Chemical Flame Retardants: Attitudes in Connecticut

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History of Flame Retardants

In an attempt to protect families from household fires, the use of chemical flame retardants began prominently around the 1960s. This implementation was, at the time, primarily found on children's products such as toys and pajamas. By 1973, the federal government required children's pajamas to be fire safe (Haberman, 2015). The growing use of chemical flame retardants sparked an interest in the study of potential health effects. One of the most influential flame retardant research articles was published by Arlene Blum and Bruce Ames in 1977 on the use of brominated tris found in children's pajamas. These findings concluded that the urine of children who wore tris-BP treated sleepwear contained mutagenic metabolite which could lead to cancer and sterility (Cordner, 2013). At this time, cigarettes were one of the leading reasons for household fires, yet a safer cigarette was not being developed. Because of this, the Big Tobacco organization united with the National Association of State Fire Marshals to gain public credibility (Callahan, 2012). In doing this, public attention would be turned away from the risky cigarettes, as the fire marshals advocated the use of flame retardants on more household items. Though the fire marshals' president claimed to be unswayed by chemical companies by 2006, the "marshals industry ties remain strong" (Callahan, 2012).

The availability of literature concerning the risks of flame retardant chemicals increased greatly during the mid-2000s, resulting in the advancement of flame retardant policies. In 2003, California and ten other states banned the production, use, and sales of the chemicals, pentaBDE and octaBDE (Cordner, 2012). Many states also went on to ban children's products and household furniture which contain TDCPP, TCEP, and TCPP ("Toxic Flame Retardants", 2016). The states have also emphasized that the chemicals cannot be replaced by other carcinogens or toxins. Chicago Tribune published its series of articles, "Playing with Fire" in May 2012, heightening the awareness of those who were completely unknowing of flame retardants, beforehand, and the concerns of those already against flame retardants (Cordner, 2013). Public concern resulted in the re-evaluation of the Environmental Protection Agency (EPA) and Consumer Products Safety Commission's (CPSC) policies. The re-evaluations then led to the signing of the Frank R. Lautenberg Chemical Safety for the 21st Century Act in June 22, 2016 which was to build upon the regulations of the Toxic Substances Control Act of 1976. The Lautenberg Act would improve upon the flaws of the 1976 act by providing new safety standards, funding the EPA to carry out the new responsibilities, and increasing public transparency for chemical information (The Frank R. Lautenberg Chemical Safety for the 21st Century Act, 2016).

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HUMAN HEALTH AND EXPOSURE

Health Effects

Chemical flame-retardants inhibit immune and endocrine system function. Hormone levels are altered and estrogen, in particular, seems to be lowered by chemical flame-retardants. While studies on laboratory animals, human cells and study of human exposure by measuring levels in urine all point to endocrine effects, more research is needed. However, it is important to consider the increased exposure to chemical flame retardants for children and the more drastic effects they may have on them due to smaller body mass.

Human Exposure to Flame Retardants

Humans have the potential to be exposed to chemical flame retardants in numerous ways. Studies have been conducted to examine amounts of chemicals including TBBPA, TCEP, TDCPP, TCPP, HBCD, and other flame retardant chemicals in various microenvironments and locations. Among these studies, amounts of the chemicals were examined in dust, children's products, breast milk, electronic devices, and other products in environments including classrooms, daycares, offices, and households. Studies have shown that flame retardants are more present in urban areas and that flame retardants are present in greater concentrations indoors (Abdallah *et al.*, 6587). Specifically, one study demonstrated that daycares have the highest concentration of flame retardants in comparison to other indoor microenvironments such as offices and homes, implying that children's toys may be more heavily treated with flame retardants (Cao *et al*., 11152-11153). In addition to this, children are exposed 2 to 10 times more than the average adult (Stapleton *et al.*, 7494). Some studies involved experiments in which subject's hands were wiped and then the wipes were tested. These demonstrated that dermal exposure is less than ingestion and inhalation (Stapleton, H *et al*., 59). Another source of exposure for infants is breast milk–the largest source of infant exposure (Zhang, *et al*, 920). Additionally, the majority of humans are exposed to these chemicals everyday by the water that they drink. Concentrations of chemical flame retardants have been found to be present in both tap and bottled water in China, indicating flame retardants could possibly be found in water around the globe. Boiling water makes things worse, though: flame retardants in the water are more likely to disperse into indoor air, which residents will eventually breathe in (Li *et al*, 58).

