Questions for the Record
Public Meeting on the Petition Regarding Additive Organohalogen Flame Retardants
U.S. Consumer Product Safety Commission
Bethesda, MD

Part 1 of 4: This file contains the questions and responses for presenters 1 through 14.

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Linda Birnbaum, Ph.D.

NIEHS/National Toxicology Program

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Additive Organohalogen Flame Retardants

Linda Birnbaum, NIEHS/National Toxicology Program

Chairman Elliot F. Kaye

1. Which, if any, of these chemicals are included in the National Health and Nutrition Examination Survey (NHANES)? What is the possibility of getting biomonitoring data on these chemicals that are not currently in NHANES? Do you believe that adding these additional chemicals would be a worthwhile effort?

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?

3. Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?

4. Could you please comment on the validity of the structure-activity relationship (SAR) method. Can the structure alone be used to determine that these chemicals pose the same risks to human health? Are there additional data needed to validate these claims? If so, what are they?

5. In order to treat these chemicals (and any future chemicals that may fall under the scope of the petition) as a single class for purposes of rulemaking, what end point or points should be considered?

Commissioner Robert S. Adler

1. Organohalogen Hazards: Dr. Birnbaum, in your testimony, you point to differential effects of different organohalogens. For example, you note that some of these chemicals are poorly absorbed, but persist in the environment whereas others are readily absorbed but also readily excreted.
   a. Given the different effects associated with different organohalogens, are you aware of any of these chemicals that do not present significant health risks?
   b. Given the broad array of organohalogens, is there sufficient commonality among them for the Commission to address them as a chemical class (as

requested by the petitioners) or should the agency examine them chemical by chemical as suggested by the American Chemistry Council?

c. If the answer to (b) is that there is sufficient commonality, can you explain what the common elements are that would justify an across-the-board treatment by the CPSC?

2. Assessment Tools: Dr. Birnbaum, please state your views on how various chemical hazard assessment tools, including but not limited to standard read-across techniques and structure-activity relationship models, could be used to support regulatory decisions for the entire class of additive, non-polymer, organohalogen flame retardants subject to the Petition.

3. Chemical Substitutes: Dr. Birnbaum, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition? If so, what chemicals are in the market today that might substitute for organohalogens if they were removed from the market?

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

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Additive Organohalogen Flame Retardants

Linda Birnbaum, NIEHS/National Toxicology Program

Chairman Elliot F. Kaye

1. Which, if any, of these chemicals are included in the National Health and Nutrition Examination Survey (NHANES)? What is the possibility of getting biomonitoring data on these chemicals that are not currently in NHANES? Do you believe that adding these additional chemicals would be a worthwhile effort

Response: NHANES information is collected on some flame retardants of public health concern, and published in the CDC's National Report on Human Exposure to Environmental Chemicals. However, mixtures are often complex, variable and may be listed as proprietary. Therefore, they are extremely difficult to monitor for public health purposes. No NHANES information is available regarding combustion byproducts associated with flame retardants. As of February 2015, 49 polybrominated diphenyl ethers and/or polychlorinated biphenyls were included in the NHANES studies. Twelve perfluorinated compounds (sometimes used as fire suppressants) are monitored. Those flame retardants recommended by the *Stockholm Convention on Persistent Organic Pollutants* as markers for enforcement (BDE-47, BDE-99) are included in the NHANES sampling efforts (see Par. 9 Article 8). While NHANES biomonitoring for exposure to selected 'indicator' flame retardants is important, it would be extremely costly and difficult to monitor for individual chemicals associated with various mixtures of flame retardants, their metabolic and/or combustion byproducts.

There is a formal process for nominations to add new chemical measurements to the NHANES National Biomonitoring Program. NIEHS would defer to CDC regarding the feasibility of including the additional chemicals in their survey and reports.

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?

Response: We recommend a stepped process that focuses on the "solution" for safety when considering the need for future application of alternative flame retardant chemicals. First, is it needed? Ascertain whether the product really needs to include a flame retardant chemical. Is there another way to achieve safety? If there is a decision that a flame retardant must be used, the next step should be a scientifically confirmed assessment that a product or mixture proposed for use is shown to effectively suppress fire. The subsequent step should employ a series of tests to assess both the potential for exposure and the inherent toxicity of the proposed substance. In focusing on solutions for safety, we would also support encouraging the use of natural alternatives (such as wool, latex, coir) wherever possible (that is, alternative materials with natural flame retardant properties).

3. Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?

Response: It may be possible that in some cases, for example based on the purpose or use of the product, that there would be no need for addition of a flame retardant chemical.

4. Could you please comment on the validity of the structure-activity relationship (SAR) method? Can the structure alone be used to determine that these chemicals pose the same risks to human health? Are there additional data needed to validate these claims? If so, what are they?

Response: Structure-activity relationships (SAR) and toxicological modeling associated with SAR have an important role in generalizing the toxicity associated with chemical classes. However, due to biological specificity and individual variability, SAR is not considered a high fidelity practice in toxicology. There are many instances where SAR has failed to accurately predict chemical toxicity or chemical safety. For this reason, NIEHS recommends a varied approach, such as combination of *in vitro* and alternate models in conjunction with at least short-term *in vivo* studies capturing relative developmental periods to estimate chemical hazard.

5. In order to treat these chemicals (and any future chemicals that may fall under the scope of the petition) as a single class for purposes of rulemaking, what end point or points should be considered?

Response: Toxicological endpoints for existing or future chemicals or mixtures should be determined based upon a spectrum of tiered analyses including SAR, *in vitro* assays and alternate animal models coupled with at least short-term in vivo studies with relevant developmental exposures (if necessary long term *in vivo*) assays.

Commissioner Robert S. Adler

1. <u>Organohalogen Hazards</u>: Dr. Birnbaum, in your testimony, you point to differential effects of different organohalogens. For example, you note that some of these chemicals are poorly absorbed, but persist in the environment whereas others are readily absorbed but also readily excreted.
    a. Given the different effects associated with different organohalogens, are you aware of any of these chemicals that do not present significant health risks?

    Response: I am not aware of any flame retardant mixtures that are not associated with toxicity.

    b. Given the broad array of organohalogens, is there sufficient commonality among them for the Commission to address them as a chemical class (as requested by the petitioners) or should the agency examine them chemical by chemical as suggested by the American Chemistry Council?

    Response: Commonalities that have been noted across these compounds include some structural similarities and similarities in biological responses and outcomes resulting from exposure. Given the limited nature of products involved in the petition, and the known toxicity of many members of this class of flame retardant chemicals, it is thus appropriate to address them as a class in order to be protective of human health.

    c. If the answer to (b) is that there is sufficient commonality, can you explain what the common elements are that would justify an across-the-board treatment by the CPSC?

    Response: When multiple members of a class have all been shown to be potentially hazardous, protection of susceptible populations is best approached by caution.

    The first element, of course, is acceptable evidence of fire suppression. Without such evidence, the expense and necessity of flame retardant application is unnecessary. Regarding common elements relevant to public health, mixtures or classes of chemicals with similar physical-chemical characteristics are expected to have similar exposure potential, a key component of risk. Exposure pathway analysis for classes of chemicals has been a cornerstone of risk assessment for decades. Additionally, classes of chemicals and mixtures can now be assessed using a combination of commonly available and widely applied SAR approaches, advanced toxicological screening methodologies and/or standard dose-response analyses.

2. Assessment Tools: Dr. Birnbaum, please state your views on how various chemical hazard assessment tools, including but not limited to standard read-across techniques and structure-activity relationship models, could be used to support regulatory decisions for the entire class of additive, non-polymer, organohalogen flame retardants subject to the Petition.

   Response: Again, the first question for each application would be, "Do you need it?" and if so, the second question is, "Does it work?" Only then do you need to move forward to a hazard assessment. Once a chemical class or mixture has been appropriately demonstrated to be necessary for its fire retardant properties using relevant conditions and the potential for exposure to both the retardant and its combustion products has been estimated to be acceptable, there are a wide variety of emerging tools that could be employed to determine toxicological potential. In addition to standardized "read-across" and SAR modeling, high throughput screening tools, a wide array of genotoxicity studies, and *in vivo* testing in alternative animal models and mammalian models are available to assess hazard prior to use. A compendium of tools available for screening chemicals and alternatives has been published by the University of Massachusetts and can be found here: http://www.sustainableproduction.org/downloads/Methods-ToolsforChemHazardAss5-2011.pdf

3. Chemical Substitutes: Dr. Birnbaum, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition? If so, what chemicals are in the market today that might substitute for organohalogens if they were removed from the market?

   Response: Research clearly shows that organohalogenated flame retardants have toxic properties and that current use results in human exposure. As far as substitutes are concerned, NIEHS does not test the occurrence or effectiveness of fire retardants in products. However, we support the *Framework to Guide Selection of Chemical Alternatives* published by the National Research Council in 2014 (ISBN: 978-0-309-31013-0).

   http://www.nap.edu/catalog/18872/a-framework-to-guide-selection-of-chemical-alternatives

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

   Response: NIEHS is a component of the National Institutes of Health. The NIEHS mission is to fund and conduct research to discover how the environment affects human health. NIEHS does not have a comprehensive listing of which chemicals are in which products. However, some of our grantees who have done studies on these chemicals have looked at the literature on this topic and may have information about specific examples of products.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

   Response: NIEHS has no information on how these chemicals are applied; this topic is outside our mission.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

   Response: Much research has been done on the organohalogenated flame retardants that are the subject of the petition. Some, but by no means all, of this research has been funded by NIEHS. These data can be found in the published scientific literature.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

   Response: Across the range of independent investigators studying exposure to flame retardants, there are some who are focusing on specific populations. NIEHS does not have a comprehensive catalog of these data, but some of our grantees are studying selected populations and may have some results to contribute.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

   Response: NIEHS does not keep or track these data, which are outside our mission.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

   Response: NIEHS has no information on this question, which is outside our mission.

William Wallace

Consumers Union

U.S. Consumer Product Safety Commission
Questions for the Record
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Additive Organohalogen Flame Retardants

William Wallace, Consumers Union

Commissioner Ann Marie Buerkle

1. In the testimony provided, it was stated that "flame retardants have been intentionally added, or are often present, in a large percentage of the products." Please define what constitutes a "large percentage" and how Consumers Union came to that conclusion. If there is any data or research supporting your conclusion, please provide that as well.

2. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record Responses
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

William C. Wallace
Policy Analyst, Consumers Union
January 29, 2016

Commissioner Ann Marie Buerkle

1. **In the testimony provided, it was stated that "flame retardants have been intentionally added, or are often present, in a large percentage of the products." Please define what constitutes a "large percentage" and how Consumers Union came to that conclusion. If there is any data or research supporting your conclusion, please provide that as well.**

Based on the research underlying the Petition for Rulemaking, the Petition concludes that "A large percentage of the products in the categories at issue in this petition contain organohalogen flame retardants as a result of the flame retardants being intentionally added to the products." We agree with this statement and offer the data below, which appear in the text of the Petition (pages 25-28).

1. Infant and Children's Products

Testing has identified organohalogen flame retardants in the foam in nursing pillows, crib mattresses, strollers, baby carriers, sleep mats, and changing table pads. For example:

A. A 2011 study of baby products sold throughout the United States found flame retardant chemicals in a range of foam-containing products, such as nursing pillows, crib mattresses, strollers, baby carriers, sleep mats, and changing table pads.[1] *Out of foam samples collected from 101 commonly used baby products, 80 samples were found to have an identifiable flame retardant additive, and 79 of these contained organohalogens.*

B. In 2012, the Chicago Tribune analyzed foam used in crib mattresses, and found that three then-popular brands of baby mattresses tested positive for organohalogen flame retardants.[2]

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[1] *Stapleton, H.M.; Klosterhaus, S.; Keller, A.; Ferguson, P.L.; van Bergen, S.; Cooper, E.; Webster, T.F.; & Blum, A. (2011). Identification of flame retardants in polyurethane foam collected from baby products. Environmental Science & Technology, 45(12), 5323-31. doi: 10.1021/es2007462.*

[2] *Patricia Callahan & Michael Hawthorne, Chemicals in the Crib, Chicago Tribune, Dec. 8, 2012, http://articles.chicagotribune.com/2012-12-28/news/ct-met-flames-test-mattress-20121228_1_tdcpp-heather-stapleton-chlorinated-tris.*

C. A 2012 survey of flame retardants in sleep products found evidence for the presence of organohalogen flame retardants in all foam samples from 29 sleeping mats from nursery schools and day care centers in the California Bay Area.[3]

D. A study published in 2012 documents extensive use of organohalogen flame retardants in infants' and children's products. The report provides the results of tests carried out on 20 foam-containing products purchased across the United States at major retailers, including baby changing mats and nursing pillows. Seventeen (85%) of the 20 products tested contained organohalogen flame retardants.[4]

The fact that a significant proportion of tested juvenile products has been found to contain organohalogen flame retardants suggests that a high percentage of all infant and children's products contain these chemicals. While consumers use these products in different ways (as toys, as carriers, as seating, and so on), the unifying feature is that infants and children come in contact with all of them, and if the product contains any organohalogen flame retardant in additive form, the use of the product — indeed, the mere presence of the product in the home — will result in exposure to the flame retardant chemical because of the semi-volatile property of these chemicals, as discussed below in Section VII.

2. Residential Furniture

Most residential seating furniture in use in this country contains additive organohalogen flame retardants. One 2012 study tested 102 samples of polyurethane foam from residential sofas purchased across the United States between 1985 and 2010 and found that 85% contained flame retardants.[5] *One of the objectives of this study was to determine which chemicals were being used after the phase-out of pentaBDE in 2005. In furniture purchased before 2005, organohalogen flame retardants were detected in 63% of the samples tested (pentaBDE in 39% of the samples, followed by TDCPP in 24%). In furniture purchased in 2005 or later, organohalogen flame retardants were detected in over 90% of the samples (most common being TDCPP in 52% and components associated with the Firemaster® 550 mixture in 18% of the samples). In other words, the 2005 phase-out of pentaBDE led to the use of other organohalogen flame retardants in polyurethane foam used in upholstered furniture.*

3. Mattresses and Mattress Pads

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[3] *Gaw, C. (2012). Sleeping on Toxins? A Study of Flame Retardants in Sleep Products. Retrieved March 3, 2015, from http://nature.berkeley.edu/classes/es196/projects/2012final/GawC_2012.pdf.*

[4] *Organohalogen flame retardants identified included tris (1,3-dichloro-2-propyl) phosphate (TDCPP), tris (2-chloroethyl) phosphate (TCEP), and tris (1-chloro-2-propyl) phosphate (TCPP), with chlorinated Tris (TDCPP) found in 80% of the products tested. Washington Toxics Coalition and Safer States (2012). Hidden Hazards in the Nursery. Retrieved March 3, 2015, from http://watoxics.org/publications/hidden-hazards.*

[5] *Stapleton, H.M.; Sharma, S.; Getzinger, G.; Ferguson, P.L.; Gabriel, M.; Webster, T.F.; & Blum, A (2012). Novel and high volume use flame retardants in US couches reflective of the 2005 PentaBDE phase out. Environmental Science & Technology, 46(24), 13,432-39. doi: 10.1021/es303471d.*

An informal 2012 survey of 28 foam mattresses and 55 mattress pads used by adults found organohalogen flame retardants in 29% and 50% of the samples analyzed.[6] *This was confirmed by the website of the American Chemistry Council / North American Flame Retardant Alliance, which lists foam mattresses as one of the product areas where flame retardants are used.*[7]

4. Electronics Enclosures

Flame retardants in additive form are commonly used in plastic casings for televisions and other electronic devices.[8] *(To be clear, this petition does not address the flame retardants in reactive form in electronic circuit boards where the flame retardants are chemically bound to the product. This petition focuses exclusively on organohalogen flame retardants in additive form used in the plastic casings for electronic devices.) DecaBDE was commonly used in plastic casings for televisions and electronics before it was phased out by the EPA due to its toxicity. Although decaBDE is no longer used in plastic electronic casings, other similar organohalogen flame retardants such as DBDPE have replaced it.*[9]

2. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Adoption of California's TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition for Rulemaking. Three of the four product categories covered by the Petition – mattresses and mattress pads, children's products and electronic enclosures – would not be covered by a national TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not prohibit the use of these chemicals in furniture. In other words, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and furniture manufacturers could voluntarily continue to add the chemicals to their products even if they were not needed to meet a flammability standard. Therefore, to ensure that non-polymeric, additive organohalogen flame retardants are not

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[6] *Gaw, C., Singla, V.; Peaslee, G.; & Busener, S. (2013). Flame retardants in foam from various consumer products. On file with Green Science Policy Institute.*

[7] *North American Flame Retardant Alliance lists foam mattresses as one of the products in which flame retardants are commonly used. North American Flame Retardant Alliance, American Chemistry Council. Flame Retardant Basics. Retrieved March 03, 2015, from http://flameretardants.americanchemistry.com/FR-Basics.*

[8] *North American Flame Retardant Alliance lists Electronics and Electrical Devices as one of the four product areas where flame retardants are commonly used including in casings for televisions and other electronic devices. Id.*

[9] *Betts, K. (2009). Glut of data on "new" flame retardant documents its presence all over the world. Environmental Science & Technology, 43(2), 236-37. doi: 10.1021/es8032154.*

added to products in these categories, the Commission should grant the Petition and adopt the regulation we have sought.

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William C. Wallace
Policy Analyst, Consumers Union
January 29, 2016

<u>**Commissioner Joseph Mohorovic**</u>

1. **Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?**

   We currently have no position on the Commission adopting California's TB 117-2013 as a national mandatory standard for upholstered furniture. However, as we noted in our July 1, 2013, comment to the Commission in Docket No. CPSC-2008-0005, we are pleased that California has been addressing the potential safety and health issues related to the use of flame-retardant chemicals, and we look forward to the Commission also addressing them. As the Petition for Rulemaking placed on the docket by CPSC on August 19, 2015, reflects, we believe there is more that urgently needs to be done.

   We would also like to note that if the Commission were to adopt California's TB 117-2013 as a national mandatory flammability standard for upholstered furniture, there should be no impact on the Petition. Adopting TB 117-2013 would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, but it would not prohibit their use in furniture. The Commission should grant the Petition because the regulation we seek would ensure that these chemicals are not added to products in the covered product categories.

2. **Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.**

   The Petition for Rulemaking referenced above discusses the presence of non-polymeric, additive organohalogen flame retardants in products at pages 25-28. Some key facts from the Petition include:

   - A 2011 study of baby products sold throughout the United States found flame retardant chemicals in a range of foam-containing products, such as nursing pillows, crib mattresses, strollers, baby carriers, sleep mats, and changing table pads.[1] Out of foam samples collected from 101 commonly used baby products, 80 samples were

[1] Stapleton, H.M.; Klosterhaus, S.; Keller, A.; Ferguson, P.L.; van Bergen, S.; Cooper, E.; Webster, T.F.; & Blum, A. (2011). Identification of flame retardants in polyurethane foam collected from baby products. *Environmental Science & Technology*, 45(12), 5323-31. doi: 10.1021/es2007462.

found to have an identifiable flame retardant additive, and 79 of these contained organohalogens.

- In 2012, the Chicago Tribune analyzed foam used in crib mattresses, and found that three then-popular brands of baby mattresses tested positive for organohalogen flame retardants.[2]

- A 2012 survey of flame retardants in sleep products found evidence for the presence of organohalogen flame retardants in all foam samples from 29 sleeping mats from nursery schools and day care centers in the California Bay Area.[3]

- A study published in 2012 documents extensive use of organohalogen flame retardants in infants' and children's products. The report provides the results of tests carried out on 20 foam-containing products purchased across the United States at major retailers, including baby changing mats and nursing pillows. Seventeen (85%) of the 20 products tested contained organohalogen flame retardants.[4]

- An informal 2012 survey of 28 foam mattresses and 55 mattress pads used by adults found organohalogen flame retardants in 29% and 50% of the samples analyzed.[5]

3. **Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.**

   No. The flame retardants' manufacturers and the foam, fabric, and plastic industries – which add the chemicals during their manufacturing processes – would be the best source for this information.

4. **Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.**

   The Petition for Rulemaking referenced above includes a review of the literature in the public domain addressing the toxicity of non-polymeric additive organohalogen flame retardants as of March 2015. (Petition, pages 43-47, and corresponding footnotes 121-148.) In addition, the Statement of Ruthann Rudel submitted with the Petition includes as

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[2] Patricia Callahan & Michael Hawthorne, *Chemicals in the Crib*, Chicago Tribune, Dec. 8, 2012, http://articles.chicagotribune.com/2012-12-28/news/ct-met-flames-test-mattress-20121228_1_tdcpp-heather-stapleton-chlorinated-tris.

[3] Gaw, C. (2012). *Sleeping on Toxins? A Study of Flame Retardants in Sleep Products*. Retrieved March 3, 2015, from http://nature.berkeley.edu/classes/es196/projects/2012final/GawC_2012.pdf.

[4] Organohalogen flame retardants identified included tris (1,3-dichloro-2-propyl) phosphate (TDCPP), tris (2-chloroethyl) phosphate (TCEP), and tris (1-chloro-2-propyl) phosphate (TCPP), with chlorinated Tris (TDCPP) found in 80% of the products tested. Washington Toxics Coalition and Safer States (2012). *Hidden Hazards in the Nursery*. Retrieved March 3, 2015, from http://watoxics.org/publications/hidden-hazards.

[5] Gaw, C., Singla, V.; Peaslee, G.; & Busener, S. (2013). Flame retardants in foam from various consumer products. On file with Green Science Policy Institute.

an attachment a bibliography and table, which identifies additional studies on health effects of organohalogen flame retardants, including non-PBDE chemicals.

5. **Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.**

Data on the exposure to different populations of non-polymeric additive organohalogen flame retardants were provided in the Petition for Rulemaking, at pages 36-41. Key data include:

- Biomonitoring data from the Centers for Disease Control and Prevention (CDC) document the occurrence of polybrominated diphenyl ethers (PBDEs) in human serum by age category and ethnicity (http://www.cdc.gov/exposurereport/). These CDC biomonitoring data show:
    - Teenagers (ages 12 to 19) had higher body burdens than adults for all flame retardants measured.
    - Mexican Americans and non-Hispanic blacks had higher levels than the non-Hispanic white population.
    - All pregnant participants in the 2003-2004 CDC biomonitoring study had measurable levels of at least one PBDE in their bodies.
- Studies have also documented exposure of pregnant women to organohalogen flame retardants, which is of particular concern because there are strong links between prenatal exposures to these chemicals and reduced IQ and greater hyperactivity in children.[6]
- A study of 416 predominantly immigrant pregnant women living in Monterey County, California, detected pentaBDE congeners in 97% of serum samples.[7]
- Flame retardant chemicals are transferred from the mother to the baby during breastfeeding.[8]

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[6] Chen, A.; Yolton, K.; Rauch, S.A.; Webster, G.M.; Hornung, R.; Sjodin, A.; Dietrich, K.N.; & Lanphear, B.P. (2014). Prenatal polybrominated diphenyl ether exposures and neurodevelopment in U.S. children through 5 years of age: The HOME study. *Environmental Health Perspectives*, 122(8), 856-62. doi: 10.1289/ehp.1307562.

[7] Castorina, R.; Bradman, A.; Sjödin, A.; Fenster, L.; Jones, R.S.; Harley, K.G.; Eisen, E.A.; & Eskenazi, B. (2011). Determinants of serum polybrominated diphenyl ether (PBDE) levels among pregnant women in the CHAMACOS cohort. *Environmental Science Technology*, 45(15), 6553-60. doi: 10.1021/es104295m.

[8] Schecter, A.; Pavuk, M.; Päpke, O.; Ryan, J.J.; Birnbaum, L.; & Rosen, R. (2003). Polybrominated diphenyl ethers (PBDEs) in U.S. mothers' milk. *Environmental Health Perspectives*, 111(14), 1723-29. doi: 10.1289/ehp.6466.

- Exposure to flame retardants in house dust is highest for toddlers and young children.[9]

- A study of 20 mothers and their children aged 1.5 to 4 found that the children had typically 2.8 times higher total PBDE levels than their mothers.[10]

- In a North Carolina study, levels of PBDEs on toddlers' hands correlated with serum PBDE levels, suggesting that the frequent hand-to-mouth contact exhibited by young children is a major exposure pathway.[11]

- In another study, toddlers in homes with contaminated house dust had up to 100-fold greater estimated exposure levels compared to toddlers who were not exposed to contaminated dust.[12]

- A recent study of 21 U.S. mother-toddler pairs confirmed that toddlers have significantly higher concentrations of TDCPP metabolites in their urine compared to their mothers, consistent with increased hand to mouth behavior and elevated dust exposure.[13]

- The highest levels of potentially harmful flame retardants in the general population are found in young children from communities of low socioeconomic status and communities of color. For instance, a North Carolina study of 80 toddlers found PBDEs in 100% of the blood samples, and the sum of BDE-47, -99 and -100 (three of the pentaBDE congeners) was negatively associated with the father's level of education.[14]

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[9] Stapleton, H.M.; Dodder, N.G.; Offenberg, J.H.; Schantz, M.M.; & Wise, S.A. (2005). Polybrominated diphenyl ethers in house dust and clothes dryer lint. *Environmental Science & Technology*, 39(4), 925-31. doi: 10.1021/es0486824.

[10] Lunder, S.; Hovander, L.; Athanassiadis, I.; & Bergman, A. (2010). Significantly higher polybrominated diphenyl ether levels in young U.S. children than in their mothers. *Environmental Science and Technology*, 44(13), 5256-62. doi: 10.1021/es1009357.

[11] Stapleton, H.M.; Eagle, S.; Sjödin, A.; & Webster, T.F. (2012). Serum PBDEs in a North Carolina toddler cohort: associations with handwipes, house dust, and socioeconomic variables. *Environmental Health Perspectives,* 120(7), 1049-54. doi: 10.1289/ehp.1104802.

[12] Jones-Otazo, H.A.; Clarke, J.P.; Diamond, M.L.; Archbold, J.A.; Ferguson, G.; Harner, T.; Richardson, G.M.; Ryan, J.J.; & Wilford, B. (2005). Is house dust the missing exposure pathway for PBDEs? An analysis of the urban fate and human exposure to PBDEs. *Environmental Science & Technology*, 39(14), 5121-30. doi: 10.1021/es048267b.

[13] Butt, C.M.; Congleton, J.; Hoffman, K.; Fang, M.; & Stapleton, H.M. (2014). Metabolites of organophosphate flame retardants and 2-ethylhexyl tetrabromobenzoate in urine from paired mothers and toddlers. *Environmental Science & Technology*, 48(17), 10432-38. doi: 10.1021/es5025299.

[14] Stapleton, H.M.; Eagle, S.; Sjödin, A.; & Webster, T.F. (2012). Serum PBDEs in a North Carolina toddler cohort: associations with handwipes, house dust, and socioeconomic variables. *Environmental Health Perspectives,* 120(7), 1049-54. doi: 10.1289/ehp.1104802.

- One analysis of data from the CDC found that individuals in lower income households (less than $20,000/year) had significantly higher PBDE exposures.[15]

- Another study also found higher body burdens of nearly all measured pentaBDE congeners (including BDE-47, -153, and -209) in 2-5 year-old Californian children born to mothers with lower education.[16]

- In a study of ethnically diverse 6-8 year-old girls in California, measured pentaBDE levels were higher in children with less educated care-givers. This study also found that black preadolescent girls had significantly higher levels than white girls.[17]

- A study of CDC data showed that, after adjusting for age, levels of pentaBDE-47 and pentaBDE-99 were significantly lower in white children as compared to Mexican American and black children.[18]

- A recent study detected 2,3,4,5-tetrabromobenzoic acid (TBBA), a urinary metabolite of the Firemaster® 550 component TBB, in 72.4% of the 64 study participants, indicating widespread exposure to Firemaster® 550 in the home environment.[19]

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

We are not aware of studies on the benefits of non-polymeric additive organohalogen flame retardants in the four product categories covered by the Petition for Rulemaking.

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[15] Zota, A.R.; Rudel, R.A.; Morello-Frosch, R.A.; & Brody, J.G. (2008). Elevated house dust and serum concentrations of PBDEs in California: unintended consequences of furniture flammability standards? *Environmental Science & Technology*, 42(21), 8158-64. doi: 10.1021/es801792z.

[16] Rose, M.; Bennett, D.H.; Bergman, Å.; Fängström, B.; Pessah, I.N.; & Hertz-Picciotto, I. (2010). PBDEs in 2-5 year-old children from California and associations with diet and indoor environment. *Environmental Science & Technology*, 44(7), 2648-53. doi: 10.1021/es903240g.

[17] Windham, G.C.; Pinney, S.M.; Sjödin, A.; Lum, R.; Jones, R.S.; Needham, L.L.; Biro, F.M.; Hiatt, R.A.; & Kushi, L.H. (2010). Body burdens of brominated flame retardants and other persistent organo-halogenated compounds and their descriptors in US girls. *Environmental Research*, 110(3), 251-57. doi: 10.1016/j.envres.2010.01.004.

[18] Sjödin, A.; Wong, L.; Jones, R.S.; Park, A.; Zhang, Y.; Hodge, C.; Dipietro, E.; McClure, C.; Turner, W.; Needham, L.L.; & Patterson Jr., D.G. (2008). Serum concentrations of polybrominated diphenyl ethers (PBDEs) and polybrominated biphenyl (PBB) in the United States population: 2003-2004. *Environmental Science & Technology*, 42(4), 1377-84. doi: 10.1021/es702451p.

[19] Hoffman, K.; Fang, M.; Horman, B.; Patisaul, H.B.; Garantziotis, S.; Birnbaum, L.S.; & Stapleton, H.M. (2014). Urinary tetrabromobenzoic acid (TBBA) as a biomarker of exposure to the flame retardant mixture Firemaster® 550. *Environmental Health Perspectives,* 122(9), 963-69. doi: 10.1289/ehp.1308028.

7. **Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?**

   We are not able to provide an estimate of a percentage of those products that would be affected by a ban on non-polymeric additive organohalogen flame retardants; however, we do know that numerous studies (such as those referenced in the response to question 2) document the presence of these chemicals in the four product categories covered by the Petition for Rulemaking.

Eve Gartner

Earthjustice Northeast Office

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Eve Gartner, Earthjustice

Commissioner Robert S. Adler

1. Additional Categories for Possible Regulatory Action: Ms. Gartner, the Petition asks for regulatory action against four broad categories of products that contain non-polymeric organohalogen flame retardant chemicals used as additives. Please explain why Petitioners chose those four categories and state whether there are additional products in homes that CPSC should be concerned about (i.e., candles, carpets, rugs, cabinets, bookcases, sheets, towels, shower curtains, appliances, sleepwear, and clothing).

2. Chemical Substitutes: Ms. Gartner, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition?

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

Responses of Eve Gartner, Earthjustice
to
U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Questions of Commissioner Robert S. Adler

1. Additional Categories for Possible Regulatory Action: *Ms. Gartner, the Petition asks for regulatory action against four broad categories of products that contain non-polymeric organohalogen flame retardant chemicals used as additives. Please explain why Petitioners chose those four categories and state whether there are additional products in homes that CPSC should be concerned about (i.e., candles, carpets, rugs, cabinets, bookcases, sheets, towels, shower curtains, appliances, sleepwear, and clothing).*

In consultation with the Petitioners and other experts, we chose these 4 product categories because non-polymeric organohalogen flame retardants are used in these products in additive form with documented human exposures, and because there is no evidence that use of organohalogen flame retardants in these products at the levels used adds any meaningful fire safety benefit.

2. Chemical Substitutes: *Ms. Gartner, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition?*

I am not an expert in fire science. For an answer to this question, I would refer you to the Comments submitted by Dr. Vyto Babrauskas on January 19, 2016, as well as to the December 9, 2015 oral testimony of Dr. Babrauskas, and to the response to Questions for the Record submitted by Dr. Babrauskas.

I am also aware that there is significant doubt about the reliability of statistics from the National Fire Incidence Report System (and the interpretation of these data by the National Fire Protection Association) regarding the number of fire deaths attributable to fires where upholstered furniture was identified as the source of the first ignition or as the principal item responsible for fire spread. A June 2015 report examining the reliability of these data conducted by the Brattle Group entitled, *A Review of the National Fire Incidence Report System and the National Fire Protection Association Upholstered Furniture Fire Statistics*, is annexed hereto. The Brattle Group concludes at page 2 that: "NFIRS-based statistics generated by NFPA and the Consumer Product Safety Commission (CPSC) are subject to substantial uncertainty, making them of limited usefulness for policy making purposes." This report raises serious questions regarding whether there is in fact any need for "fire protection" from upholstered furniture, beyond adopting TB 117-2013 as a mandatory national standard.

Commissioner Ann Marie Buerkle

1. *Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.*

Adoption of CA TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition for Rulemaking. Three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures -- would not be covered by a national TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not prohibit the use of these toxic chemicals in furniture. In other words, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and/or furniture manufacturers could voluntarily continue to add toxic flame retardants to their products even if the chemicals were not needed to meet a flammability standard. Therefore, to ensure that non-polymeric, additive organohalogen flame retardants are not added to products in these categories, the Commission should grant the Petition and adopt the regulation we have sought.

Commissioner Joseph Mohorovic

1. *Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.*

The flame retardants manufacturers and the foam, fabric, and plastic industries which add the chemicals during their manufacturing processes would be the best source for this information. Based on publicly available studies, the Petition for Rulemaking submitted to the CPSC on June 30, 2015 discusses the presence of non-polymeric, additive organohalogen flame retardants in products at pages 25-28. In addition, documents released by EPA in August 2015, in connection with its initial work to conduct risk assessments of four "clusters" of flame retardants, provide extensive information about the uses of certain flame retardants. In particular, EPA's documents include these data:

- TBBPA is one of the most widely used brominated flame retardants and is used as both an additive and reactive flame retardant (EPA, 2008a). Because manufacturers can incorporate additive flame retardants into the product up until the final stages of manufacturing, it is usually easier for them to use additive rather than reactive flame retardants TBBPA has also been used as a chemical intermediate in the synthesis of other brominated flame retardants (NIEHS, 2002). TBBPA's main consumer use categories as a flame retardant are 1) electrical and electronic products and 2) plastic and rubber products not covered elsewhere. The category "plastic and rubber products not covered elsewhere" means that products are not covered under any other plastic or rubber product categories within the CDR. and dust. With respect to TBBPA's use in plastics and rubber products, it is likely the majority of this use is in electrical and electronic products. For example, a primary application of TBBPA is its use as an additive flame retardant in acrylonitrile butadiene styrene (ABS) resins (a type of plastic). These ABS resins are used in the enclosures or casings around electronics such as TV or computer monitor casings or components in printers, fax machines, photocopiers, vacuum cleaners, coffee machines and plugs/sockets. TBBPA is used in ABS and other plastics at 14 to 22% by weight, often in combination with antimony trioxide (EC, 2006). As of September 6, 2014, TBBPA has been reported for use as a surface coating flame retardant in **artists'** accessories. It has also been reported to be present as synthetic polymer flame retardant **in powered "viewing toys," "toy/games variety packs" and in powered toy vehicles.** Additionally, it is reported to be used as a flame retardant in textiles in baby car/booster seats; baby carriers; baby play pens/dens and baby swings. The concentrations of TBBPA in these products were reported as ranging from < 0.05 to > 1% (Washington State Department of Ecology, 2014b).

A more detailed discussion of the uses of TBBPA can be found at pages 22-26 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment Tetrabromobisphenol A and Related Chemicals Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/tbbpa_problem_formulation_august_2015.pdf

- TCEP **has also been reported to be used as a flame retardant in children's car seats** (Washington State, 2014) and has been detected in changing table pads, sleep positioners, portable mattresses, nursing pillows, baby carriers and infant bath mats (Stapleton et al., 2011).
- TCPP **is reported to the CDR in a variety of industrial use categories such as "furniture and related products" for the manufacture of flexible polyurethane foam and under "textiles, apparel and leather" for fabric finishing processing. TCPP is reported to be used** in a variety of commercial and consumer use categories as well. Potential end-uses within the reported commercial and consumer products include household upholstered furniture and foam baby products. TCPP has been detected in household furniture including footstools, ottomans and chairs (Stapleton et al., 2009). TCPP has also been detected in polyurethane foam in certain baby products including car seats, changing table pads, sleep positioners, portable mattresses, nursing pillows and rocking chairs (Stapleton et al., 2011).
- TDCPP has been detected in furniture such as sofas, chairs and futons and in baby products including rocking chairs, baby strollers, car seats, changing pads, sleep positioners, portable mattresses, nursing pillows and infant bathmats (Stapleton et al., 2009; Stapleton et al., 2011). TDCPP has also been reported to the Washington State

Children's Safe Product Act database (2014) for its use as a flame retardant in "arts/crafts variety pack" and also as a contaminant in footwear for children.

