012) (Darnerud, 2003).

PBDEs have historically been used in polyurethane foam, electronics and some textiles. With the increasing demand of these materials in consumer products, BFRs in 1990 had a market of 145,000 metric tons and doubled to 310,000 metric tons in 2000 (BSEF, 2006). Deca-BDE, penta-BDE and octa-BDE are three different commercial mixtures of PBDEs, and were named based on their respective bromination level. In 2001, deca-BDE comprised 83.3% of the global PBDE market, while penta-BDE was 11.1% and octa BDE 5.6% (Renner, 2004). Penta-BDE and octa-BDE were banned in EU in 2004, while in the US, the manufacturer of pentaBDE voluntarily agreed to phase out the chemicals in 2005. Even with the phase out, the continuous use of old furniture, either by individuals

or by recycling, contributes to continuous emissions of PBDE into the environment and human exposure (La Guardia, 2006).

As PBDEs were restricted, new flame retardant chemicals have increasingly been used and are now detected in indoor environments (Stapleton, et al., 2009) (Wensing, 2005). OPFR have become a popular replacement for PBDE. In Europe, the production and application rate of OPFR was initially larger than PBDE. But more recent studies have now found higher OPFR levels compared to PBDE in indoor environments (Reemtsma, 2008) (Meeker, 2010). The major types of OPFR detected in the indoor environment include: tris(1-chloro-2-propyl)phosphate (TCPP), tris(1,3-dichloroisopropyl) phosphate (TDCPP), triphenyl phosphate (TPP) and tris(2-chloroethyl)phosphate (TCEP). The more widely used chemicals are TPP and TDCPP since they are also used as plasticizers (Stapleton H. M., 2005) (Birnbaum, 2004) (Wu, 2007) (Sjodin, Patterson, & Bergman, 2003). Another flame retardant chemical mixture used as a replacement for pentaBDE is FM 550, which contains two brominated compounds, 2,3,4,5-tetrabromo-ethylhexylbenzoate (TBB) and 2,3,4,5-tetrabromo-bis(2-ethylhexyl) phthalate (TBPH). These two chemicals have been detected in some environmental settings though information about their toxicity and health effects is limited (Bearr, 2010).

Human Exposure Pathways

Human can be exposed to flame retardants through dietary intake, inhalation, dermal absorption, or inadvertent ingestion of dust particles (Daso, 2010). Because halogenated and organo-phosphorus flame retardants are ubiquitous and lipophilic, dietary intake

from meat, fish or chicken can contribute to exposure (Daso, 2010). A study found that serum PBDE levels in vegetarians were 23% lower than in omnivores in the United States (Fraser, 2009). Several European studies have observed correlations between fish or meat ingestion and flame retardants concentrations in the body (Daso, 2010). The time spent in some microenvironments such as living rooms, office rooms or cars can contribute most to exposure since people may stay in those environments for most of the time (Daso, 2010). In addition, due to the continuous leaching and persistence of most flame retardants, indoor dust is a sink for these chemicals (Daso, 2010).

However, exposure pathways are different for people in the US when compared to people in the EU or Asia. Among the general US population, inhalation and ingestion of indoor dust, are suggested to be the primary exposure pathway to PBDEs (Lorber, 2008). According to this review, exposure to house dust from various studies range from 3 ng/day (assuming 1 mg/day dust ingestion) to 400 ng/day while exposure due to food ingestion was only 0.5-2.0 ng/day in the US population. Increasing PBDE levels in human serum was found to be associated with increasing PBDE detected in household dust (Johnson et al. 2011; Stapleton et al. 2012). Thus, the analyses of flame retardants concentrations in dust is a key factor in determining human exposure and health risks to flame retardants in these environments.

Mechanism of toxicity and health concerns

PBDE health concerns

Several animal studies suggest that PBDEs might cause endocrine disruption, especially thyroid hormone disruption and neurodevelopmental alterations. Because of the similar structure of PBDE and their hydroxylated metabolites to thyroid hormones, which include triiodothyronine (T3) and thyroxine (T4), PBDE and their metabolites have been found to compete with T3 and T4 in binding to thyroid hormone transport proteins or thyroid hormone receptors (Meerts, 2000). Rats and mice with a sub-chronic dietary exposure (14 days) to pentaBDE were observed to have decreased T4 (Fowles, 1994) (Darnerud, 2003). Another study indicted that the administration of 7 mg/kg pentaBDE and 5 mg/kg octaBDE would result in a 20% decrement in serum T4 (Zhou, 2001). Two mechanisms were suggested. First, PBDEs may induce liver enzymes such as P450 1A1, cytochrome P450 2B and UDP-glucuronosyltransferases (UGT), which increases the conjugation and excretion of T4. Second, as is stated before, with the similar structure f PBDEs and their metabolites to thyroid hormones, they could bind to the hormone transporter (i.e., transthyretin). Transthyretin (TTR) is important in transporting T4 from mother to fetus and in transfer across the blood-brain barrier. Thus, the preferable binding of hydroxyl-PBDEs may also lead to its bioaccumulation in fetal brain (McDonald, 2002).