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Environmental Prevalence of Chemical Flame Retardants

Researchers have determined that chemicals are often found in soils and sediments, but air and water can carry the chemicals and allow them to disperse on a large scale (Yogui et al., 2009). In one study, researchers found no correlations between rain and soil concentrations or snow and soil concentrations, but discovered that snow was more efficient at moving chemicals (Mihajlović & Fries, 2012). Studies have also shown that concentrations are higher in more urbanized areas and that electronic waste recycling plants and sewage treatment plants are significant sources for the introduction of flame retardants into the environment (Yogui et al., 2009). Study results have also shown that there was generally a significant increase in the concentrations of flame retardant chemicals in rivers near water treatment plants, with data also showing that chemical concentrations were the highest at points downstream from the plants (Maruya et al., 2016).

Flame retardant chemicals have been found to build up in organisms over time and appear in increasingly higher concentrations as they move up the food chain (Yogui et al., 2009). In one study, concentrations of flame retardant chemicals were shown to persist in fish even after the end of exposure to the chemicals, some of which were shown to remain in the fish long after exposure, even after they had been moved to clean water (de Jourdan, 2014). Researchers also found that chemical concentrations in fish and otters were present in the highest levels near urban centers rather than rural areas, meaning coastal cities may be sources of contaminants being released into the environment (Yogui et al., 2009).

Flame retardant chemicals have also been observed to be present in house dust. One study, which investigated 20 homes for flame retardants in their dust, found that these chemicals would typically move into the indoor environment through the use of household products that would then enter hair, dust, clothes, and hands. This study showed that overall, 21 flame retardant compounds were found in household dust, introduced mostly through insulators and foam found in furniture and nightwear. Since these products are used commonly, they release chemicals into indoor environments on a regular basis, allowing them to build up over time. The study also showed that different light exposure and temperature affect the type of flame retardants that are found indoors (Schreder & La Guardia, n.d.).

Another study found that flame retardants can bind to dust, which can be connected to the study involving dust above, which also investigated the effects of laundry wastewater ("Characterizing the Peroxisome," n.d.). The study done by Schreder & La Guardia found that flame retardants moved from clothes to laundry wastewater, then to aquatic environments, where they remain resistant to treatment. Thus, researchers speculated that laundry wastewater is a significant contributor to the environmental prevalence of flame retardant chemicals. Overall, total yearly amounts of certain flame retardants released into aquatic environments were estimated to be about 2-4% of annual production (Schreder & La Guardia, n.d.).

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REGULATION OF CHEMICAL FLAME RETARDANTS

Regulation of Chemical Flame Retardants by State

Only a handful of states have passed laws that ban flame retardants and even then, these laws typically only focus on a select few of the many toxic flame retardants used in common manufacturing. Many of the laws in each state do not strictly ban a flame retardant but rather restrict the use of the flame retardant to certain products (Toxic Flame Retardants, n.d.). Additionally, many of these laws include a grace period where companies have a certain period of time, often years, in which they can gradually phase out the use of flame retardants in their products (House Bill 4609, 2016). Furthermore, most laws proposed by states exempt stores from recalling all of their products manufactured before the law was passed, but rather have stores inform their customers that the product they purchased may contain a flame retardant that was banned from further use (S.B. 81 NC 2015, LD 1790 2006, House Bill No. 44 n.d.).

A list of states where the top 5 chemical flame retardants is banned in children's products and furniture was compiled and is represented below in Table 1. It is important to note that only a small majority of states restrict the use of flame retardants. Besides the overarching law banning HBCD, at most only thirteen or fourteen of fifty states ban the use of one of the flame retardants of interest. In general, regulation of chemical flame retardants is patchy and inconsistent throughout the United States.