A more detailed discussion of the uses of TCEP, TCPP and TDCPP can be found at pages 17-21 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment Chlorinated Phosphate Ester Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/cpe_fr_cluster_problem_formulation.pdf

- TBPH (CASRN 26040-51-7) and TBB (CASRN 183658-27-7) are two components of **Chemtura's flame retardant Firemaster® 550, an additive f**lame retardant (Chemtura, 2013b; Stapleton et al., 2008a). Bearr, et al. (Bearr et al., 2010) states that Firemaster® BZ-54 is made up of the same TBB-TBPH formulation as is in Firemaster®550. The **product's technical data sheet describes it as a "tetrabromophthalic anhydride derivative,"** with a bromine content of 54% (Chemtura, 2007b). Firemaster® 550 is a liquid flame retardant for flexible polyurethane applications. Firemaster® 550 is mainly applied to furniture containing polyurethane foam, such as couches, ottomans and chairs. According to the 2008 End-Use Market Survey on the Polyurethane Industry in the US, Canada, and Mexico, 230 million pounds of flexible slabstock was used in furniture in the United States in 2008, of which 210 million pounds was used in residential furniture and 20 million pounds was used in non-residential furniture (ACC, 2009). However, the percentage of this market that utilizes Firemaster® products is unknown. Firemaster® BZ-54 is also used for flexible polyurethane foam applications and can be blended with alkyphenyl diphenyl phosphate or used alone (Chemtura, 2007b; Weil and Levchik, 2009). TBPH and TBB have also been detected in gymnastics equipment, including foam pit cubes, landing mats, sting mats, and vault runway carpets (Carignan et al., 2013). These chemicals may therefore possibly be found in other facilities containing foam pits or equipment. Carpet cushions are manufactured largely from flexible polyurethane slabstock foam scraps and recycled foam (EPA, 2005) and have lifespans of five to 15 years (Luedeka, 2012). Given that carpet backing is often manufactured from recycled foam scrap, carpet backing may have the same amount of TBB/TBPH as furniture foam if the scrap foam is from a manufacturer that uses Firemaster® 550 (Polyurethane Foam Association, 2012). ...

A more detailed discussion of the uses of TBB and TBPH, the organohalogen flame retardants in Firemaster 550, can be found at pages 8-13 of TSCA Work Plan Chemical Technical Supplement - Use and Exposure of the Brominated Phthalates Cluster (BPC) Chemicals, available at http://www.epa.gov/sites/production/files/2015-09/documents/bpc_data_needs_assessment_technical_supplement_use_and_exposure_assessment.pdf

- HBCD is used as a flame retardant in polystyrene foam, textiles, and high impact polystyrene. A detailed discussion of the uses of HBCD in products can be found at pages 18-21 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment Cyclic Aliphatic Bromides Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/hbcd_problem_formulation.pdf

2. *Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.*

I do not have any information about this.

3. *Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.*

The Petition for Rulemaking includes a review of the literature in the public domain addressing the toxicity of non-polymeric additive organohalogen flame retardants as of March 2015. (Petition, pages 43-47, and corresponding footnotes 121-148.) In addition, the Statement of Ruthann Rudel submitted with the Petition includes as an attachment a bibliography and table which identifies additional studies on health effects of organohalogen flame retardants, including non-PBDE chemicals.

4. *Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.*

This is discussed in the Petition for Rulemaking at pages 36-41.

5. *Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.*

I am unaware of data showing any consumer benefits from the use of non-polymeric additive organohalogen flame retardants in the four product categories covered by the Petition for Rulemaking.

6. *Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?*

I do not have the information necessary to provide this estimate. I do know, however, that numerous studies document the presence of these chemicals in infant and children's products, mattress and mattress pads, residential furniture and electronic casings. (See response to Question 1 above).

Exhibit 1

A Review of the National Fire Incidence Report System and the National Fire Protection Association Upholstered Furniture Fire Statistics

PREPARED FOR

The Fire Prevention Alliance

PREPARED BY

Mark Berkman, Ph.D.
Charles Gibbons, Ph.D.
Stephen Lagos

June 15, 2015

THE Brattle GROUP

This report was prepared for the Fire Prevention Alliance. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group, Inc. or its clients.

Table of Contents

Executive summary

This report was prepared for and funded by the Fire Prevention Alliance (FPA), a non-profit 501(c)(3) corporation established in 2002 to promote public fire safety education among segments of the population who are likely to experience a household fire. FPA contributors include trade associations associated with the manufacture of home furnishings and suppliers of raw materials and components used for the manufacture of upholstered furniture and mattress sets.

The FPA asked The Brattle Group to assess the reliability of upholstered furniture fire deaths reported by the National Fire Incidence Report System (NFIRS) data and the interpretation of these data by the National Fire Protection Association (NFPA). The NFIRS data has served as the primary basis to determine fire risks and fire related costs (deaths, injuries, and property losses attributable to upholstered furniture since 1980).

More specifically, the FPA asked us to evaluate two statistics: 1) the number of deaths attributable to fires where upholstered furniture was identified as the source of first ignition (smolder + small open flame + other ignition sources) and 2) the number of deaths attributable to upholstered furniture designated as the principal item responsible for fire spread (numerous larger smolder and larger open flame ignition sources).

The NFPA finds that there has been a 67 percent decline in deaths where upholstered furniture was the source of first ignition between 1980 and 2009.[1] But the NFPA also asserts that deaths due to upholstered furniture contributing to fire spread should be counted as well. (NFIRS did not record this information until 1999.) According to the NFPA, including these deaths adds an additional 130 deaths to the average number of deaths attributable to upholstered furniture over the period 2006-2010 – 27 percent more than considering first ignition alone.[2] This would imply that, while the number of fire deaths is falling, the number of fire deaths due to upholstered furniture has been underreported in the past and that the current fire risk is higher than generally thought. Deaths per million, a standard risk measure, is 1.36 based on ignition-related deaths and 1.77 when fire spread-related deaths are included.

Since this assertion has important implications for fire safety policy, it is an appropriate time to review the reliability of the NFIRS-based fire statistics. We conducted an analysis to address this question and have concluded the following:

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1 NFPA. 2011. *Home Structure Fires that Began with Upholstered Furniture.* Quincy, MA.

2 John R. Hall Jr. 2014. *Estimating Fires When a Product is the Primary Fuel But Not the First Fuel, With an Application to Upholstered Furniture.* NFPA: Quincy, MA.

1. NFIRS-based statistics generated by NFPA and the Consumer Product Safety Commission (CPSC) are subject to substantial uncertainty, making them of limited usefulness for policy making purposes.

2. The high degree of uncertainty is not widely recognized and is not reported in NFIRS, NFPA, and CPSC documents.

3. The number of deaths arising from fires where upholstered furniture is first ignited has large confidence intervals. The confidence interval for the 2012 upholstered furniture fire death estimate of 412 based on first ignition, for example, has a confidence interval that is wider than the estimate itself: +/- 246. Thus, the actual number of fire deaths could be as low as 206 (412-246) or as high as 698 (412+246).

4. The confidence interval for the 2012 upholstered furniture fire death estimate of 73 based on source of fire spread also has a wide confidence interval: +/-64. Consequently, addition of fire spread adds as few as 9 deaths (73-64) or as many as 137 (73+64) to total deaths attributable to upholstered furniture.

5. These confidence intervals understate the extent of the uncertainties associated with the NFIRS data for several reasons:
   a. The NFIRS-based values include allocations of both missing and unknown source types because fire department reports are often incomplete. These values represent a large proportion of responses. In 2012, over 30 percent of the source of first ignition responses is missing and about 2 percent are listed as unknown. With respect to primary source of spread, about 75 percent are missing and about 10 percent are unknown.
   b. A raking technique designed to overcome these gaps is sensitive to several key assumptions. Changes in these assumptions results in notably different estimates. For example, raking using national estimates—the method commonly employed—results in higher losses and wider confidence intervals than applying regional and metro-area scaling factors to the same unknown data fields. Allocating these fires to known sources requires assuming that these fires in reality resemble those whose sources were recorded. Because such a significant proportion of the data have unassigned sources, estimates are very sensitive to their inclusion. Performing this allocation more than doubles the number of deaths related to upholstered furniture.
   c. The accuracy of fire department reporting is unknown. We are unaware of any forensic analysis to determine the accuracy of the reports. We do not, for example, know the basis used by departments for determining whether a piece of furniture was the source of spread; this may be the opinion of a fire fighter without the benefit of careful analysis. We do not even know whether missing data reflect that the information is unknown or that the question was simply not answered.

I. Introduction and summary

This report was prepared for and funded by the Fire Prevention Alliance (FPA), a non-profit 501(c)(3) corporation established in 2002 to promote public fire safety education among segments of the population who are likely to experience a household fire. FPA contributors include trade associations associated with the manufacture of home furnishings and suppliers of raw materials and components used for the manufacture of upholstered furniture and mattress sets.

The FPA asked The Brattle Group to assess the reliability of data regarding upholstered furniture fire deaths reported by the National Fire Incidence Report System (NFIRS) data and this data as interpreted by the National Fire Protection Association (NFPA). The NFIRS data has served as the primary basis to determine fire risks and fire related costs (deaths, injuries, and property losses attributable to upholstered furniture since 1980).

More specifically, the FPA asked us to evaluate two statistics – 1) the number of deaths attributable to fires where upholstered furniture was identified as the source of first ignition (smolder + small open flame + other ignition sources) and 2) the number of deaths attributable to the upholstered furniture designated as the principal item responsible for fire spread as an item of secondary ignition (numerous larger smolder and larger open flame ignition sources).

The fire spread statistic has only recently been proposed as an additional source of upholstered furniture fire related deaths. Whether this addition actually improves the accuracy of the fire death statistics is unclear especially in view of other limitations of the NFIRS data. Addressing this requires a broader and more sophisticated review of NFIRS and its applications. This paper is an attempt to accomplish this.

Our analysis of the reliability question leads us to the following basic conclusions:

1. NFIRS based statistics generated by NFPA and the Consumer Product Safety Commission (CPSC) are subject to substantial uncertainty making them of limited usefulness for policy making purposes
2. The degree of uncertainty is not widely recognized and is not reported in NFIRS, NFPA, and CPSC documents
3. The confidence intervals we estimate are large, but still understate the extent of the uncertainties associated with the NFIRS data because of data reporting limitations.

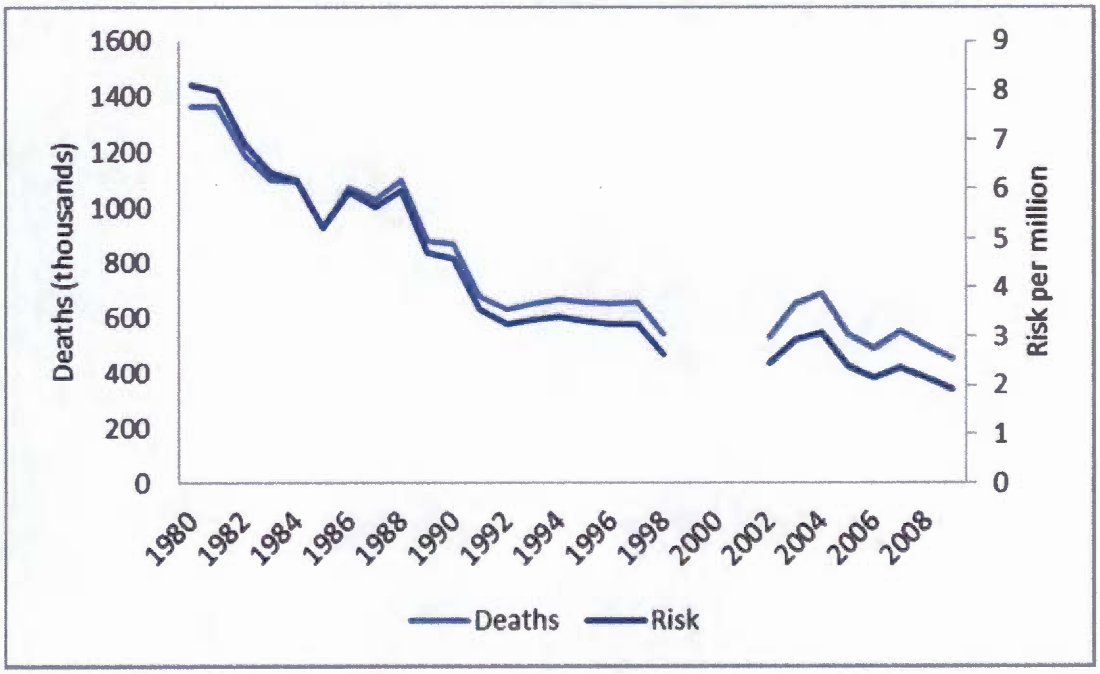
These conclusions are elaborated on in the body of the report.

The report is organized in six sections following this introduction. Section II provides a brief background, Section III reviews the raking technology currently used to account for data gaps in NFIRS. Section IV provides an alternative method. Section V presents a discussion of handling the data gap problem. Section VI discusses how to treat uncertainty in the data and how to calculate confidence intervals. Section VII presents our results and conclusions.

II. Background

NFIRS data have been collected via survey since the 1970s and became a more exhaustive questionnaire beginning in 1999.[3] It has been the primary source of information for researchers and policy makers regarding the trends and causes of residential fires and fire deaths. The NFPA and the Consumer Product Safety Commission have both relied on these data to make policy recommendations. Using the NFIRS data, these institutions and the U.S. Fire Administration, have noted that residential furniture fires and related deaths have fallen considerably since 1980. According to the NFPA, upholstered furniture fire related deaths have fallen from 1,360 in 1980 to 450 in 2009.[4] Accounting for population growth, the risk of death from furniture fire has fallen from 8.1 per million to 1.9 per million.[5] These trends are shown in Figure 1.

Figure 1: Estimated furniture fire-related deaths (thousands) and risk per million



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[3] U.S. Fire Administration. 2015. *National Fire Incident Reporting System Complete Reference Guide.*

[4] NFPA. 2011. *Home Structure Fires that Began with Upholstered Furniture.* Quincy, MA. Note that the NFPA does not report estimates for 1999-2001.

[5] Risk measured by deaths per million is standard practice for government agencies and academic research. See, for example, U.S. Department of Homeland Security, U.S. Fire Administration, "Fire Risk in 2011," Topical Fire Report Series, Vol. 15, Issue 8, January 2015. Population data is from US. Bureau of Labor Statistics, *Civilian Noninstitutional Population* [CNP16OV], retrieved from FRED, Federal Reserve Bank of St. Louis.

Despite these trends, the NFPA, the CPSC and the FPA remain concerned about upholstered furniture fires and related deaths. A recent study by John Hall of the NFPA suggest that the number of furniture-related deaths is understated because it refers only to deaths attributed to fires where furniture is the source of first ignition.[6] Hall asserts that furniture fires that have been identified as the primary source of fire spread should also be counted. Based on his calculations, this would add 130 deaths to the 480 deaths reported on average from 2006 through 2010 from first ignition, a 61 percent increase. This would increase the risk level from 1.57 to 1.87 per million on average for the period.

The FPA is concerned that making this addition is problematic in view of several important limitations to the NFIRS data. In view of these limitations, the proposed addition is not necessarily a real step towards improving the accuracy of the NFIRS data. Others, including Hall, have recognized these limitations as well.[7]

III. The National Estimates Approach

We understand that estimates of the number of fires in the U.S. are traditionally calculated following the National Estimates (NE) approach of Hall and Harwood (1989).[8] The values in Figure 1 reflect this approach. In this section, we discuss this approach and its underlying assumptions.

A. Summary of the NE Approach

The steps are:

1. Using the NFIRS data, proportionally allocate fires with unknown or missing sources to each possible source based upon the reported frequency of the source. The reported

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6 John R. Hall, Jr., "Estimating Fires When a Product is the Primary Fuel But Not the First Fuel, with an Application of Upholstered Furniture," National Fire Protection Association, February 2014.

7 National Fire Protection Association, "White Paper on Upholstered Furniture Flammability, September, 2013 and Lori Moore-Merrell, "Fire Data: Quantity and Quality, International Association of Fire Fighters, Flame Retardants Meeting, March 8, 2015

8 John R. Hall Jr. and Beatrice Harwood. "The National Estimates Approach to U.S. Fire Statistics." *Fire Technology*. 25(2): 99-113. May 1989.

frequencies are calculated using a cross tabulation of first ignition sources and primary sources of spread.[9] This process is called *raking*.

2. Calculate the total number of fires reported in the NFIRS database.
3. Using the NFPA annual survey of fire departments, calculate the total number of fires in the U.S.[10]
4. Calculate a scaling factor equal to the number of fires implied by the NFPA survey (step 3) divided by the number reported to NFIRS (step 2).
5. Apply the scaling factor (step 4) to the number of fires imputed to have upholstered furniture as the source of first ignition (step 1) and add the number of unconfined fires for which upholstered furniture was not the source of ignition, but was the primary source of spread (also from step 1).

These steps are repeated separately for counts of fires and deaths.

The logic behind the NE approach is:

- Because the NFPA survey includes a (stratified) random sample of fire departments, it can produce an accurate estimate of the total number of fires in the country.[11]
- The NFPA survey asks for fewer details about the fires than are provided to NFIRS.
- The NFIRS fire counts by source can be scaled to a national level by applying the scaling factor calculated using total fire counts from the survey.
- NFIRS reports with missing or unknown values for the sources of ignition or spread are similar to those with these values completed.

B. ASSUMPTIONS OF THE NE APPROACH

For this logic to hold, the following assumptions must be true:

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9 The NFPA rakes separately for fires recorded as contained and those that were not contained. Contained fires are assumed not to have a source of spread. They also rake separately by fire size. We impute separately for contained and uncontained fires, but not by fire size.

10 While the NFPA annual survey asks each department how many fires it responded to, the department is not asked for detailed information about those fires, such as the source of ignition or spread.

11 Of course, even if the departments surveyed are a random sample, the departments that respond are not.

- Departments responding to the NFPA survey are a random sample of U.S. fire departments and accurately report the number of fires that they responded to. This leads to an accurate estimate of the total fires in the country.
- The composition of fires within NFIRS must reflect the typical or average composition of fires in the U.S. This implies an accurate assignment of total fires to particular categories.
- Fires with missing values for the sources of ignition or spread must have a similar composition of these sources as those for which these values are reported.

Put differently, the average department reporting to NFIRS can respond to more or fewer fires than the average U.S. department; scaling based on the NFPA survey ensures that the total number of fires is accurate. But the average individual fire report in the NFIRS sample must be like the average fire in the U.S. to ensure that the composition of fires is accurately estimated. Furthermore, when these values are missing, these fires must be similar to fires for which these values are recorded.

C. Evaluating the Representativeness of Fires in the NFIRS Database

To the second NE assumption, we find that departments in urban areas are overrepresented relative to those in rural areas and some states are overrepresented while others are underrepresented. Furthermore, the extent and degree of these differences change over time. If the proportion of fires of a given type (such as those with upholstered furniture as the first ignition source) differs between urban and rural areas or across states, then they will be disproportionally represented in the NE approach, leading to incorrect estimates of fire counts and trends. Hence, representativeness of the NFPA survey, the departments reporting to NFIRS, and the types of fires with complete information are all required to reach correct policy conclusions.

We consider how the changing composition of NFIRS departments over time influences the fire trends that are estimated using these data. There are 5,668 departments that report at least one fire to NFIRS every year from 2005 to 2012; call this the "constant sample." All other departments are part of the "varying sample." Figure 2 shows the average number of fires per department for these two samples. We see that the departments that tend to consistently report to NFIRS tend to be larger than those that do not.[12]

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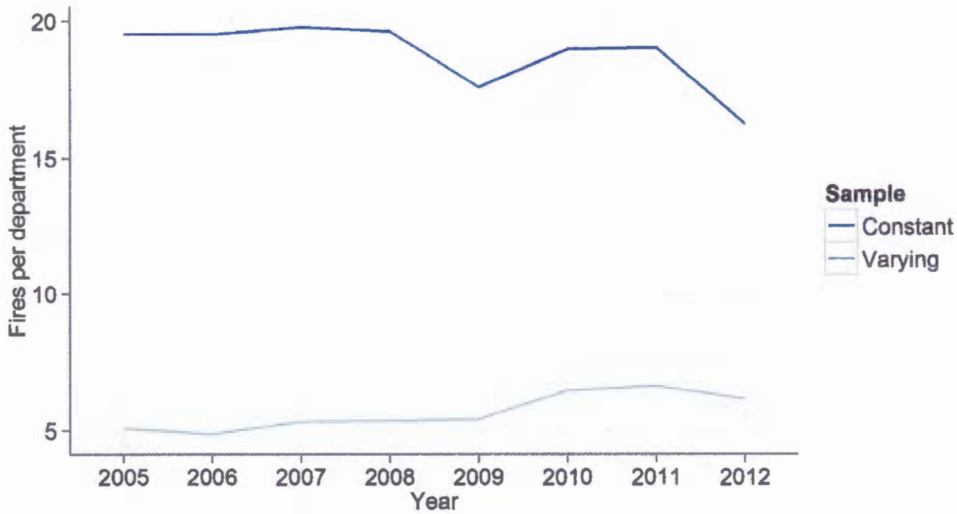
12 This is partly a selection effect; smaller departments may not report every year because they do not experience a fire every year.

Figure 2: Average fires per department for a constant sample of NFIRS departments versus all other departments



By the end of the period, the average number of fires per department in the constant sample decreased by about 17%, while it increased by about 20% for the varying sample. Given that the constant sample effectively controls for unobservable factors, the trend experienced by these departments should be pretty reliable (at least for this group). On the other hand, because the departments contained in the varying sample are changing, many other factors could be affecting the trend. Taken together, these results suggest that (a) larger departments are more likely to consistently report to NFIRS, possibly inflating total fire estimates (especially when NFIRS counts are scaled by the number of departments, as we do in the next section of this report) and (b) the most reliable indication of fire trends in the NFIRS data indicates that fires have decreased since 2005.

IV.An alternative approach: Scaling by region

In this section, we offer an alternative approach to scaling NFIRS counts to estimates of nationwide fires. We calculate scaling factors using the NFIRS data supplemented with the USFA National Fire Department Census for each combination of states and urban versus rural distinctions.[13]

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13 We also use a data set from the National Center for Health Statistics and the U.S. Center for Disease Control that classifies U.S. counties as either urban or rural.

A. Scaling by Region

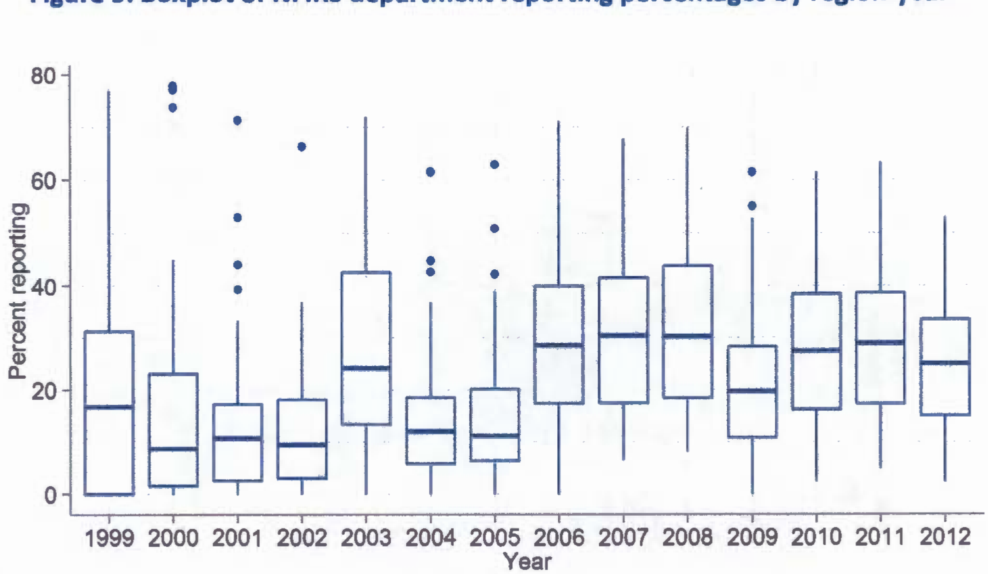
In our approach, we stratify fire departments by state and metro status (such as urban New York departments), find the average number of fires reported to NFIRS within that area, and scale by the number of departments in the census in that area. Here the assumption is that the average respondent to NFIRS is the same as the average department by state and metro status pair. We assert that it is more likely that an urban New York respondent to NFIRS is representative of that area than the average NFIRS respondent is of a typical U.S. department.

This approach is used to scale not only total fires, but also fires by category (such as those in which upholstered furniture was the source of first ignition). Hence, if the composition of fires varies by region, our approach takes those differences into account. Region-weighting also takes into account differences in propensities to report to NFIRS across the country. For example, some state fire agencies may encourage local departments to report more than those in other states. Also, larger urban departments may have more resources for filing reports than small rural departments and thus may be more likely to do so. Region weighting is able to take these factors into account, while the NE approach does not.

Figure 3 shows the distribution of the percentage of departments reporting by year across all regions. The figure reveals that the median proportion of reporting departments begins to exceed 20% in 2006. The results that we present in this report focus on 2005 and later.

Even in this later period, there is tremendous range in this proportion; indeed, in some years, some regions have few to no departments reporting. Hence, if each fire is weighted equally, as in the NE approach, then some regions will be overrepresented (those with a high proportion of departments reporting) and some will be underrepresented (those with a low proportion of reporting departments). Our method ensures that each region contributes to the national total in proportion to their actual size, not in proportion to the number of their departments that report to NFIRS.

Figure 3: Boxplot of NFIRS department reporting percentages by region-year[14]



B. COMPARISON TO THE NE APPROACH

The NE approach requires that the composition of fires in NFIRS be nationally representative, while the region scaling approach requires that NFIRS only be representative in each region separately. This is a weaker assumption: NFIRS can be representative by region, but if those regions are disproportionally represented in NFIRS, NFIRS will not be nationally representative. The NE approach requires that the NFPA survey provide accurate estimates of the total number fires each year, while the region scaling approach requires the USFA census to be comprehensive.[15]

In light of this comparison of assumptions, the region-scaling approach is preferred on NFIRS representativeness grounds. It is preferred entirely if the USFA census contains every U.S. department. The USFA estimates that 88% of departments are registered with the census.[16] The

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14 A boxplot shows a distribution of values. Each box indicates the median value by a thick line in the middle of the box. The box is bounded by the 25th and 75th percentiles of the distribution. The "whiskers" extend from the box to the most extreme value unless there are outliers, which are denoted with dots.

15 For the NFPA survey to accurately estimate total U.S. fires, however, the NFPA must also have a complete census of U.S. fire departments.

16 If the propensity to be included in the census is the same across regions, then analysis of trends will be accurate, but the total number of fires will be underestimated.

NE approach is preferred if the NFPA survey well represents the typical U.S. department and those respondents provide accurate counts of their fires and if the composition of fires is relatively constant across the country.

Our approach allows us to produce national estimates of fire counts using publicly available data that may be more reliable for both total fire counts and counts by category of fire than the NE approach.

V. Handling missing values

There are two types of fires with unassigned sources in the NFIRS data: values that are not completed ("missing") and those where the respondent specifically stated that the source is "unknown." In this section, we reveal how often NFIRS records fall into these categories and discuss the implications for calculating nationwide estimates of fires and deaths.

A. FREQUENCY OF UNOBSERVED SOURCES

Figure 4 and Figure 5 show the proportions of unassigned fires for first ignition and primary spread sources.[17] In the case of first ignition, there are many more unknown classifications than missing classifications. Further, the proportion of unknowns is increasing over time, rather than decreasing, as one might expect if the quality of NFIRS data was improving.

On the other hand, for the source primarily responsible for fire spread, there are many more missing values than unknown values. Notice that about 70% of these values are missing, even in the most recent reporting year. Hence, allocating these values to known sources can have a substantial impact on estimates of nationwide fires and deaths.

17 Following Hall (2014), we focus on uncontained fires when considering the source of spread.

Figure 4: Proportion of raw NFIRS fires with the source of first ignition categorized as missing or unknown

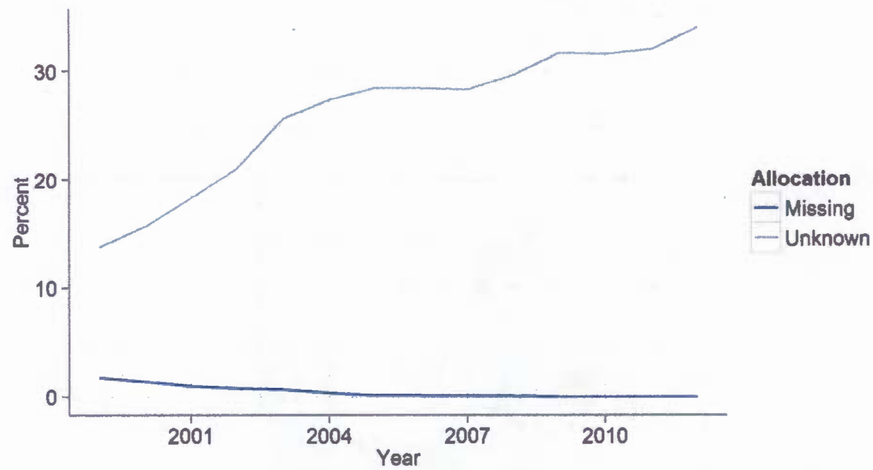
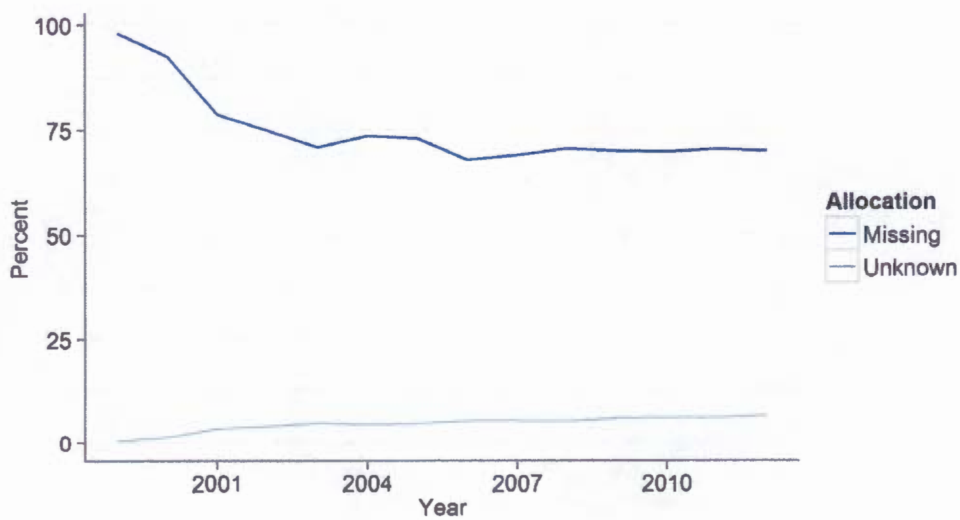


Figure 5: Proportion of raw uncontained NFIRS fires with the source of fire spread categorized as missing or unknown



B. THEORETICAL DISCUSSION

Missing values could reflect either that the recorder skipped the question or that he was unsure of the correct response. In the former case, perhaps it is reasonable to assume that the fires with missing values are similar to those whose values have been completed. In the latter case, missing values are more similar to those sources recorded as unknown. Without a forensic analysis of the scene of the fire, these unknown fires cannot be accurately categorized.

For both primary ignition and for fire spread, the source is imputed when the reported value is either missing entirely or listed as unknown. But these are two distinctively different cases. Yet, the NE approach treats both cases in the same manner.

When the true value is unknown, as opposed to missing, it is unlikely that the true sources of these fires are similar to those of fires where the respondent was confident of the source. For example, if a fire was ignited by a transformer, it is likely known to be the source and, contrarily, a fire with an unknown source was unlikely to have been started by a transformer. Hence, a simple proportional allocation of these unknown values is likely inaccurate.

Additionally, the source of first ignition may be clearer than the source of spread. For example, in the case of a bedroom fire, it may not be clear whether bedding or clothing, two distinct sources in the NFIRS data, were responsible for furthering the spread of the fire.

Inferences for missing or unknown values must be based upon known values, however. The NFPA assumes that a missing value from any department in the country can be randomly allocated a source from the nationwide distribution of fire types. Our approach is more refined, as it assumes that the missing value be similar to those from a department in the same region. A yet more refined approach would create a statistical model that incorporates many other known features of the fire to predict the most likely source of the fire.

C. IMPLICATIONS FOR RESULTS

Table 1 and Table 2 show a comparison of three allocations. First, we estimate the number of upholstered fires by scaling fires reported to be ignited by upholstered furniture. Second, we allocate missing fires, but not unknown fires, to each source (including to an unknown source). Lastly, we provide an estimate based upon allocating both the missing and unknown values, which is comparable to the approach used by the NFPA and used in the remainder of this report due to this comparability.

Table 1: Comparison of total fires attributable to upholstered furniture under three allocations (2006-2010 average)

Allocation	First ignition	Source of spread	Total
No allocation	6,560	670	7,230
Allocate missings	6,566	2,262	8,828
Allocate missings and unknowns	9,243	3,503	12,746

Table 2: Comparison of total fire deaths attributable to upholstered furniture under three allocations (2006-2010 average)

Allocation	First ignition	Source of spread	Total
No allocation	211	20	231
Allocate missings	211	56	267
Allocate missings and unknowns	452	102	554

Allocating missing (as opposed to unknown) values has the largest impact on estimates of the source of fire spread, as we would expect upon comparing Figure 4 and Figure 5. But, we find that allocating fires whose source is unknown has the biggest impact on estimates of both fires and deaths. Indeed, allocating these fires more than doubles the estimated number of deaths attributable to upholstered furniture. Allocating fires missing with missing sources greatly increases fires with spread attributed to furniture and allocating unknowns greatly increases fires with a source of ignition attributed to furniture. If these fires of unknown provenance have a different distribution of sources than fires with recorded sources, then estimates obtained using proportion allocation could be very inaccurate.

VI. Estimating uncertainty and creating confidence intervals

Extrapolating from NFIRS counts of fires related to upholstered furniture to total U.S. fires related to this source requires calculating a scaling factor that inflates NFIRS fire counts to nationwide fire counts and allocating missing (and unknown) sources to a known source.

Theoretically, the scaling factor is a known quantity in our approach: the scaling factor is the number of departments in the region (known exactly from the USFA census) relative to the number of departments reporting to NFIRS (a tabulation of observed departments).[18] In reality, there is an unknown degree of underreporting to the USFA census, which introduces

[18] This is a simplification. The appropriate denominator to this scaling factor is the number of departments that would report to NFIRS *if they confronted a fire*. Otherwise, the scaling factor would be too high, as the numerator counts departments that may not face a fire in a given year, while the denominator would not. We apply a correction factor assuming that the distribution of fires within a region-year follows a Poisson distribution. The number of departments estimated to experience no fires in a year is generally miniscule and this correction reduces the number of upholstered furniture-related deaths by less than five in a year. This correction introduces uncertainty, as the number of departments without any fires is estimated, rather than known, but we do not consider this source of uncertainty in our estimates.

uncertainty. We do not account for this uncertainty in our calculations, however, because we do not have data available to us that would permit us to identify the variation in underreporting that arises across regions.

We focus on the uncertainty arising from allocating fires to specific categories.[19] Begin first with fires assigned to a known source. These fires follow a multinomial distribution. A multinomial distribution can be conceptualized by thinking of a loaded die with the probability of each face arising potentially being different. The multinomial distribution characterizes the chance of observing each side of the die over the course of many throws. Here, the probability of each fire type among those fires with recorded sources (*i.e.*, the probability of landing on that face of the die) denoted p_s is equal to the observed proportion of that type. The variance in the number of recorded fires attributable to this source is

$$Var(N_s) = Np_s(1 - p_s),$$

where N is the number of fires with their sources recorded and N_s is the number of fires attributed to source s.

Next, we allocate missing and unknown fire sources to known categories by assuming that the probability that a missing or unknown fire is due to a specific source is equal to the proportion of known fires that are attributable to that source. This is equivalent to scaling up the number of fires known to belong to a particular category by the total number of fires in NFIRS relative to the number of fires with their sources recorded.[20] This scale factor is squared when calculating the variance of total fires allocated to source s:

$$Var\left(\left(\frac{N+M}{N}\right)N_s\right) = Np_s(1 - p_s)\left(\frac{N+M}{N}\right)^2,$$

where M is the number of fires with missing or unknown sources.