Other studies have observed learning and behavioral deficits in mice exposed to PBDEs and the deficits worsen with aging (McDonald, 2002). The effects on neurodevelopment may result from thyroid disruption since thyroid hormones regulates a series of brain

development activities such as neuronal migration, differentiation and neuronal connectivity(Porterfield, 2000). Alternatively, this may also occur from disruption of secondary messengers and alterations in neurotransmitter systems (McDonald, 2002).

In a rodent bioassay study by the National Toxicology Program (NTP), liver neoplastic nodules were associated with high doses of decaBDE administered to rats. Hepatocellular carcinomas, thyroid gland follicular cell adenomas and carcinomas were also observed (NTP, 1986). However, another study using a lower dose found no increase in tumors in rats (Kociba, 1975). Genetic recombination in mammalian cells and the formation of macromolecular adducts in rats tissues were observed in rodent studies with exposure to the lower molecular weight PBDE in pentaBDE (Helleday, 1999) (Orn, 1998). Thus, PBDEs may also be carcinogenic (McDonald, 2002).

From human research studies, PBDEs are suggested to cause adverse effects on reproduction, thyroid hormone homeostasis, and neurodevelopment in children. In a study measuring women's fertility with PBDE exposures, prolonged pregnancy time was associated with increasing PBDE concentrations in serum of women (n=223) (Harley, 2010). Increasing thyroid hormone levels in human subjects was also associated with increasing PBDE levels in several studies. In a study where the researcher measured PBDE concentrations in serum and thyroid hormone levels of a cohort of 140 pregnant women, positive associations were observed between PBDE and T4. In two other studies, increasing PBDE exposure was associated with rising concentrations of T4 in non-pregnant women cohorts [Meeker 2009, Turyk 2008]. A negative association of PBDE

and thyroid stimulating hormones (TSH) was also observed in one study (Harley, 2010). Considering these effects on thyroid hormone regulation, sensitive populations may be pregnant women and developing infants.

In one epidemiology study researchers measured the concentrations of PBDE in blood of the mothers and children and observed a negative association between PBDEs and test scores in both mental and physical development (Herbstman, 2010). In a study on healthy women from central Taiwan, researchers found a negative association between PBDEs in breast milk and unfavorable birth outcomes such as reduced birth weight and birth length of infants (Chao, 2007). In another study in California, serum PBDE were negatively linked to the neurodevelopmental function of children, including assessments of attention, movement and cognition. PBDEs was were also found to be positively associated with increasing attention and motor coordination problems and reduced IQ (Eskenazi, 2013).

OPFR health concerns

According to several animal studies, exposure to OPFRs is associated with adverse effects on reproduction and neurodevelopment. In an *in vitro* study, TPP was observed to activate enzymes that regulate steroid hormones (Honkakoski P, 2004). In a study on rats, an association of TPP exposure with reproductive effects like reduced fertility was observed (Latendresse, 1994).

In human studies, OPFR concentrations in the residential indoor dust were negatively associated with thyroid hormone levels in men (Meeker, 2010). A positive relationship between TDCPP and TPP with prolactin, a protein that regulates reproduction, metabolism and homeostasis of immune response, was also observed (Meeker, 2010). As stated previously, hormones are critical for development. In addition, thyroid hormones regulate a series of essential physiologic processes in human such as cardiac output, basal metabolic rate, endometrium thickening in females and metabolism of proteins and carbohydrates (Gelfand, 1987). Selected toxicity effects of some flame retardants with effective doses are listed in Table 1.

Project Goals

In this project, the use of flame retardant additives, and their potential exposure in health care settings was examined. The goal of this study was to investigate the potential use of flame retardant chemicals in products common to health care settings, and provide information on the relative hazards of the chemicals to help health care managers make more informed decisions. This was to be accomplished by conducting a survey of manufacturers marketing items common to most medical centers, such as hospital beds, and patient cubicle curtains, collecting data on the types of chemicals used by these manufactures and/or information on how they meet flammability standards in their products. However, a majority of the manufactures that were conducted were reluctant to provide information for this survey. As an alternative approach samples from health care settings were sampled and tested for flame retardant chemicals, including samples of polyurethane foam from hospital furniture products, and dust samples collected from

hospitals across the country. This report was prepared for Health Care without Harm (HCWH) and Healthier Hospital Initiative (HHI), who have helped to sponsor and support this project.