Table 1: Regulation of Flame Retardants by State

Flame Retardant	**States where flame retardant are banned from use in children's products and furniture**
HBCD (Hexabromocyclododecane)	All States
TDCPP (Tris(1,3-dichloro-2-proply)phosphate)	Alaska, Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, Minnesota, New York, North Carolina, Tennessee, Vermont, Washington, West Virginia

TCEP (Tris(2-chloroethyl) phosphate)	Alaska, Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, Minnesota, New York, North Carolina, Tennessee, Vermont, Washington, West Virginia
TCPP (Tris(chloropropyl)phosphate)	Alaska, Connecticut, Delaware, District of Columbia, Massachusetts, Minnesota, New York, Tennessee, Washington
TBBPA (Tetrabromobisphenol A)	Alaska, Maine, Massachusetts, Tennessee, Washington

(Act No. 85 S.81 2013, S.B. 81 NC 2015, H7977 2016 , HF 1100 2016, House Bill 4609 2016, LD 1790 2006, Senate Bill 5056 2015,Toxic Flame Retardants n.d.)

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Furniture Flammability Standards and Testing

The recent development of the flammability standards for upholstered furniture in California – which has become the "de facto" federal regulation due to the preference to be more economically efficient by making products suitable in all state – has been made with evident consciousness of the health deficits related to chemical flame retardants.

On November 21, 2013, the approval of California's new standard was announced by the governor, Edmund G. Brown, Jr., and, on the first day of 2014, became law; the deadline for manufacturers to switch to the newly legislated testing procedures was the first day of 2015 (AHFA). The previous flammability standard had been adopted in 1975. The new standard, found in California's Technical Bulletin 117-2013, allows for the possibility of a line of upholstered furniture passing the flammability test without needing chemical flame retardants or other expensive, not-researched materials.

The flammability testing is comprised of four tests, one for each type of material in the upholstered furniture. However, the standard does not account for either interactions between different materials in the furniture or what would occur in the setting of a house, though the humidity and temperature are adjusted to be similar.

Each test follows pretty much the same protocol, which uses a lit cigarette to expose furniture to flames. Both mock-up tests and specimen tests are said to "fail" if one of three events occurs: 1) the specimen "continues to smolder" after forty-five minutes; 2) a char longer than 1.5 inches is found on the cover fabric after the test; or, 3) the specimen bursts into flames. Specimens are tested multiple times to ensure accuracy.

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CHEMICAL FLAME RETARDANT INDUSTRY

Effectiveness of Chemical Flame Retardants

The overall goal of chemical flame retardants in upholstered furniture is to make sure that the foam does not catch on fire, and if it does, to make sure that it has as small an impact as possible on anything else in the room. There are three main ways in which the chemicals work to stop this process (Green, 1996, p. 429, Horrocks, Price, & Georlette, 2001, p.264-292, Martini, Spearpoint, & Ingham, 2010, p.238-248). The first way is to increase the amount of time that it takes for the heat from the fire to cross through the fabric and ignite the foam. The test was done by putting a piece of copper on top of a piece of upholstery fabric, placing an open flame under the fabric, and measuring how long it took for the copper to reach 300^{o}C. The results are shown in Figure 1 and show that different fabrics had different impacts (Martini et al., 2010, p. 242). The second of the ways in which the chemicals work is by lowering how hot the foam burns once it catches on fire. A test of this was done by intentionally burning a cushion made of the fabric and foam and measuring the amount of energy released by the resulting fire. The results, shown in Figure 2, show that different fabrics led to different amounts of energy release, where a lower line indicates a lower burning temperature (Martini et al., 2010, p. 245). The last way that the chemicals work is by lowering the rate at which the fabric burns. This test was done using the device shown in Figure 3, which analyzes the fabric as it burns as well as the smoke that it gives off. The slower that a material burns, represented by a smaller peak, could help prevent the fire from spreading as quickly through a house (Martini et al., 2010, p. 243). The results of these three experiments show that from a purely chemical standpoint, these chemicals can make a difference in the flame retardancy of a fabric in a laboratory setting.