19 Because we do not consider uncertainty arising from our scaling factors, we do not estimate error bounds for total U.S. fires, only fires for particular ignition or spread sources.

20 For this calculation, we hold the number of fires with recorded sources and the number of fires with missing sources fixed; in statistical jargon, we are conditioning on these values. In reality, these values are random and thus we are understating the randomness present in the data.

These calculations give the total number of fires in NFIRS that are attributable to source *s*. Suppose that there are *D* departments in the USFA Census and *d* departments report to NFIRS.[21] Then, the estimated number of fires attributable to source *s* is

$$\frac{D}{d}\left(\frac{N+M}{N}\right)N_s$$

and the variance of this estimate is[22]

$$Np_s(1-p_s)\left(\frac{N+M}{N}\right)^2\left(\frac{D}{d}\right)^2.$$

All these calculations occur separately for each region and are aggregated to reach an annual total.[23] The same calculations can be performed using injuries and deaths, rather than fire counts.

Ninety-five percent confidence intervals are reported for the counts in this report. These ranges are calculated by adding and subtracting roughly two times the square root of the variance (a quantity known as the standard error) to the estimated number of fires to calculate the upper and lower bounds of the interval. These confidence intervals are created such that, were we to create 20 of these intervals, we would expect the true value to fall within 19 (*i.e.*, 95%) of them.

It must be emphasized that these intervals are based on the same assumptions that we have discussed in prior sections, notably:

- Departments reporting to NFIRS are similar to others in their regions in terms of number of fires, deaths, and injuries and the sources of those fires;
- Fires with missing sources have the same distribution of source types as those with recorded sources within their region;

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21 Here, *d* is itself scaled to account for the (small) proportion of departments that do not experience a fire as estimated using a Poisson distribution, but it is assumed to be non-random. See footnote 18 for further discussion.

22 This discussion outlines the approach for calculating the expected counts and their variance for fires with upholstered furniture as the first source of ignition. For fires where upholstered furniture was the primary source of spread, this calculation is more complicated. Notably, all fires whose ignition sources are recorded to be or are imputed to be upholstered furniture are removed. Careful accounting of the number of known and missing fires is required.

23 A further complication is that, in 2005 (and in many earlier years), some regions did not have any departments report to NFIRS. In this case, we scale annual totals by the ratio of fires in 2006-2012 estimated to have occurred in these regions relative to the number of fires in regions that did report to NFIRS. As with other scaling factors, this factor is squared in variance calculations.

- Fires with unknown sources have the same distribution of source types as those with recorded sources within their region.

Our estimates of uncertainty do not take these factors into account; indeed, they *cannot* take the uncertainty of these assumptions into account without either data from an additional source or by imposing different assumptions on the NFIRS data. We are unable to ascertain whether our results are over- or underestimates of true counts of fires, injuries, and deaths. Undoubtedly, our estimates of the uncertainty of these estimates, however, are too low as they do not account for the uncertainty in the reliability of the assumptions. Interpretation of our results must be done with these caveats clearly in mind.

VII. Results

In this section, we present detailed results from our scaling and allocation approaches.

A. TOTAL FIRES AND DEATHS

Figure 6 shows the Brattle and NFPA estimates of total U.S. fires in thousands from 2005 to 2012. There is a general downward trend in both estimates, though the timespan is too short for this effect to be evident. Though both approaches yield similar estimates of total fires, the estimates of total deaths (shown in Figure 7) are lower using our method as compared to the NFPA values.

Figure 6: Brattle and NFPA estimates of total U.S. fires

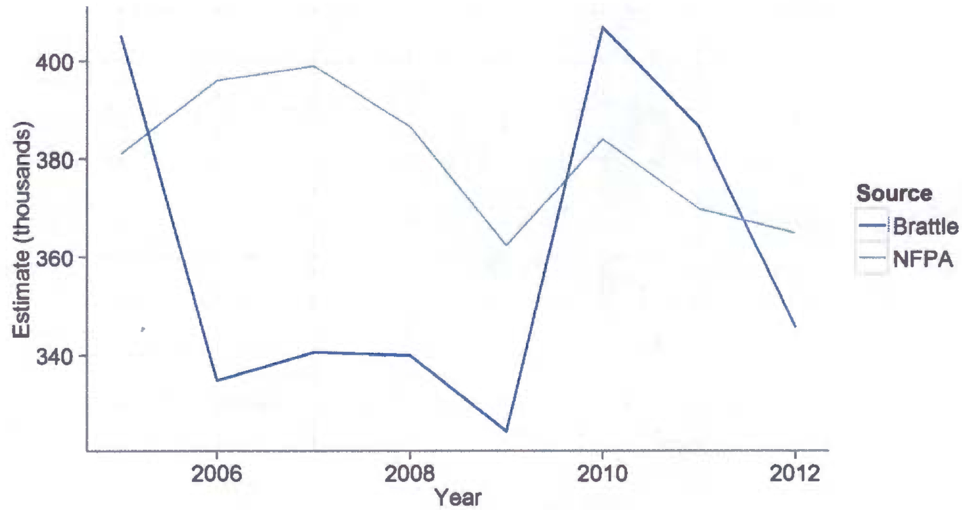
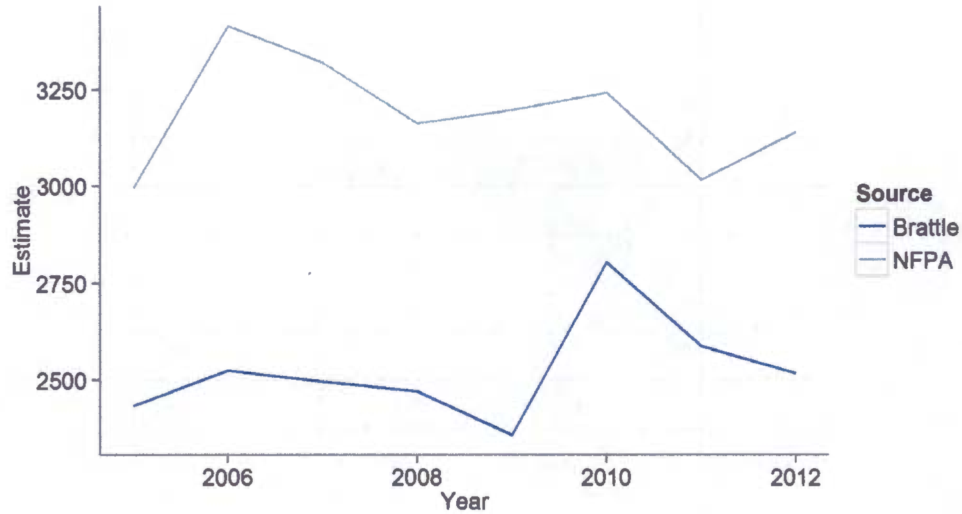


Figure 7: Brattle and NFPA estimates of total U.S. fire deaths



B. FIRES ATTRIBUTABLE TO UPHOLSTERED FURNITURE

Estimates of fire deaths attributable to upholstered furniture as the source of first ignition are shown in Figure 8 along with confidence intervals (depicted as red bars). Notice that the year-to-year changes are overwhelmed by the uncertainty present in these estimates. This result is even more pronounced in Figure 9, which shows the deaths attributable to upholstered furniture as the primary source of spread (though not ignition). Indeed, in this case, the confidence intervals extend to the single digits in 2012.

Figure 8: Estimates of deaths attributable to upholstered furniture as the source of first ignition with 95% confidence intervals

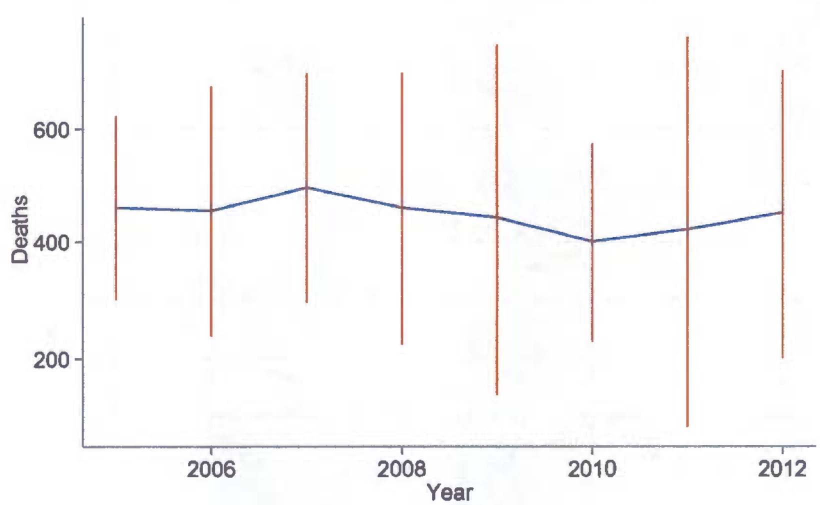
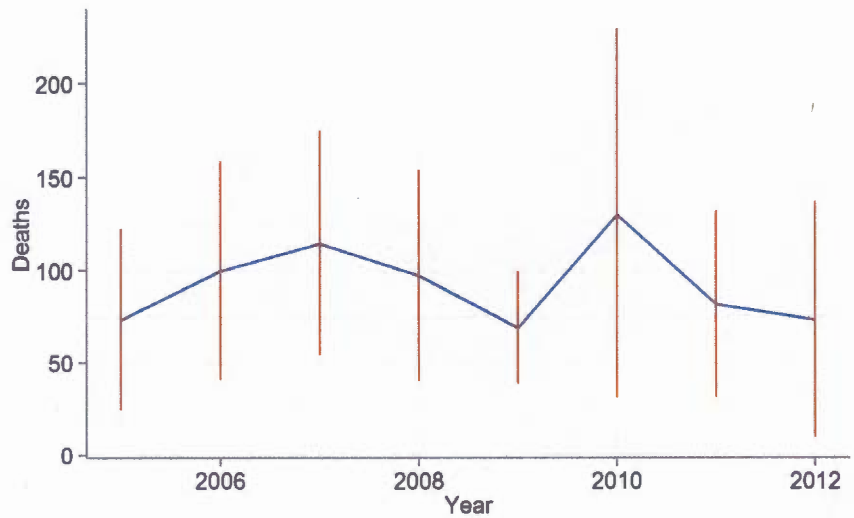


Figure 9: Estimates of deaths attributable to upholstered furniture as the source primarily responsible for fire spread (though not first ignition) with 95% confidence intervals



C. Conclusions

These results show that widely-used fire statistics generated by NFIRS and the NFPA are subject to substantial uncertainty. Because of this uncertainty, these estimates must be used cautiously, especially for policy making purposes. Impacts of policy changes will be difficult to detect among these uncertainty bands. Furthermore, secular changes in upholstered furniture-related deaths will also be obscured by this uncertainty. Lastly, as discussed in the introduction, summing deaths attributed to upholstered furniture as either a first ignition source or a source of spread may not provide a statistic that is useful for designing a comprehensive fire prevention strategy.

As shown in Table 3, differences in raking techniques influence the estimates and the confidence intervals, especially for deaths related to source of fire spread, are very large.

Table 3: Comparison of estimates of annual fire deaths attributable to upholstered furniture with confidence intervals (2006-2010 average)

	First ignition		Source of spread	
	Estimate	C.I.	Estimate	C.I.
Hall (2014)	480	not provided	130	not provided
Brattle	452	345-558	102	77-128
Difference (%)	6.2%		27.5%	

About The Brattle Group

The Brattle Group, an economic and financial consulting firm, was established in 1990. The firm's 200 employees are located in Cambridge, New York, Washington, D.C., San Francisco, London, Madrid, and Rome. The Brattle Group's principals include several leading academics in economics and finance, including a Nobel Prize winner. Brattle principals and senior staff have broad experience assisting clients worldwide in matters regarding antitrust, intellectual property, environmental, health and safety regulation, energy, securities, telecommunications and valuation. Our experts are regularly called to testify before regulatory agencies, courts, and arbitrations panels.

Dr. Mark P. Berkman, a Brattle principal, is an expert in applied microeconomics. His experience spans the areas of the environment, energy, and natural resources; environmental health and safety; labor and employment; and public finance. He has assisted both public and private clients and provided testimony before state and federal courts, arbitration panels, regulatory bodies, and legislatures.

Prior to joining Brattle he was a co-founder and director at Berkeley Economic Consulting and a vice president at both Charles River Associates and NERA Economic Consulting. He has also held positions at the Congressional Budget Office and the Urban Institute and served as a staff assistant to U.S. Representative Charles Vanik of Ohio. Dr. Berkman earned his PhD from the Wharton School of the University of Pennsylvania in public policy and applied economics. He also holds degrees from Harvard University and George Washington University.

Dr. Charles Gibbons, a Brattle associate, specializes in applying sophisticated econometric and statistical models to legal, regulatory, and policy issues. He has produced analysis for a variety of litigation matters, including models of mortgage delinquencies, forensic analysis of product defects, and local impacts of environmental damages. His work has been used for class certification, liability determination, and damage calculations. He has also developed models for forecasting electricity sales and peak demand for utilities.

Additionally, Dr. Gibbons is a lecturer at the University of California, Berkeley where he is currently teaching a graduate-level course in probability and statistics. He received a Ph.D. in economics and an M.A. in statistics from the University of California, Berkeley. His dissertation proposed new methods in applied econometrics and a theory of competition for online advertising auction platforms. He also holds a bachelor's degree from Cornell University.

Stephen Lagos, a Brattle research assistant, has substantial experience regarding economic and statistical analysis especially where large complex data must be managed. Prior to joining The Brattle Group, Mr. Lagos served as a research assistant at the University of Chicago. He earned a BA in economics from Colorado College.

4 & 5

Joint Responses from

Arlene Blum, Ph.D.

Simona Balan, Ph.D.

Green Science Policy Institute

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

<u>Arlene Blum, Green Science Policy Institute</u>

Chairman Elliot F. Kaye

1. How was the scope of the petition, both product areas and chemicals, decided?

2. Are there data for identifying what flame retardants within the scope of the petition are in which of the four product areas covered in the petition? If there are other FR chemicals used in these products, what are they (chemical name or class)?

3. Do all of these chemicals have the same health effects? Is the dose-response for each chemical similar or different?

4. What are other sources of these flame retardants that are not included within the scope of the petition?

5. Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?

Commissioner Robert S. Adler

1. <u>Organohalogen Hazards</u>: Dr. Blum, we heard testimony during the hearing that different organohalogens produce different effects depending on their unique chemical characteristics.
    a. Given the different effects associated with different organohalogens, are you aware of any of these chemicals that do not present significant health risks?
    b. Given the broad array of organohalogens, is there sufficient commonality among them for the Commission to address them as a chemical class (as requested by the petitioners) or should the agency examine them chemical by chemical as suggested by the American Chemistry Council?
    c. If the answer to (b) is that there is sufficient commonality, can you explain what the common elements are that would justify an across-the-board treatment by the CPSC?

2. <u>Assessment Tools</u>: Dr. Blum, please state your views on how various chemical hazard assessment tools, including but not limited to standard read-across techniques and structure-activity relationship models, could be used to support

regulatory decisions for the entire class of additive, non-polymer, organohalogen flame retardants subject to the Petition.

3. Chemical Substitutes: Dr. Blum, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition? If so, what chemicals are in the market today that might substitute for organohalogens if they were removed from the market?

Commissioner Ann Marie Buerkle

1. If the characteristic of bioaccumulation is present in an organohalogen flame retardant, does that automatically mean there are adverse consequences to exposure?

2. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Simona Balan, Green Science Policy Institute

Chairman Elliot F. Kaye

1. Are there additional unpublished toxicity and/or exposure data to defend/discount petition claims? Are the toxicokinetics of these chemicals similar? For example, do these chemicals exhibit the same type of absorption characteristics (same uptake, same tissues impacted, etc.)? Do all of these chemicals have the same persistence in the environment? Are these data directly comparable (i.e., the same endpoint(s), methods, etc.)? Could these data be provided to staff?

2. Do all of these chemicals have the same health effects? Is the dose-response for each chemical similar or different?

Commissioner Robert S. Adler

1. Organohalogen Hazards: Dr. Balan, we heard testimony during the hearing that different organohalogens produce different effects depending on their unique chemical characteristics.
   a. Given the different effects associated with different organohalogens, are you aware of any of these chemicals that do not present significant health risks?
   b. Given the broad array of organohalogens, is there sufficient commonality among them for the Commission to address them as a chemical class (as requested by the petitioners) or should the agency examine them chemical by chemical as suggested by the American Chemistry Council?
   c. If the answer to (b) is that there is sufficient commonality, can you explain what the common elements are that would justify an across-the-board treatment by the CPSC?

2. Assessment Tools: Dr. Balan, please state your views on how various chemical hazard assessment tools, including but not limited to standard read-across techniques and structure-activity relationship models, could be used to support regulatory decisions for the entire class of additive, non-polymer, organohalogen flame retardants subject to the Petition.

3. Chemical Substitutes: Dr. Balan, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition? If so, what chemicals are in the market today that might substitute for organohalogens if they were removed from the market?

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

Green Science Policy Institute

January 28, 2016

Arlene Blum PhD and Simona Balan PhD, Green Science Policy Institute

We are submitting these answers below jointly, representing the views of the Green Science Policy Institute.

Re: U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Chairman Elliot F. Kaye

1. ***How was the scope of the petition, both product areas and chemicals, decided?***

In consultation with the Petitioners and other experts, we chose these 4 product categories because:

(1) non-polymeric organohalogen flame retardants are used in these products in additive form with documented human exposures, including to infants, children, and other vulnerable populations, and

(2) there is no evidence that additive organohalogen flame retardants at the levels used in these products add any meaningful fire safety benefit.

2. ***Are there data for identifying what flame retardants within the scope of the petition are in which of the four product areas covered in the petition? If there are other FR chemicals used in these products, what are they (chemical name or class)?***

We have presented in the Petition numerous studies indicating that non-polymeric additive organohalogen flame retardants are found in the four product categories listed in the petition (infant and children's products, residential furniture, mattresses and mattress pads and electronic enclosures). However, identifying what flame retardants are present in a specific product is costly, and the chemicals used can vary greatly with time and manufacturer, so few studies have obtained this information. It would be best requested of the flame retardants manufacturers and of the manufacturers of products in the four categories included in the Petition.

Below is what we know in terms of which flame retardants have been found in which product categories:

1. Infant and Children's Products

pentaBDE (before the phase out, and potentially still in imported products), tris(1,3-dichloroisopropyl) phosphate (TDCPP), FireMaster 550® components 2-ethylhexyl, 2,3,4,5-tetrabromobenzoate (TBB) and bis (2-ethylhexyl) 2,3,4,5-tetrabromophthalate (TBPH), tris (20chloro-2-propyl) phosphate (TCPP), tris (2-chloroethyl) phosphate (TCEP),[1] and V6[2]

2. Residential Furniture

pendaBDE (before the phaseout, and potentially still in imported products), TDCPP, FireMaster 550®[3]

3. Mattresses and Mattress Pads

pentaBDE (before the phaseout)

Currently, mattresses are mostly flame retarded using barrier technologies such as cotton treated with boric acid, wool, synthetic fibers such as VISIL, Basofil, Polybenzimidazole, KEVLAR, NOMEX, and fiberglass.[4] However, mattresses can still contain additive non-polymeric flame retardants. Approximately half of the mattress manufacturers who responded to a recent market survey "do not actively source fully flame retardant-free foam," even though they use a barrier technology to comply with flammability standards.[5]

4. Electronics Enclosures

decaBDE (before the phaseout, and potentially still in imported products), TBBPA, allyl-2,4,6-tribromophenyl ether (ATE), 1,2,3,4,5-pentabromobenzene(PBBz), 2,3,5,6-pentabromoethyl benzene (PBEB), hexabromobenzene (HBB), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB or TBB), bis(2-ethyl-1-hexyl) tetrabromophthalate (BEHTBP or TBPH), octabromotrimethylphenylindane (OBIND), decabromodiphenylethane (DBDPE), pentabromotoluene (PBT), and tris(1,3-dichloro-2-propyl) phosphate (TDCPP) in the casings of several electronics products.[6]

In terms of other flame retardants found in these product categories, studies have found a few organophosphate flame retardants used, including mostly triphenyl phosphate (TPP) (which is also one of four FireMaster 550® components)[7]

3. Do all of these chemicals have the same health effects? Is the dose-response for each chemical similar or different?

No, these chemicals do not all have the same health effects. But, they all do have adverse health effects as far as we know. Dr. Eastmond's study found that 70% are potential carcinogens. Dr. Birnbaum pointed out in her December 9, 2015 testimony that developmental toxicity is an even more concerning

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[1] Stapleton, H.M.; Klosterhaus, S.; Keller, A.; Ferguson, P.L.; van Bergen, S.; Cooper, E.; Webster, T.F.; & Blum, A. (2011). Identification of flame retardants in polyurethane foam collected from baby products. *Environmental Science & Technology*, 45(12), 5323-31. doi: 10.1021/es2007462.

[2] https://fortress.wa.gov/ecy/publications/documents/1404021.pdf

[3] Stapleton, H.M.; Sharma, S.; Getzinger, G.; Ferguson, P.L.; Gabriel, M.; Webster, T.F.; & Blum, A (2012). Novel and high volume use flame retardants in US couches reflective of the 2005 PentaBDE phase out. *Environmental Science & Technology*, 46(24), 13,432-39. doi: 10.1021/es303471d.

[4] http://www.epa.gov/sites/production/files/2013-12/documents/ffr_foam_alternatives_vol1.pdf (accessed January 26, 2016)

[5] http://www.conservationminnesota.org/redesign/wp-content/uploads/SafeMattressReport-final.pdf (accessed Jan. 26, 2016)

[6] Abbasi G, Saini A, Goosey E, Diamond ML. (2015). Product screening for sources of halogenated flame retardants in Canadian house and office dust. Sci Tot Environ. 545-546: 299-307.

[7] Ibid.

adverse health effect associated with exposure to these chemicals. Many of the studied non-polymeric additive flame retardants were also found to disrupt the endocrine system, including the thyroid hormone, or to impact reproduction.

According to the available data, non-polymeric organohalogen flame retardants may cause different kinds of "substantial injury or illness," such as cancer, developmental or reproductive toxicity, endocrine disruption, etc. The FHSA is only concerned with whether the chemicals can cause "substantial injury or illness" and in that sense, yes, all these additive non-polymeric organohalogen flame retardants qualify. We don't know of any such chemical studied that was not found to cause "substantial injury or illness."

The dose-response for each chemical could be different, but there aren't many available data to draw conclusions about this. However, dose-response information is not necessary in order to make a finding that chemicals "may cause" substantial illness or injury. The EPA regularly makes findings under the New Chemicals Program that chemicals "may present" an unreasonable risk with no specific information on the chemical in question except its structure (using Structure-Activity Relationship or SAR models) and how the chemical will be used, which speaks to potential exposures.

4. ***What are other sources of these flame retardants that are not included within the scope of the petition?***

- Carpet padding – flame retardants are found in carpets mostly because carpet padding contains recycled foam with flame retardants.
- Children's car seats – this is a "children's product", but does not fall under the CPSC's jurisdiction.
- Motor vehicles and motor vehicle components – not under CPSC's jurisdiction.
- Non-cabinetry plastics of electronics and electrical equipment, e.g. printed circuit boards – here the flame retardants are used in reactive form.
- Wires and cables – flame retardants are added mostly for industrial and commercial applications, not for household use, and the chemicals typically used are polymers.
- Plastic (foam) building insulation.

5. ***Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?***

Yes. For all four product categories, organohalogen flame retardant chemicals are unnecessary, or ineffective as commonly used, or both.

Furthermore, existing flammability standards for furniture and children's products (the updated TB117-2013) and mattresses and mattress pads (16 CFR 1632 and 16 CFR 1633) can be met without the use of additive organohalogen flame retardants or any other chemical substitutes.

In the case of electronics enclosures, additive non-polymeric organohalogen flame retardants are typically added in the U.S. due to UL standards, primarily UL 60065 and UL 62368-1. Please note that chemical flame retardants in electronics enclosures are not needed to meet the equivalent international (IEC 60065 and IEC 62368-1) and European standards (EN 60065 and EN 62368-1). The UL has modified the international standard by adding a reference to its flammability test UL 94 for TV enclosures, which is typically met using flame retardants. In 2019, the UL will update the standard, and could adopt the international (IEC) version followed throughout the world outside the U.S., for which flame retardants are not needed in electronics enclosures. The CPSC adopting this Petition and finding that the use of any chemical flame retardant in additive non-polymeric form in these product categories is likely to cause more harm than benefit could contribute to the U.S. following the global standard, reducing harm for consumers. This would especially benefit children who have the highest levels of exposure to flame retardants that migrate into dust from TV enclosures.

6. ***Are there additional unpublished toxicity and/or exposure data to defend/discount petition claims? Are the toxicokinetics of these chemicals similar? For example, do these chemicals exhibit the same type of absorption characteristics (same uptake, same tissues impacted, etc.)? Do all of these chemicals have the same persistence in the environment? Are these data directly comparable (I.e., the same endpoint(s), methods, etc.)? Could these data be provided to staff?***

We are not aware of additional unpublished toxicity data. Unpublished data from universities and other public institutions will eventually be published. New data on the adverse health effects, exposure routes, and physical-chemical properties of additive non-polymeric organohalogen flame retardants continue to be published. Several new studies have been published since the Petition was submitted, and we have provided references to those in our public comments and in our other answers herewith. There are also probably additional data from industry that might remain unpublished. The source of such data would be the manufacturers of flame retardants.

As to the other part of this question: while organohalogen flame retardants don't all have the same toxicity endpoints, absorption characteristics, or main impacted tissues, there are enough commonalities to warrant grouping them in one class, as explained in the petition (also summarized in our answer to Commisioner Adler's question below).

Commissioner Robert S. Adler

1. *Organohalogen Hazards:* ***Dr. Blum and Dr. Balan, we heard testimony during the hearing that different organohalogens produce different effects depending on their unique chemical characteristics.***
    a. ***Given the different effects associated with different organohalogens, are you aware of any of these chemicals that do not present significant health risks?***
    b. ***Given the broad array of organohalogens, is there sufficient commonality among them for the Commission to address them as a chemical class (as requested by the petitioners) or should the agency examine them chemical by chemical as suggested by the American Chemistry Council?***
    c. ***If the answer to (b) is that there is sufficient commonality, can you explain what the common elements are that would justify an across-the-board treatment by the CPSC?***

a. We are not aware of any non-polymeric organohalogen flame retardant shown not to present significant health risks.

b. Yes, there is sufficient commonality to justify addressing these chemicals as a class, and we do not recommend addressing them chemical by chemical, since this will only lead to more "regrettable substitutions."
c. Commonalities include:
   - Non-polymeric organohalogen flame retardants are semi-volatile, which leads to potential for exposure. This is explained in detail in the Statement of Dr. Miriam Diamond submitted with the Petition for Rulemaking.
   - As Dr. Diamond explained in her statement and her testimony, chemicals used as flame retardants are specifically designed to be persistent, in order not to break down within the products to which they are added. This environmental persistence indoors and outdoors, and potential for long range transport also increase the potential for exposure. Please see Dr. Diamond's statement for more details. Also, her study, published this month, looked at 94 "novel" flame retardants, most of them halogenated, and found that ~60% have persistence and long range transport similar to the PBDEs they are replacing.[8]
   - Non-polymeric, non-phosphate organohalogen flame retardants have the potential for bioaccumulation, tending to accumulate in fat (please see Dr. Diamond's statement).
   - All organohalogens are unnatural to mammalian biochemistry, so they are not recognized by efflux (ABC) transporters. They passively diffuse across cell membranes into cells, and stay here for long time periods, and some inhibit the cell's ability to remove other toxicants. This is explained in more detail in Dr. Epel's statement, submitted with the Petition.
   - As Dr. Webster and Dr. Lucas pointed out in their statements in support of the Petition, organohalogen flame retardants can contain toxic impurities and form toxic combustion byproducts, such as the highly carcinogenic dioxins and furans.
   - In addition, all organohalogen flame retardants have the potential for serious adverse human health effects, such as cancer, diabetes, thyroid disruption, obesity, neurotoxicity, reproductive and developmental impairments.

2. ***<u>Assessment Tools</u>: Dr. Blum and Dr. Balan, please state your views on how various chemical hazard assessment tools, including but not limited to standard read-across techniques and structure-activity relationship models, could be used to support regulatory decisions for the entire class of additive, non-polymer, organohalogen flame retardants subject to the Petition.***

The CPSC's regulatory decisions regarding the chemicals in the Petition must be made within the framework of the FHSA. Under the FHSA, the CPSC "*may by regulation declare to be a hazardous substance ... any substance or mixture of substances*," which is "*toxic*," if such substance "*may cause substantial personal injury or substantial illness during or as a proximate result of any customary or reasonably foreseeable handling or use.*" The FHSA defines "*toxic*" to mean any substance that has "*the capacity to produce personal injury or illness to man through ingestion, inhalation, or absorption through any body surface.*" CPSC's regulation explains that "*[s]ubstantial personal injury or illness means any*

[8] Zhang Z, Suhring R, Serodio D, Bonnell M, Sundin N, Diamond ML. Novel flame retardants: Estimating the physical-chemical properties and environmental fate of 94 halogenated and organophosphate PBDE replacements. Chemosphere 2016;144:2401-8.

injury or illness of a significant nature. It need not be severe or serious. What is excluded by the word 'substantial' is a wholly insignificant or negligible injury or illness."

When there is a lack of sufficient data in the public domain to determine whether particular non-polymeric organohalogen flame retardants are "hazardous substances" under the FHSA, there are many available chemical hazard screening tools, including QCAT® from the Washington State Department of Ecology, Design for the Environment (DfE) from the U.S. EPA, and GreenScreen™ from the Clean Production Action. All these require data to assess various hazard categories. Where empirical data is unavailable, scientists use model predictions based on the chemical's structure. These models are called Structure-Activity Relationships (SAR) or Quantitative Structure-Activity Relationships (QSARs). According to the U.S. EPA, "QSARs are mathematical models used to predict measures of toxicity from the physical characteristics of the structure of chemicals (known as molecular descriptors)."[9]

The U.S. EPA has developed numerous such models and tools, including several hazard models that can help predict whether the chemicals are "*toxic*" within the meaning of the FHSA, and several exposure and fate models, which can help predict whether the toxic chemicals "*may cause substantial personal injury or substantial illness during or as a proximate result of any customary or reasonably foreseeable handling or use*" within the meaning of the FHSA.

EPA's hazard models relevant to the Petition:

- Toxicity Estimation Software Tool (T.E.S.T.) – estimates ecotoxicity, bioconcentration factors, developmental toxicity, mutagenicity, physical properties[10]
- Ecological Structure Activity Relationships (ECOSAR) – estimates aquatic toxicity[11]
- OncoLogic – evaluates "cancer potential of untested chemicals based on their structural similarity to chemicals for which studies have been conducted"[12]
- Non-Cancer Health Assessment[13]
- Analog Identification Methodology (AIM) – supports read across approaches and data gap filling[14]
- Chemical Assessment Clustering Engine (ChemACE) – highlights analogous chemicals for potential read across[15]

EPA's exposure and fate models relevant to the Petition:

- Estimation Programs Interface (EPI) Suite – a collection of other programs estimating physical/chemical properties and environmental fate[16]

[9] http://www.epa.gov/chemical-research/toxicity-estimation-software-tool-test (accessed Jan. 27, 2016)
[10] http://www.epa.gov/chemical-research/toxicity-estimation-software-tool-test (accessed Jan. 27, 2016)
[11] http://www.epa.gov/tsca-screening-tools/ecological-structure-activity-relationships-ecosar-predictive-model (accessed Jan. 27, 2016)
[12] http://www.epa.gov/tsca-screening-tools/oncologictm-computer-system-evaluate-carcinogenic-potential-chemicals (accessed Jan. 27, 2016)
[13] http://www.epa.gov/tsca-screening-tools/non-cancer-screening-approaches-health-effects (accessed Jan. 27, 2016)
[14] http://www.epa.gov/tsca-screening-tools/analog-identification-methodology-aim-tool (accessed Jan. 27, 2016)
[15] http://www.epa.gov/tsca-screening-tools/chemical-assessment-clustering-engine-chemace (accessed Jan. 27, 2016)
[16] http://www.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface (accessed Jan. 27, 2016)

- Consumer Exposure Model (CEM)[17] – estimates indoor air concentrations, indoor dust concentrations, dermal exposure, and mouthing exposure for a wide variety of consumer products and materials; estimates inhalation, ingestion, and dermal exposures
- Multi-chamber Concentration and Exposure Model (MCCEM) – estimates indoor air concentrations of chemicals released from products or materials in houses, apartments, townhouses, or other residences over time[18]
- Exposure and Fate Assessment Screening Tool (E-FAST) – estimates consumer, general public and environmental exposures to chemicals released to air, surface water, landfills, and consumer products[19]

Dr. Eastmond described in his statement accompanying the Petition the results of a hazard screen for 85 non-polymeric organohalogen flame retardants using the Quick Chemical Assessment Tool (QCAT®) and several of the EPA's hazard models and exposure and fate models. Under the QCAT®, Dr. Eastmond's team assessed the chemicals' acute mammalian toxicity, carcinogenicity, reproductive toxicity, developmental toxicity, mutagenicity/genetic toxicity, endocrine disruption – all of which provide an indication of "*the capacity to produce personal injury or illness to man through ingestion, inhalation, or absorption through any body surface*." They also assessed persistence and bioaccumulation, which, combined with the fact that these chemicals are semivolatile (SVOCs) and used in additive form, indicate a high likelihood of consumer exposure during "*customary or reasonably foreseeable handling or use*" of the product containing the chemicals. Based on the performance under these hazard end-points, Dr. Eastmond's team found that 94% of the studied non-polymeric organohalogen flame retardants were toxic (receiving an "F" grade), and the others were of high concern (receiving a "D" grade).

Please note however that the chemical hazard assessment tools currently available tend to err on the side of false negatives, that is, they correctly identify potential adverse human health effects, but may not identify all of them. In other words, if a chemical receives a "D" in a QCAT® hazard screen or a similar assessment, it might actually deserve an "F."

Also, currently available models are unable to determine the potential human health effects of chemical mixtures at relevant human exposure levels. Several international universities, research centers and analytical labs joined forces in 2012 to form the Consortium for Environmental Omics & Toxicology (CEOT), which attempts to tackle within the next decade the grand challenge of measuring the effects of thousands of chemicals and their mixtures at environmentally relevant concentrations and understand effects on humans and non-human species.[20] We encourage the CPSC to follow these efforts, and we will also report any relevant findings while the CPSC reviews the Petition.

3. ***Chemical Substitutes:* Dr. Blum and Dr. Balan, do you believe that organohalogens are necessary to provide fire protection in the product categories covered in the petition? If so,**

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[17] http://www.epa.gov/tsca-screening-tools/approaches-estimate-consumer-exposure-under-tsca (accessed Jan. 27, 2016)
[18] ibid.
[19] http://www.epa.gov/tsca-screening-tools/e-fast-exposure-and-fate-assessment-screening-tool-version-2014 (accessed Jan. 27, 2016)
[20] https://engen.bham.ac.uk:8443/display/CEOT/Consortium+for+Environmental+Omics+and+Toxicology (accessed Jan. 27, 2016)

what chemicals are in the market today that might substitute for organohalogens if they were removed from the market?

We do not believe that organohalogens, or any other chemical flame retardants, are necessary to provide fire protection in the product categories covered by the petition. As discussed above in our response to Chairman Kaye's question #5, current U.S. flammability requirements for furniture, mattresses/mattress pads, and children's products can be met without additive flame retardants. Many U.S. TV manufacturers comply with voluntary UL standards by adding flame retardants to the plastic enclosures. However the equivalent international flammability standards for electronics can be met without flame retardants. In fact, the International Electrotechnical Commission, which has 83 member countries, has rejected "candle standard" requirements that would be met by adding flame retardants to electronics enclosures numerous times, citing a lack of significant fire safety benefit and potential for human health harm.

The lack of fire safety benefit from the use of flame retardants in these consumer product categories has been documented in detail in several papers.[21,22,23,24,25] Nevertheless, depending on the scope of the action the Commission takes in response to the petition, use of certain flame retardants in these products could still be permitted. For example, manufacturers could use in the four product categories:

- Polymeric flame retardants, halogenated or others
- Reactive flame retardants, halogenated or others, polymeric or non-polymeric
- Non-halogenated flame retardants – though we caution the commission against replacement with additive non-polymeric phosphate flame retardants, as those also raise human health concerns based on available data.