Materials and methods

Literature review and surveys

A literature review was first conducted to collect information on flame retardant applications in different products, especially those that are commonly used in health care settings, like hospital interior furnishings. Products containing polyurethane foam were a focal point because several reports indicate that foam is often chemically treated to meet flammability standards. Based on the list of manufacturers provided by HCWH, a list of 18 manufacturers (Appendix I) were prepared. Requests for survey responses were initially conducted by email, and then followed up by a phone interview. The survey primarily requested information about chemical applications used in products to meet different types of flammability standards (e.g.CA TB 117). In addition, the manufacture was asked whether they would like their response to be kept confidential, and not disclosed in any public documents A copy of the survey questionnaire can be found in Appendix II. Surveys were conducted in June-July 2013.

Chemical Analyses

Sample collection

Due to limited information from manufacturers, more focus was placed on chemical analyses of products used in health care settings. Samples of polyurethane foam were collected from an infant incubator (n=1), baby beds (n=2), hospital beds in use (n=1), hospital bed in surplus (n=1), and sofas (n=2) present in the Duke University surplus center (Durham, NC), where the hospital surpluses many of their old or discarded items. In addition, in cooperation with HCWH, dust samples from 15 health care settings across the country were collected and shipped to Dr. Heather Stapleton's laboratory at Duke University. A list of the health care centers that provided dust samples for this study are provided in appendix III.

Chemical analyses

Detailed sample extraction and analysis methods and techniques can be found in Stapleton et al 2012 and Stapleton et al 2014. Briefly, small foam samples were cut out of the hospital furniture to be tested. All foam samples were wrapped in aluminum foil and stored at room temperature until analysis. Approximately 1 cm^3 foam samples were used for an initial screening analysis to determine if, and what type, of flame retardant chemical was present in the foam. If a flame retardant was identified, a secondary analysis was conducted in which a second piece of foam (around 1 cm^3) was cut out and its mass recorded. Accelerated solvent extraction (ASE) with dichloromethane was used to extract FRs from the foam. After a 100-fold dilution of the extract, samples were analyzed by gas chromatography-mass spectrometry (GC-MS) for quantification of flame

retardants. Dust samples from vacuum bags were first sieved to 500 μm using a stainless steel sieve. Hexane and di-chloromethane (50:50) were used to extract chemicals in the dust samples. The extracts were concentrated to 1 mL in hexane and solid phase extraction (SPE) was applied to eliminate impurities in the extracts. PBDEs and OPFR were elued separately during the SPE step into two fractions. PBDE were quantified using gas chromatography mass spectrometry (GC/MS) operated in negative chemical ionization mode (GC/ECNI-MS) and OPFRs were quantified using GC/MS in electron ionization mode (GC/EI-MS).

QA/QC

Detailed quality control procedures can be found in Stapleton et al 2012 and Stapleton et al 2014. Laboratory blanks, replicate samples (n=6), standard dust reference material (SRM 2585; NIST, Gaithersburg, MD) and labeled internal standards were used for data quality control. In the dust analyses, samples were divided into three batches, in which each batch contained one laboratory blank and one SRM sample. All the measured values in the samples were compared to the reported SRM values for quality control. Average blank levels were subtracted from FR levels in samples. Method detection limit (MDL) was three times of the standard deviation of the laboratory blank levels. Dust samples with concentrations less than MDL were assigned a value of ½ MDL.

Results and observations

Manufacturer Surveys

Surveys were conducted with the assistance of Ms. Noelle Wyman, an associate in the research translation core of Duke's Superfund Research Center. 19 manufacturers were contacted about the use of flame retardants using the questionnaire. The survey was first conducted by email. With a zero response rate from email solicitations, a request for a phone interview was then employed. During the phone survey, the number for customer service was used first. Generally, customer service representatives knew little about the application of flame retardants and they forwarded us to sale managers or information department; some representatives also suggested we search for information and request samples using their website.