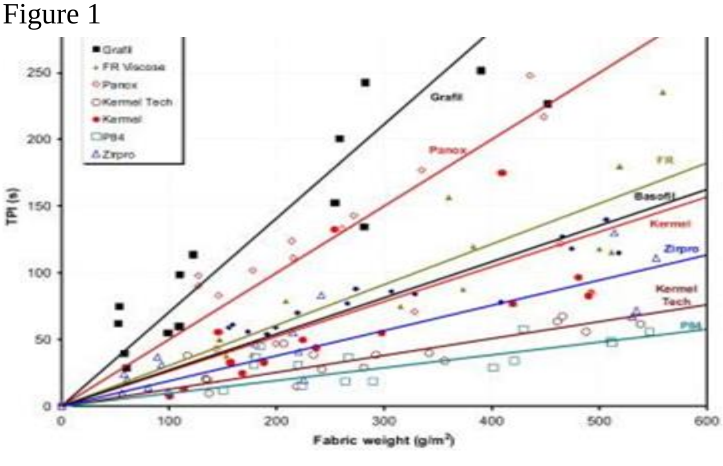
Outside of a laboratory though, statistics regarding the frequency of house fires and house fire-related deaths fail to show whether flame retardants are effective in house fire prevention. While the number of house fires has decreased by tens of thousands and home fire-related casualties by hundreds, this information cannot be correlated to the effectiveness of the flame retardants (Waxman, Moore, & Fox, 2008, p. 34-39, Alpert, Christiani, Orav, Dockery, & Connolly, 2014, p. e56). Part of the inconclusiveness lies in the idea that there are many confounding variables such as: decreases in cigarette smokers, increases in sprinklers in residential buildings, more demanding flammability standards for upholstered furniture, and a surge of smoke alarms across the United States. However, according to Table 2, the number of house fires and related deaths have decreased significantly in the late twentieth century, which means that the effectiveness of flame retardants may have played a role in said decreases (Haynes, 2016). The ambiguity and uncontrolled nature of the studies that portray chemical flame retardant effectiveness and deaths related to home fires lead to no conclusive answer in regards to the relationship between them.

Table 2: Home Fire Statistics from NFPA (1977-2015)

				Direct Property Damage (in Billions)	
Year	**Fires**	**Civilian Deaths**	**Civilian Injuries**	**As Reported**	**In 2015 Dollars**
1977	723,500	5,865	21,640	$2.70	$10.70
1978	706,500	6,015	20,400	$2.10	$7.50
1979	696,500	5,500	18,825	$2.40	$7.80
1980	734,000	5,200	19,700	$2.80	$8.20
1981	711,000	5,400	19,125	$3.10	$8.10
1982	654,500	4,820	20,450	$3.10	$7.70
1983	625,500	4,670	20,750	$3.20	$7.60
1984	605,500	4,075	18,750	$3.40	$7.70
1985	606,000	4,885	19,175	$3.70	$8.10
1986	565,500	4,655	18,575	$3.50	$7.50
1987	536,500	4,570	19,965	$3.60	$7.50
1988	538,500	4,955	22,075	$3.90	$7.80
1989	498,500	4,335	20,275	$3.90	$7.40
1990	454,500	4,050	20,225	$4.20	$7.50
1991	464,500	3,500	21,275	$5.51	$9.51
1992	459,000	3,705	21,100	$3.80	$6.40
1993	458,000	3,720	22,000	$4.82	$7.82
1994	438,000	3,425	19,475	$4.20	$6.70
1995	414,000	3,640	18,650	$4.30	$6.60
1996	417,000	4,035	18,875	$4.90	$7.40
1997	395,500	3,360	17,300	$4.50	$6.60
1998	369,500	3,220	16,800	$4.30	$6.20
1999	371,000	2,895	16,050	$5.00	$7.10

2000	368,000	3,420	16,975	$5.50	$7.60
2001	383,500	3,110	15,200	$5.50	$7.40
2002	389,000	2,670	13,650	$5.90	$7.80
2003	388,500	3,145	13,650	$5.93	$7.73
2004	395,500	3,190	13,700	$5.80	$7.30
2005	381,000	3,030	13,300	$6.70	$8.20
2006	396,000	2,580	12,500	$6.80	$8.00
2007	399,000	2,865	13,600	$7.44	$8.44
2008	386,500	2,755	13,160	$8.25	$9.10
2009	362,500	2,565	12,650	$7.60	$8.40
2010	369,500	2,640	13,350	$6.90	$7.50
2011	370,000	2,520	13,910	$6.90	$7.30
2012	365,000	2,380	12,875	$5.70	$7.20
2013	369,500	2,755	12,200	$6.80	$6.90
2014	367,500	2,745	11,825	$6.80	$6.90
2015	365,500	2,650	11,075	$7.00	$7.00