As Mr. Timothy Reilly from Clariant Corporation said during his December 9, 2015 testimony, reactive halogen-free flame retardants are already available for furniture, and other halogen-free alternatives are available for textiles, plastics such as electronics enclosures, and mattresses.

Commissioner Ann Marie Buerkle

1. ***If the characteristic of bioaccumulation is present in an organohalogen flame retardant, does that automatically mean there are adverse consequences to exposure?***

Although bioaccumulation by itself does not inherently imply adverse health consequences, the bioaccumulation of a potentially harmful chemical, such as an organohalogen flame retardant, does lead to increased risks of adverse consequences to exposure.

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[21] Shaw SD, Blum A, Weber R, Kannan K, Rich D, Lucas D, Koshland CP, Dobraca D, (2010). Hanson S, Birnbaum LS. Halogenated flame retardants: do the fire safety benefits justify the risks? Rev Environ Health 25(4):261-305.

[22] Babrauskas V, Blum A, Daley R, Birnbaum L. (2011) Flame retardants in furniture foam: benefits and risks. Fire Safety Science 10.

[23] DiGangi J, Blum A, Bergman A, de Wit CA, Lucas D, Mortimer D, Schecter A, Scheringer M, Shaw SD, Webster TF. (2010). San Antonio statement on brominated and chlorinated flame retardants. Environ Health Perspect 118(12): A516-A518.

[24] http://greensciencepolicy.org/wp-content/uploads/2015/01/Case-against-candle-resistant-electronics-2015.pdf

[25] http://greensciencepolicy.org/wp-content/uploads/2013/10/Case-against-Candle-Resistant-TVs-2015.pdf

2. ***Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.***

Adopting CA TB 117-2013 as a mandatory national standard would not impact on this Petition. First, TB 117-2013 covers residential upholstered furniture and some juvenile products, but not the other products in the categories included in the Petition. Second, while TB 117-2013 can be met without additive non-polymeric organohalogen flame retardants and would likely reduce the use of these chemicals in residential upholstered furniture significantly, it is not a ban. Thus, absent the regulation sought in the Petition, furniture and other manufacturers could continue to use foam or fabric with additive non-polymeric organohalogen flame retardants.

Commissioner Joseph Mohorovic

1. ***Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.***

The best source for this information are the flame retardants manufacturers and the foam, fabric, and plastic industries that add the chemicals during their manufacturing processes.

The Petition includes some of the available data. A more recent study also found allyl-2,4,6-tribromophenyl ether (ATE), 1,2,3,4,5-pentabromobenzene(PBBz), 2,3,5,6-pentabromoethyl benzene (PBEB), hexabromobenzene (HBB), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB or TBB), bis(2-ethyl-1-hexyl) tetrabromophthalate (BEHTBP or TBPH), octabromotrimethylphenylindane (OBIND), decabromodiphenylethane (DBDPE), pentabromotoluene (PBT), and tris(1,3-dichloro-2-propyl) phosphate (TDCPP) in the casings of several electronics products.[26]

Some information can also be found for instance in documents released by EPA in August 2015, in connection with its initial work to conduct risk assessments of four "clusters" of flame retardants, as summarized below:

A detailed discussion of the uses of TBBPA can be found at pages 22-26 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment of Tetrabromobisphenol A and Related Chemicals Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/tbbpa_problem_formulation_august_2015.pdf. In summary:

- TBBPA is one of the most widely used brominated flame retardants, in both additive and reactive forms.[27] It is used mainly in electrical and electronic products and in other types of plastic and rubber. For example, a primary application of TBBPA is as an additive flame retardant in acrylonitrile butadiene styrene (ABS) resins (a type of plastic), used in the enclosures or casings around electronics such as TV or computer monitor casings or components in printers, fax machines, photocopiers, vacuum cleaners, coffee machines

[26] Abbasi G, Saini A, Goosey E, Diamond ML. 2015. Product screening for sources of halogenated flame retardants in Canadian house and office dust. Sci Tot Environ. 545-546: 299-307.

[27] EPA (US Environmental Protection Agency). 2008. Partnership to Evaluate Flame Retardants in Printed Circuit Boards: Draft Report. Design for the Environment, Office of Pollution Prevention and Toxics, Washington, DC.

and plugs/sockets. TBBPA is used in ABS and other plastics at 14 to 22% by weight, often in combination with antimony trioxide.[28]

- TBBPA has been reported to be used as a flame retardant in textiles in baby car/booster seats; baby carriers; baby play pens/dens and baby swings. The concentrations of TBBPA in these products were reported as ranging from < 0.05 to > 1%.[29]
- As of September 6, 2014, TBBPA has also been reported for use as a surface coating flame retardant in artists' accessories.

A detailed discussion of the uses of TCEP, TCPP and TDCPP can be found at pages 17-21 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment of Chlorinated Phosphate Ester Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/cpe_fr_cluster_problem_formulation.pdf. In summary:

- TCEP is used as a flame retardant in children's car seats (Washington State, 2014) and has been detected in changing table pads, sleep positioners, portable mattresses, nursing pillows, baby carriers and infant bath mats as an impurity in another chlorinated flame retardant called V6.[30]
- TCPP is found in a variety of industrial use categories such as "furniture and related products" for the manufacture of flexible polyurethane foam and under "textiles, apparel and leather" for fabric finishing processing. TCPP is reported to be used in a variety of commercial and consumer use categories as well. Potential end-uses within the reported commercial and consumer products include household upholstered furniture and foam baby products. TCPP has been detected in household furniture including footstools, ottomans and chairs.[31] TCPP has also been detected in polyurethane foam in certain baby products including car seats, changing table pads, sleep positioners, portable mattresses, nursing pillows and rocking chairs.[32]
- TDCPP has been detected in furniture such as sofas, chairs and futons and in baby products including rocking chairs, baby strollers, car seats, changing pads, sleep positioners, portable mattresses, nursing pillows and infant bathmats.[33,34] TDCPP has also

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[28] EC (European Commission). 2006. European Union Risk Assessment Report for 2,2',6,6'-Tetrabromo- 4,4'-Isopropylidenediphenol (Tetrabromobispheonl-a or TBBP-A) Part II – Human Health, CAS No. 79-94-7, EINECS No. 201-236-9. 4th Priority List, Volume: 63, EUR22161 EN. Institute for Health and Consumer Protection, Joint Research Centre, Luxembourg. http://esis.jrc.ec.europa.eu/doc/risk_assessment/REPORT/tbbpaHHreport402.pdf

[29] Washington State Department of Ecology. 2014b. The Reporting List of Chemicals of High Concern to Children (CHCC). http://www.ecy.wa.gov/programs/swfa/cspa/chcc.html (accessed on February 2, 2015).

[30] Stapleton HM, Klosterhaus S, Keller AS, Ferguson PL, van Bergen S, Cooper EM, Webster TF, Blum A. 2011. Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products. Environ Sci & Tech, 45(12), 5323-5331.

[31] Stapleton HM, Klosterhaus S, Eagle S, Fuh J, Meeker JD, Blum A, Webster TF. 2009. Detection of Organophosphate Flame Retardants in Furniture Foam and U.S. House Dust. Environ Sci & Tech, 43(19), 7490-7495.

[32] Stapleton HM, Klosterhaus S, Keller AS, Ferguson PL, van Bergen S, Cooper EM, Webster TF, Blum A. 2011. Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products. Environ Sci & Tech, 45(12), 5323-5331.

[33] Stapleton HM, Klosterhaus S, Eagle S, Fuh J, Meeker JD, Blum A, Webster TF. 2009. Detection of Organophosphate Flame Retardants in Furniture Foam and U.S. House Dust. Environ Sci & Tech, 43(19), 7490-7495.

been reported to the Washington State Children's Safe Product Act database (2014)[35] for its use as a flame retardant in "arts/crafts variety pack" and also as a contaminant in footwear for children.

A detailed discussion of the uses of TBB and TBPH, the organohalogen flame retardants in Firemaster 550, can be found at pages 8-13 of TSCA Work Plan Chemical Technical Supplement - Use and Exposure of the Brominated Phthalates Cluster (BPC) Chemicals, available at http://www.epa.gov/sites/production/files/2015-09/documents/bpc_data_needs_assessment_technical_supplement_use_and_exposure_assessment.pdf. In summary:

- Firemaster® 550 is mainly applied to furniture containing polyurethane foam, such as couches, ottomans and chairs.
- TBPH and TBB have also been detected in gymnastics equipment, including foam pit cubes, landing mats, sting mats, and vault runway carpets.[36] These chemicals may therefore possibly be found in other facilities containing foam pits or equipment.
- Carpet cushions are manufactured largely from flexible polyurethane slabstock foam scraps and recycled foam[37] and have lifespans of five to 15 years.[38] Given that carpet backing is often manufactured from recycled foam scrap, carpet backing may have the same amount of TBB/TBPH as furniture foam if the scrap foam is from a manufacturer that uses Firemaster® 550.[39]

A detailed discussion of the uses of HBCD in products can be found at pages 18-21 of TSCA Work Plan Chemical Problem Formulation and Initial Assessment of Cyclic Aliphatic Bromides Cluster Flame Retardants, available at http://www.epa.gov/sites/production/files/2015-09/documents/hbcd_problem_formulation.pdf. The main uses of HBCD are as a flame retardant in polystyrene foam, textiles, and high impact polystyrene.

2. ***Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.***

We don't. The best source for this information are the flame retardants manufacturers and the foam, fabric, and plastic industries that add the chemicals during their manufacturing processes.

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[34] Stapleton HM, Klosterhaus S, Keller AS, Ferguson PL, van Bergen S, Cooper EM, Webster TF, Blum A. 2011. Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products. Environ Sci & Tech, 45(12), 5323-5331.
[35] https://fortress.wa.gov/ecy/cspareporting/Default.aspx
[36] Carignan CC, Heiger-Bernays W, McClean MD, Roberts SC, Stapleton HM, Sjödin A, Webster TF. 2013. Flame retardant exposure among collegiate United States gymnasts. 2013. Environ Sci & Tech, 47(23), 13848-13856.
[37] EPA (US Environmental Protection Agency). 2005. Furniture Flame Retardancy Partnership: Environmental Profiles of Chemical Flame-Retardant Alternatives for Low-Density Polyurethane Foam Volume 1. EPA/742-R-05-002A. Design for the Environment.
[38] Luedeka RJ (Polyurethane Foam Association). 2012. United Nations Industrial Development Organization. Guidance Document Submission: Flexible Polyurethane Foam Waste Management & Recycling. http://www.pfa.org/Library/UNIDO_PFA_submission_rev_05102012.pdf.
[39] Ibid.

3. ***Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.***

The Petition for Rulemaking includes a review of the literature in the public domain addressing the toxicity of non-polymeric organohalogen flame retardants as of March 2015 (pages 43-47, and corresponding footnotes 121-148). In addition, the Statement of Ruthann Rudel submitted with the Petition includes as an attachment a bibliography and table that identify additional studies on health effects of organohalogen flame retardants, including non-PBDE chemicals.

As shown in the Petition and accompanying statements, human epidemiological studies have been performed mainly on pentaBDE, due to its long-term widespread use. Much of the toxicity data for non-polymeric flame retardants are based on animal and in vitro studies. In the absence of toxicity data, scientists use modeling to estimate the potential hazards posed by chemicals. The research of Professor David Eastmond, described in his Statement submitted in support of the Petition, is the most thorough hazard screen of organohalogen flame retardants we are aware of. Dr Eastmond conducted a literature search for data on about 90 non-polymeric organohalogen flame retardants and then used modeling to fill data gaps.

Several new studies on the toxicity of non-polymeric organohalogen flame retardants have been published since the petition was submitted, for instance:

- A long-term epidemiological study of 256 sets of mothers and children found a link between prenatal exposure to PBDEs and behavior regulation problems in school-aged children.[40]
- An animal study found that maternal exposure of zebrafish to FireMaster 550® during pregnancy resulted in reduction in social behaviors and hypoactivity when the offspring reached adolescent stages.[41] According to the authors, this indicates that FireMaster 550® may cause lasting neurobehavioral changes.
- An in vitro study found that tris(1,3-dichloro-2-propyl) phosphate (TDCPP) can induce prostate and endometrial cancer cell genes activation and protein expression. This indicates that it is potentially a significant endocrine disruptor.[42]
- Another in vitro study exposed zebra fish embryos to 44 halogenated and organophosphate flame retardants found that 41 (93%) elicited at least one adverse effects among those tested.[43]
- A modeling study found that three organohalogen flame retardants (allyl 2,4,6-tribromophenyl ether (ATE), 2-bromoallyl 2,4,6-tribromophenyl ether (BATE), and 2,3-dibromopropyl-2,4,6-tribromophenyl ether (DPTE)) act as androgen receptor antagonists and disrupt the function of certain genes needed for the uptake of amino acids across the

[40] Vuong AM, Yolton K, Webster GM, Sjödin A, Calafat AM, Braun JM, Dietrich KN, Lanphear BP, Chen A. (2016). Prenatal polybrominated diphenyl ether and perfluoroalkyl substance exposures and executive function in school-age children. Environ Res. Doi: 10.1016/j.envres.2016.01.008.

[41] Bailey JM, Levin ED. Neurotoxicity of FireMaster 550® in zebrafish (Danio rerio): Chronic developmental and acute adolescent exposures.

[42] Reers AR, Eng ML, Williams TD, Elliott JE, Cox ME, Beischlag TV. The flame-retardant tris(1,3-dichloro-2-propyl) phosphate represses androgen signaling in human prostate cancer cell lines. J Biochem Mol Toxicol 2015; DOI: 10.1002/jbt.21786.

[43] Noyes PD, Haggard DE, Gonnerman GD, Tanguay RL. Advanced morphological-behavioral test platform reveals neurodevelopmental defects in embryonic zebrafish exposed to comprehensive suite of halogenated and organophosphate flame retardants.

blood-brain barrier.[44] The study's authors thus concluded that these organohalogen flame retardants are potential neurotoxicants and endocrine disruptors.

4. ***Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.***

Please see the in depth discussion of this data in the Petition for Rulemaking, pages 36-41. Most of these available exposure data are for PBDEs (especially pentaBDE), TBBPA, TDCPP, and FireMaster 550®. Overall, infants and children tend to have higher exposures to organohalogen flame retardants than other populations.

Here are some new data, published this month:

- A group of researchers estimated children's exposure to PBDEs through mouthing of toys and found that this exposure route is potentially more significant than through diet or dust (Table 2 in their paper compares PBDE exposure levels from different sources for infants, 0-1 years old).[45]
- Another study found that electronics casings are a source of organohalogen flame retardants to house and office dust resulting in human exposure. Specifically, the researchers study looked at 10 PBDE congeners (BDE-17, 28, 47, 71, 99, 100, 153, 154, 183, 209) and 12 "novel" halogenated flame retardants: allyl-2,3,4-tribromophenyl ether (ATE), 1,2,3,4,5-pentabromobenzene (PBBz), 2,3,5,6-pentabromoethyl benzene (PBEB), hexabromobenzene (HBB), syn-dechlorane Plus (syn-DP), anti-dechlorane Plus (anti-DP), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB or TBB), bis(2-ethyl-1-hexyl) tetrabromophthalate (BEHTBP or TBPH), octabromotrimethylphenylindane (OBIND), decabromodiplenylethane (DBDPE), pentabromotoluene (PBT), and tris(1,3-dichloro-2-propyl) phosphate (TDCPP).[46]
- According to another study published this year, inhalation is an important route of exposure to additive non-polymeric chlorinated organophosphate flame retardants (such as TDCPP, TCEP, and TCPP), exceeding intake via dust ingestion (unlike for PBDEs and other brominated flame retardants for which dust ingestions is a bigger exposure route compared to inhalation).[47] The authors conclude that their "results indicate that the U.S., overall exposure may be much higher – by one or more orders of magnitude – than previously believed based on dust ingestion as a primary exposure route."

5. ***Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.***

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[44] Kharlyngdoh JB, Pradhan A, Asnake S, Walstad A, Ivarsson P, Olsson P-E. Identification of a group of brominated flame retardants as novel androgen receptor antagonists and potential neuronal and endocrine disrupters. Environ Int 2015;74:60-70.

[45] Ionas AC, Ulevicus J, Gomez AB, Brandsma SH, Leonards PEG, van de Bor M, Covaci A. Children's exposure to polybrominated diphenyl ethers (PBDEs) through mouthing of toys. Eniron Int 2016;87:101-7.

[46] Abbasi, G. et al., 2016. Product screening for sources of halogenated flame retardants in Canadian house and office dust. Science of The Total Environment, 545-546, pp.299–307.

[47] Schreder ED, Uding N, La Guardia MJ. 2016. Inhalation a significant exposure route for chlorinated organophosphate flame retardants. Chemosphere. Doi:10.1016/j.chemosphere.2015.11.084.

To our knowledge, non-polymeric additive organohalogen flame retardants as used in the four consumer product categories covered by the Petition provide no benefits to consumers. We know of no impartial studies proving otherwise.

6. ***Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?***

We are unable to provide such an estimate. Calculating this percentage would require knowing:

1. what percentage of the total number of products regulated by the CPSC fall in the four product categories covered by the petition
2. what percentage of the products in the four product categories covered by the petition contain additive non-polymeric organohalogen flame retardants.

We don't know where to get the information relating to the first point. As to the second point, that information could be provided to the CPSC by product manufacturers. Previous studies have found this number to be very high (e.g. even over 85%) for some product categories such as certain children's products, sofas, and TV casings (please see the Petition for data on the occurrence of organohalogen flame retardants in these product categories).

Miriam Diamond, Ph.D.

University of Toronto

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Miriam Diamond, University of Toronto

Chairman Elliot F. Kaye

1. Are there additional unpublished toxicity and/or exposure data to defend/discount petition claims? Are the toxicokinetics of these chemicals similar? For example, do these chemicals exhibit the same type of absorption characteristics (same uptake, same tissues impacted, etc.)? Do all of these chemicals have the same persistence in the environment? Are these data directly comparable (i.e., the same endpoint(s), methods, etc.)? Could these data be provided to staff?

2. Do all of these chemicals have the same health effects? Is the dose-response for each chemical similar or different?

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

Earth Sciences
UNIVERSITY OF TORONTO

January 29, 2015

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US Consumer Product Safety Commission
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Dear Mr. Stevenson,

Below are my responses to the questions posed to me after I presented at the hearing into the petition requesting rulemaking on products containing organohalogen flame retardants on December 9, 2015.

Your questions are important and merit full and thoughtful answers. The challenge is that many of the questions could form a PhD thesis (one thesis per question!). I have answered each question to the best of my knowledge, but also respecting the limited time available.

Chairman Elliot F. Kaye

1. Are there additional unpublished toxicity and/or exposure data to defend/discount petition claims? Are the toxicokinetics of these chemicals similar? For example, do these chemicals exhibit the same type of absorption characteristics (same uptake, same tissues impacted, etc.)? Do all of these chemicals have the same persistence in the environment? Are these data directly comparable (i.e., the same endpoint(s), methods, etc.)? Could these data be provided to staff?

Answer: I am not privy to additional unpublished toxicity and/or exposure data. Such data are held by those who conduct the studies (or own the data) and will or will not be published at their discretion. Data held by researchers in public institutions are customarily published and open for review.

Please note that new information and data are constantly being published. This is a fast-moving field in which many environmental researchers are engaged. I am aware of additional information that has emerged since the petition was tabled and that is not included in the petition. These new studies offer additional support for the statements made in the petition. For example, I found eight papers, which support the arguments in the petition, that are either "in progress" or "in press" this month in the journal ***Chemosphere***[i]. If I had time, I would have found many more papers relevant paper that either have just been published or are in press in other relevant and high impact journals.

The new papers add to the evidence in the petition that halogenated flame retardants are persistent or have persistent break down products, that the distribution of halogenated flame retardants in air, water, soils is widespread globally which is indicative of persistence, and that human exposure to halogenated flame retardants is also widespread. Amongst the eight papers that I mentioned above, Schreder, E. et al.[ii] are the first to measure U.S. exposure to chlorinated organophosphate flame retardants. They found that inhalation of indoor air was an important route of exposure and that those indoor concentrations can be much higher than those of the brominated flame retardants. The significance of finding relatively high levels of these chlorinated organophosphate flame retardants is that their use is increasing, in part as replacements for now-controlled polybrominated diphenyl ethers (PBDEs). The relatively high indoor air concentrations of these additive halogenated flame retardants are a source of concern.

Also amongst the eight papers that I mentioned is one by de Boer, J.[iii] et al. that summarizes exposure to halogenated flame retardants via dust. De Boer et al. describe the proliferation of numerous halogenated compounds. The proliferation is due to shifts in the flame retardant market where "new" halogenated flame retardants come to replace controlled compounds (e.g., PBDEs, HBCD) and compounds where evidence of harm is mounting (e.g., TDCPP). De Boer et al. comment on the high concentrations of halogenated flame retardants measured indoors, the lack of toxicological information for most of these compounds, and particularly the lack of toxicological data on exposure to multiple flame retardants. They call for moving away from focusing on impacts of single flame retardants and towards understanding the health impacts of exposure to mixtures of multiple flame retardants brought on by this proliferation.

My lab group has added to the avalanche of information by the submission of two papers on halogenated flame retardants within the past month. One paper documents the widespread levels of brominated flame retardants in homes in the U.S., Canada and Czech Republic where concentrations in U.S. homes were highest amongst the three countries (Venier et al.[iv]). The second paper documents elevated levels of chlorinated organophosphate flame retardants in Arctic air from 2007-2013. Our analysis indicates that most of these compounds arrive in the Artic by long range transport (Suhring et al.[v]). These chlorinated organophosphate flame retardants we have measured in Arctic air are the same as those measured by Schreder et al. in the U.S. exposure study.

I cannot comment on the toxicokinetics of these chemicals more than to say that the toxicokinetics will be chemical-dependent. Tissue absorption is also expected to be chemical dependent. There is no reason to expect that the same tissues will necessarily be impacted.

Regarding chemical persistence, we just published an assessment of the environmental persistence and likelihood of long range transport (LRT) of 94 flame retardants, of which 71 were halogenated (Zhang and Suhring et al. 2016[vi]). Based on data and our best estimates to fill the data gaps and acknowledging these uncertainties, we estimated (by modelling) that persistence ranged up to 216 days for several brominated flame retardants (BTBPE, EBTEBPI, OBTMPI, and TTBP-TAZ, please see the paper for full names). We estimated that up to 60% of all 94 flame retardants have environmental persistence similar to PBDEs. In other words, up to 60% of these flame retardants have the chemical structure to enable them to undergo long range transport, i.e., reach the Arctic. Although I have not broken out the percentage of only the halogenated flame retardants, I expect the halogenated flame retardants to be most persistence because that is exactly what halogenation is intended to do – make a molecule persistent. The study by Suhring et al. (submitted) provides direct, empirical support for our modelling estimates by showing the persistence of chlorinated organophosphate flame retardants and their ability to travel far from their point of use.

2. Do all of these chemicals have the same health effects? Is the dose-response for each chemical similar or different?

<u>Answer:</u> I am not a health specialist or toxicologist and so I am not able to answer this question.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

Answer: Yes, my graduate students and myself just published a study (Abbasi et al. 2016[vii]) in which we investigated the presence and amounts of 10 congeners of polybrominated diphenyls (PBDEs) and 12 "novel" brominated flame retardants (NFRs) in 65 electronic products. We did this by wiping the surface of the polymer casings of these products. I have provided a copy of this paper for your review. Briefly, we found many non-polymeric, halogenated flame retardants in these products where the flame retardants are known to be used as additives (and not chemically bound). The data show that a variety of halogenated flame retardants were used in each product category. As such, it is not possible to predict which halogenated flame retardant will be in which product or product category.

In this paper, we also commented on the potential for human exposure to additive halogenated flame retardants by directly contacting the exterior polymer casings treated with halogenated flame retardants. The products include those that one would normally touch such as television sets, food processors, toasters, keyboards. The concern for direct exposure by touching the exterior of products comes from the ease with which we were able to remove these additive halogenated flame retardants from tested products. We are following up with testing for ease of transfer from product to hands in a study being conducted now in which we are measuring halogenated flame retardants on the hands of participants and the same chemicals present on the surface of their electronic products such as cell phone casings, plastic casing of tablets, etc.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

Answer: No, I do not have data on this.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

Answer: No, I do not. This is not my field of investigation. However, I do know that more data continue to be published on this topic as the toxicologists and health specialists attempt to understand the toxicity of the flame retardants that we are measuring in products and in indoor and outdoor environments.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

Answer: No, I do not. In 2005 we published the first exposure assessment calculations for PBDEs indicating that dust is the main exposure route to all non-breast-fed age categories of Canadians (Jones-Otazo et al. 2005[viii] . These estimates have since been confirmed by measurement studies.

As I noted in my answer to Question 1, my collaborators and my lab group are currently estimating indoor exposure to brominated and chlorinated (and non-chlorinated) organophosphate flame retardants in 51 women of child-bearing age in Toronto, Ottawa and Hamilton cities in Ontario, Canada. Data are not yet available from this study.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

Answer: I have looked into the literature about benefits, searching for data and studies. I have not found data showing the benefit(s) of additive organohalogen flame retardants. Indeed, this is a critical aspect of the debate regarding halogenated flame retardants – the lack of data demonstrating their benefit.

It is noteworthy that hundreds if not thousands of papers have now been published in the peer reviewed literature (that is publically available), that document the environmental sources, concentrations, exposure, toxicity and health effects of halogenated flame retardants. These studies use state-of-the-science methods and have undergone peer review. However, one cannot find papers with data that show the benefit(s) of flame retardants in terms of reducing fire-related morbidity and mortality or reducing property damage.

Results are available of products tested for their flammability using standard flammability testing procedures conducted under controlled conditions. However, these tests do not demonstrate the benefit of adding flame retardants to products that are in use, under "real" circumstances. In contrast, arguments have been made that the addition of flame retardants could cause increased morbidity and mortality by reducing combustion temperature and thereby producing toxic gases under smolder conditions (e.g., carbon monoxide).

The differential expectation for evidence documenting adverse impacts versus fire safety benefits is frustrating. Regulatory agencies correctly demand from environmental chemists and toxicologists unequivocal demonstration of adverse effects caused by halogenated flame retardants, prior to taking any action to control their use. That same expectation from regulatory agencies should be demanded of clear and unequivocal demonstration, published in the peer review literature, of the benefit(s) of adding halogenated flame retardants to products.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

Answer: No, I cannot make this estimate.

I hope these answer are satisfactory. I would be pleased to discuss further any aspects of details contained in response.

Sincerely,

Miriam Diamond

Miriam Diamond
Professor
Department of Earth Sciences
Cross-appointed to:
Department of Chemical Engineering and Applied Chemistry
Dalla Lana School of Public Health
School of the Environment
Department of Physical and Environmental Sciences, UoT Scarborough

[i] Environmental risks of Hexabromocyclododecane (HBCD, Yi, S. et al.); exposure to organophosphate flame retardants (Wu, M. et al.); breakdown products in air of five brominated flame retardants (Zhang, Y-N. et al.); breakdown products in air of brominated phenols (of which some are flame retardants such as PBDEs and TBBPA, Saeed et al.); seasonal air concentrations of PBDEs (Zhang, L. et al.); environmental behaviour of tetrabromobisphenol A (TBBPA, Liu, K. et al.); concentrations of legacy and emerging flame retardants in UK air and soil (Drage, D.S. et al.).

[ii] SCHREDER, ED, UDING, N., LA GUARDIA, M.J., Inhalation a significant exposure route for chlorinated organophosphate flame retardants. Chemosphere.

[iii] DE BOER, J., BALLESTEROS-GÓMEZ, A., LESLIE, H.A., BRANDSMA, S.H., LEONARDS, P.E.G., Flame retardants: Dust – And not food – Might be the risk. ***Chemosphere.*** In press.

[iv] VENIER M, O AUDY, S VOJTA, J BECANOVA, K ROMANAK, L MELYMUK, M KRATKA, P KUKCHKA, J OKEME*, A SAINI*, **ML DIAMOND**, J KLANOVA. Brominated flame retardants in indoor environment – comparative study of indoor contamination from three countries. ***Environ Sci Technol*** Submitted Jan 2016.

[v] SÜHRING R[+], ML DIAMOND, M SCHERINGER, F WONG, M PUCKO, G STERN, H HUNG, P FELLIN, LM. JANTUNEN. Seven Years of Geographic and Temporal Trends of Organophosphate esters in the Canadian Arctic Long-range Transport of Organophosphate esters Part 2. ***Environ Sci Technol*** Submitted Jan 2016.

[vivivi] ZHANG X, R SŰHRING[+] R, D SERODIO*, M BONNELL, N SUNDIN, **ML DIAMOND.** 2015. Novel flame retardants: estimating the physical-chemical properties and environmental fate of 94 halogenated and organophosphate PBDE replacements. ***Chemosphere.*** 144: 2401-2407. 10.1016/j.chemosphere.2015.11.017

[vii] ABBASI G*, A SAINI*, E GOOSEY[+], **ML DIAMOND**. 2016. Product screening for sources of halogenated flame retardants in Canadian house and office dust. ***Sci Total Environ.*** 545-546: 299-307.

[viii] JONES-OTAZO H, JP CLARKE, ML DIAMOND, JA ARCHBOLD, G FERGUSON, T HARNER, MG RICHARDSON, JJ RYAN, B WILFORD. 2005. Is house dust the missing exposure pathway for PBDEs? An analysis of urban fate and human exposure to PBDEs. Environ. Sci. Technol. 39: 5121-5130.

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Product screening for sources of halogenated flame retardants in Canadian house and office dust

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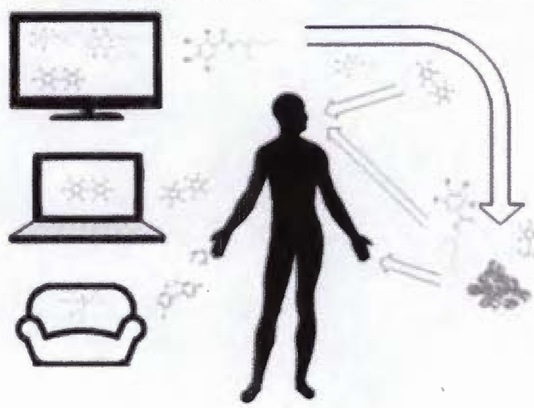
HIGHLIGHTS

- Concentrations of flame retardants in dust correlated with product surface wipes
- Most abundant FRs in electronics were PBDEs, TDCPP, DBDPE, EH-TBB and BEHTBP.
- Descending order of FRs in CRTs, TVs, PCs, A-V devices, and small household appliances
- Product wipe testing, but not XRF, useful for non-destructive screening of BFRs
- Removal of FR retardants from product surfaces raises concerns for human exposure.

GRAPHICAL ABSTRACT



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TVs

ABSTRACT

Human exposure to halogenated flame retardants (HFRs) such as polybrominated diphenyl ethers (PBDEs) and their replacements, can be related to exposure to indoor dust and direct contact with HFR-containing products. This study aimed to identify electronic products that contributed to HFRs measured in indoor dust and to develop a screening method for identifying HFRs in hard polymet products. Concentrations of 10 PBDEs and 12 halogenated replacements in dust and surface wipe samples of hard polymer casings of electronic products plus Br in the surfaces of those casing measured using X-ray fluorescence (XRF) were analyzed from 35 homes and 10 offices in Toronto (ON, Canada). HFR concentrations in dust and product wipes were positively correlated. Thus, we hypothesize that electronic products with the highest HFR concentrations contribute the most to concentrations in dust, regardless of the volatility of the HFR. Abundant HFRs in dust and product wipes were PBDEs (BDE-47, 99, 100, 153, 154, 183, 209), TDCPP, DBDPE, EH-TBB and BEHTBP. Older CRT TVs had the highest concentration of BDE-209 of all products tested. This was followed by higher concentrations of HFRs in PCs, Audio/Video (A/V) devices, small household appliances (HHAs) and flat screen TVs. The removal of HFRs from polymer surfaces using wipes supports concerns that HFRs could be transferred from these surfaces to hands as a result of direct contact with HFR-containing products. Surface wipe testing shows promise for screening additive HFRs. In comparison,

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the Br-content obtained using a handheld XRF analyzer did not correspond to concentrations obtained from surface wipe testing.

1. Introduction

PBDEs, as three main commercial mixtures of c-pentaBDE, c-octaBDE and c-decaBDE,[2] were widely used as flame retardants (FRs) in various consumer products beginning in the 1970s (Prevedouros et al., 2004; Abbasi et al., 2015). Elevated concentrations of PBDEs are well documented in indoor (e.g., Allen et al., 2008; Harrad et al., 2008, 2010; Zhang et al., 2011; Shoeib et al., 2012) and outdoor environments (e.g., de Wit, 2002; Hites, 2004; Melymuk et al., 2012), and have resulted in widespread human and ecosystem exposure (e.g., Sjödin et al., 2008; Siddique et al., 2012; Crimmins et al., 2012; Buttke et al., 2013). Exposure to PBDEs continues to raise concerns due to increasing evidence of their endocrine modulation effects (Bellanger et al., 2015 inter alia, Lyche et al., 2015 inter alia) such as alteration of thyroid and estrogen and androgen hormones (Ernest et al., 2012), delayed time to pregnancy (Harley et al., 2011), and developmental neurotoxicity (Herbstman et al., 2010; Eskenazi et al., 2013; Roth and Wilks, 2014).

As a result of health concerns and persistence, the congeners of c-penta- and c-octaBDE were added in 2009 to the list of chemicals for elimination under the Stockholm Convention (UNEP, 2010). The production of c-penta- and c-octaBDE was voluntarily phased out by chemical producers in the U.S. in 2004. Canada banned the production and new use of c-penta- and c-octaBDE in 2008 (Environment Canada, 2013). DecaBDE was listed for authorization under REACH[3] in 2010, meaning that decaBDE will be progressively replaced by alternative flame retardants in new products. In 2013, Norway nominated decaBDE for inclusion as a POP (persistent organic pollutant) under the Stockholm Convention (UNEP, 2013). As of 2010, three main manufacturers of decaBDE began to voluntarily phase out the export and sale of decaBDE for certain applications in Canada (Environment Canada, 2013). In Canada, there are no specific controls on PBDEs in products although this is currently under consideration (Environment Canada, 2015). The production, importation and sales of decaBDE were expected to be discontinued in the U.S. following 2013 (U.S. EPA, 2015). Despite the cessation in production and new uses in North America and Europe, the stock of PBDEs in in-use products, which was estimated to be ~120,000 tonnes in the U.S. and Canada in 2014 (Abbasi et al., 2015), remains a source of PBDEs to the indoor and ultimately outdoor environment.

The replacement of PBDEs with "novel flame retardants" (NFRs) has resulted in a proliferation of other brominated flame retardants (BFRs) and halogenated and non-halogenated organophosphate flame retardants (OPFRs) (Ceresana, 2014). A growing literature is documenting the levels of NFRs in indoor dust (e.g., Ali et al., 2011; Cao et al., 2014; Cequier et al., 2014; de Wit et al., 2012; Newton et al., 2015; Shoeib et al., 2012; Stapleton et al., 2012a) and outdoor environments (e.g., Ma et al., 2012, 2013; Salamova and Hites, 2011, 2013).

Exposure to halogenated flame retardants (HFRs), particularly in North America, can occur through ingestion and inhalation of contaminated house dust (Jones-Otazo et al., 2005; Lorber, 2008; Trudel et al., 2011). Several studies have correlated concentrations of PBDEs in house dust with those in serum and breast milk (Björklund et al., 2012; Johnson et al., 2010; Wu et al., 2007; Watkins et al., 2011). However, given the stronger correlation between PBDEs in hand wipes or hand-to-mouth behavior and serum (rather than dust), PBDE transfer via hands may be the more likely route of exposure (Stapleton et al., 2008, 2012b; Watkins et al., 2011, Buttke et al., 2013). Similar evidence of exposure via hands is now emerging for NFRs (Stapleton et al., 2014). Thus, direct contact with FR-containing products and FR-contaminated dust are the two suggested sources of FR to hand transfer (Stapleton et al., 2008, 2014).