From the questionnaire, eight people from six companies replied. Three companies were unwilling to reveal their names in the report, and thus C1, C2 and C3 are assigned as their aliases. The remaining companies were Pallas, Carnegie Fabric, and Architex. All six companies produce cubicle curtains while Pallas, Architex and C3 also produce chairs and sofas for hospitals. A question about the use of polyurethane foam was asked since polyurethane foam is a common filler material with high flammability, leading to higher application rates of flame retardants. However, all companies reported that no polyurethane foam was used in their products.

On the company websites, twelve companies listed fire resistance as one of the characteristics for safer products, in which six companies listed the specific fire

protection standards their products met. NFPA 701 (National Fire Protection Association) is the flammability standard most companies conformed to. Other standards include CA 117 (CA Bulletin), NFPA 260, and UFAC Class 1(Upholstered Furniture Action Council). Information about how the products meet the flammability standards is summarized in Table 2.

As to the reason why the specific chemicals were used, Architex indicated that chemicals are applied at the mill so the company does not make the decisions. C2 indicated that it is for human and environmental health concerns while C3 used the chemicals because of product performance. Four companies (Architex, C1, C2 and C3), indicated that they used flame retardants, and three companies (Architex , C2 and C3) have changed the flame retardant chemicals (like changing the formula) due to potential health impacts. The change included changing the chemical formula, like using non-brominated or non-halogenated flame retardants, or using non-toxic materials with inherent flame resistance properties.

Regarding customers' concerns over flame retardants, three companies have received calls expressing concerns about health impacts of these chemicals while one company received calls about concerns over the fire resistance performance of the product. However, both calls were cited as rare situations. Regarding the health concerns, the customers wanted to know if there were flame retardants in the products, and if they were non-halogenated or halogenated flame retardants.

In considering health/toxicity testing of the chemical treatments, three companies stated that they do not consider this, but one company said they rely on the finishers or mill to make that decision. The other three companies were concerned about the chemical ingredients in their products. The guidelines these companies used include LEED (Leadership in Energy and Environmental Design) and Greenguard.

Flame Retardant Chemical Analyses

Analysis of furniture products

A total of 7 foam samples were collected from an incubator mattress, baby bed, patients' bed and hospital sofas for flame retardant testing. The sample IDs with description of the sampled products are listed in Table 3. An initial screening was first made on the foam samples for flame retardants additives by running chemical extracts on a GC/MS system. Chemicals were identified by comparing the responses to the NIST mass spectral database (2005) and by comparison to authentic standards. During the screening, the following FRs were identified: the OPFR such as TDCPP and BFRs such as PBDE, TBB and TBPH. The detected chemicals were then quantified. The concentrations (mg/g foam) are provided in Table 3. No FR chemicals were detected in the incubator mattress. These identified flame retardants are similar to FR treatments identified in residential furniture and baby products (Stapleton et al. 2011; 2012).

Analyses of dust samples

Samples of dust were collected in 15 health care setting during the summer of 2013. Extracts were analyzed by GC/MS and quantified (ng/g dry dust). Table 4 details the summary statistics of the measured concentrations. Both OPFR and brominated FR were commonly detected. The four OPFRs detected were TCPP, TDCPP, TCEP and TPP and their concentrations ranged from 121 to 9,420 ng/g, 1,640 to 54,100 ng/g, 186 to 5,770 ng/g and 344 to 38,400 ng/g, respectively. BDE 209 had the highest concentration and ranged from 1,030 to 62,800 ng/g. Also detected were the BFRs TBB and TBPH, components of FM 550. Total BFR are lower than total OPFR since OPFR are more likely a new-use FR following the phase of PBDE, and are also used as plasticizers in some building materials and products.

A normality test (Spearman test) was conducted and all chemicals were found not to be normally distributed. The distribution is highly skewed to the right. After log transformation, all the chemicals were normally distributed. Correlation analyses were conducted on the different FR measured in the dust samples. No significant correlation (with p value < 0.05) was found between PBDE, OPFR and FM 550. However, significant correlation was only found between several BDE congeners. Table 5 shows the correlation coefficient for the various BDE congeners.