Figure 1



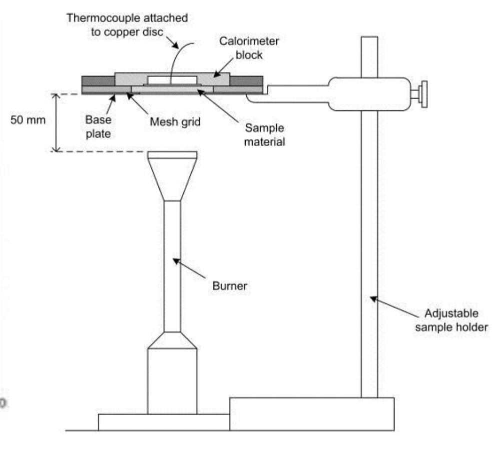


Figure 2

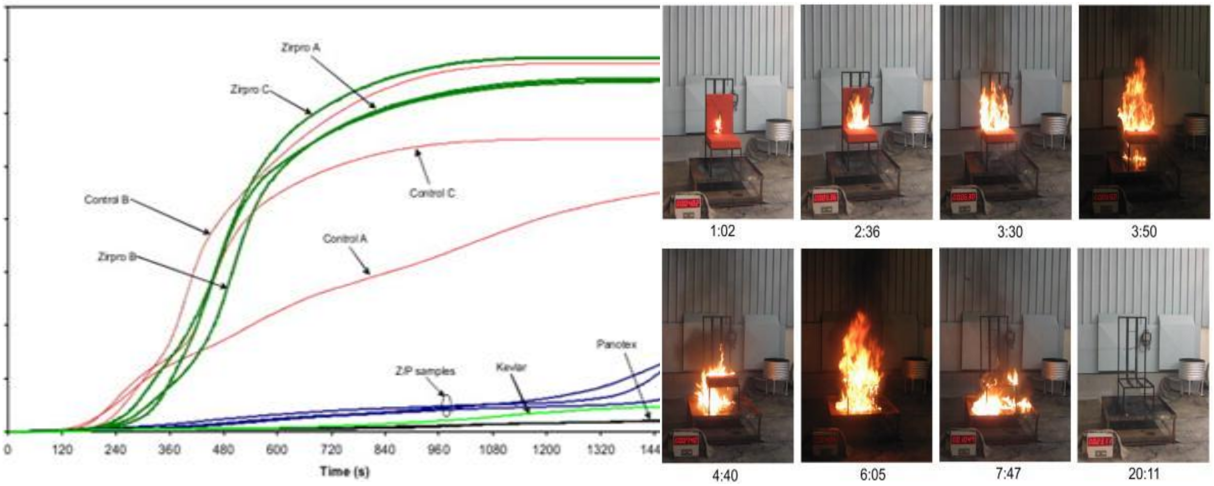
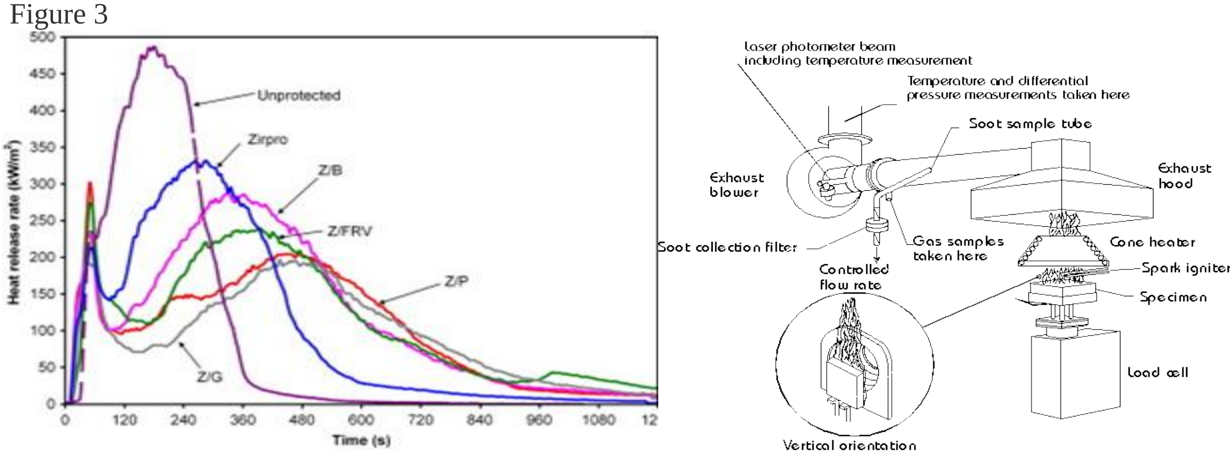