To minimize exposure from FR-contaminated dust or direct contact with FR-containing products, the sources need to be traced back to products with the highest FR release rate or mobility. Studies that have sampled dust from specific room locations have found that particular products, such as electronics, contribute to FR concentrations in dust (Muenhor and Harrad, 2012; Harrad et al., 2009). By assessing patterns among rooms, several studies have found correlations between FRs in dust and the prevalence of electronic equipment or furniture containing polyurethane foam (PUF) (Hazrati and Harrad, 2006; de Wit et al., 2012). Recently, Li et al. (2015) found a strong positive correlation between the power consumption of electronics and PBDE levels in a large room, which they attributed to heat generated from in-use electronics enabling the release of FRs. In contrast, several studies have failed to find a correlation between the PBDE concentrations in house dust and the number of electronic products or furniture in indoor environments (Kang et al., 2011; Kefeni and Okonkwo, 2012).

Upon failing to find a correlation between PBDEs in house dust and the number of products likely to have contained PBDEs, Allen et al. (2008) used X-ray fluorescence (XRF) to identify products containing bromine (Br) as an indicator of PBDEs. They found a correlation between Br levels measured by XRF (XRF-Br) and PBDE concentrations measured by means of GC–MS and an association between Br levels in products and PBDE concentrations in house dust. Stapleton et al. (2011) confirmed the results of Allen et al. (2008) for foam samples, but reported that XRF-Br over-predicted Br determined by GC–MS in those samples containing Firemaster 550. They also reported false positives of XRF-Br in foam products that yielded OPFRs upon GC–MS analysis. Kajiwara et al. (2011) also used XRF to screen for FRs in selected electronic products. Imm et al. (2009), using XRF to identify the sources of PBDEs in 38 U.S. households, found that XRF-Br from televisions (TVs) and upholstered living room chairs were correlated with total pentaBDE congeners in passive air samplers. They also reported that XRF-detected Br levels in sleeping pillows and vehicle seats were strongly correlated with PBDE concentrations in participants' lipid-adjusted blood serum. By means of XRF and forensic microscopy, Webster et al. (2009) explained the mechanisms of PBDEs migration from PBDE-containing products and their distribution in house dust. Three hypotheses have been proposed to account for the migration of additive FRs to dust from products or more specifically, the polymer to which they have been added: (1) volatilization from the polymer followed by air-dust partitioning, (2) abrasion of the polymer surface causing the release of FR-enriched particles or fibers, and (3) direct transfer of FRs from the FR-containing polymer to dust (Kemmlein et al., 2003; Takigami et al., 2008; Webster et al., 2009; Rauert et al., 2014a, 2014b inter alia). Volatilization is expected to be the main mechanism for the release of more volatile compounds whereas abrasion is considered more likely for less volatile compounds (Webster et al., 2009; Rauert et al., 2014a).

The main goal of this study was to understand which products act as a source of PBDEs and replacement HFRs to indoor dust in the context of human exposure. We hypothesized that higher concentrations of HFRs in products would be related to higher concentrations in associated dust. Second, we aimed to further develop the rapid and non-destructive technique of product wipe testing to identify selected HFRs in products.

[2] Congeners of each PBDE commercial mixture considered in this study: c-PentaBDE: BDE-17, -28, -47, -71, -99, -100, -153, and -154; c-OctaBDE: BDE-153, -154, and -183; c-DecaBDE: BDE-209.

[3] REACH is the regulation on Registration, Evaluation, Authorization and Restriction of Chemicals. It entered into force in 2007. It streamlines and improves the former legislative framework on chemicals in the European Union (EU).

2. Materials and methods

2.1. Sampling from homes and offices

Dust and product wipe samples were collected from the most used room (MUR) in 35 homes and 10 offices in the Greater Toronto Area, Canada, in August 2012. In most cases this was the TV room. As well, the Br content of selected products that were thought to be treated with FRs was measured by means of XRF (XRF-Br). In open concept homes where the kitchen was attached to the MUR, Br readings were also taken of kitchen appliances. Participants were selected based on a sample of convenience and were mainly of mid-socio-economic status. The University of Toronto Ethics Board authorized all aspects of this study and all participants gave informed consent prior to sample collection from their homes.

2.2. XRF measurements

Br content was measured by a portable Niton-XL3t XRF analyzer (Thermo-Scientific, Canada) in 553 products including upholstered furniture, electrical and electronic equipment (EEE), and selected plastic products in homes and offices. Chlorine (Cl) was also monitored with the aim of identifying Cl-containing FRs (Cl-FR) however XRF-Cl also could be indicative of a chlorinated polymer such as polyvinyl chloride. Prior to sampling at each location, the XRF device was calibrated in plastic testing mode against a polymer bead with known elemental content. Plastic products were wiped with dry, pre-cleaned KimWipes™ to remove dust contamination before screening. Three readings at different locations on each product were taken to obtain an average value. Readings were also taken from couches with multiple seat and back cushions. Where possible, the inner part of the cushion was screened in addition to the seat cover with upholstery. The XRF-Br content was measured at the exterior of EEE casings and plastic items. At least one reading from EEE products was taken from the area close to the fan, circuit board or motherboard as these parts are most likely to be treated with FRs. Readings were taken from each part if the product had various types of plastic, e.g. front and back of TVs.

2.3. Wipe samples

Products in the MUR were selected for wipe testing if the XRF-Br content was at least 10 times higher than 0.1% (RoHS level).[4] Prior to sampling, dust from the surface of products was removed with dry, pre-cleaned KimWipes™. An average surface area of 5×5 cm^2 was wiped for 1 min with isopropanol-wetted medical wipes (Health Care Plus, Canada). Blank medical wipes had levels of PBDEs and NFRs < limit of detection (LOD, listed in Table S1). Wipe samples were stored in pre-cleaned glass vials at −20 °C and thawed at room temperature prior to chemical analysis.

2.4. Dust samples

Dust samples were collected from carpet or hardwood floors of the MUR using a conventional vacuum cleaner. Dust samples were collected in pre-cleaned nylon socks (XUTRECHT02 Vacuum Bag; Allied Filter Fabrics Ltd., Australia) attached to the end of the vacuum cleaner hose, which was cleaned using isopropanol prior to each sampling. An average area of 2×2 m^2 was vacuumed from the easily accessible center area of the floor. If insufficient dust was obtained, a larger area was sampled and the area was noted. Study participants were asked to not vacuum this area for at least 1 week prior to our sampling to ensure sufficient dust accumulation for collection. Following collection, samples were refrigerated prior to being sieved. Samples were sieved (150 μm) using a pre-baked sieve (at 250 °C for at least 3 h) to produce a fine dust fraction (Wilford et al., 2005). One person sieved all the dust samples to minimize variability in dust preparation. The fine dust samples were stored in pre-cleaned glass vials at −20 °C and then thawed at room temperature prior to chemical analysis.

2.5. Sample analysis

All dust and wipe samples were analyzed for 10 PBDE congeners and 12 NFRs: BDE-17, 28, 47, 71, 99, 100, 153, 154, 183 and 209 and allyl-2,4,6-tribromophenyl ether (ATE), 1,2,3,4,5-pentabromobenzene (PBBz), 2,3,5,6-pentabromoethyl benzene (PBEB), hexabromobenzene (HBB), *syn*-dechlorane Plus (syn-DP), *anti*-dechlorane Plus (anti-DP), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB or TBB), bis(2-ethyl-1-hexyl) tetrabromophthalate (BEHTBP or TBPH), octabromotrimethylphenylindane (OBIND), decabromodiphenylethane (DBDPE), pentabromotoluene (PBT), and tris(1,3-dichloro-2-propyl) phosphate (TDCPP).

To determine recoveries, samples were spiked with surrogate ^{14}C-labeled standards (mPBBz, mHBB, mBDE-28, mBDE-154, and mBDE-183) prior to sample extraction. Approximately 0.1 g of dust and whole product wipe (0.5 g) samples were extracted in hexane: DCM (1:1, v/v) (HPLC grade, Fisher Scientific) via pressurized liquid extraction using an Accelerated Solvent Extractor (ASE; Dionex ASE 350). Extracts were cleaned using pre-cleaned alumina (5 g) and sodium sulfate (10 g) added to the ASE cells (Saini et al., 2015). Each extract was concentrated to 0.75 mL under a steady stream of nitrogen in a Zymark Turbovap, then transferred to 1.5 mL GC vials and further reduced using nitrogen. The final volume was made to 0.5 mL using isooctane (HPLC grade, Fisher Scientific). Samples were analyzed using GC–MS (Agilent 6890N/5975C) equipped with DB-5 15 m column and MS operated in negative chemical ionization (NCI) mode, using methane as the reagent gas. Quantification was performed using a 5-point calibration curve obtained from a PBDE standard mixture (Accustandard, U.S.A.) and individual standards of each NFR (Wellington Laboratories, Canada).

2.6. Quality assurance and quality control (QA/QC)

QA/QC of chemical analysis was monitored by measuring recoveries and blanks. Field blanks for dust and wipes were taken at one in 10 sampling locations. Dust field blanks consisted of 1 g of Na_2SO_4 on pre-cleaned aluminium foil placed on the floor of the MUR and vacuumed using the same method as for dust collection. Product wipe blanks, consisting of medical wipes, were exposed to air in the MUR for approximately 1 min. Laboratory and field blanks were extracted and analyzed (spiked with surrogate standards and internal standard) in every batch of 10 samples. Surrogate standards were added to each sample prior to extraction to check recoveries throughout the extraction and preparation processes (Table S2). Recoveries varied between 71 and 108%. The data were quantified using BDE-118 as an internal standard which was added to the final volume of the extracts prior to injection. Laboratory blanks spiked with surrogate standards prior to extraction were analyzed with every batch of 6 samples. Further details of QA/QC methods are provided in Supplementary information (SI) including results from the analysis of certified reference material (NIST SRM-2585-organic contaminants in house dust, Fig. S1), detection limits (Table S1), and the blank correction method followed.

2.7. Data analysis

Statistical analyses were performed using Statistica (Six Sigma, version 7) and included descriptive statistics, Pearson and Spearman correlations, and multivariate regression with statistical significance defined at $\alpha = 0.05$. For compounds not detected at the concentrations > LOD, LOD divided by square root of two was assigned for statistical analysis.

[4] The RoHS directive aims to restrict certain dangerous substances commonly used in EEE.

Dust and product wipe concentrations were log-transformed prior to principal component analysis (PCA). PCA and *k*-mean partitioning analysis on log-transformed data were performed in open source "R" software.

3. Results

3.1. Br content determined by XRF

The XRF results were used as an indicator of BFRs in numerous product types in home and office environments (Table 1). Out of 553 products in homes and offices that were screened for Br using XRF, 45% (217) of products had a XRF-Br of >0.1% or 1000 μg/g. FRs must be added to products at a minimum level of 2% in order to effectively delay the spread of fire (Weil and Levchik, 2009). We found that only 13% of the products met this criterion with respect to the effective level of BFRs. Products with low or no XRF-Br levels could have been mis-identified using XRF (see below), could have contained other FRs such as Cl-FRs or OPFRs, or could have an FR concentration below that to be effective (e.g., Stapleton et al., 2011; Kajiwara et al., 2011). The back casings of TVs (both flat screen and cathode ray tube or CRT) consistently had XRF-Br > 100,000 μg/g (10% w/w). Other products that had a relatively high XRF-Br content were the plastic casings of power bars, chargers for electronic goods and batteries, internet routers (cable and wireless), power surge protectors, DVD players and microwaves. The highest XRF-Br content among all products was measured in a 2-year old food dehydrator (~160,000 μg/g or 16% w/w). The highest variability within a product was observed in furniture and carpet padding which could be related to the heterogeneous nature of PUF, the unevenly distributed BFRs in PUF products, and/or the inability of XRF to provide reliable measurements of elements in soft materials (Stapleton et al., 2011).

Comparing our results of 45% of 553 products exceeding 0.1% Br, Gallen et al. (2014) found that 28% of 1714 products screened using XRF exceeded 0.1% Br (they sampled products available in the Australian market in 2012, the same year as sampling conducted here).

3.2. FR concentrations in product wipes

A total of 65 wipe samples were taken from products with XRF-Br content >10,000 μg/g or 1% (Fig. 1, Table S3). Congeners of c-pentaBDE (BDE-47, 100, 99, 153, 154) were measured in all wipes taken from personal computers (PCs) and more than 70% of small household appliances (HHAs) (other congeners of c-pentaBDE, BDE-17, 28, 71, were not consistently detected >LOD). The highest concentrations of c-pentaBDE (ΣBDE-47, 100, 99, 153, 154) were detected on the surfaces of PCs, followed by audio/video (A/V) devices and large HHAs at 454, 207 and 143 ng/wipe, respectively. DecaBDE (BDE-209) was found in all wipes of CRT TV casings with the geomean and highest concentration of 5800 and 62,856 ng/wipe, respectively. BDE-209 was also detected in most small HHA wipe samples, with concentrations ranging from <LOD up to 33,325 ng/wipe. ΣPBDE concentrations measured by Gallen et al. (2014) of 600–20,000 ng/wipe were in the same range as those measured in this study.

Among all NFRs, DBDPE was measured in 64% of flat screen TVs with the highest concentration of 6262 ng/wipe and a geomean of 1.74 ng/wipe (Table S3). We note that the results for DBDPE generally have high uncertainty due to analytical variability (Melymuk et al., 2015). BEHTBP was measured in all PCs, small HHAs and 85% of flat screen TVs with geomean values of 7.44, 2 and 0.52 ng/wipe, and with maximum concentrations of 194, 14.2, and 74.7 ng/wipe, respectively. EH-TBB was measured in all PCs and 80% of A/V devices with geomean values of 57 and 0.77 ng/wipe, and with maximum concentrations of 1010 and 514.9 ng/wipe, respectively. TDCPP was detected in 36% of flat screen TVs and 43% of large HHAs at maximum concentrations of 193.3 and 494 ng/wipe, respectively. PBBz, PBT, PBEB and OBIND were detected in <50% of products sampled with concentrations ranging from <LOD to 30 ng/wipe. ATE was detected in about half the products sampled but concentrations were close to the LOD; DPs were not detected in product wipes.

3.3. FR concentrations in dust samples

TDCPP and pentaBDE contributed most to total HFR concentrations in home and office dust, respectively (Fig. 2). Of the PBDEs, pentaBDE congeners BDE-47 and -99 were the most abundant in dust samples with concentrations in home dust ranging from <LOD to 5300 and 12,500 ng/g dust and with geomean values of 53 and 74 ng/g dust, respectively. Geomean values of BDE-47 and -99 in office dust were 2097 and 3840 ng/g dust, respectively (Table S4). DecaBDE (BDE-209) was detected in most dust samples from homes (97%). Concentrations of BDE-209 ranged from 0.01 to 12,100 ng/g with geomean values of 44 and 195 ng/g dust in home and office dust, respectively.

The median levels of c-pentaBDE and c-octaBDE congeners ranging from 1.2–195.6 ng/g were in good agreement with those reported by Shoeib et al. (2012) (1.5–350 ng/g) for dust from 116 houses sampled in Vancouver, Canada in 2007–2008 and Wilford et al. (2005) (1–430 ng/g) for dust from 68 houses sampled in Ottawa, Canada in 2002–2003. However, the median level of BDE-209 (148.2 ng/g) was lower by a factor of 8 in this study compared with Shoeib et al. (2012). The presence of pentaBDE and octaBDE congeners in dust samples despite their curtailment in new products since 2005 reflects the continued release of these compounds from in-use PBDE-containing products (Abbasi et al., 2015). The lower concentrations of decaBDE in our dust samples compared to those measured by Shoeib et al. (2012) could reflect the retirement of CRT TVs and other older EEE in late 2000s that contained high concentrations of decaBDE (Abbasi et al., 2015).

The geomean values of BDE-47, -99 and -100 were 10–50 times higher in office dust samples than those of homes. This may be due to more stringent flammability requirements applied to office and public spaces than residences, such as California Technical Bulletin 133 that

Table 1
Mean, geometric mean (geomean), minimum and maximum values of Br content (μg/g) of products screened using XRF.

Product	Total number of products	% of product with [Br] >0.1%	% of product with [Br] >2%	Mean	Geomean	Min	Max
Flat screen TV (front)	25	80%	64%	73,500	4900	10	112,900
Flat screen TV (rear)	25	60%	28%	25,000	225	10	99,400
CRT TV	6	100%	100%	103,500	103,200	85,700	120,200
PC (laptop & desktop)	62	29%	4%	2800	0.5	<LOD	116,000
Flat screen monitors	9	44%	0%	340	3	<LOD	2000
CRT monitors	5	20%	25%	21,500	1	<LOD	86,000
Audio/video	76	36%	15%	10,400	35	<LOD	145,000
Fax/printer/copier	20	40%	5%	4500	10	<LOD	87,000
Small HHA	148	43%	14%	12,500	10	<LOD	160,000
Large HHA	49	24%	6%	4000	0.2	<LOD	69,000
PUF furniture	98	36%	2%	2000	2	<LOD	21,500
Carpet	30	23%	0%	500	1	<LOD	5000

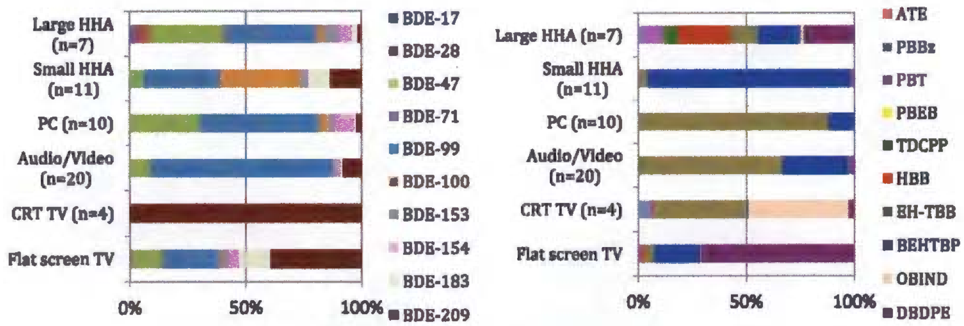

Fig. 1. Percentage contributions of PBDEs and NFRs concentrations in product wipes.

pertains to PUF furniture in public spaces (Shaw et al., 2010). DecaBDE concentrations in office samples were within the same range as home samples (0.012–1600 ng/g dust) with a geomean of 195 ng/g dust. The geomean of c-pentaBDE concentrations in offices measured here (7230 ng/g dust) was three times higher than those measured in 31 U.S. offices but the geomean of the decaBDE concentration was lower by a factor of 20 (Watkins et al., 2011). However, caution is needed in comparing these results as only 10 offices were sampled here.

TDCPP was detected in more than 80% of house dust samples, with the highest concentrations of all HFRs measured. Concentrations ranged from <LOD to 46,000 ng/g dust with a geomean of 690 ng/g. The median of 1700 ng/g was 20 times higher than that reported from New Zealand, Belgium and Spain (Ali et al., 2012; van den Eede et al., 2011; García et al., 2007). Stapleton et al. (2014) reported a range of 62–13,000 ng/g dust of TDCPP in dust sampled from 30 U.S. houses in 2012. In office samples, TDCPP concentrations ranged from <LOD to 200,000 ng/g dust, with a geomean of 8687 ng/g dust, more than twice that of homes. EH-TBB was measured in more than 90% of dust sampled from houses and offices with geomean values of 215 and 543 ng/g, respectively, and a range of <LOD to 7540 ng/g dust, with no significant difference between these two microenvironments. The geomean values of BEHTBP in house and office dust samples were 77 and 156 ng/g dust, respectively. However, the maximum BEHTBP concentration of 52,000 ng/g measured in one office sample was ~7 times higher than those of EH-TBB. The measured concentrations of EH-TBB and BEHTBP are in good agreement with those reported by Shoeib et al. (2012) and Stapleton et al. (2014) for house dust from Canada and the U.S., respectively. DPs (*anti* & *syn*) were detected in 97% of house dust samples with concentrations ranging from <LOD to 153 ng/g dust, which is in the same range reported for Canadian dust by Shoeib et al. (2012) and Zhu et al. (2007). No significant differences in BFR profiles or concentrations were observed according to the type of home, dust collected from floors with and without carpets, or age of the buildings sampled.

3.4. Comparison of Br concentrations from XRF and in product wipes

A relationship was not found between XRF-Br and Br measured in product wipes (Figure S2). Moreover, XRF-Br tended to be at least 10–1000 times greater than that measured using product wipes. For example, the total Br content in 56% of product wipes ranged from 2 to 80 ng/wipe with a geomean of 13 ng/wipe whereas the XRF-Br ranged from 1000 to 145,000 μg/g with a geomean of 50,000 μg/g. In 27% of product wipes, the total Br content ranged from 80 to 800 ng/wipe with a geomean of 180 ng/wipe, while XRF-Br ranged from 1000 to 160,000 μg/g with a geomean of ~25,000 μg/g. In the remaining samples (17%), the total Br content measured in wipes ranged from ~800–50,000 ng/wipe with a geomean of ~3800 ng/wipe, while XRF-Br ranged from ~70,000–110,000 μg/g with a geomean of ~90,000 μg/g.

Allen et al. (2008) reported a strong correlation ($r > 0.9$) between XRF-Br and Br in PBDE analyzed by GC–MS. However, this relationship was weak when XRF-Br > 100 mg/g for all samples and, as well, for TV and foam samples. Stapleton et al. (2011) found a strong correlation between XRF-Br and BFRs identified by GC–MS in foam samples in some, but not all cases, noting that XRF was calibrated for hard but not soft polymers. Gallen et al. (2014) found that XRF poorly approximated Br content of hard plastic products determined by GC–MS destructive analysis. It should be noted that they only analyzed PBDEs and TBBPA. Reliable test methods for measuring Cr, Br, Cd, Hg and Pb in polymeric matrices have been established with dwell times of 5–10 min per product for a stationary XRF (ASTM F2617-08). U.S. Consumer Product Safety Commission (CPSC) (2009) found that portable XRF reported Pb concentrations in polymers that were within 30% of those determined by ICP-OES (inductively coupled plasma optical emission spectrometry). Furthermore, portable XRF is routinely used to screen for hazardous levels of elements in polymers. Although we did not destructively analyze samples for Br, our results were consistent with those of Gallen et al. (2014) that the portable XRF may not be reliable for screening products for BFRs. Alternatively, XRF-Br could have originated from Br

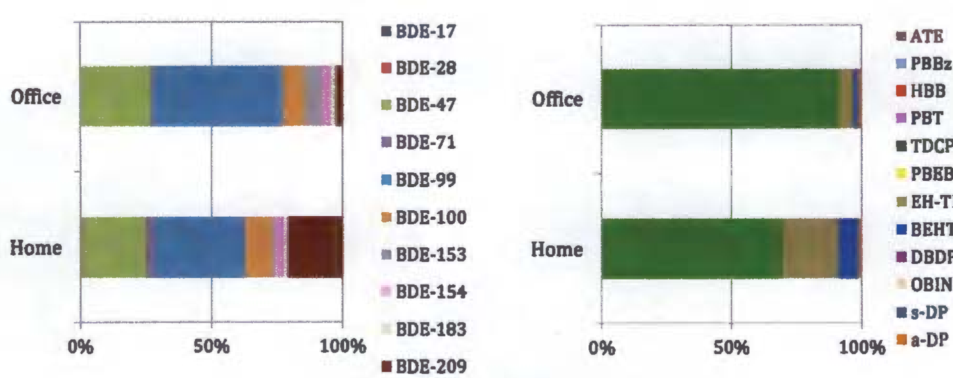

Fig. 2. Percentage contributions of PBDEs and NFRs in home (n = 35) and office (n = 10) dust.

in BFRs not analyzed or Br-containing additives (but not FRs) in polymers (e.g., Stapleton et al., 2011; Kajiwara et al., 2011). Also, the wipes may not have quantitatively remove BFRs and as such, the BFRs in the wipes may reflect just that — BFRs that can be removed by wiping.

3.5. Association between FRs in product wipes and dust

The geomean concentrations of HFRs in home and office dust were positively correlated with those in product wipes ($r^2 = 0.53$, $p = 0.002$, Fig. 3). Stronger correlations ($r^2 = 0.7$–0.8, $p = 0.005$) were obtained for HFRs when separated into compounds with <600 and >600 g/mol (Fig. S3). These correlations suggest that in general, the higher the concentration of each HFR in a product wipe, the higher the concentration in dust. The lack of correlation between FRs in dust and K_{oa}, as an indicator of volatility (Fig. S4), could suggest that the main migration pathways from products to dust were abrasion and weathering processes or migration via direct transfer to dust particles rather than volatilization (Webster et al., 2009; Rauert et al., 2014a). However, another explanation is that the higher concentrations of HFRs such as octa- and decaBDE, and DBDPE in dust could be related to the higher and longer power usage, and hence operating temperature, of products containing higher concentrations of these HFRs such as TVs, which could increase volatilization of these chemicals (Li et al., 2015). A correlation between the number of electronics containing PBDEs, in particular display devices, and PBDE levels in indoor dust has been found in previous studies (Allen et al., 2008; de Wit et al., 2012). TVs have been also identified as the main source of other HFRs, such as HBCD, in indoor environments (Harrad et al., 2009).

The elevated concentrations of pentaBDE and its replacements (TDCPP, EH-TBB and BEHTBP) in dust samples compared to product wipes could reflect their presence in PUF products that could not be wiped, such as foam furniture and baby products (Stapleton et al., 2011; Imm et al., 2009). However, pentaBDE, TDCPP, EH-TBB and BEHTBP were also measured in wipes from EEE casings including A/V devices, PCs and small HHAs. The differences among the ratios of EH-TBB:BEHTBP in dust (~10), product wipes (~25) and Firemaster 550 (~3) (Stapleton et al., 2014) suggest that these compounds are either released from products at different rates or that they do not necessarily originate from products treated with Firemaster 550. Overall, these results suggest that PCs and A/V devices could act as sources of pentaBDE and its replacements to indoor environments.

We used PCA to further investigate the relationship between HFRs in product wipes and home and office dust samples. Principal components (PC) 1 and 2 explained 68% of the variation in our dataset (Fig. 4). Five clusters were delineated using *k*-means partitioning and simple structure index (ssi) methods (Fig. S5). PCA identified several clusters that grouped dust and product wipe samples together rather than by sample type, consistent with the positive correlation between HFR concentrations in product wipes and dust. Cluster A consisted of dust samples (>80%) and some product wipe samples that had elevated concentrations of pentaBDE and its replacements TDCPP, EH-TBB and BEHTBP. DPs in dust were also included in this cluster. DPs were not detected in any product wipes likely because our analysis was biased towards wiping products with XRF-Br > 1% and not Cl, and evidently because DPs are not used in conjunction with BFRs in the products tested. As such, we concluded that other products not sampled here, such as building materials or wire coatings (Shoeib et al., 2012), could have been DP sources to dust samples.

Cluster B was dominated by product wipes and dust containing high concentrations of octa- and decaBDE. This grouping, and the finding of high concentrations of decaBDE in CRT TVs, followed by the relatively high concentrations of octa- and decaBDE in A/V devices, small HHAs and PCs, suggested that these products could act as sources of octa- and decaBDE to dust. Cluster C was dominated by those dust and wipe samples with high concentrations of DBDPE and OBIND (decaBDE replacements). DBDPE was measured mainly in flat screen TVs, followed by A/V devices and small and large HHAs. OBIND was measured in the same products but at lower concentrations than DBDPE. Cluster D was dominated mainly by product wipes with high concentrations of PBEB and PBT although these concentrations tended to be low in comparison to other FRs in wipes. Cluster E was comprised of the wipe and dust samples that had the lowest concentrations of the FRs targeted in this study.

4. Discussion

These results have several implications. First, we found that HFRs with high concentrations in product wipes had high concentrations in dust. Those HFRs with the highest concentrations in product wipes and dust were PBDEs, TDCPP, DBDPE, EH-TBB and BEHTBP. Of the products tested, those with consistently high concentrations of these HFRs were CRT TVs (decaBDE, OBIND), PCs (pentaBDE, EH-TBB, BEHTBP), A/V devices (pentaBDE, EH-TBB), small HHA (decaBDE, DBDPE), flat screen TVs (TDCPP, EH-TBB, BEHTP) and large HHA (TDCPP). Elevated

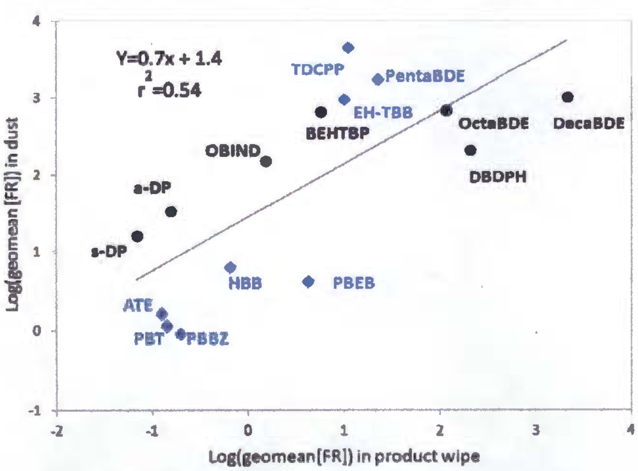

Fig. 3. Correlation between logarithms of the geomean concentrations of FRs in product wipes and dust samples. Blue diamonds represent FRs with molecular weight < 600 g/mol, and black dots represent FRs with molecular weight > 600 g/mol. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

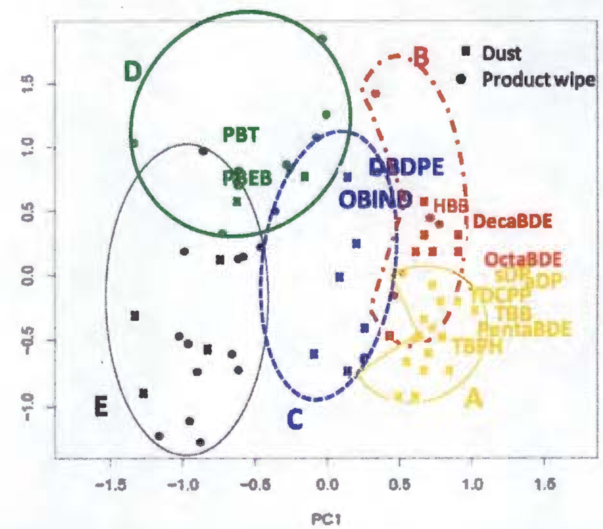

Fig. 4. Analysis of FRs in product wipes and dust by means of principal components analysis. PC 1 and PC 2 account for 68% of variability in the dataset. Five clusters were identified using *k*-means partitioning and simple structure index. Crosses "x" represent dust samples and dots "•" represent product wipe samples.

concentrations of pentaBDE and its replacements TDCPP, EH-TBB and BEHTBP could have originated from products that were not sampled because we did not target products containing Cl-FRs or sample PUF-containing products. By far the highest concentration of all HFRs was decaBDE in CRT TVs. TVs have been noted as likely sources of human exposure (Takigami et al., 2008; Buttke et al., 2013) and sources of FRs to dust (Allen et al., 2008). Other electronic devices could also act as sources of FRs (Kajiwara et al., 2011; de Wit et al., 2012). We note that Imm et al. (2009) failed to find a correlation between XRF-Br in household products and pentaBDE in indoor dust.

Second, in terms of human exposure, the ability of medical alcohol wipes to remove FRs from product surfaces, even at low concentrations, suggests that these chemicals can be easily transferred to hands directly from handling products or indirectly through product-contaminated dust. This supports concerns for direct contact with FR-containing products as a key exposure pathway of HFRs (Stapleton et al., 2008, 2012b, 2014; Watkins et al., 2011, Buttke et al., 2013).

Third, the use of product wipes to screen for HFRs merits further investigation. We were able to detect a wide range of HFRs in product wipes the levels of which were related to dust concentrations. Our results support those of Gallen et al. (2014) who found that surface wipes of products provided a reasonable approximation of concentrations of PBDEs in electronic products compared with destructive analysis by means of GC–MS. Our results, and those of Gallen et al. (2014), suggest that screening products for BFRs using only a portable XRF may not provide reliable results. We recommend that more research be conducted to optimize the consistency and efficiency of the product wipe method as a rapid, reliable and non-destructive testing technique to quantify additive FRs in consumer products, noting that the ability to remove HFRs from the surface of a polymer using the product wipe method has not been evaluated.

Finally, our results showed that HFR concentrations in dust were related to their concentrations in product surface wipes regardless of the volatility of the compounds. These results are consistent with abrasion and weathering processes or transfer via direct contact with dust particles as the main pathways by which HFRs, especially less volatile compounds, migrate from products into dust (Webster et al., 2009; Rauert et al., 2014a, 2014b). As we did not test for the relationship between the power usage of products and the release of HFRs (Li et al., 2015), the alternative hypothesis is also possible of greater release as a function of power usage due to volatilization from heated plastic or greater release from abrasion of heated plastics.

5. Uncertainties and limitations

Several limitations require attention as follows: (1) Product wipes could not be taken from all HFR-containing products at each location, notably foam products as well as building insulation and electrical cables; (2) product wipes may not have removed HFRs from product surfaces in a quantitative and unbiased fashion; (3) product wipes were not taken from samples with XRF-Br < 1% which may have biased our results since we found that XRF-Br did not reliably predict Br in product wipes (i.e., we missed products containing BFRs); (4) XRF could not be used to dependably to identify products containing TDCPP and DPs measured here as well as other Cl-FRs because it was not possible to unambiguously distinguish Cl in polymers from Cl-FRs nor was it possible to use XRF reliably for foam products (Stapleton et al., 2011). In addition, XRF is not reliable for screening for OPFRs because of the low sensitivity of XRF for detecting light elements such as phosphorus (Kajiwara et al., 2011); and (5) inconsistencies and human error undoubtedly occurred during the sampling procedures that contributed to inaccuracies, such as variable pressure applied while taking wipe samples, duration of wiping and area wiped (Gallen et al., 2014).

Uncertainties associated with our study included the following: (1) Sample locations did not represent homes with a variety of socio-economic status; (2) product wipe results could have been confounded by the heterogeneous distribution of HFRs in polymers; (3) a single, centrally located dust sample may not have been representative of the room sampled (Muenhor and Harrad, 2012); and (4) not all dust particles may have been removed from product surfaces by dry wiping before collecting the surface wipe, which could have produced false positives.

Gallen et al. (2014) discussed two major sources of errors when using product wipes to identify BFRs in products. Contamination of products with dust containing-BFRs from other sources could generate false positives of identifying BFRs in products when in fact those BFRs were not present. We assumed that removing dust from the surfaces of products prior to sampling reduced this type of false positive. Conversely, false negatives could be generated when product wipes could not remove BFRs at the surface of a product despite their presence in the product. Quantifying false positives and negatives was beyond the scope of this study. However, we offer an alternative explanation for false positives: HFRs not intentionally added to a polymer will partition from indoor air into any polymer as a function of the physical-chemical properties of the HFR and polymer. In fact, the partitioning of any semi-volatile compound present in air (e.g., released from other products) into a polymer would be expected. Thus, a product wipe reflecting this surface sorption would indicate the presence of an HFR in another product in proximity rather than added intentionally to the polymer. As product screening using this wipe method shows promise, further investigation is needed to improve the method. As well, further testing is needed of the use of a portable XRF as a screening tool to approximate BFRs in polymeric materials whereby BFRs continue to dominate the global market (but noting that OPFR production will soon exceed that of BFRs, China Market Research Reports, 2015).

6. Conclusions

The presence of HFRs in indoor dust has provided strong evidence of the release of these chemicals from consumer electronic products, such as TVs, into indoor environment, consistent with the findings of other studies. We found that the concentrations of 10 PBDE congeners and 12 halogenated NFRs in home and office dust were positively correlated with concentrations measured in surface wipes of polymer casings of electronic products. Thus, we hypothesize that products with the highest HFR concentrations contribute most to concentrations in dust, regardless of the volatility of the HFR. HFRs found at relatively high concentrations in dust and product wipes were the three PBDE commercial mixtures, TDCPP, DBDPE, EH-TBB and BEHTBP. Products with the highest concentrations of these FRs were (in decreasing order) CRT TVs, PCs, A/V devices, small HHAs and flat screen TVs. The ease of removal of HFRs from polymer surfaces by wiping is consistent with concerns regarding human exposure via direct hand contact with these surfaces. To determine products containing PBDEs and to identify HFR alternatives to PBDEs under scrutiny, developing a rapid and non-destructive screening method for HFR identification is needed. Whereas the portable XRF did not provide reliable results for screening for BFRs and cannot be used to reliably identify Cl-FRs or OPFRs, the product wipe method used here deserves further attention.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2015.12.028.

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Novel flame retardants: Estimating the physical–chemical properties and environmental fate of 94 halogenated and organophosphate PBDE replacements

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HIGHLIGHTS

- Physical–chemical properties, degradation rates of 94 flame retardants estimated.
- Most estimates within 10^2–10^3, compounds >800 g/mol or polar could differ by 10^{12}.
- Using OECD Screening Model, 50% of FRs have high to medium persistence.
- About half of FRs have LRTP potential, which is likely an underestimation.