The chemical concentrations measured in hospital dust were then compared to household dust measurements reported in the scientific literature. The median values of household

dust from previous research studies are provided in Table 6 along with the median concentrations measured in the hospital dust samples. Concentrations in home settings are from Dodson, 2012 in which the researchers analyzed dust samples from 16 households in California in 2011. Except for the large amount of BDE 209 detected in the hospital dust, all the other BDE congeners in hospital dust were lower than levels previously measured in household dust. Since the major source of BDE209 is polymer and organic matrix while source of other pentaBDE congeners is polyurethane foam, the higher concentration of BDE209 and lower concentrations of other BDE congeners in hospital dust could be an implication of higher density of polymer products. TBB and TBPH appear to be higher in hospital dust samples. The median concentrations of total TBB and TBPH in hospital dust samples were almost 6 times the amount measured in home dust (Dodson, 2012). For the OPFR, TCPP and TCEP concentrations are lower in the hospital dust samples while TDCPP appears to be higher, compared to reported house dust levels. In general, when comparing concentrations of the FR commercial mixtures (e.g. PBDE or FM 550), the measurements in hospital dust are higher. Since most of the dust samples in healthcare settings were collected in the waiting area, the higher number of furniture items like waiting room chairs or sofas compared to limited pieces of furniture in household settings could contribute to the higher concentrations in the hospital dust.

Conclusion and discussion

With comparison to FR concentration in home settings, people in the sampled health care settings may be exposed to higher levels of some flame retardant chemicals.

To better assess the exposure rate, the US EPA dust ingestion model was used. In the EPA model, 1 to 5 year-old children are assumed to ingest 100-200 mg dust per day on average and adults ingest approximately 20-50 mg dust per day. By multiplying the dust ingestion rate and the median FR concentrations measured in the hospital dust, the exposure rate in health care settings was estimated. The minimum (or maximum) exposure is calculated by multiplying the lowest (or highest) dust ingestion rate with the minimum (or maximum) flame retardants concentration in the dust. To calculate the exposure rate in a most conservative way, which assumed a lowest dust ingestion rate (100 mg dust per day for children and 20 mg dust per day for adults), the mean exposure rate was calculated by multiplying the minimum dust ingestion rate with the median flame retardants concentration in the dust.

Table 7 displays the results of the exposure calculations. The cumulative min, max and mean exposure to total FR (including total PBDE, TBB and TBPH and total OPFR) for adult was estimated to be 209 ng/day, 47.1 ng/day and 377 ng/day, respectively and for children was 898 ng/day, 202 ng/day and 2,710 ng/day, respectively. The mean exposure is consistent with reported exposure to household dust, where the mean exposure for adult is 325 ng/day for adults and 1,600 ng/day for children (Stapleton, et al., 2009).

By comparing the LOAEL in animal studies and the exposure rate, none of the chemicals reached the hazardous level. However, several risk factors should be considered in the comprehensive assessment of risk. First, there are uncertainties in translating animal data to human health effects. In addition, people in health care settings are likely a more

vulnerable population, which includes sick patients, the elderly, pregnant women and children. Thus they may be more sensitive to effects than the general population. Thirdly, mean values were used to estimate the exposure, however, in the real world, one or two hospitals were found to have much higher concentrations than others. People in those health care settings could be exposed to a level that may be significantly higher. Thus, due to these uncertainties, a conclusion as to whether the FR levels detected in hospital dust would pose a health risk or not can not be made.

Lastly, the limited information about the specific settings of the indoor environments sampled in these hospitals is also a limitation. The information gathered only includes hospital names. More detailed information, including room area, furniture covering area, furniture type, the amount of electronic equipment, room building date, furniture production date and furniture replacement rate, would be useful in understanding potential differences in FR levels among these dust samples.

Table 1: Critical effects and LOAEL of long-term exposure to flame retardants chemicals.

Hazardous FR	Suggested Adverse Effects	Species	LOAEL	Reference
PentaBDE	Developmental neurotoxicity	Rats	0.6-0.8 mg/kg body wt. per day	(Darnerud, 2003)
	Altered thyroid hormone homeostasis	Rats		
OctaBDE	Morphological effects	Rats	10 mg/kg body wt. per day	(Darnerud, 2003)
	Fetal toxicity (weight decrease, reduced ossification and bent ribs)	Rats	2 mg/kg body wt. per day	
	Maternal effects	Rats	15 mg/kg body wt. per day	
DecaBDE	Effect on kidney (thyroid hyperplasia, liver enlargement and hyaline degeneration)	Rats	80 mg/kg body wt. per day	(Darnerud, 2003)
	Carcinogenesis (tumor induction)	Rats	1200 mg/kg body wt. per day	
TPP	No data available			
TCPP	No data available			
TDCPP	Increase occurrence of liver carcinomas	Rats	5-80 mg/kg body wt. per day	(WHO, Flame retardants: tris(chloropropyl)phosphate and tris(2-chloroethyl)phosphate, 1998)
	Increase in relative liver weight	Mice	171 mg/kg body wt. per day for males; 62 mg/kg body wt. per day for females	(Kamata E, 1989)
TCEP	Hippocampal lesisons	Rats	44 mg/kg body wt. per day	(Matthews HB, 1990)

Table 2: How companies meet fire protection standards and if chemicals are used.