Figure 3



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Economics of Chemical Flame Retardants

While there have been increasing concerns regarding the safety of chemical flame retardants in furniture, the industry has been growing, with one firm projecting it to reach a net worth of $12.81 billion by the end of 2021 (Flame Retardant Market, 2016). Since California's TB117-2013 eliminated the need for furniture to contain flame retardants in order to meet flammability standards, demand for furniture flame retardants and revenues for companies that produce them has fallen. At the end of the year in which TB117-2013 took place, one flame retardants manufacturer's yearly report specifically mentioned a decline in "demand for flexible foam flame retardant products … as the year progressed" (Forsyth, 2015).

In addition, the CPSC has claimed it will start forcing toxic chemicals off the market by the start of 2016 (Hawthorne, 2015). The flame retardants industry is now more reliant on use in construction and electronics and less reliant on use in furniture as a result (Flame Retardant Market, 2016).

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Alternatives to toxic flame-retardants

I. Expandable Graphite (EG) (Gharehbagh and Ahmadi)

The mechanism of the fire extinguisher begins with EG expanding under the impact of heat - up to about 500 times of its original volume, which creates an extremely large surface area. This expanded area allows for a quick oxidation of carbon, during which oxygen is taken out of the air in large quantities, which makes the air inert. This inert air extinguishes the fire. EG doesn't create flames while oxidizing. Therefore, oxidizing EG will generate no sources of fire. Among other advantages of EG is its durability, as it does not degrade over time. EG does not negatively affect the environment. Disadvantages of EG are its high corrosiveness and complicated process of manufacture.

II. Butadiene Styrene Brominated Copolymer (BSBC) (Polyurethane Foam Association)

Even though a flame retardant, it is a polymer with a molecular weight (MW) much greater than 10,000 Daltons. Based on the studies done by EPA it was found that because of its extremely high molecular weight (hence volume) it can't be absorbed by human bodies or metabolized. Hence it poses extremely low health risks. Additionally, it is not expected to have crosslinking, swell ability, reactive functional groups and potential for inhalation or hindered amine groups. That is why, even if absorbed by the organism, this chemical has a low potential for carcinogenicity. Apart from posing extremely low health risks to people, BSBC also doesn't have any serious adverse effects on the environment.

III. Non-Flammable Urethane Material (NUM) (Sekisui Chemical)

NUM is a flame-retarding compound technology developed by SEKISUI CHEMICAL CO., LTD. The technology is based on the mechanism that a fire blaze spreads quickly in a structure that utilizes normal rigid urethane foam, however non-flammable urethane form prevents the bonding of O_2 through a special carbonized layer, which is created when the urethane is heated. This carbonized layer instantly suppresses the spread of fire.

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Connecticut Consumers View of Chemical Flame Retardants

We conducted an online survey of Connecticut consumers to gather information on how aware people are of the presence of flame retardants in their homes and where they can be found. The survey was developed on Survey Monkey and distributed to friends and family electronically. It was taken by 73 individuals, 84% of whom are residents of the state of Connecticut. Ages of participants ranged from under 18 years old to 64 years old, with the majority falling in the 18-24 category. We wanted to know how likely it was for our participants to be in contact with these chemicals on a daily basis. 95% of our subjects said they owned at least one of the products listed that are known to be at a high risk of containing flame retardants. One of the ways that the presence of flame retardants in a household can be gaged is through the concentration of chemicals in house dust. Most commonly, our subjects would clean their floors a few times a month, meaning that in between these times, chemicals would be building up in their house dust and placing them at a higher risk (Stapleton et al., 2009). Based upon a question involving how effective and important people believe the presence of flame retardants to be, 22% claimed that they were effective at reducing house fires however most said that they were unsure. We also polled our subjects to gain an understanding of their knowledge of types of products that they think contain flame retardants in their homes. In general, the most frequent answers were "no idea" or "I think so". We also asked if flame retardants were something they took into consideration when shopping and if they knew what a TB117 label was and most consumers said no. Ultimately, this survey showed an overall lack of understanding and attention to chemical flame retardants.