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ABSTRACT

In the wake of the listing by the Stockholm Convention of PBDEs, an increasing number of "novel" flame retardants (NFRs) are being used in products. The properties that make for desirable flame retardants can also lead to negative health effects, long environmental residence times and an affinity for organic matrices. While NFRs are currently in use, little information is available regarding their physical–chemical properties and environmental fate. In this study, 94 halogenated and organophosphate NFRs were evaluated for their persistence and long-range transport potential. Physical–chemical properties (namely liquid sub-cooled vapor pressure P_l and solubility S_l, air–water (K_{AW}), octanol–water (K_{OW}), and octanol-air (K_{OA}) partition coefficients) of the NFRs were predicted using three chemical property estimation tools: EPI Suite, SPARC and Absolv. Physical–chemical properties predicted using these tools were generally within 10^2–10^3 for compounds with molecular weight < 800 g/mol. Estimated physical–chemical properties of compounds with >800 g/mol, and/or the presence of a heteroatom and/or a polar functional group could deviate by up to 10^{12}. According to the OECD P_{OV} and LRTP Screening Tool, up to 40% of the NFRs have a persistence and/or long range transport potential of medium to high level of concern and up to 60% have persistence and or long range transport potential similar to the PBDEs they are replacing. Long range transport potential could be underestimated by the OECD model since the model under-predicts long range transport potential of some organophosphate compounds.

1. Introduction

Flame retardants (FRs) are used to reduce the flammability of a product or to slow down the spread of the flames once it is burning. Halogenated FRs have been in use since the 1940's with a sharp increase in demand and production since then due to the implementation of flammability standards and increased use of synthetic

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materials. The increasing demand has been met by the synthesis of new chemicals with more desirable properties in terms of flame retardancy (Hindersinn, 1990). Polybrominated diphenyl ethers (PBDEs) were one of the most widely used organic FRs that were added to a variety of polymers used in numerous consumer products, building materials, and vehicles (Darnerud et al., 2001; Abbasi et al., 2015). Following the discontinuation of penta-, octa- and decabrominated diphenyl ethers (BDEs), other "novel" FRs (NFRs), are being used in higher quantities in order to meet flammability standards (Babrauskas et al., 2011; Covaci et al., 2011). These chemicals are now being found in house dust (Ali et al., 2011), Arctic air (de Wit et al., 2010; Möller et al., 2011; Jantunen et al., 2014), urban air and streams (Salamova and Hites, 2011), and sediments (Klosterhaus et al., 2012; Yang et al., 2012). However, we have limited understanding of their potential risks and persistence, including their physical–chemical properties used for assessment.

NFRs replace their banned predecessors by sharing similar properties: fire retardancy, resistance to weathering, polymer compatibility, etc. (Hindersinn, 1990). These desirable qualities of FRs can cause them to be of environmental concern. The flame retardancy of halogenated FRs is given by the easily released halogen group, a chemical structure which is recognized for its potential mutagenic effects (Blum and Ames, 1977; Darnerud, 2003). Non-halogenated FRs such as certain organophosphate FRs (OPFRs) confer fire retardancy through char formation. Both groups react with radicals produced by fire (Lewin and Weil, 2001). FRs must be inherently stable (i.e., persistent) during the lifetime of the product to which they have been added. Polymer compatibility for additive and reactive FRs is provided by their non-polar structure, which also makes them compatible with other non-polar organic matrices, such as lipid-rich animal tissue. If the FR meets the criteria of persistence, bioaccumulation, and toxicity (PBT), it could be classified as a persistent organic pollutant (POP) under Annex D of the Stockholm Convention. As such, it is of utmost importance to determine if the alternative FRs that have replaced PBDEs also exhibit POP-like, PBT behavior.

Several government and non-governmental organizations such as Canada's Chemical Management Plan, REACH and the Stockholm Convention have assessed compounds in commerce against PBT criteria (Government of Canada a; European Commission; Stockholm Convention, 2008). Recently, Stieger et al. (2014) assessed the PBT properties of 36 NFRs but found that the quality and quantity of measured physical–chemical properties were insufficient to conduct a reliable hazard assessment. Kuramochi et al. (2014) conducted an evaluation of the estimated overall persistence (P_{OV}) and long-range transport potential (LRTP) of 52 brominated NFRs and found that at least 19 NFRs require closer monitoring and further study as they exhibited estimated P_{OV} and LRTP similar to that of POPs or PBDEs. Liagkouridis et al. (2015) reviewed 57 NFRs by providing "best estimates" of physical–chemical properties and evaluating P_{OV} and LRTP. They found that some low molecular weight compounds had lower P_{OV} and LRTP and, as such, could be viewed as better alternatives to the higher molecular weight FRs, noting significant uncertainties in the analysis. Selected NFRs are now being assessed under Canada's Chemical Management Plan (Table S1, Government of Canada b, http://www.chemicalsubstanceschimiques.gc.ca/group/flame_retardant-ignifuges/index-eng.php).

High quality physical–chemical property data are needed not only because of their use in environmental modeling exercises to inform on the potential fate and hazards of pollutants, but because they also provide the foundation in regulatory risk assessment for data interpretation of all endpoints (e.g., fate and behavior, toxicity and exposure). The importance of physical–chemical properties extends to their use in regulatory risk assessment for read-across in the structure–activity relationship toxicity assessments of compounds (Wu et al., 2010; Patlewicz et al., 2013; Blackburn and Stuard, 2014). Read across, the use of chemical analogue information to fill data gaps, is a useful tool but its effectiveness depends on high quality comparative information, is endpoint specific, and requires expert judgment (ECHA, 2008). As such, high uncertainty related to the information used in the read-across will lead to high uncertainty in data estimates (Blackburn and Stuard, 2014).

The goal of this paper was to compare NFRs according to the similarity of P_{OV} and LRTP to that of PBDEs and other POPs. In order to do this, we first compiled a list of 94 halogenated (HFRs) and organophosphate flame retardants (OPFRs) used or marketed as PBDE replacements for which we obtained estimated physical–chemical properties using EPI Suite v4.1 (USEPA, 2013), SPARC (ARC, 2013), and Absolv (ACD/Labs, 2013). Environmental degradation rates were estimated using EPI Suite (USEPA, 2013), PBT profiler and CATALOGIC (LMC, 2011), as well as data reported in previous studies. We used half-lives of compounds with similar properties for the 12 compounds for which no data on environmental half-lives could be obtained. Second, we modeled P_{OV} and Characteristic Travel Distance (CTD), as defined by Beyer et al. (2000), as a proxy for LRTP using the OECD P_{OV} and LRTP Screening Tool v2.2 (OECD, 2013). Because NFRs are PBDE replacements, we used the overall persistence and LRTP of PBDEs, as well as other POPs, to guide our assessment. In contrast to previous work on the environmental persistence of NFRs (Kuramochi et al., 2014; Liagkouridis et al., 2015), our work includes an extensive list of HFRs, as well as halogenated and non-halogenated OPFRs. Additionally, we used the more advanced CATALOGIC model (Dimitrov et al., 2011) to estimate the biodegradation rate of NFRs.

2. Methods

The list of HFRs was assembled using the FR list compiled by Bergman et al. (2012) as PBDE replacements (note that physical–chemical properties listed by Bergman et al. were obtained using Absolv). To this list, we added six HFRs (OEHHA, 2008) and seven non-halogenated OPFRs (Stapleton et al., 2009; Brommer et al., 2014). Finally, we added five additional OPFRs, C12-30 α-bromo chloro alkenes, C12-30 α-chloro alkenes, and melamine, compounds that may be considered under the Canadian Chemical Management Plan, phase 3. Thus, in total 94 chemicals were studied, of which 71 were HFRs and 23 were non-halogenated (Table S2).

A full description of methods can be found in SI. Briefly, the U.S. Environmental Protection Agency's EPI Suite v4.1 (USEPA, 2013) and SPARC Performs Automated Reasoning in Chemistry's online calculator (ARC, 2013) were used to estimate: liquid sub-cooled vapor pressure (P_l) and liquid sub-cooled solubility (S_l); Henry's Law Constant (HLC), which can be converted into the air–water partition coefficient (K_{AW}) by dividing by temperature (298 K) and gas constant, R (8.314 Pa/K/mol); octanol–water (K_{OW}) and octanol-air (K_{OA}) partition coefficients at 25 °C. Estimates of partition coefficients were also obtained using Absolv (ACD/Labs, 2013).

In order to assess the efficacy of the three estimation programs, goodness-of-fit and root mean square error (RMSE) were evaluated between P_l, S_l, K_{AW}, K_{OW} and K_{OA} measured and estimated values for seven polycyclic aromatic hydrocarbons (PAHs), six polychlorinated biphenyls (PCBs), five PBDEs, and p,p′-dichlorodiphenyltrichloroethane (p,p′-DDT). Additionally, measured P_l values for 11 OPFRs (Brommer et al., 2014) were also compared to estimated values obtained from EPI Suite and SPARC.

Air and water half-lives ($t_{air,1/2}$ and $t_{wat,1/2}$) were obtained using EPI Suite's Atmospheric Oxidation Program (AOP), AOPWIN v1.92, and HYDROWIN v2.00, respectively (USEPA, 2013). Compounds with no or extremely high $t_{water, 1/2}$, denoted as "no or high $t_{water, 1/2}$", were assessed separately for their P_{OV} and LRTP, taking note of the high uncertainty of the results (see S1.3, S5 for more details).

The half-lives for primary and ultimate biodegradation in soil ($t_{soil, 1/2}$) were obtained using EPI Suite's BIOWIN v4.10 model (USEPA, 2013) and CATALOGIC 301C model (LMC, 2011). See Table S3 for conversions used between BIOWIN's rank and assigned quantitative value (Aronson et al., 2006). In some cases, the chemicals were out of the domain for the different physical–chemical properties and degradation estimation models. However, when faced with having no estimates for these NFRs we chose to use the estimated values, taking note of this uncertainty.

P_{OV} and LRTP of the NFRs were assessed using the *P_{OV} and LRTP Screening Tool* v.2.2 (OECD, 2013). Using each pair of partition coefficients obtained from EPI Suite (including literature and PBT-profiler data), SPARC, and Absolv, the *Screening Tool* was run using ultimate and primary $t_{soil,1/2}$ from CATALOGIC and EPI Suite for a total of 12 runs plus an additional four runs for the set of substances with "no or high $t_{water, 1/2}$" (for a breakdown of each run's specifications see Figs. S11-13). Each run consisted of three emission scenarios, where the chemical was directly emitted to air, water or soil.

NFRs were screened for their POP-like environmental behavior by comparing their estimated P_{OV} and CTD values to those of the original 12 POPs under the Stockholm Convention provided by the *Screening Tool*. We used the estimate of P_{OV} of hexachlorocyclohexane (HCH) of 195 days and the estimate of CTD of PCB-28 of 5097 km as these limits (OECD, 2013). Similarly, PBDE-like behavior was categorized into three classes by comparing the NFRs' maximum estimated P_{OV} and CTD values from all three emission scenarios to the maximum estimated P_{OV} and CTD of the congeners in the penta- and octa-BDE mixtures that have been designated as POPs under the Stockholm Convention (Stockholm Convention, 2008; UNEP, 2009). Finally, LRTP of the NFRs was assessed using the CTD values based on emission into air according to the following ranges: if <700 km, low LRTP; if 700 km–2000 km, medium LRTP; and, if >2000 km, high potential for LRT (Beyer et al., 2000).

3. Results and discussion

3.1. Comparison of measured and modeled properties

Model predicted and measured partition coefficients were generally within one order of magnitude (Fig. S1-S3); DDT was the notable exception for which measured values of K_{AW} were overestimated by the three programs. EPI Suite estimates best approximated measured K_{AW} values with a RMSE of 0.43 for log K_{AW}, compared to SPARC's 0.51 and Absolv's 0.89. Predicted K_{OW} was generally overestimated (Fig. S2). K_{OW} estimated by Absolv using ppLFER best approximated measured values with a RMSE of 0.34 for log K_{OW}, compared to EPI Suite's 0.52 and SPARC's 0.63 (Fig. S2). Finally, K_{OA} estimates had no distinguishable over- or underestimation, with RMSE of 0.65, 0.51 and 0.56 for log K_{OA} predicted by EPI Suite, SPARC and Absolv, respectively (Fig. S3). Heavier PCBs were the exceptions as they were progressively overestimated with increasing molecular weight (or more likely molar volume). The "true" values of the K_{OA} of high molecular weight PCBs are difficult to know since measured values could be in error given the difficulty of the measurements.

EPI Suite tended to overestimate the measured values of P_l of PCBs and PBDEs by $10–10^2$ times (Fig. S4). In comparison, SPARC tended to underestimate measured P_l by 10^2, with the exception of PAHs which were generally well estimated. Overall, EPI Suite estimates showed the best fit to the measured log values with an RMSE of 0.81 for log P_l, compared to SPARC's 1.46.

In contrast to P_l, S_l estimates fitted less well with measured values (Fig. S5). Of the two EPI Suite models used, WSKOWWIN estimates approximated measured values best, with a RMSE of 0.79 for log S_l, but the measured values of S_l for all the compounds except PAHs, were underestimated by $10–10^3$. The heavier PBDEs were especially problematic. WATERNT produced estimates with a higher RMSE of 1.18 than WSKOWWIN and the latter did not show bias. Estimated and measured S_l of PAHs and lower molecular weight PBDEs were closely approximated whereas S_l of PCBs and DDT were underestimated by $10–10^2$. Finally, S_l from SPARC, with a RMSE of 1.22 for log S_l, showed more variation in the estimates than the EPI Suite models. While SPARC tended to overestimate the S_l of PAHs by a factor of 10, its estimated values fitted the lighter PCBs but underestimated the heavier PCBs and PBDEs by $10–10^2$. Again, it is difficult to know the "true" values of S_l for sparingly soluble chemicals.

Measured values of P_l of TCEP, TPhP, TBEP, and EHDPP were underestimated by $10–10^2$ by EPI Suite, while values of TCIPP, ToCP, and TDCIPP were overestimated by one order of magnitude (Fig. S6). The RMSE for EPI Suite was 1.01 for log P_l. SPARC tended to overestimate P_l by $10–10^2$ with a RMSE of 1.15 for log P_l, except for the P_l of TCIPP and TBEP, which showed a good fit, and TCEP, which was underestimated by one order of magnitude. Similarly, Brommer et al. (2014) found the Modified Grain Method used by EPI Suite's MPBPVP model provided closer approximations to measured values of P_l than SPARC.

3.2. Estimated physical–chemical properties of NFRS

Table S4 lists values of logs of S_l, P_l, K_{AW}, K_{OW}, and K_{OA} of NFRs while Table S5 contains values for $t_{air, 1/2}$, $t_{wat, 1/2}$, and primary and ultimate $t_{soil, 1/2}$.

Log P_l (Pa) ranged from 4.24 (SPARC) for TMP (140 g/mol) to −27 (SPARC) for BPBTP (1451 g/mol) (Fig. S7). The largest variation was for BPBTB with estimated log P_l between −15 (EPI Suite) and −27 (SPARC). The average difference was $<10^4$ (RMSE of log P_l was 3.86). However, the average difference in P_l was over 10^8 (RMSE of log P_l was 8.47) for NFRs with molecular weight > 800 g/mol (see S2.1 for the list of compounds) in comparison to $<10^3$ difference for NFRs <800 g/mol (RMSE of log P_l was 2.72). Chemicals with higher molecular weight generally have lower vapor pressures, the measurement values of which are subject to larger bias. When these data are used as a training set for the regression based QSAR model such as EPI Suite, the predicted values tend to have larger bias.

TMP and BPBTB had the maximum (6, EPI Suite WATERNT) and minimum (−17.5, EPI Suite WSKOWWIN estimate) log S_l (mg/L) values (Fig. S8). Generally, the three estimates differed by $10^2–10^3$ for a given compound (RMSE of log S_l ranged 1.9–2.7). The largest discrepancy was for 4′-PeBPOBDE208, which had an estimated log S_l from −17.5 (EPI Suite WSKOWWIN) to −6 (EPI Suite WATERNT), and BPBTB with −17.5 (EPI Suite WSKOWWIN) and −6 (EPI Suite WATERNT). As with P_l, estimates of S_l of compounds with molecular weight > 800 g/mol differed by 10^7 between the estimates from WSKOWWIN and WATERNT of EPI Suite, 10^2 between WSKOWWIN and SPARC estimate and 10^5 between WATERNT and SPARC. The average difference was 10^2 for those compounds having molecular weight < 800 g/mol.

Log K_{AW} ranged from 1.2 (SPARC) for TiPP (224 g/mol) to −18.8 (EPI Suite) for EBTEBPI (952 g/mol) (Fig. S9). Among the three partition coefficients, K_{AW} had the largest variation among estimates. Generally, K_{AW} differed by 10^3 between the three estimates (RMSE of log K_{AW} ranged 2.1–3.6). OPFRs had the largest variations of $10^3–10^8$ (see S2.2 for the list of compounds). The largest variation was for BCMP-BCEP (583 g/mol) with log K_{AW} of −12.2 (Absolv) to −5.4 (SPARC). TBBPA also exhibited large variation with log K_{AW} of −11.03 (EPISuite) to −5.26 (SPARC). The variation was most pronounced between SPARC and the other two programs, which are based on a fragment method.

Log K_{OW} ranged from −1.9 (Absolv) for melamine (126 g/mol) to 16.5 for BPBTB (1451 g/mol, Absolv) (Fig. S10). Variability in K_{OW} was within 10^{-2} (RMSE range 1.1–1.9). The largest variations in K_{OW} was $>10^5$ for BCMP-BCEP (583 g/mol) of log K_{OW} of 3.3 (EPI Suite) and 8.8 (SPARC). The variation between the estimates for other OPFRs tended to be greater than the average, particularly between SPARC and the other two programs (see S2.3 for the list of compounds).

Log K_{OA} ranged from 2.5 (SPARC) for TMP (140 g/mol) to 30.2 (EPI Suite) for BPBTP (1451 g/mol) (Fig. 1). Each compound's three estimates typically differed by $<10^2$ (RMSE ranged 1.8–1.9). The largest variation was for BDBP-TAZTO with log K_{OA} of 21.2 (EPI Suite) and 14.4 (SPARC). Discrepancies in estimates of 10^4–10^8 occurred for compounds that have a heteroatom N in the structural backbone and molecular weights varying from <400 to >800 g/mol. No program was performed better than another.

The difference among all the model estimates was consistently greater for compounds >800 g/mol, compared to those with <800 g/mol. This is not surprising given that the training sets used to develop these models are predominantly composed of lower molecular weight compounds (Arp et al., 2006; Zhang et al., 2010). Compounds ≥800 g/mol are typically beyond the models' parametric and structural domains and their estimated properties should be used with caution. Beyond the model domain, other factors also impact the large differences in estimated properties. First among these is the training set used; if the molecular structure of the compound of interest is not well represented among the training set compounds then a higher level of uncertainty is associated with the estimate. This is especially true for EPI Suite's HENRYWIN and WSKOWWIN models which predict partitioning behavior using a fragment method (Meylan and Howard, 1991, 1995; Zhang et al., 2010). Among NFRs, the phosphine oxide (P=O) structure of the OPFRs is not well represented in EPI Suite's training sets. Likewise, the theory used, and therefore assumptions made, when developing the algorithms used to calculate the estimated properties play a significant role in the overall variation among estimates. For example, although EPI Suite does contain polar chemicals in its training set, its inability to accurately account for the effect of polar functional groups to the overall partitioning of organic compounds is generally acknowledged (Zhang et al., 2010). In contrast, partition coefficients calculated using solute descriptors emphasize the polar sections of the molecular structure (Japertas et al., 2007). This may explain the large variation among EPI Suite, SPARC and Absolv for K_{AW} with the more polar OPFRs. Arp et al. (2006) found EPI Suite most poorly estimated the partitioning behavior of slightly polar highly fluorinated compounds relative to measured data, in comparison to SPARC and a pp-LFER technique similar to the one used in this work, that had more accurate predictions. The source(s) of the large variation in the estimation of NFR physical–chemical properties is likely an aggregate of all these model characteristics, but mostly the lack of structural representation in the training sets. What is clear from these results is that there is a growing need for estimation programs that can more accurately and precisely predict the physical–chemical properties of NFRs.

3.3. *Estimated environmental half-lives*

Half-life estimates, in general, varied widely between different models and literature. Estimates for $t_{water,\ 1/2}$ in particular were uncertain. For the 82 NFRs with $t_{water,\ 1/2}$ estimated using HYDROWIN, PBT profiler or literature data (see S1.3, Table S5), $t_{water,\ 1/2}$ ranged from 208 h for TnBP to 581 d for PBB-Acr. Compounds with extreme values of $t_{water,\ 1/2}$ from HYDROWIN were as high as 2.9×10^{14} h (HBCYD, see S2.5 for the list of compounds). Estimated $t_{water,\ 1/2}$ ranged from 912 h for DBP-TAZTO, DBS, TDMPP, TPPP and TTMN to 180 d for 4′-PeBPOBDE208, HBCYD, OBPB, OBTMPI, PBBC, TBBPS-BME and TTBP-TAZ for the 12 compounds with no $t_{water,\ 1/2}$ estimates in either HYDROWIN, PBT profiler or literature.

Primary $t_{soil,\ 1/2}$ estimates from CATALOGIC ranged from 1.7 h for MC 984, TDBPP, TmCP and TTBNPP to 164 d for TBP-DBPE (Table S5). EPI Suite estimates of primary $t_{soil,\ 1/2}$ ranged from 12 h (BPDP, TCP, TTBPP) to 3650 d (considered recalcitrant) for compounds >500 g/mol. No compounds were considered recalcitrant according to CATALOGIC estimates. Even for low molecular weight compounds, CATALOGIC and EPI Suite estimates of primary $t_{soil,\ 1/2}$ differed unsystematically by up to two orders-magnitude. This variation increased by up to four orders-of-magnitude for some compounds >650 g/mol (EBTEBPI, BPBTerPBTBPE).

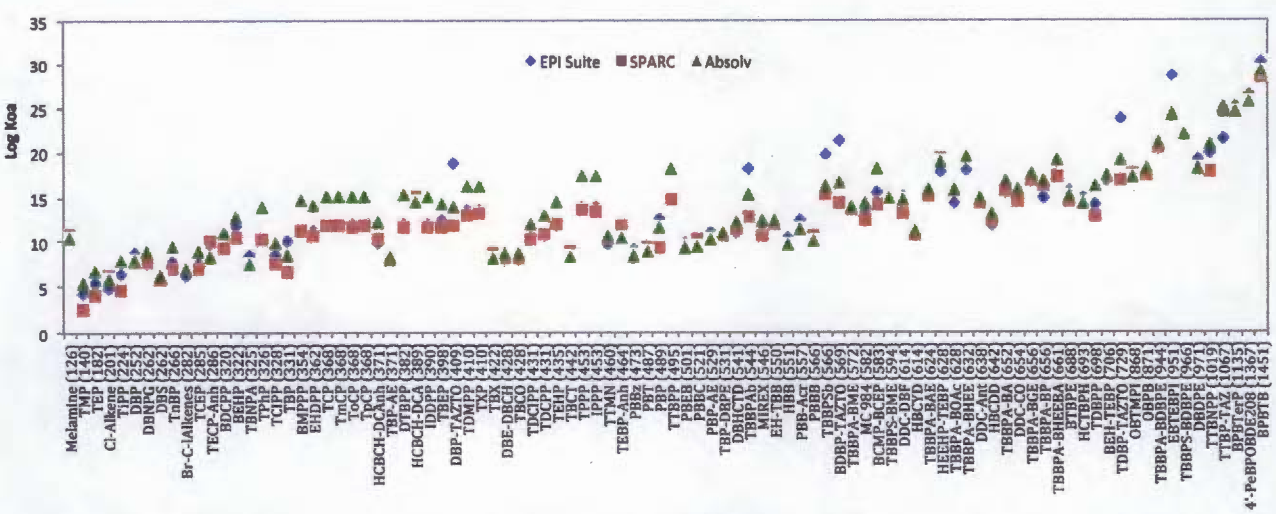

Fig. 1. Estimated log K_{OA} of NFRs, listed by increasing molecular weight (g/mol). EPI Suite estimates are represented by the blue diamonds, SPARC's by the red squares, and Absolv's by the green triangles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Ultimate $t_{soil,\ 1/2}$ estimates were more variable than primary because of greater complexity of degradation pathways. CATALOGIC's estimates of ultimate $t_{soil,\ 1/2}$ varied from 11 to 14 h for Br–Cl-Alkene, Cl-Alkene, PIP, TiPP and TXP to 3650 d for 9 compounds (4′-PeBPOBDE208, BCMP-BCEP, DBDPE, DBNPG, HCTBPH, OBTMP, PBP-AE, TCEP and TTBP-TAZ). Compounds with molecular weight < 400 g/mol generally had the shortest $t_{soil,\ 1/2}$, with EPI Suite and CATALOGIC estimates ≤1000 d (with several exceptions that were longer). EPI Suite estimated that compounds of >400 g/mol were predominantly recalcitrant while CATALOGIC estimates of ultimate $t_{soil,\ 1/2}$ showed no discernable pattern as a function of molecular weight. Using CATALOGIC, the potential degradation pathways of OBPB, TBBPS-BME, EH-TBB, BEH-TEBP, OBTMPI, and TBP-DBPE were identified as having stable degradation products of potential environmental concern given their bioaccumulation and bioconcentration factors, as estimated by EPI Suite's BCFBAF model (Arnot et al., 2009). Further work regarding the potential for toxicity and/or bioaccumulation of these degradation products is warranted but is beyond the scope of this work.

3.4. Estimated overall persistence and long range transport

The minimum P_{OV} and CTD of the 82 compounds with reliable values of $t_{water,\ 1/2}$ (S1.3, Table S5) and using primary $t_{soil,\ 1/2}$ was 14 h (TEHP) and <1 km (melamine, 126 g/mol), respectively. The maximum P_{OV} and CTD for this group was 216 d (BTBPE, EBTEBPI, OBTMPI and TTBP-TAZ) and 21,197 km (PBBz, 473 g/mol), respectively. When ultimate $t_{soil,\ 1/2}$ was used, P_{OV} ranged from 19 h (TEP and TMP) to 218 d (TBBPA-BHEEBA). P_{OV} for the group "no or extremely high $t_{water,\ 1/2}$" (S1.3, Table S5) ranged from 40 d (DBS) to 34 years (HBCDD). CTDs were not impacted by changes in soil degradation rates. Fig. 2 shows the results from model runs 1–3, using K_{AW} and K_{OW} estimates from EPI Suite, SPARC, and Absolv and CATALOGIC's ultimate $t_{soil,\ 1/2}$. Results for the 16 runs are shown in Figs. S11–S13.

NFRs were categorized into three classes according to their POP-like and PBDE-like behavior based on model runs using

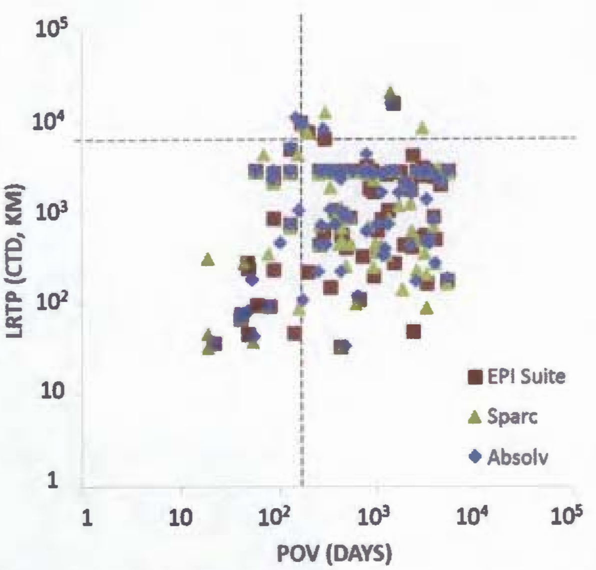

Fig. 2. P_{OV} and LRTP results from runs 1–3 obtained assuming using CATALOGIC's ultimate $t_{soil,\ 1/2}$ and K_{AW} and K_{OW} estimates from EPI Suite (red square), SPARC (green triangle), and Absolv (blue diamond). The dashed lines represent the limits for the POP-like comparison. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

CATALOGIC's ultimate $t_{soil,\ 1/2}$ (aggregate of runs 1–3 using physical–chemical properties from EPI Suite, SPARC and Absolv) and EPI Suite's ultimate $t_{soil,\ 1/2}$ (aggregate of runs 4–6 obtained using physical–chemical properties from each program). Classification differed significantly between results based on CATALOGIC versus EPI Suite estimates. Using CATALOGIC's ultimate $t_{soil,\ 1/2}$, 0% fell into Class I (POP-like behavior), 12% fell into Class II (POP-like P_{OV} or CTD), and 88% fell into Class III (do not exhibit POP-like behavior). Using EPI Suite's ultimate $t_{soil,\ 1/2}$, 2% exhibited POP-like behavior (Class I), 40% fell into Class II, and 58% fell into Class III. Using PBDE-like behavior as the criterion and CATALOGIC's ultimate $t_{soil,\ 1/2}$, 7% fell into Class I (exhibit PBDE-like behavior), 38% fell into Class II (PBDE-like P_{OV} or CTD), while 55% fell into Class III (do not exhibit PBDE-like behavior). Using EPI Suite's ultimate $t_{soil,\ 1/2}$, 29% fell into Class I, 30% into Class II, and 41% into Class III.

LRTP of NFRs was assessed using the emission-to-air scenario. Out of the three emission scenarios offered by the *Screening Tool*, this is most representative of NFRs' entrance into the environment via indoor-air to outdoor-air transfer or industrial emissions to air. CTD of the 94 NFRs ranged from <1 km for melamine (126 g/mol, EPI Suite, SPARC and Absolv partition coefficients, EPI Suite ultimate $t_{soil,\ 1/2}$) to >20,000 km for PBBz (473 g/mol, SPARC partition coefficients, EPI Suite ultimate $t_{soil,\ 1/2}$). Overall, 47–50% of NFRs had a CTD <700 km or low LRTP; 12–20% had a CTD of 700–2000 km or a medium LRTP; and, 30–41% had a CTD >2000 km or high LRTP (Beyer et al., 2000).

The results from the *Screening Tool* need to be interpreted in light of evidence of long range transport of some NFRs and the model's strengths and weakness. Recent studies have measured TDCIPP, TCEP, TCIPP, TPhP, TnBP, TBEP, TEHP and EHDPP in Arctic air at concentrations 10–10^2 higher than that of other BFRs and even higher than PBDEs at their peak usage (Jantunen et al., 2014; Salamova et al., 2014). In addition, Möller et al. (2011) measured PBBz, HBB, TBP-DBPE, PBT and BEH-TEBP in Arctic air at concentrations exceeding those of PBDEs. The measurements were taken from remote Arctic locations which do not suggest local sources of contamination (e.g., Hale et al., 2008). In comparison, the *Screening Tool* estimated that all OPFRs measured in Arctic air had low-to-medium LRTP except for TEHP for which LRTP ranged between low and high (runs 1–6). The *Screening Tool* did, however, estimate high LRTP for 9 of the tested OPFRs (IDDPP, MC 984, PIP, TEHP, TTBNPP, TTBPP, TPPP, TDMPP and TXP).

The *Screening Tool* estimated that OPFRs would partition mainly to the water compartment (68–99% of the mass of TCEP and TCIPP, respectively). The chemical mass in air of about half of the OPFRs was estimated to be predominantly in the gas phase that reacts rapidly with the OH radical. However, measurements show OPFRs sorb to particles (Jantunen et al., 2014; Salamova et al., 2014) where they are not subject to OH radical reaction, thereby greatly increasing their atmospheric life span and making long-range transport viable (Liu et al., 2014). The *Screening Tool* was better able to predict the LRTP of other NFRs measured in the Arctic at elevated concentrations. PBBz, PBT, HBB and TBP-DBPE measured by Möller et al. (2011) were estimated by the *Screening Tool* to have a high LRTP except for TBP-DBPE, which was estimated to have a medium LRTP. In spite of Möller et al. (2011) detecting these compounds in the gas phase, the *Screening Tool* predicted that most PBT and TBP-DBPE mass in air would be particle-sorbed.

Scheringer and co-workers who developed the *OCED Screening Tool* model noted several sources of uncertainty in the model such as its inability to capture the episodic transport to the Arctic of particle-sorbed compounds (Scheringer, 2009; Scheringer et al., 2009). They also commented that the model's reliance on K_{OA} to estimate gas-particle partitioning could potentially be a source of error. Another explanation for the misclassification of LRTP of

OPFRs may come from the very high variability, and presumably uncertainty, in K_{AW} as noted here. This uncertainty, together with potentially underestimating the fraction of particle-sorbed chemical, may explain the model's estimate of most OPFRs partitioning to water and underestimation of atmospheric transport.

4. Implications

Of the 94 NFRs identified here as PBDE replacements, up to 30% exhibited an environmental fate similar to PBDEs while 2% showed a P_{OV} and LRTP similar to other POPs. Furthermore, when released into the air, upwards of 40% have the potential to undergo LRTP. These results are not surprising given the tendency to replace banned substances with the next-best-alternative; chemicals that have a similar function and that can be used in a similar way in products as controlled substances are likely to have a similar environmental fate. For this reason, the one-by-one regulatory approach is problematic for ensuring that alternative FRs to the (mostly) controlled PBDEs will be less hazardous than their predecessors. Rather, NFRs, as a class, need to be evaluated for their "environmental acceptability" as well as environmental hazard. For example, the Government of Canada's action on a grouping of Certain Organic Flame Retardants under the Chemicals Management Plan is intended to assist with informed substitution (http://www.chemicalsubstanceschimiques.gc.ca/group/flame_retardant-ignifuges/profile-eng.php).

The screening results presented here for NFR persistence and LRTP require a more critical assessment because of the wide variability in many physical–chemical property estimates obtained from EPI Suite, SPARC and Absolv, and potentially erroneous results obtained for some compounds using these estimation programs and the OECD *Screening Tool*. Although the EPI Suite models showed the best overall performance when judged relative to measured physical–chemical properties, the same cannot be said for NFRs until more empirical data become available for comparison. Furthermore, EPI Suite provided unreasonable estimates for the environmental degradation rates of several compounds. If used without further review, these estimates could dramatically affect the results of the assessment of environmental fate of these compounds. These results underscore the urgent need to update the programs' training sets with compounds more representative of those in use as FRs. The environmental and health hazards associated with these compounds can only be properly assessed if the environmental fate and read-across toxicological assessments are based on trustworthy and reliable information, notably physical–chemical properties.

Selecting which estimation program to use depends on the purpose they serve. CATALOGIC can be useful when conducting an in-depth assessment of the degradation of chemicals. The OECD Toolbox provides much of the same functionality as CATALOGIC and is publicly available (http://www.oecd.org/chemicalsafety/risk-assessment/theoecdqsartoolbox.htm). When screening compounds for their persistence and LRTP, our results show that using EPI Suite is an acceptable alternative, even though estimated data on environmental fate should be used with caution and re-evaluated where necessary. As an added bonus, EPI Suite is publicly available. Finally, the seeming misclassification of LRTP of OPFRs should remind us to exercise caution when interpreting results from the OECD *Screening Tool*, which is intended to be just that – a screening tool.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.chemosphere.2015.11.017.

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Jennifer Lowery, MD, FAAP

American Academy of Pediatrics

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Jennifer Lowery, American Academy of Pediatrics

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Responses to Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants
January 28, 2016

Jennifer Lowry, MD, FAAP, American Academy of Pediatrics

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA TB 117-13 by the Commission would impact or influence the requests within the organohalogen petition.

The American Academy of Pediatrics (AAP) believes that adoption of CA TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition regarding additive organohalogen flame retardants ("Petition"). Three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures -- would not be covered by the TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not prevent the use of these toxic chemicals in furniture. That is, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and/or furniture manufacturers could continue to add toxic flame retardants to their products even if the chemicals were not needed to meet a flammability standard. We therefore believe that it is necessary for the Consumer Product Safety Commission (CPSC) to grant our Petition in order to best protect children.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB 117-2013 as a national mandatory standard for upholstered furniture?