Companies	How to meet fire protection standards	Chemicals used
Pallas	Fire barriers, interliners, do not use flame retardants	None
Carnegie, customer service	Some are inherent fire resistant (like Trevira CS, Polyester fabric), some are chemically treated (not topical but could be requested by certain products)	Did not indicate
Carnegie, director of technical service	For cubicle curtains, all inherently fire resistant (like Trevira CS and Trevira FR). Flame retardants are used in other products.	None
Architex	Chemical flame retardants, fire barriers (interliners), some are inherently fire resistant (cubicle curtains are inherently flame retardant, for upholstery, 50% is inherently flame retardant and 50% is chemically treated.	Do not know. (Information is at mills' and patented)
C1	Chemical flame retardants, may be some coatings or treatment	Do not know.
C2	Chemical flame retardants, inherently flame retardant material is fire like wool and trevira	Potassium Hexaflourozircona and Zirconium Acetate
C3	Some are inherently flame retard while others treated with chemical flame retardants (a few upholstery and woven wall coverings)	Phosphrous

Table 3: Summary statistics for brominated and organophosphate FR (mg/g foam) in furnishings.

	Foam samples	Total PBDE	FM 550[1]	TDCPP[2]
F1	Baby bed1	/	18.8	/
F2	Baby bed2	/	15.1	/
F3	Incubator mattress	/	/	/
F4	Sofa1	13.7	/	/
F5	Sofa2	12.9	/	/
F6	Patient bed in surplus	36.2	/	/
F7	Patient bed in use	/	/	29.0

1. Concentrations of TBB and TBPH were calculated as FM 550, which represents approximately 50% of FM 550;
2. TDCPP is a type of OPFR.

Table 4: summary statistics for brominated and organophosphate FR (ng/g dry dust) in dust samples.

				Geome	Percentile				
	%detected	**min**	**max**	**an**	**10th**	**25th**	**50th**	**75th**	**90th**
BDE 28,33	96.6	0	35.9	35.9	2.03	4.43	10.1	26.4	106
BDE47	100.0	25.8	2740	440	49.1	81.2	243	592	863
BDE100	100.0	2.72	666	87.4	7.42	14.9	38.5	136	181
BDE99	100.0	17	8740	1,340	91.6	223	425	1,840	3,580
BDE154	100.0	0.92	349	67	4.63	12.3	39.8	98.1	132
BDE153	100.0	3.67	433	91	8.99	20.9	75.2	128	175
BDE209	100.0	1,030	62,800	8,750	1,550	2,150	6,730	9,820	12,500
TBB	100.0	56.9	1,990	369	79.5	123	204	291	826
TBPH	94.1	0	11,300	2,460	439	918	1,610	3,460	4,070
Total PBDE		1,080	75,800	10,800	1,710	2,500	7,560	12,600	17,600
Total Br-FR		1,140	89,100	13,600	2,230	3,540	9,370	16,400	22,500
TCEP	100	186	5,770	1,070	243	537	726	1,170	1,910
TDCPP	100	1,640	54,100	6,720	1,940	2,430	4,640	6,420	9,700
TCPP	100	121	9,420	2,340	698	986	1,760	2,890	4,170
TPP	100	344	38,400	7,770	782	2,630	3,530	6,860	19,100
Total OPFR		2,290	108,000	17,900	3,670	6,580	10,700	17,300	34,800

Table 5: A correlation matrix for PBDEs in dust.

	BDE 28,33	BDE 47	BDE 100	BDE 99	BDE 154	BDE 153	BDE 209
BDE.28.33	1						
BDE.47	0.69*	1					
BDE.100	0.49*	0.83*	1				
BDE.99	0.4	0.65*	0.66*	1			
BDE.154	0.62*	0.95*	0.8*	0.53*	1		
BDE.153	0.51*	0.85*	0.74*	0.48*	0.87*	1	
BDE.209	0.61*	0.51*	0.36	0.19	0.49	0.47	1

Values with * are with p value less than 0.05

Table 6: Comparison levels in health care to levels (ng/g dry dust) in household.