Table 3

	Definitely do not	I don't think so	No idea	I think so	Definitely do	Total	Weighted Average
Crib mattress	4.76% 3	11.11% 7	33.33% 21	38.10% 24	12.70% 8	63	3.43
Upholstered furniture	11.27% 8	22.54% 16	29.58% 21	23.94% 17	12.68% 9	71	3.04
Car seat	4.69% 3	12.50% 8	26.56% 17	35.94% 23	20.31% 13	64	3.55
Hand wipes	14.93% 10	23.88% 16	41.79% 28	14.93% 10	4.48% 3	67	2.70

Reference

Stapleton H.M., Klosterhaus S., Eagle S., Fuh J., Meeker J.D., Blum A., Webster T.F., (2009). Detection of organophosphate flame retardants in furniture foam and U.S. house dust. *Environmental Science Technology.*

Phone Interviews of Connecticut Retailers

We called twenty-four stores that sell furniture in Connecticut and asked them questions about their use of flame retardants. Overall, of the eighteen stores that gave complete responses, eight stores did not use flame retardants in their products. Three of these 8 told us they followed the California TB 117-2013 law. For furniture to pass this test without the use of flame retardants, it either must be made from man-made fire-resistant materials or natural flame retardants. One of the stores followed the GreenGuard Certification, which is a standard against the use of harmful chemicals in products, including flame retardants. The other retailers were unsure of their standards, showing that sales associates did not know what was in their products. On the other hand, of the companies with flame retardants, four companies followed the CA TB 117-2013 law. Another type of regulation is CertiPUR, which is a certification for environmentally safe products that allows certain flame retardants ("About Certified Foam"). Since there are so many certifications, most store representatives could not explain the regulations they follow. Sales associates reported that customers rarely ask about them.

In general, we found that most retailers had limited knowledge of flame retardants and rarely, if ever, had to answer questions of consumers. This shows a lack of public knowledge regarding flame retardants.

References

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Connecticut Furniture Store Visits

Our goal was to determine the in-store awareness of chemical flame retardants from the perspective of the concerned consumer. To do this, five different local furniture stores were visited. At the stores, we first checked if it housed different types of furniture that normally include foam, including baby furniture. After finding out what furniture the store had in stock, we asked sales representatives to guide us to older furniture and for some info on whether the store contained secondhand furniture. Then, we checked for furniture for labels, and recorded if these labels were found, the process of finding them, and what information the label contained. Specifically, we looked for things like uniform registry numbers (URNs), new TB-117 notices, a foam percentage composition chart, and any other prevalent information. In sum, we determined the knowledge of sales associates at each of these stores, and if these stores were prepared to handle a customer with concerns over flame retardants.

Our observations show myriad problems. First, the age of the furniture in multiple stores is not typically made clear. In one major furniture store, not even the store manager was sure of the time at which their older furniture was built when questioned, and it was not made inherently clear from the builds of the furniture. In addition, sales representatives were either very confused by or very hesitant to answer questions about flame retardants. We received many answers that did not sound confident, or we were told to check with the manufacturer, or in one case, a sales representative refused to answer some of our questions. Even at stores where inventory tends to be newer, it was difficult to find information on chemical flame retardants. At all the stores, placement and information of furniture labels needs to be improved. At all stores, it is very difficult to find the label, and not all of them contain all information desired. We had to lift pillows or get under furniture to find labels and in a few cases, labels were completely inaccessible in zip tied furniture or in furniture which was bolted to the display unit. While much of the furniture observed in most stores contained the URN and foam composition chart, this was not the case at every store. At one major furniture store, labels only contained general information, and lacked an URN or any prevalent facts on flame retardants and at another major furniture store, labels were typically missing information, and none of their furniture mentioned anything about flame retardants. There were problems with missing or inaccessible labels and/or missing or inaccessible information on labels – required by law – at all five furniture stores we visited.