Overall, yes, however we believe that adoption of CA TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition regarding additive organohalogen flame retardants ("Petition"). Three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures -- would not be covered by the TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not prevent the use of these toxic chemicals in furniture. That is, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and/or furniture manufacturers could continue to add toxic flame retardants to their products even if the chemicals were not needed to meet a flammability standard. The AAP therefore believes that it is necessary for the Consumer Product Safety Commission (CPSC) to grant our Petition in order to best protect children.

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

No data/unable to answer question.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

No data/unable to answer question.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

As a threshold matter, it should be stated that the studies referenced in this response are not an exhaustive list of all relevant studies, but are instead examples of what is in the literature. Much of the literature on adverse effects from non-polymeric additive organohalogen flame retardants has been from research on animals and in vitro experiments. This is largely due to the fact that studies cannot be done in humans (especially children) to fully understand the toxicity of chemicals. Thus, health care practitioners must weigh the science from animal studies and those from human epidemiologic studies which show association. That said, what is currently know about some of the substitute flame retardants is enough to give concern.

A recently published article (December 2015) assessed sic organophosphate flame retardants on the ability to repress endocrine signaling in human prostate cancer cell lines. Tris(1,3-dichloro-2-propyl) phosphate (TDCIPP), a non-polymeric additive organohalogen flame retardant, was found to induce the cancer cell genes activation and protein expression. This indicates that it is potentially significant endocrine disruptor. (Reers et al. J Biochem Mol Toxicol 2015) Interestingly, similar findings were seen in a study from 1978 (Gold et al. Science 1978).

Similar findings have been seen in animal and marine studies finding that TDCIPP can alter thyroid hormones and gene expression of other proteins critical to growth and reproduction. Additionally, this flame retardant was shown to bioaccumulate in the zebra fish. While this may not be significant at first glance, understanding that bioaccumulation is occurring in marine animals can have grave implications regarding exposures to humans when we consider our food consumption. Lastly, early exposure to TDCIPP in fish has been associated with adult ability for reproduction.

In addition to endocrine effects, TDCIPP has been found to cause developmental toxicity in zebrafish embryos raising a concern for human children given the frequent presence in indoor dust and potential human exposures. (Fu et al. Environ Sci Technol. 2013)

Another non-polymeric organohalogen additive flame retardant, decabromodiphenyl ethane (DBDPE), has been found to induce drug metabolizing enzyme activities including those that effect thyroid hormone homeostasis. This is a concern given the ubiquitous exposures that humans have to flame retardants and the endogenous and exogenous compounds that rely on these drug metabolizing enzymes for, ultimate, effect.

FireMaster 550® is the second most commonly used flame retardant in consumer goods and is detected in house dust. In a recent study (Bailey et al. Neurotoxicol Teratol 2015), maternal exposure of zebrafish during pregnancy resulted in reduction in social behaviors and hypoactivity when the offspring were in their adolescent stages and more significant compared to those exposures that occurred during their adolescence.

While these are only a few of "all the non-polymeric additive organohalogen flame retardants included in the petition", it is known that those that all that are assessed are found in humans. For example, several emerging brominated flame retardants (BFRs) including 2-ethyl-1-hexyl-2,3,4,5-tetrabromobenzoate (TBB), bis(2-ethylhexyl) tetrabromophthalate (TBPH), 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), 4,5,6,7-tetrabromo-1,1,3-trimethyl-3-(2,3,4,5-tetrabromophenyl)-indane (OBIND), and decabromodiphenyl ethane (DBDPE) have been found in human breast milk. (Zhou et al. Environ Sci Technol 2014) Additionally, a study assessing 44 halogenated and organophosphate flame retardants found that 41 (93%) elicited adverse effects among one or more of the bioassays and concentrations tested. (Noyes et al. Toxicol Sci 2015).

Thus, the available literature suggests that molecules used as flame retardants and having similar structure and mechanisms will have similar adverse effects. Thus, taking all of them in consideration is needed rather than assessing them one as a time. The idea that a chemical with similar structure will not have similar biological effects even if it hasn't been studied does not make sense with what we know about adverse reactions in organisms.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

As a threshold matter, it should be stated that the studies referenced in this response are not an exhaustive list of all relevant studies, but are instead examples of what is in the literature. The majority of data on adverse effects on flame retardants is what has occurred in animal studies and in vitro experiments. In order to assess vulnerable populations, it is important to know how exposures to non-polymeric additive organohalogen flame retardants will occur. Non-polymeric additive organohalogen flame retardants are reactive and will release from the product it is in over time. Many studies have assessed the presence of flame retardants in house dust. While this is common source, it is not the only source.

At study assessing urinary concentrations of flame retardants and house dust found that dust may be an important source for some, but not all flame retardants. Bis(1,3-dichloro-2-propyl) phosphate (BDCPP) and diphenyl phosphate (DPP), metabolites of the OPFRs tris(1,3-dichloro-2-propyl) phosphate (TDCPP) and triphenyl phosphate (TPP) were found in men tested over a course of three months. BDCPP and DPP were detected in more than 90% of urine samples and had a strong temporal reliability with what was found in dust. Similar results were found with TDCPP, but not TPP. (Meeker et al. Environ Health Perspect 2013). However, it is important to note that men are not the population most likely to be exposed to household dust. The same researcher did find that organophosphate flame retardants may be associated with altered hormone levels and decreased semen quality. The study concluded that more research on sources and levels of human exposure to organophosphate flame retardants and associated health outcomes are needed. (Meeker et al. Environ Health Perspect 2010)

As was noted above, several emerging brominated flame retardants (BFRs) including 2-ethyl-1-hexyl-2,3,4,5-tetrabromobenzoate (TBB), bis(2-ethylhexyl) tetrabromophthalate (TBPH), 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), 4,5,6,7-tetrabromo-1,1,3-trimethyl-3-(2,3,4,5-tetrabromophenyl)-indane (OBIND), and decabromodiphenyl ethane (DBDPE) have been found in human breast milk. (Zhou et al. Environ Sci Technol 2014)

Infants and children are more likely to have higher exposures to organohalogen flame retardants than other populations. The only exception may be the geriatric population who spend more than 90% of their time indoors. However, many studies have brought attention to the former population compared to the latter. One study assessed the exposures of organohalogen flame retardants via indoor dust from elementary schools and domestic houses. (Mizouchi et al. Chemosphere. 2015). Significantly higher concentrations of tris(butoxyethyl)phosphate (TBOEP), tri-n-butyl phosphate (TNBP), triphenyl phosphate (TPHP), tris(methylphenyl)phosphate (TMPPs), and total-flame retardants were found in dust samples from elementary schools than from domestic houses. It might be due to that higher concentrations of TBOEP (as leveling agent) were detected from the floor polisher/wax products collected in those elementary schools. On the other hand, significantly higher concentrations of tris(2chloroethyl)phosphate (TCEP), tris(2-chloroisopropyl)phosphate (TCIPPs), and total chloroalkyl-flame retardants were found in domestic houses than in elementary schools.

Needless to say, children have many sources of exposure. Multiple studies have shown elevated organohalogen flame retardant levels in children from dust in their homes, daycares and schools. The dust may be inhaled or ingested resulting in increased exposure with most resulting from hand-to-mouth activity. Further studies have shown a decrease in exposures with handwashing. However, it is commonly known that children under the age of 3 have high hand to mouth activity increasing their exposures to many toxins. It is those same children who are undergoing rapid development, especially neurodevelopment, were exposures can cause more harm. This has been seen with lead poisoning and should not be treated much differently.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

I am not aware of any such studies and could not find any in the medical literature.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

It should be clarified that the Petition seeks a ban on non-polymeric additive organohalogen flame retardants in four classes of consumer products, not all 16,000. However, what percentage of the 16,000 is represented by the four classes is information that we believe the CPSC is in a better position to ascertain.

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Patrick Morrison

International Association of Fire Fighters

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

<u>Patrick Morrison, International Association of Fire Fighters</u>

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

Stevenson, Todd

From: Morrison Pat <pmorrison@iaff.org>
Sent: Friday, January 29, 2016 4:57 PM
To: Stevenson, Todd
Subject: RE: Organohalogen Public Hearing Questions for the Record

Dear Mr. Stevenson,

Below you will find the International Association of Fire Fighters answers to the QFR's from Commission on the Public Hearing on the Petition Regarding Additive Organohalogen Flame Retardants.

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

   The adoption of CA-TB117-13 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture. However three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures would not be covered by a national CA-TB117-13 standard. Too ensure that non-polymeric, additive organohalogen flame retardants are not added to products in these categories, the Commission should grant the Petition and adopt the regulation we have sought. The adoption of CA-TB117-13 in conduction with the ban on organohalogens flame retardants in the categories outlined in this petition will greatly impact the health and safety of the general public and fire fighters.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide. ---The IAFF does not have access to this data. However, the flame retardants manufacturers and the foam, fabric, and plastic industries which add the chemicals during their manufacturing processes would be the best source for this information.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.--- The IAFF does not have access to this data.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide. ---The IAFF does not have access to this data.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.--- The IAFF does not have access to this data.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.--- The IAFF is not aware of any studies that show the benefits non-polymeric additive organohalogen flame retardants.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?--- The IAFF is unable to provide an estimate as to what percentage of the products that CPSC regulates would be impacted by a ban of on non-polymeric additive organohalogen flame retardants .

Sincerely,

Patrick Morrison
International Association of Fire Fighters
Assistant to the General President for Health and Safety
1750 New York Avenue NW
Washington, DC 20006
202-824-1570

Commissioner Joseph Mohorovic

7. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

8. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

9. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

10. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

11. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

12. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

From: Stevenson, Todd [mailto:TStevenson@cpsc.gov]
Sent: Wednesday, December 30, 2015 10:32 AM
To: Morrison Pat <pmorrison@iaff.org>
Cc: Adkins, Patricia <PAdkins@cpsc.gov>; Ziemer, Michelle <MZiemer@cpsc.gov>; Hammond, Rocky

<RHammond@cpsc.gov>
Subject: Organohalogen Public Hearing Questions for the Record

Dear Mr. Morrison:

Thank you for your participation in the public hearing on the petition requesting rulemaking on products containing organohalogen flame retardants on December 9, 2015. As indicated at the conclusion of the hearing, the Commission indicated that additional questions would be sent to the panelists and the responses would be included in the public record, along with your original testimony and other supporting documents.

Attached is your list of questions for the record (QFRs) from the Commission. Please send your QFR responses to me by Friday, January 29, 2016. My email address is tstevenson@cpsc.gov and I can be reached by telephone at 301-504-6836, if you have any questions.

Sincerely,

Todd Stevenson
Director, The Secretariat
Office of the General Counsel
US Consumer Product Safety Commission
4330 East West Highway
Bethesda, MD 20814-4408
(301) 504-6836, Fax (301) 504-0127

Luis Torres

League of United Latin American Citizens

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Luis Torres, League of United Latin American Citizens

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?
2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.
3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.
4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.
5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.
6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.
7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

<u>Luis Torres, League of United Latin American Citizens</u>

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Adoption of CA TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition for Rulemaking. Three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures -- would not be covered by a national TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not *prohibit* the use of these toxic chemicals in furniture. In other words, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and/or furniture manufacturers could voluntarily continue to add toxic flame retardants to their products even if the chemicals were not needed to meet a flammability standard. Therefore, to ensure that non-polymeric, additive organohalogen flame retardants are not added to products in these categories, the Commission should grant the Petition and adopt the regulation we have sought.

Commissioner Joseph Mohorovic

1. *<u>Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?</u>*

Although the LULAC National members have not taken a formal position (our national assembly meets July 2016), we would be inclined to support the adoption of TB 117-2013 as a mandatory national standard.

2. *<u>Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.</u>*

The flame retardants manufacturers and the foam, fabric, and plastic industries which add the chemicals during their manufacturing processes would be the best source for this information. In addition, we are aware that the Petition for Rulemaking submitted to the CPSC on June 30, 2015 discusses the presence of non-polymeric, additive organohalogen flame retardants in products at pages 25-28.

3. *Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.*

No, we do not.

4. *Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.*

The Petition for Rulemaking (pages 43-47, and corresponding footnotes 121-148) includes a review of the literature in the public domain addressing the toxicity of non-polymeric additive organohalogen flame retardants. This is also discussed in several of the statements supporting the Petition, including the statement of Ruthann Rudel.

5. *Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.*

The answer to this question is discussed in the Petition for Rulemaking at pages 36-41. Of particular interest to LULAC is the disproportionate body burdens of children, and especially children in communities of color. For example:

- Biomonitoring data from the Center for Disease Control and Prevention (CDC) documents the occurrence of PBDEs in human serum by age category and ethnicity (http://www.cdc.gov/exposurereport/). This CDC biomonitoring data shows:
  - Teenagers (ages 12 to 19) had higher body burdens than adults for all flame retardants measured.
  - Mexican Americans and non-Hispanic blacks had higher levels than the non-Hispanic white population.
  - All pregnant participants in the 2003-2004 CDC biomonitoring study had measurable levels of at least one PBDE in their bodies.
- The highest levels of harmful flame retardants in the general population are found in young children from communities of low socioeconomic status and communities of color. For instance, a North Carolina study of 80 toddlers found PBDEs in 100% of the blood samples, and the sum of BDE-47, -99 and -100 (three of the pentaBDE congeners) was negatively associated with the father's level of education.[1]

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[1] Stapleton, H.M.; Eagle, S.; Sjödin, A.; & Webster, T.F. (2012). Serum PBDEs in a North Carolina toddler cohort: associations with handwipes, house dust, and socioeconomic variables. *Environmental Health Perspectives,* 120(7), 1049-54. doi: 10.1289/ehp.1104802.

- Studies have also documented exposure of pregnant women to organohalogen flame retardants, which is of particular concern because there are strong links between prenatal exposures to these chemicals and reduced IQ and greater hyperactivity in children.[2]
- A study of 416 predominantly immigrant pregnant women living in Monterey County, California, detected pentaBDE congeners in 97% of serum samples.[3]
- Flame retardant chemicals are transferred from the mother to the baby during breastfeeding.[4]
- Exposure to flame retardants in house dust is highest for toddlers and young children.[5]
- A study of 20 mothers and their children aged 1.5 to 4 found that the children had typically 2.8 times higher total PBDE levels than their mothers.[6]
- In a North Carolina study, levels of PBDEs on toddlers' hands correlated with serum PBDE levels, suggesting that the frequent hand-to-mouth contact exhibited by young children is a major exposure pathway.[7]

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- In another study, toddlers in homes with contaminated house dust had up to 100-fold greater estimated exposure levels compared to toddlers who were not exposed to contaminated dust.[8]
- A recent study of 21 US mother-toddler pairs confirmed that toddlers have significantly higher concentrations of TDCPP metabolites in their urine compared to their mothers, consistent with increased hand to mouth behavior and elevated dust exposure.[9]
- Another study also found higher body burdens of nearly all measured pentaBDE congeners (including BDE-47, -153, and -209) in 2-5 year-old Californian children in born to mothers with lower education.[10]
- In a study of ethnically diverse 6-8 year-old girls in California, measured pentaBDE levels were higher in children with less educated care-givers. This study also found that black preadolescent girls had significantly higher levels than white girls.[11]
- A study of CDC data showed that, after adjusting for age, levels of pentaBDE-47 and pentaBDE-99 were significantly lower in white children as compared to Mexican American and black children.[12]

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6. *Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.*

We are unaware of such studies.

7. *Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?*

We are unable to provide an estimate.

Maureen Swanson, MPA

Learning Disabilities Association of America

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Maureen Swanson, Learning Disabilities Association of America

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Maureen Swanson, Learning Disabilities Association of America

Commissioner Ann Marie Buerkle

1. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

The Learning Disabilities Association of America believes that adoption of CA TB 117-2013 as a mandatory national residential furniture flammability standard should have no impact on the Petition for Rulemaking. Three of the four product categories covered by the Petition -- mattresses and mattress pads, children's products and electronic enclosures -- would not be covered by a national TB 117-2013 standard. In addition, while adopting TB 117-2013 as a mandatory national residential furniture flammability standard would likely significantly reduce the use of additive, non-polymeric organohalogen flame retardants in residential furniture, it would not *prohibit* the use of these toxic chemicals in furniture. In other words, while the TB 117-2013 standard could be met without adding chemicals, absent the regulation sought in the Petition, foam and/or furniture manufacturers could voluntarily continue to add toxic flame retardants to their products even if the chemicals were not needed to meet a flammability standard. Therefore, to ensure that non-polymeric, additive organohalogen flame retardants are not added to products in these categories, the Commission should grant the Petition and adopt the regulation we have sought.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

The Learning Disabilities Association of America supports adopting California's TB117-2013 as a national mandatory standard for upholstered furniture. However, the adoption of TB117-2013 is a national standard for upholstered furniture is, by itself, absolutely insufficient to protect children from halogenated, non-polymeric flame retardant chemicals. We urge the CPSC to grant the Petition banning the four product categories if they contain any additive, non-polymeric organohalogen flame retardants.

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

   The Learning Disabilities Association of America provided and referenced all information we have on the use of non-polymeric additive organohalogen flame retardants in the written comments submitted to the CPSC on January 19, 2016 and attached again to the e-mail accompanying these responses.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

   The Learning Disabilities Association of America is not able to answer this question.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

   The Learning Disabilities Association of America provided and referenced all information we have on the toxicity of the non-polymeric additive organohalogen flame retardants included in the petition in the written comments submitted to the CPSC on January 19, 2016 and attached again to the e-mail accompanying these responses.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

   The Learning Disabilities Association of America provided and referenced all information we have on prenatal and children's exposures to non-polymeric additive organohalogen flame retardants in the written comments submitted to the CPSC on January 19, 2016 and attached again to the e-mail accompanying these responses.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

   The Learning Disabilities Association of America does not have any studies on the benefits of non-polymeric additive organohalogen flame retardants.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

   The Learning Disabilities Association of America is not able to answer this question.

Chairman Elliot Kaye
Consumer Product Safety Commission
4330 East West Highway
Bethesda, MD 20814

Comments on the Notice of Proposed Rulemaking
Petition Requesting Rulemaking on Products Containing Organohalogen Flame Retardants
Docket No. CPSC-2015-0022

January 19, 2016

Dear Chairman Kaye:

Our organizations represent millions of people with learning, developmental and intellectual disabilities, along with their families, physicians, teachers, therapists and other service providers. We are joined in these comments by leading scientists and physicians in the fields of neurodevelopment, toxicology and children's health. We submit the following comments in strong support of the rule proposed in Docket No. CPSC-2015-0022 to ban four categories of products – furniture, children's products, electronics enclosures and mattresses – if they contain any halogenated flame retardant chemicals. While halogenated flame retardants are implicated in many serious adverse health outcomes, including cancers and reproductive problems, our comments focus on the neurodevelopmental toxicity associated with this class of chemicals.

Our organizations are particularly concerned with halogenated flame retardant exposures to the fetus, infants and children. Infants and children are often more highly exposed to toxic chemicals than adults and more vulnerable to harm from those exposures as a result of their size and weight, rapid rate of growth and development, metabolism and behaviors. This is true of children's exposures to halogenated flame retardants.

We are witnessing an alarming increase in multiple adverse neurodevelopmental outcomes. One in six children in the United States has a reported developmental disability including autism, attention deficit hyperactivity disorder, and other developmental delays.[1] As of 2012, 5.9 million children in the United States had been diagnosed with attention deficit hyperactivity disorder (ADHD)[2]. According to a 2014 analysis from the U.S. Centers for Disease Control and Prevention (CDC), an estimated 1 in 68 children in the United States has an autism spectrum disorder[3]. This new estimate is 30% higher than the CDC estimate for 2008 (1 in 88), 60% higher than the estimate for 2006 (1 in 110), and 120% higher than the estimates for 2002 and 2000 (1 in 150).[4] The increasing trend in autism spectrum disorder cannot be fully explained by changes in awareness, ascertainment or diagnostic criteria.[5]

Uses and Exposures:
Halogenated flame retardants are ubiquitous in products, including furniture, baby and children's products, electronics enclosures and mattresses. A 2011 study of baby products found that 80% of the items tested contained flame retardants; all but one was halogenated. Many baby products contain more than one identifiable halogenated flame retardant.[6]

These chemicals migrate from products into household dust. The U.S. EPA estimates that children ages 1–5 ingest on average approximately 100–200 mg dust/day, while adults ingest about 20–50 mg dust/day.[7] A 2014 study of 40 daycare facilities and preschools in California found halogenated flame retardants, specifically tris phosphate, Firemaster 550 and polybrominated diphenyl ethers (PBDEs), in 100% of dust samples from the facilities. Levels of these flame retardants in dust were significantly higher in those facilities using napping materials made from foam.[8]

A 2012 study found that toddlers were significantly exposed to polybrominated diphenyl ether (PBDE) flame retardants due to transfer of house dust particles from their hands, and objects such as toys, to their mouths. There was a strong correlation between the PBDE levels on the children's hands and the levels measured in their blood. It is likely that other halogenated flame retardants commonly detected in house dust are similarly ingested by babies and young children.[9]

Some of the halogenated flame retardants of greatest emerging concern for neurodevelopment are also high volume chemicals.[10] [11]As with PBDEs, these "replacement" flame retardants cross the placenta to the fetus and are detected in umbilical cord blood and in increasing levels in breast milk.[12] Because halogenated flame retardants are high volume production, used in a wide range of consumer products including baby and children's products, migrate from products into house dust, are ingested in house dust through hand to mouth behaviors and in food, and bioaccumulate in human tissue, the public is widely exposed to halogenated flame retardants, with children likely to experience higher chronic exposures than adults.[13]

Unreasonable Risk of Harm to Neurodevelopment:
Beginning *in utero,* the developing brain is exquisitely vulnerable to harm from toxic chemicals, even at extremely low levels of exposure.[14],[15],[16] Mounting scientific evidence shows that halogenated flame retardants can interfere with brain development, and are implicated in problems with learning, attention and behavior. In studies of mammals, some of the halogenated flame retardants have effects on development and behavior that are transgenerational.[17]

Thyroid Disruption:
Halogenated flame retardants, which are structurally similar to thyroid hormones, disrupt thyroid function.[18] Proper levels of thyroid hormone are essential to healthy brain development. Even "subclinical hypothyroidism" – insufficient levels of thyroid hormones in the absence of apparent symptoms – in pregnant women can result in children with lower IQs, attention deficits, motor impairments and trouble with auditory and visual processing.[19]

In 2015, researchers with the Endocrine Society reviewed evidence on PBDEs and neurodevelopmental outcomes, and concluded that PBDE exposure interferes with thyroid hormone action during development.[20] Recent studies of halogenated flame retardants that have replaced PBDEs show that these chemicals also can disrupt thyroid hormone and alter brain development, posing an unreasonable risk of harm to neurodevelopment.[21]

PBDE flame retardants and prenatal exposures:

PBDEs, which are much more thoroughly studied than other flame retardant chemicals, are associated with lower IQ scores and neurobehavioral disorders.[22] Maternal exposure to PBDEs during pregnancy is especially dangerous, because PBDEs that enter a mother's body pass from her circulation to that of her unborn child, enter the baby's brain and can cause lasting damage.

In the last five years, three separate studies of hundreds of pregnant women and children in California, New York and Ohio have resulted in strikingly similar findings: children more highly exposed to PBDE flame retardant chemicals prenatally have lower IQs, cognitive delays and attention problems.[23],[24],[25] These effects appear to be permanent; long-term follow-up studies of these children found the association between prenatal PBDE exposure and decrements in IQ scores persisted throughout their school years.

As it became clear that PBDEs are persistent, bioaccumulative and toxic to human health, the U.S. EPA reached voluntary agreements in 2004 with chemical manufacturers to phase out the use of certain PBDEs. Unfortunately, the chemical manufacturers responded by replacing PBDEs with other halogenated flame retardants. Below, we highlight three key examples of "replacement" halogenated flame retardants that present increasing concerns for neurodevelopment, while emphasizing that there are hundreds of other untested halogenated flame retardants that may present similar health concerns.

Firemaster 550 (TBB and TBPH)

FM550 is the second most commonly detected flame retardant in polyurethane foam used and sold in the United States.[26] FM550 is used in baby products, including nursing pillows and changing pads, and in furniture. Two of FM550's main components, TBB and TBPH, are brominated compounds. TBPH is a high production volume chemical produced at more than a million pounds per year; chemical manufacturers withhold information on production volumes for TBB.[27] TBB and TBPH are found in house dust.[28]

In 2012, research implicated FM550 as an endocrine disrupting chemical at exposure levels relevant to humans, with potential adverse effects at levels much lower than the "no observable adverse effects level" reported by the manufacturer. The study results suggest that FM 550 may impact neurodevelopmental endpoints, particularly by disrupting thyroid hormones.[29]

Hexabromocyclododecane (HBCD)

HBCD is a flame retardant chemical used in furniture upholstery and in polystyrene foam. It is found in household dust, indoor air and food. The European Union has identified HBCD as a

Substance of Very High Concern that meets the criteria of a PBT (persistent, bioaccumulative, toxic) substance.[30] Levels of HBCD have increased and continue to increase in the environment and in human tissues. HBCD crosses the placenta to the fetus and is found in umbilical cord blood and breast milk, with levels in human breast milk increasing over recent decades.[31]

In 2013, HBCD was added to the list of persistent organic pollutants (POPs) under the Stockholm Convention, with the recommendation that HBCD should be eliminated from the global marketplace to protect human health and the environment.[32] Scientific studies in mammals show that HBCD is a neurodevelopmental toxicant, with some adverse effects on development and behavior that are transgenerational. In recent years, scientific advances have resulted in a better understanding of HBCD's potential to interfere with thyroid function and disrupt brain development.[33]

<u>tris(1,3-dichloro-2-propyl)phosphate (TDCPP)</u>
In the late 1970s, manufacturers voluntarily stopped using TDCPP in children's pajamas because of its mutagenicity.[34] Instead of halting production and use of TDCPP in light of grave risks to children's health, manufacturers have added TDCPP to other children's products, mattresses and furniture. A recent study found that TDCPP was the most commonly detected flame retardant in baby products containing polyurethane foam, detected in 36% of the items.[35] TDCPP is also commonly detected in furniture and house dust.[36]

In 2006, the Consumer Products Safety Commission (CPSC) estimated that children's exposure to TDCPP from treated furniture was five times higher than the agency's acceptable daily intake.[37] The researchers who found TDCPP in more than a third of baby products tested predict that infants may receive greater exposure to TDCPP from baby products compared to the average child or adult's exposures from upholstered furniture, all of which are higher than acceptable daily intake levels of TDCPP set by the CPSC.[38]

In 2011, scientists found that TDCPP, as well as other replacement "tris" flame retardants, may affect neurodevelopment *with similar, or even greater, potency* than chemicals already known or suspected to be neurotoxicants.[39]

<u>Address Halogenated Flame Retardants as a Class</u>
The above examples represent three of the "replacement" halogenated flame retardants for which emerging evidence indicates unreasonable risks of harm to brain development in the fetus, infants and children. There are likely hundreds more. Chemical and product manufacturers add flame retardant chemicals to products without having to identify the chemicals or test them for health effects, although halogenated flame retardants are similar in structure to known neurodevelopmental toxicants. It is important to note that the 2011 study of baby products containing polyurethane foam identified for the first time *two chlorinated organophosphate flame retardants not previously detected in the environment or baby products.* [40]

Taken together, the emerging evidence of widespread exposures, thyroid disruption and neurodevelopmental toxicity make it imperative that the halogenated flame retardants are restricted from use in products as a class. We urge the CPSC to issue the proposed rule and end the cycle whereby manufacturers replace one halogenated flame retardant with another. Restricting a few flame retardant chemicals at a time is a failed approach that results in lasting harm to children's health and development.

Thank you for your consideration of these comments.

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[37] California Environmental Protection Agency, Dept. of Toxic Substances Control. Priority Product Profile: children's foam-padded sleeping products containing TDCPP. 2014 March; page 4.

[38] Stapleton H., et al. Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products. *Environ. Sci. Technol.*, 2011, *45* (12), pp 5323–5331

[39] Dishaw, L.V. et al. Is the PentaBDE replacement, tris (1,3-dichloro-2-propyl) phosphate (TDCPP), a developmental neurotoxicant? Studies in PC12 cells. Toxicol Appl Pharmacol. 2011 Nov 1;256(3):281-9. doi: 10.1016/j.taap.2011.01.005.

[40] Stapleton, H. et al. Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products *Environ. Sci. Technol.*, 2011, *45* (12), pp 5323–5331

11

Daniel Penchina

The Raben Group/Breast Cancer Fund

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Daniel Penchina, The Raben Group/Breast Cancer Fund

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

BREAST CANCER FUND

PREVENTION STARTS HERE.

January 29, 2016

U.S. Consumer Product Safety Commission
4330 East West Highway, Room 820
Bethesda, MD 20814

Breast Cancer Fund Responses to Questions for the Record
Public Hearing on the Petition Regarding Additive Organohalogen Flame Retardants

Dear Commissioners,

Thank you again for the opportunity to testify at the December 9th public hearing on the petition to ban the sale of certain consumer products containing non-polymeric, additive organohalogen flame retardants. We also appreciate the opportunity to respond to these questions for the record. Please find our responses below.

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

Yes, the Breast Cancer Fund would strongly support the Consumer Product Safety Commission adopting California's TB117-2013 as a mandatory national standard. We have seen the positive effects of the policy here in California – reducing the use of toxic flame retardants without jeopardizing fire safety – and support the Commission concluding its long deliberation on a flammability standard for upholstered furniture by adopting this standard.

We note that making TB117-2013 a national mandatory standard would not render this petition unnecessary. TB117-2013 allows furniture to be manufactured without flame retardant chemicals, but it does not prohibit their use, as the petitioners are requesting. In addition, the petition covers a much broader set of consumer products, including children's products, mattresses and electronics casings, while the scope of TB117-2013 is limited to upholstered furniture.

2. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

The Breast Cancer Fund does not have any information to add to what the petitioners have submitted.

3. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

The Breast Cancer Fund does not have any information on how these flame retardants are applied. The best source for this information would be the industries that use the chemicals.

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4. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

One of the primary groups of organohalogen flame retardants is polybrominated diphenyl ethers or PBDEs. PBDEs are structurally similar to polychlorinated biphenyls (PCBs); known carcinogens[i] that have been banned since the 1970's yet still persist in the environment.

Organohalogen flame retardants are endocrine-disrupting compounds, exerting effects on a number of hormonal systems, including androgens, progestins and estrogens. The major system affected by PBDEs —the thyroid hormone—has a prominent role in regulating brain development.[ii] As a result the most well-studied health outcome related to PBDE exposure is brain development. [iii,iv]

Very few data directly address the possible effects of PBDEs on breast cancer risk. However, *in vitro* studies have shown associations between at least some PBDEs and promotion of the proliferation of human breast cancer cells.[v] Recent studies indicate that penta-BDE can counteract the anti-cancer effects of Tamoxifen in cultured breast cancer cells.[vi] Finally, some studies suggest that PBDE's disrupt mammary gland development, an early endpoint linked to increased risk of later life breast cancer.[vii] Clearly more data is needed in the area of breast cancer risk, but the existing evidence is deeply concerning.

Even as PBDEs are being used less often as fire retardants in common consumer products, there is now evidence that the chemicals being used as substitutes – including Firemaster 550, a common substitute – are increasingly contaminating our environment.[viii, ix] Although the physiological effects of exposures to Firemaster 550 have not yet been studied extensively, one study demonstrated that feeding mother rats low doses during pregnancy and lactation led to changes in behavior, weight gain and earlier puberty in female pups.[x] Earlier puberty in females is a known risk factor for breast cancer. Other flame retardant substitutes also show toxicity, including chlorinated tris (Tris (1,3-dichloro-2-propyl) phosphate (TDCPP) and TCEP (Tris (2-chloroethyl) phosphate), which are both on the State of California's list of substances "known to cause cancer."[xi]

5. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

PBDEs have been used extensively in both consumer and industrial products.[xii]Although both penta- and octa-BDEs have been banned in the European Union and have not been produced in the United States since 2004, products containing them remain throughout the world. Due to the persistent nature of these chemicals, PBDEs are found ubiquitously in the environment and are detected in air, dust, soil and food, wildlife and humans. The 2003-2004 National Health and Nutrition Examination Survey conducted by the CDC found that 97% of the study participants were exposed to at least one PBDE.[xiii] Exposures at sensitive stages of development have been shown to have the highest impact on human health, which leads to serious concerns about exposures among pregnant women and children.

There is considerable geographic variability in exposures to the chemicals; people in California, which until 2013 had a particularly stringent furniture flammability standard, have much higher levels of PBDE exposures than do people in Massachusetts. Within the California group, lower socioeconomic status is associated with higher PBDE levels.[xiv,xv] Mexican Americans living in California have significantly higher PBDE levels in blood serum than do Mexicans living in their homeland.[xvi]

Data from young girls (ages 6 to 9) from California and Ohio support these findings. Although PBDEs were found in almost all samples tested, girls in California had significantly higher blood serum PBDE levels than did girls from Ohio, and young African American girls had higher levels than either white or Hispanic girls.[xvii]

6. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

We do not have access to, nor do we know of, any studies showing any benefit from these toxic chemicals.

7. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

The Breast Cancer Fund has no knowledge of how many or what percentage of the 16,000 products regulated by the CPSC contain non-polymeric additive organohalogen flame retardants. The fact that the Commission does not know this information underscores a major flaw in our chemical regulatory system – lack of transparency on what chemicals are used in what products. This lack of information about the chemicals contained in a particular product makes it difficult for agencies to regulate toxic chemicals and impossible for consumers to make educated choices in their purchasing decisions in order to protect their health and the health of their families. Consumers increasingly want to know this information, but unfortunately agencies like the Commission cannot provide it and manufacturers most often refuse to do so. Disclosure of ingredients in consumer products would give consumers information to choose safer products, regulatory agencies information to make better decisions on where to focus their limited resources, and push the market to safer products through substitution and innovation.

Once again, thank you for the opportunity to respond to these questions. If the Commissioners have any additional questions, we would be please to provide any information available to us.

Sincerely,

Jeanne Rizzo

Jeanne Rizzo, R.N.
President and CEO

[i] IARC Known Carcinogens Available Online: http://monographs.iarc.fr/ENG/Classification/latest_classif.php Accessed December 2, 2015.

[ii] Costa, L., Giordano, G., Tagliaferri, S., Caglieri, A., & Mutti, A. (2008). Polybrominated diphenyl ether (PBDE) flame retardants: environmental contamination, human body burden and potential adverse health effects. ACTA Biomed, 79, 172–183.

[iii] Costa, L., & Giordano, G. (2007). Developmental neurotoxicity of polybrominated diphenyl ether (PBDE) flame retardants. Neurotoxicology, 28, 1047–1067.

[iv] Talsness, C. (2008). Overview of toxicological aspects of polybrominated diphenyl ethers: A flame-retardant additive in several consumer products. Environ Res, 108, 158–167.

[v] Meerts, I., Letcher, R., Hoving, S., Marsh, G., Bergman, A., Lemmen, J., … Brouwer, A. (2001). In vitro estrogenicity of polybrominated diphenyl ethers, hydroxylated PBDEs, and polybrominated bisphenol A compounds. Environ Health Persp, 109, 399–407.

[vi] Li, Z. H., Liu, X. Y., Wang, N., Chen, J. S., Chen, Y. H., Huang, J. T., ... & Chen, D. J. (2012). Effects of Decabrominated Diphenyl Ether(PBDE-209) in Regulation of Growth and Apoptosis of Breast, Ovarian, and Cervical Cancer Cells. Environmental health perspectives, 120(4), 541-546.

[vii] Kodavanti PR, Coburn CG, Moser VC, MacPhail RC, Fenton SE, et al. Developmental exposure to a commercial PBDE mixture, DE-71: neurobehavioral, hormonal, and reproductive effects. Toxicol Sci. 2010; 116:297–312. [PubMed: 20375078]

[viii] Dodson, R.E., Perovich, L.J., Covaci, A., Van den Eede, N., Ionas, A.C., Dirtu, A.C., Brody, J.G., & Rudel, R.A. (2012). After the PBDE phase-out: A broad suite of flame retardants in repeat house dust samples from California. Environ Sci Tech,46, 13056-13066.

[ix] Patisaul, H. B., Roberts, S. C., Mabrey, N., McCaffrey, K. A., Gear, R. B., Braun, J., ... & Stapleton, H. M. (2013). Accumulation and endocrine disrupting effects of the flame retardant mixture Firemaster® 550 in rats: an exploratory assessment. Journal of biochemical and molecular toxicology, 27(2), 124-136.

[x] Patisaul, H. B., Roberts, S. C., Mabrey, N., McCaffrey, K. A., Gear, R. B., Braun, J., ... & Stapleton, H. M. (2013). Accumulation and endocrine disrupting effects of the flame retardant mixture Firemaster® 550 in rats: an exploratory assessment. Journal of biochemical and molecular toxicology, 27(2), 124-136.