	Hospital dust		Household dust
	Geometric mean	**Median**	**Median**
BDE47	440	243	1,000
BDE100	87.4	38.5	240
BDE99	1,340	425	1,100
BDE154	67	39.8	110
BDE153	91	75.2	150
BDE209	8,750	6,730	1,200
Total PBDE	**10,800**	**7,550**	**3,800**
TBB	369	204	100
TBPH	2460	1,610	260
FM 550	**2,830**	**1,810**	**360**
TCPP	2,340	1,760	2,200
TDCPP	6,720	4,640	2,100
TCEP	1,070	726	2,700
Total OPFR	**10,100**	**7,130**	**7,000**

Household dust concentrations from (Dodson, 2012).

Table 7: Estimated exposure rate (ng/day) for adults and children in health care settings.

	Adult			Children		
	Min	Max	Mean	Min	Max	Mean
BDE47	1	137	10.7	5	548	46.1
BDE100	0.1	33	1.84	0.3	133	7.89
BDE99	1	437	23.1	5.1	1,750	99.2
BDE154	0	18	1.46	0.1	70	6.24
BDE153	0.1	22	2.34	0.4	87	10
BDE209	16.5	3,090	170	82.4	12,400	729
Total PBDE	18.7	3737	209	93.3	14988	898
TBB	0.6	100	5.88	3.2	398	25.2
TBPH	1.3	555	41.3	6.5	2,220	177
FM550	1.9	655	47.2	9.7	2618	202
TCEP	3.7	289	27.6	18.6	1,150	118
TDCPP	32.8	2,710	157	164	10,800	674
TCPP	2.4	471	55	12.1	1,880	236
TPP	6.9	1,920	137	34.4	7,680	587
Total OPFR	45.8	5,390	376	229	21,500	1,620
Total FR	66	9,770	633	332	39,100	2,710

For adults, minimum (or maximum) exposure was calculated by multiplying the minimum (or maximum) flame retardant concentrations with the minimum dust ingestion rate, 20 mg dust per day (or 50 mg dust per day); mean exposure was calculated by multiplying the mean flame retardant concentrations with the median dust ingestion rate (35 mg dust per day);
For children, minimum (or maximum) exposure was calculated by multiplying the minimum (or maximum) flame retardant concentrations with the minimum dust ingestion rate, 100 mg dust per day (or 200 mg dust per day); mean exposure was calculated by multiplying the mean flame retardant concentrations with the median dust ingestion rate (150 mg dust per day).

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Appendix I: The list of located manufacturers for the survey

Manufacturer	Phone number	Webpage	Products / material
Architex	800-621-0827	www.architec-ljh.com	Upholstery / Polyurethane
Brite, Inc	800-791-2946	www.briteinc.com	Cubicle curtains / Textiles
Canegie Fanbrics	800-727-6770	www.canegiefabrics.com	Upholstery / Polyurethane
CF Stinson	800-841-6279	www.cfstinson.com	Upholstery / Polyurethane face
DesignTex	800-221-1540	www.dtex.com	Upholstery / Polyurethane
Draeger	704-796-1378	no website	Mattress / Foam
Herman Miller[1,2]	888-443-4357	www.herman miller.com	Furniture / Textiles
Hill-Rom[2]	704-737-3566 919-426-7673	www.hill-rom.com	Furniture: beds hrc.serviceparts@hill-rom.com
Hospi-Tel	800-678-7100	www.hospitel.com	Shower curtains / Textiles
Stryker	941-234-8699	www.stryker.com	Furniture: beds, recliners
Hinkel, Inc.[2]	704-283-5919 704-282-0088 704-996-6904	www.hinkelinc.com info@hinkelinc.com	Curtains / Textiles
InPro Corporation[2]	704-615-5794 704-287-5522 888-715-8390	www.inprocorp.com rblankenburg@inprocorp.com Ric Blankenburg	Curtains / Textiles
Maharam	800-645-3943	www.maharam.com	Upholstery / Polyurethane
Momentum Textiles	800-366-6839	www.themomgroup.com	Upholstery / Polyurethane
Pallas	800-472-5527	www.pallastextiles.com	Upholstery / Polyurethane
Steelcase	800-333-9939	www.steelcase.com	Furniture / Foams, textiles
Teknion	877-835-6466	www.teknion.com	Furniture / Foams, textiles
Ultrafabrics	914-460-1730	www.ultrafabrics.com sales@ultrafabrics.com	Upholstery / Polyurethane

1: companies indicating that their products are not flame retardants free or companies offering no information regarding flame retardants;
2: companies with which DUHS purchase hospital equipment.

Appendix II: Questionnaire to manufacturers in health care products

Thank you for participating in our research on the use of flame retardants in health care settings. Data collected will be used for Zhouyuan Chen's master's project at the Nicholas School of the Environment at Duke University. Information gathered for this research will be written in a publicly-available report. You may choose to remain anonymous in the final report. We anticipate that this project, and the final report, will be completed in one year.

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Date:_____

Company Name:_____
Name_____
Phone_____

Questions:

1. Which of the following products does your company sell to health care organizations (e.g. hospitals, clinics, etc)? Please check all that apply.
   - ☐ Chairs or Sofas
   - ☐ Cubicle curtains/drapes for patients
   - ☐ Baby/infant mattresses
   - ☐ Patient Beds/mattresses

2. Which products contain polyurethane foam?
   (You may include the specifications (e.g. label or model names or specific name) of the products, if applicable in question 2(a).)
   - ☐ Chairs
   - ☐ Sofas
   - ☐ Baby/Infant Mattress
   - ☐ Patient Beds/mattress
   - ☐ No products
   - ☐ Others:_____

   2(a) Models of the product (if applicable)

3. If you sell products that meet state or federal flammability standards, how do you meet those standards?
   ☐ Chemical flame retardants
   ☐ Fire barrier (interliners)
   ☐ No materials are chemically treated
   ☐ Others_____

   3. (a) If your products are treated with flame retardant chemicals, please note which products are chemically treated.

   3. (b) Which types of chemicals are used most frequently?

4. If your products are treated with flame retardant chemicals, can you tell us why this specific chemical was chosen?
   ☐ Affordability/Cost
   ☐ Availability
   ☐ Performance
   ☐ Don't know
   ☐ We do not use flame retardants chemicals
   ☐ Other_____
5. Do you know which company provides the polyurethane foam for your products?
   ☐ Yes, and they are
   _____
   ☐ No, I don't know.
   ☐ Not applicable
   ☐ I prefer not to answer
6. Have you ever received calls or emails from customers concerned with the use of flame retardant chemicals in your products?
   ☐ Yes
   ☐ No
   ☐ Not applicable
   If yes, approximately how many calls/emails?_____
   If yes, what were the primary concerns?
7. Does your company review or consider any available health/toxicity testing information/data on these chemical treatments before you use them in your products?
   ☐ Yes
   ☐ No
   ☐ Not applicable
   Why or Why Not?

8. Has your company ever changed the flame retardant chemicals in your products or the method for achieving a state or federal flammability standard due to concerns about potential public health concerns?
   ☐ Yes
   ☐ No
   ☐ Not applicable
   If yes, what prompted that decision?
9. We would like to list all the companies that participated in this survey in our publicly-available final report. May we publish the name of your company in our final report. (If you choose no, your responses will be anonymous in the final report.)
   ☐ Yes
   ☐ No

10. May we publish information on specific products your company sells that are treated with flame retardants and which you report to us in this survey? (If you want to publish only a part of the information, please indicate in other.)
    ☐ Yes, all information provided in this survey can be published in your report.
    ☐ Yes, but only report on products that meet specific flammability standards (e.g. TB 133) without listing which chemical ingredients are used.
    ☐ No, I don't want to publish any of the information.
    ☐ Not applicable because our products do not contain chemical flame retardants.
    ☐ Other:
    _____.

Thank you for your time.

Appendix III: Hospitals where dust samples were collected

Hospital ID Number	Hospital name	State	Date collected
1	Michigan Hospital	Michigan	6/24-27/13
2	California	California	6/25/13
3	Mercy Gilbert Medical Center	Arizona	6/27/13
4	French Hospital	California	6/28/13
5	Methodist Hospital 1st floor Methodist Hospital 2nd floor Methodist Hospital 3rd floor Methodist Hospital 4th floor	California	7/1/13
6	Mcgee Womens Hospital, old carpet in clinic Mcgee Womens Hospital, new carpet in clinic	California	6/29/13
7	Mercy San Juan Medical Center, public areas Mercy San Juan Medical Center, patient area	California	6/13/13
8	CHWST Mary's Medical Center (hallways, waiting rooms, offices)	California	7/2/13
9	Fletcher Allen Health Care	Vermont	Aug. 2013
10	UM Mott Children's Hospital, 7th floor east side UM Mott Children's Hospital, 3rd floor on-call area	Michigan	7/31/13
11	UCSF Medical Center, Pedi clinic, Post St. 3rd floor UCSF Medical Center, L-Adult patient rooms, 1st floor	California	
12	Condell Medical Center	Illinois	7/9/13
13	California Hospital	California	9/11/13
14	Duke Clinic Cancer center	North Carolina	July, 2013
15	Duke South	North Carolina	July, 2013