[xi] Proposition 65 Available Online: http://oehha.ca.gov/prop65.html. Accessed December 2, 2015.

[xii] Costa, L., Giordano, G., Tagliaferri, S., Caglieri, A., & Mutti, A. (2008). Polybrominated diphenyl ether (PBDE) flame retardants: environmental contamination, human body burden and potential adverse health effects. ACTA Biomed, 79, 172–183.

[xiii] Sjodin, A.; Wong, L.; Jones, R.S.; Park, A.; Zhang, Y.; Hodge, C.; Dipietro, E.; McClure, C.; Turner, W.; Needham, L.L.; & Patterson Jr., D.G. (2008). Serum concentrations of polybrominated diphenyl ethers (PBDEs) and polybrominated biphenyl (PBB) in the United States population: 2003-2004. Environmental Science & Technology, 42(4), 1377-84. doi: 10.1021/es702451p.

[xiv] Petreas, M., Nelson, D., Brown, F. R., Goldberg, D., Hurley, S., & Reynolds, P. (2011). High concentrations of polybrominated diphenylethers (PBDEs) in breast adipose tissue of California women. Environ Int, 37(1), 190–197.

[xv] Zota, A. R., Rudel, R. A., Morello-Frosch, R. A., & Brody, J. G. (2008). Elevated house dust and serum concentrations of PBDEs in California: Unintended consequences of furniture flammability standards? Environ Science Technol, 42(21), 8158–8164.

[xvi] Eskenazi, B., Fenster, L., Castorina, R., Marks, A. R., Sjödin, A., Rosas, L. G., … Bradman, A. (2011). A comparison of PBDE serum concentrations in Mexican and Mexican-American children living in California. Environ Health Persp, 119(10), 1442–1448.

[xvii] Windham, G., Pinney, S., Sjodin, A., Lum, R., Jones, R., Needham, L., … Kushi, L. (2010). Body burdens of brominated flame retardants and other persistent organo-halogenated compounds and their descriptors in US girls. Environ Res, 110(3), 251–257.

12 & 13

Robert Simon

American Chemistry Council/North American Flame Retardant Alliance

Note: Mr. Robert Simon responded on behalf of the American Chemistry Council.

Mr. Michael Walls did not provide responses.

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Robert Simon, American Chemistry Council/North American Flame Retardant Alliance

Chairman Elliot F. Kaye

1. Are there data showing the clear benefits of flame retardants within the scope of the petition in the four product areas covered in the petition?

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?

3. Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?

Commissioner Robert S. Adler

1. Contribution of FR Chemical Additives to Reduced Fire Risks: Mr. Simon, you correctly point out that fire risks in the United States have dropped dramatically over the past decades. A number of factors have contributed to this drop, including less smoking, greater use of smoke alarms, and increased use of FR chemicals. Realizing that exact statistics are difficult to obtain, can you provide any data to demonstrate what the exact contribution of FR chemicals – as opposed to the other fire factors – is to reduced fire risks?

2. FHSA Applicability: Mr. Simon, in your testimony, you indicate that ACC and NAFRA believe the Petition "does not meet criteria outlined in the Federal Hazardous Substances Act (FHSA) to ban a product." Could you please give a more detailed analysis regarding this conclusion?

3. Unpublished Data on Organohalogen Hazards: Mr. Simon, please share with the Commission any unpublished data in the possession of ACC, NAFRA, or its member companies related to toxicity and exposure of organohalogens covered by the Petition. In addition, please indicate whether ACC, NAFRA, or its member companies share this information with product manufacturers.

4. Regrettable Substitution: Mr. Simon, if the Commission were to proceed to assess the hazard and risk profile of each individual organohalogen flame

retardant compound instead of treating all these FR additives as a class, how would you suggest the Commission avoid the problem of "regrettable substitution?"

5. List of Non-Hazardous FR Organohalogens: Mr. Simon, are you aware of any non-polymeric, additive organohalogen flame retardants that have been determined by any expert body such as the U.S. Environmental Protection Agency (EPA) not to present a significant health hazard? If so, please provide a list of such chemicals.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?
2. During the hearing you cited a study that shows the human exposure to the flame retardant TBBPA is 7 million times below the level associated with potential health effects. Is the study you cited the "Development of toxicity values and exposure estimates for tetrabromobisphenol A: application in a margin of exposure assessment," accepted for publication in the Journal of Applied Toxicology on January 19, 1995 and funded by the North American Flame Retardant Alliance Panel of the American Chemistry Council? Has this study been refuted in any way?
3. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.
4. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.
5. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.
6. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.
7. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.
8. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Michael Walls, American Chemistry Council

Chairman Elliot F. Kaye

1. Are there data showing the clear benefits of flame retardants within the scope of the petition in the four product areas covered in the petition?

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?

3. What are other sources of these flame retardants that are not included within the scope of the petition?

4. Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?

Commissioner Robert S. Adler

1. The 50 Non-Hazardous FR Chemicals: Mr. Walls, in your testimony you refer to 50 flame retardants that you claim EPA says are unlikely to pose a risk to human health. How many of these are non-polymeric, additive, organohalogen flame retardants covered by the Petition? Please provide a list of each such chemical.

2. Regrettable Substitution: Mr. Walls, if the Commission were to proceed to assess the hazard and risk profile of each individual organohalogen flame retardant compound instead of treating all these FR additives as a class, how would you suggest the Commission avoid the problem of "regrettable substitution?"

Commissioner Ann Marie Buerkle

1. Can you prioritize the 83 chemicals mentioned in the petition according to risk, hazard and exposure as it related to the four product categories: Children products, upholstered furniture, mattresses, electrical or electronic devices?

2. Please explain how the adoption of CA-TB117-13 by the Commission would impact or influence the requests within the organohalogen petition.

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

2. In your testimony you stated that "EPA has identified approximately 50 flame retardants that is says are unlikely to pose a risk to human health." Please provide the appropriate documentation from EPA to support your statement.

3. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

4. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

5. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

6. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

7. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

8. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Responses from the American Chemistry Council's
North American Flame Retardant Alliance

Chairman Elliot F. Kaye

1. **Are there data showing the clear benefits of flame retardants within the scope of the petition in the four product areas covered in the petition?**

   Yes. Section III of the North American Flame Retardant Alliance's (NAFRA's) comments filed in the docket for Petition HP 15–1 provide an extensive overview of the benefits of flame retardants. Key highlights from our comments include:

   There are a broad range of third-party, objective studies that demonstrate the fire-safety benefits provided by flame retardants. For example, the publication "Fire and Polymers VI: New Advances in Flame Retardant Chemistry and Science" presents peer-reviewed summaries of research from 32 national and international studies concluding that the application of flame retardants in furniture, home insulation, and electronics helps prevent or slow the spread of fire.[1] When commenting on the position that flame retardants do not work, the editors of the volume state unequivocally that the claim flies in the face of decades of work by thousands of fire scientists, chemists, and others, reported in thousands of peer reviewed papers, showing that from laboratory to full scale tests that flame retardants and flame retardant materials are effective [and]. . . effectively states that decades of peer reviewed work confirmed by thousands of scientists in multiple countries is worthless and that opinion trumps data.[2]

   The main function of flame retardants is to inhibit or suppress the combustion process in a way that reduces the overall heat release and flame spread. For the types of consumer products named in the petition, flame retardants are used to reduce potential fire hazard and risk by interfering with the combustion behavior of polymeric materials in those products. In so doing, flame retardants can provide an important layer of fire protection by stopping or delaying the onset or spread of fires. As discussed below in more detail, flame retardants can reduce the rate of heat release and the spread of flames from a fire. Flame retardants can also reduce smoke production during a fire, and they do not contribute significant additional toxicity to the smoke produced in a fire. Importantly,

[1] Morgan, A.B., Wilkie, C.A., and Nelson, G.B. (eds.). 2012. Fire and Polymers VI: New Advances in Flame Retardant Chemistry and Science. American Chemical Society, Washington, DC.
[2] *Id.* at 4.

flame retardants can provide occupants of a home or building additional life-saving time to escape a fire, as well as time for firefighters to respond to a fire.

The peak heat release rate is the key property governing the intensity of a fire,[3] and flame retardants are used to reduce the rate of heat release. As the heat release rate increases, more materials will ignite, burn, and propagate the fire. On the other hand, if heat release rate remains small, it is possible (or even likely) that the fire will be confined to the area or object of origin. By reducing heat release rate, flame retardants also reduce the spread of flames.

A set of studies on the effects of flame retardants on the heat release of natural and synthetic combustible materials showed the effectiveness of flame retardants.[4,5,6] The percentage improvement in peak heat release rate due to the addition of various flame retardant systems can be higher than 80%. Another compared the fire performance of 5 non-flame-retarded plastic products and with that of 5 identical but flame retarded products.[7] The amount of heat released by the non-flame-retarded products was nearly 5 times higher than that the amount of heat released by the flame retarded products (1,640 kW vs. 345 kW). The investigators also found the amount of material consumed in the fire tests for the flame retarded products (in spite of the additional burner) was less than half the amount lost in the tests for the non-flame-retarded products. Several subsequent studies have shown that when flame retarded products are involved in a fire, the fire is much less likely to spread to other products and much more likely to remain small.[8,9,10,11,12]

Generally, when products produce significantly lower heat release and much less material is burnt or destroyed, less smoke is released, leading to better visibility for first responders and for victims trying to escape. In 90% of studies of room-corner fire tests

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[3] Babrauskas, V., and Peacock, R.D. 1992. Heat release rate: the single most important variable in fire hazard. Fire Safety Journal 18: 255-272.
[4] Hirschler, M.M. 2015. Effect of flame retardants on polymer heat release rate. Pages 484-498 in Proceedings of the 14[th] International Conference Fire and Materials 2015. San Francisco, CA, Feb. 2-4, 2015. Interscience Communications, London, UK.
[5] Hirschler, M.M. 2015. Flame retardants and heat release: review of traditional studies on products and on groups of polymers. Fire and Materials 39(3): 207-231.
[6] Hirschler, M.M. 2015. Flame retardants and heat release: review of data on individual polymers. Fire and Materials 39(3): 232-258.
[7] Babrauskas, V., Harris, R.H., Gann, R.G, Levin, B.C., Lee, B.T., Peacock, R.D., Paabo, M., Twilley, W., Yoklavich, M.F., and Clark, H.M. 1988. Fire Hazard Comparison of Fire-Retarded and Non-Fire-Retarded Products. Special Publ. 749. National Bureau of Standards, Gaithersburg, MD. Available at http://www.nist.gov/el/fire_research/upload/2-Gilman.pdf (accessed Oct. 14, 2015).
[8] *Supra*, footnote 4.
[9] *Supra*, footnote 5.
[10] *Supra*, footnote 6.
[11] Hirschler, M.M. 2009. Heat release testing of consumer products. Journal of ASTM International 6(5).
[12] Bundy, M.F., and Ohlemiller, T.J. 2005. Fire performance of flame retarded polymers used in consumer electronics. Pages 85-97 in Proceedings of Fire and Materials 2005. January 31-February 1, 2005, San Francisco, CA. Interscience Communications, London, UK.

(where flame propagation, heat release and smoke release are assessed), the products with lower heat release also had lower smoke release.[13]

Finally, combustion of flame retardants does not contribute significant additional toxicity to the combustion byproducts. During the fire cycle, the flashover stage occurs when all exposed surfaces reach ignition temperature more or less simultaneously and fire spreads rapidly throughout a space.[14] *At the moment when fires go to flashover, the concentration of combustion products (i.e. toxic gases) accelerates significantly, so that there is both a quantitative and a qualitative difference in the toxicity of the atmosphere as soon as the fire reaches flashover. That is one of the key reasons why fire atmospheres are much more toxic after flashover.*[15]

There is a general consensus in the fire safety community that the smoke toxicity of virtually all common products, whether they contain flame retardants or not, and irrespective of the combustible substrate involved, have very similar smoke toxic potencies.[16,17,18] *For example, in the National Bureau of Standards study comparing flame retarded and non-flame retarded products, the results showed that none of the test specimens produced smoke of extreme toxicity.*[19] *The smoke from both sets of products was similar in potency and comparable to the potency of the smoke produced by materials commonly found in buildings. However, in terms of the total quantities of toxic gases produced in the room fire tests, expressed in carbon monoxide equivalents, the quantities produced by the flame retarded products were one third of the amounts of toxic products produced by the non-flame-retarded products. With regard to the overall fire hazard, the impact of flame retardant materials on the survivability of the building occupants was assessed by comparing the time to untenability in the burn room. The results showed that the average available escape time was more than 15-fold greater for the flame retarded products than for the non-flame-retarded products.*

With regards to the specific product categories covered in the petition, we highlight the following information that helps demonstrate the benefits of flame retardants in these categories:

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[13] *Supra*, footnote 11.

[14] In practice, fire statistics classify any fire that goes beyond the room of origin as a "flashover fire." A fire that went beyond the room of origin was clearly a large fire.

[15] Gann, R.G., Babrauskas, V., Peacock, R.D., and Hall, J.R., Jr. 1994. Fire conditions for smoke toxicity measurement. Fire and Materials 18: 193-199.

[16] Babrauskas, V., Harris, R.H., Braun, E., Levin, B.C., Paabo, M., and Gann, R.G. 1991. The role of bench-scale data in assessing real-scale fire toxicity. NIST Technical Note 1284. National Institute of Standards Technology, Gaithersburg, MD.

[17] Hirschler, M.M. 1994. Fire retardance, smoke toxicity and fire hazard. Pages 225-237 in Proceedings of Flame Retardants '94, British Plastics Federation. Interscience Communications, London, UK.

[18] Hirschler, M.M. 2006. Fire safety, smoke toxicity and acidity. Pages 47-58 in Proceedings of Flame Retardants 2006, February 14-15, 2006, London, UK. Interscience Communications, London, UK.

[19] *Supra*, footnote 7.

Furniture & Mattresses

The number of flammable consumer products in our homes and workplaces has increased, making consumer product fire safety a critical issue. For example, upholstered furniture and mattresses and beddings, two of the four product categories subject to the petition, are often some of the first products to ignite in a home structure fire. The percentage of upholstered furniture open flame fires in the US has increased slightly over the last 30 years (from 19% in 1980 to 20% in 2009), and fires starting with upholstered furniture caused approximately 17% of US home fire deaths between 2009 and 2013.[20] *When mattresses/bedding are added, the percentage of deaths rises to 31%.*[21] *Two analyses of fire statistics for the period 2005-2009, showed that upholstered furniture and mattresses/bedding were the first items ignited in 1.9% and 2.7% of home structure fires, respectively. Despite those relatively small percentages, 18.9% of fire fatalities and 6.97% of fire injuries were from home fires where upholstered furniture was the first item ignited. For mattresses/bedding, the death and injury figures were 14% and 10.4%, respectively.*[22, 23,24]

NFPA has also found that fires that begin on upholstered furniture do not stay on that piece of furniture. Only 6% of fires that started on upholstered furniture stay on the furniture while 68% of them spread beyond the room of origin.[25] *Upholstered furniture also can contribute to fires and fire losses, even when it is not the first item ignited. A recent analysis of NFPA's statistics found "that one-quarter of upholstered furniture fires, civilian injuries, and direct damages, and one-fifth (21%) of associated civilian deaths are associated with fires in which upholstered furniture is the primary item contributing to fire or flame spread but not the item first ignited."*[26]

Many burnable products also have a major role as the largest fuel package in the room even if not the first item ignited. As NFPA notes with respect to products that are the primary, but not first, fuels for fires:

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[20] *Id.*
[21] *Id.*
[22] Home Structure Fires that Began with Upholstered Furniture. 2011. NFPA Fire Analysis and Research. Available at http://www.nfpa.org/~/media/Files/Research/Fact%20sheets/UpholsteredFactSheet.pdf (accessed Oct. 13, 2015).
[23] Evarts, B. 2011. Home Fires That Began with Mattresses and Bedding, Ben Evarts. NFPA Fire Analysis and Research. Available at http://www.nfpa.org/research/reports-and-statistics/fire-causes/household-products/mattresses-and-bedding (accessed Oct. 13, 2015).
[24] *Home Structure Fires*, Marty Ahrens, NFPA Fire Analysis and Research, June 2011, available at http://www.nfpa.org/press-room/news-releases/2011/nfpa-releases-report-on-home-fires/?p=1 (accessed Oct. 13, 2015).
[25] Ahrens, M. Home Structure Fires. 2011. NFPA Fire Analysis and Research. Available at http://www.nfpa.org/press-room/news-releases/2011/nfpa-releases-report-on-home-fires/?p=1 (accessed Oct. 13, 2015).
[26] Hall, J.R., Jr. 2014. Estimating Fires when a Product is the Primary Fuel but not the First Fuel, with an Application to Upholstered Furniture. National Fire Protection Association. Page 1. Available at http://www.nfpa.org/~/media/Files/Research/NFPA%20reports/Major%20Causes/osprimaryfuel.pdf (accessed Jan. 11, 2016).

[C]omplete prevention may be an unattainable goal, but if such a product can be reengineered so that it burns with a slower rate of growth and/or a lower, less intense peak, then there should be fewer large fires and potentially substantial reductions in fire loss.[27]

A common starting point in product design is to choose materials that resist ignition from sources of fire, which is why flame retardants are often used by consumer product manufacturers.

Dr. Marcelo Hirschler of GBH International conducted large scale studies comparing two identical sofas, one of which had foam compliant with California's Technical Bulletin 117 (CA TB 117)[28] *and one of which had non-flame retarded foam (with no flame retarded fabrics). The flame retarded CA TB 117-compliant foam required an ignition source four times as intense to ignite than did the non-retarded foam, and even after ignition, the sofa with the flame retarded foam offered an extra minute of escape time.*[29]

Hirschler performed another study in which two upholstered chair mock-ups were tested, one with flame retarded foam (CA TB 117 compliant) and a flame retarded cotton fabric (NFPA 701 compliant) and the other with non-flame retarded foam and a non-flame retarded cotton fabric. The chair with the flame retarded materials survived the fire while the other chair without flame retardants was destroyed quickly.[30] *A video of the burn tests is available at https://www.youtube.com/watch?v=2K9hz7Wiw7c.*

Another study that speaks to the important use of additive organohalogen flame retardants in upholstered furniture comes from the Southwest Research Institute (SRI). Building upon work from a National Institute of Justice study on better quantifying the heat release rate from upholstered furniture,[31] *SRI found that the flame retardants used in the study were effective in slowing the spread of fire and providing valuable escape*

[27] *Id.* at 3.
[28] California, Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation. Requirements, Test Procedure and Apparatus for Testing the Flame Retardance of Resilient Filling Materials Used in Upholstered Furniture (March 2000).
[29] Hirschler, M.M. 2004. Residential Upholstered Furniture in the United States and Fire Hazard. Pages 300-319 in M. Lewin (ed.) Proceedings of the Fifteenth Annual Conference on Recent Advances in Flam Retardancy of Polymeric Materials, June 7-9, 2004, Stamford, CT. Business Communications Company, Norwalk, CT.
[30] Hirschler, M.M., Blais, M.S., and Janssens, M.L. 2013. Fire Performance of Polyurethane Foam: California Technical Bulletin CA TB 117 and British Standard BS 5852. Pages 319-330 in Proceedings of the Fire and Materials Conference, Jan. 28-30, 2013, San Francisco, CA. Interscience Communications, London, UK.
[31] Janssens, M. 2012. Reducing uncertainty of quantifying the burning rate of upholstered furniture, Report on grant no. 2010-DN-BX-K221. National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. Available at https://www.ncjrs.gov/pdffiles1/nij/grants/239050.pdf (accessed Jan. 10, 2016).

time.[32] *Indeed, the flame retardants in the furniture foam delayed the fire by three to four minutes. In tests of furniture with fire-protected cover and fire-protected foam, the initial flames died out and ultimately the furniture did not burn. These extra minutes would provide valuable time for people to escape and for fire fighters to respond. A video that explains this study in more detail can be found at https://www.youtube.com/watch?v=3lRcza_nPKI.*

In order to prevent fast developing fires once ignition has occurred, NAFRA believes that the filling contents of upholstered furniture must be either resistant to small open flame or it must be protected by an effective fire barrier. Rather than adopting a proscriptive ban without conducting the full risk assessment and cost benefit analysis required by the FHSA, manufacturers must be given the choice of either using fire resistant fillings that are also proven to be safe in regards to health effects, and/or using fire barriers, to fully and durably encase the non-FR foams inside their furniture, recognizing the technical challenges posed to furniture makers given the intricate designs and shapes seen with modern furniture.

Plastic Casing of Electronics

Non-Polymeric, additive organohalogen flame retardants play a critical fire safety role in the plastic casings of electronics. According to the NFPA, the incidence of home structure fires involving electronics has dropped from an average of 75,000 home fires per year in 1980 to an average of 47,700 between 2007 and 2011.[33] *This fire decrease has occurred even as the presence of electronics and electrical equipment has become more complex and more prevalent. NIST notes that "[t]he fact that fires originating from consumer electronic equipment represent less than one percent of all residential fires in the United States is largely credited to the use of flame retardant plastics.*[34]

Studies demonstrate that flame retardants in the plastic casings of electronic products materially advance consumer product safety. A recent study evaluated televisions meeting U.S. standards for flammability against other less stringent fire safety standards in Brazil and Mexico and found that televisions manufactured for the U.S. market were more resistant to external ignition than the others.[35] *Notably, in four out of the six trials from the study, the external casings of the televisions with flame retardants did not*

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[32] Blais, M., and Carpenter, C. 2015. Flexible Polyurethane Foams: A Comparative Measurement of Toxic Vapors and Other Toxic Emissions in Controlled Combustion Environments of Foams with and without Fire Retardants. Fire Technology 51:3-18. Available at http://link.springer.com/article/10.1007%2Fs10694-013-0354-5#page-2 (accessed Jan. 10, 2016).

[33] Hall, J.R., Jr. 2013. Home Electrical Fires. National Fire Protection Association. Available at http://www.nfpa.org/-/media/Files/Research/NFPA%20reports/Major%20Causes/OSHomeElectricalFires.pdf (accessed Oct. 8, 2015).

[34] Bundy, M., and Ohlemiller, T. 2004. Full-Scale Flammability Measures for Electronic Equipment. National Institute of Standards and Technology Technical Note 1461. Available at http://fire.nist.gov/bfrlpubs/fire04/PDF/f04101.pdf (accessed Jan. 10, 2016).

[35] Blais, M., and Carpenter, C. 2014. Combustion Characteristics of Flat Panel Televisions With and Without Fire Retardants in the Casing. Fire and Technology 51: 19-40.

achieve sustained ignition. In the instances when ignition did occur, it required more than 10 times the energy to cause flame retardant televisions to ignite.[36]

These results are entirely consistent with an earlier study conducted by the United Kingdom. Noting the increase in television fire incidents beginning in 1993, the U.K. Consumer Affairs Directorate with the Department of Trade and Industry (DTI) wanted to identify the causes of television fires and whether the use of different materials in the construction of the televisions could impact the incidence and severity of fires.[37] *As part of the study, DTI compared flammability of EU-sourced TVs against TV produced for the U.S. market, which were largely manufactured with the use of additive flame retardants in their exterior casings to meet a voluntary fire safety standard. The authors reported the following findings:*

- *Televisions on sale in the U.K. and Europe are manufactured to IEC 60065, but televisions in the U.S. are manufactured to a voluntary U.S. standard that specifies the use of flame-retardant plastic in the TV case. Both United States and European standards appear to give an adequate level of protection from the risk of fire started by an internal fire source in the TV.*

- *However, differences exist in how easily TVs manufactured to each standard can be ignited by an external source. If a TV does catch fire, or is involved in a fire, it represents a high fire load factor. Tests, undertaken by FRS [Fire Research Station] as part of this project, show that TVs manufactured to the basic requirements of the international regulations IEC 60065 can be ignited by a relatively low energy source, such as a nightlight. Once ignited, they burn fiercely and give off toxic smoke.*

- *In contrast, TV cases built to the voluntary US standard are dosed with flame-retardant and are very difficult to ignite and tend to self-extinguish.*[38]

In a study of computer monitor casings and keyboards, NIST reported that "[t]he use of flame retardant materials (including non-halogenated) provided adequate protection against the needle flame that represented a 'candle size' ignition source. The fire hazard from needle flame ignition of the enclosure having a non-flame-retarded material . . . was significant and resulted in the threat of fire spread to nearby objects."[39] *Specifically, the study's authors note that the "23 kW fire resulting from the ignition of a keyboard would be a threat to any item in close contact (such as a monitors used in this study), and was*

[36] The video can be seen at http://flameretardants.americanchemistry.com/Videos-on-Flame-Retardants.
[37] U.K. Department of Trade and Industry. 2001. Causes of Fires Involving Television Sets in Dwellings. Available at http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file21805.pdf (accessed Jan. 10, 2016).
[38] *Id.* at 4 (emphasis added).
[39] *Supra*, footnote 34.

shown to have an ignition threat radius of up to 27 cm for an item such as an upholstered office chair."[40]

Indeed, NIST measured flame plumes 1.5 meters high for some of the monitors tested in the study, and found that flaming, melting plastics can drip on floors or spread on a surface, which can increase fire spread. NIST makes clear that "[w]hile the objects studied here were computer monitor enclosures and keyboards, the qualitative conclusions should apply to other electronic equipment that could be similarly ignited, such as printers or other peripherals, as well as TV sets, that are enclosed in similar housings."[41]

Finally, the NIST study says, "It should also be noted that in recent years the number of electronic fires has increased in many European countries following a reduction in the use of some flame retardant compounds due to environmental concerns . . . It is anticipated that this trend could follow in the United States."[42]

Based on the studies referenced above concerning the flammability of consumer electronics and the potential of such fires to contribute to the ignition of nearby objects, it should be clear to the Commission that granting a petition that calls for the CPSC to ban flame retardants in the plastic casing of electronics will compromise consumer safety by exposing consumers to an increased chance of more and more intense fires, which is directly counter to the Commission's mission.

2. **Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?**

Flame retardants are not readily interchangeable. Their areas of application are often specific and substitution can be difficult. The diversity of materials that need to be made fire-resistant and to which flame retardants are added can have very different physical and chemical properties. Similarly, end-use performance requirements, including certification to national standards, must be considered when choosing a flame retardant for a particular application. A product manufacturer cannot simply substitute one flame retardant for another without significant time and cost devoted to formulation, performance testing, certification, and, in the case of plastic components, blending, molding, and extrusion as well. And in some cases certain flame retardants may not even be suitable for use as replacements due to their individual physical and chemical properties.

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40 *Id.* at ii.
41 *Id.* at i.
42 *Id.* at 1.

As it relates to new chemicals, it is important to reinforce that there are significant regulations in place for the development and introduction of new substances in the U.S. Newly developed substances are subject to rigorous evaluation before they can be manufactured commercially. The Toxic Substances Control Act requires companies to submit "pre-manufacture notices" to the U.S. Environmental Protection Agency (EPA) with information on physical/chemical characteristics, any available health or environmental effects data, and anticipated use and exposure information, including any information on potential byproducts and disposal. EPA has the authority to prohibit the manufacture of the new substance entirely, impose restrictions on its use, or require additional testing at any time. EPA also has key criteria that it utilizes to prioritize and identify chemical characterizes and properties that require more information (e.g., criteria for bioaccumulation, persistence and toxicity).

Regarding non-chemical alternatives, it will be important for the Commission to assess how these potential alternatives could impact the fire safety and overall performance of a product. Analyses of appropriate substitutes should also consider factors such as cost to consumers and life cycle aspects of a consumer product that may be changed by mandating its reformulation or redesign.

Finally and perhaps most importantly, evaluations of appropriate substitution are not and should not be limited to just one factor like the potentially hazardous properties of a substance used in a product. To the question regarding "how to identify and avoid the unintended consequences of alternatives and what factors should the CPSC be considering," when conducting an alternatives assessment or evaluating policies that may drive chemical substitution, it is critical to take a comprehensive approach that considers multiple factors including chemical safety, product safety (including fire safety), performance, cost, product life cycle, etc. This extends well beyond the chemical that may be substituted and requires a holistic approach to product design.

3. **Some speakers claimed that they expected that no chemicals would be used as a substitute for these flame retardants in at least some of the products. Do you agree and why?**

No current regulation or standard requires the use of flame retardants today. Flame retardants are used by product manufacturers to help address fire safety issues for specific products. To the extent flame retardant chemicals are part of the overall layer of fire protection to help address the fire risk of specific products, chemicals will be used.

As noted in Dr. Blais's testimony, product designers typically take a multi-layered approach to fire safety. There is no one, single fire safety tool. While some have indicated that flame retardants might not be used in certain applications if restricted, each product manufacturer will need to consider the best tools to address relevant fire risks associated with their product, product performance, and cost. It is critical that *manufacturers have access to safe and effective flame retardants in the future and the flexibility to utilize the fire safety tools that best meet their needs.*

While we cannot speak for product manufacturers, we believe for some applications, flame retardants will continue to be used and may be necessary to address fire safety within the product categories identified in the petition. Many of the applications identified in the petition present a very real fire risk, so product manufacturers will need to factor in these fire safety considerations when designing products to ensure overall product safety and limit product liability.

Commissioner Robert S. Adler

1. **<u>Contribution of FR Chemical Additives to Reduced Fire Risks</u>: Mr. Simon, you correctly point out that fire risks in the United States have dropped dramatically over the past decades. A number of factors have contributed to this drop, including less smoking, greater use of smoke alarms, and increased use of FR chemicals. Realizing that exact statistics are difficult to obtain, can you provide any data to demonstrate what the exact contribution of FR chemicals – as opposed to the other fire factors – is to reduced fire risks?**

   Given that the purpose of flame retardants is to reduce the probability of a fire in products, it is difficult to identify specific statistics that demonstrate the exact contribution of flame retardant chemicals. Having said that, the bottom-line is that product manufacturers would not pay to utilize a product that doesn't work.

   NAFRA's comments for the record on Petition HP 15-1 outline the benefits of flame retardants for specific product categories.

   One area that is well documented relates to the use of non-polymeric, additive organohalogen flame retardants in televisions. In the early 1970s, the CPSC found that TVs posed an unusual risk for fire. An average of 160 people died each year due to television fires. In response, TV manufacturers developed a voluntary fire safety standard and used flame retardants to meet this standard. In 1979, CPSC credited stringent standards, like this one, for the decline in TV fires and the drastic drop in deaths related to those fires. (Source: 4 Nelson, G., Morgan, A. & Wilkie, C. (2012). Fire Retardancy in 2012. In Fire and Polymers VI: New Advances in Flame Retardant Chemistry and Science (pp.4). Washington, DC: American Chemical Society.)

   The visual demonstration presented by Dr. Blais at the December 9, 2015, CPSC public hearing summarizes research by the Southwest Research Institute and helps reinforce this point. The comparative burn video is available at: *<u>http://flameretardants.americanchemistry.com/Videos-on-Flame-Retardants</u>*

Another example is research conducted by the National Institute of Standards and Technology (NIST). In a study of computer monitor casings and keyboards, NIST reported that "[t]he use of flame retardant materials (including non-halogenated) provided adequate protection against the needle flame that represented a 'candle size' ignition source. The fire hazard from needle flame ignition of the enclosure having a non-flame-retarded material . . . was significant and resulted in the threat of fire spread to nearby objects." Specifically, the study's authors note that the "23 kW fire resulting from the ignition of a keyboard would be a threat to any item in close contact (such as a monitors used in this study), and was shown to have an ignition threat radius of up to 27 cm for an item such as an upholstered office chair."

Indeed, NIST measured flame plumes 1.5 meters high for some of the monitors tested in the study, and found that flaming, melting plastics can drip on floors or spread on a surface, which can increase fire spread. NIST makes clear that "[w]hile the objects studied here were computer monitor enclosures and keyboards, the qualitative conclusions should apply to other electronic equipment that could be similarly ignited, such as printers or other peripherals, as well as TV sets, that are enclosed in similar housings."

Finally, the NIST study says, "It should also be noted that in recent years the number of electronic fires has increased in many European countries following a reduction in the use of some flame retardant compounds due to environmental concerns . . . It is anticipated that this trend could follow in the United States."

2. **<u>FHSA Applicability</u>: Mr. Simon, in your testimony, you indicate that ACC and NAFRA believe the Petition "does not meet criteria outlined in the Federal Hazardous Substances Act (FHSA) to ban a product." Could you please give a more detailed analysis regarding this conclusion?**

Section II of NAFRA's comments filed in the docket for Petition HP 15–1 outline in detail why the petition does not meet the criteria outlined in the FHSA to ban a product. These comments emphasize that:

- *Assessment on a product-specific basis will demonstrate that the FHSA criteria are not met for all non-polymeric, additive organohalogen flame retardants.*
- *As a class, the CPSC cannot find that all non-polymeric, additive organohalogen flame retardants are "toxic".*
- *When taking into account the exposure potential of specific products the CPSC will be unable to find that exposure may cause substantial personal injury or substantial illness.*
- *A ban is legally impossible because the CPSC cannot meet its burden of demonstrating a hazard exists to support cautionary labeling, much less determine that labeling is inadequate to protect public health and safety.*

- *Evaluation of the potential costs and benefits under the FHSA will not justify a rulemaking classifying all the identified product categories containing non-polymeric, additive organohalogen flame retardants as banned hazardous substances.*

3. **<u>Unpublished Data on Organohalogen Hazards</u>: Mr. Simon, please share with the Commission any unpublished data in the possession of ACC, NAFRA, or its member companies related to toxicity and exposure of organohalogens covered by the Petition. In addition, please indicate whether ACC, NAFRA, or its member companies share this information with product manufacturers.**

   NAFRA members operate in a global regulatory environment and are required to develop and share a broad range of environmental, health and safety information on their chemicals including unpublished information. Extensive information on a chemicals properties, intended use and potential exposure are required for the registration and production of chemicals in many countries. Public access to some of this information may be limited due to laws and regulations that protect proprietary data and information or legal limitations on sharing data generated for regulatory purposes by consortia of companies. Attachment 1 accompanying these responses outlines publicly available resources for information on flame retardant chemicals.

   As stated elsewhere, it is important to reinforce that NAFRA members do not manufacture all of the non-polymeric, additive organohalogen flame retardants that would likely be covered by the petition.

   NAFRA members share relevant information, including unpublished data, with regulators and downstream users. With regard to downstream users, information regarding a chemical's properties is regularly provided to the value chain through Safety Data Sheets. As members of the American Chemistry Council, NAFRA members implement Responsible Care®, the chemical industry's world-class environmental, health, safety and security performance initiative. This includes implementation of the ACC Responsible Care Product Safety Code,[43] which goes beyond regulatory requirements and obligates chemical manufacturers to manage the safety of their chemical products, from inception to end-of-life. A core element of the Product Safety Code is to enhance cooperation and communications along the chemical value chain, so that chemical producers and the manufacturers, distributors and retailers who use, handle or sell chemicals, work together to improve awareness about the safety and risks of certain chemicals, and how to manage chemicals safety along the value chain.

4. **<u>Regrettable Substitution</u>: Mr. Simon, if the Commission were to proceed to assess the hazard and risk profile of each individual organohalogen flame retardant**

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[43] *See http://responsiblecare.americanchemistry.com/Responsible-Care-Program-Elements/Product-Safety-Code*.

compound instead of treating all these FR additives as a class, how would you suggest the Commission avoid the problem of "regrettable substitution?"

Please see the response above to the similar question posed by Chairman Kaye.

5. <u>List of Non-Hazardous FR Organohalogens</u>: **Mr. Simon, are you aware of any non-polymeric, additive organohalogen flame retardants that have been determined by any expert body such as the U.S. Environmental Protection Agency (EPA) not to present a significant health hazard? If so, please provide a list of such chemicals.**

As NAFRA stated it is written comments, its oral and written testimony and in meetings with the CPSC, the exact scope of the petition is not clear, and, by the Petitioners own admission, the precise number of substances that would be covered by their proposed ban is not known.

The following are specific examples of where an expert body has determined that the use of specific non-polymeric, additive organohalogen flame retardants do not present a significant health hazard. In evaluating these examples and other expert body evaluations regarding the potential hazards of a chemical, it is critical to distinguish between studies that describe a chemical's hazard properties and more comprehensive assessments that incorporate exposure to evaluate the potential for any risk to human health or the environment. Consideration of both hazard and actual exposure to understand risk is a fundamental tenant of effective chemical management as recognized by the FHSA. Exposure is a critical component of making a hazardous substance determination under the FHSA.

These examples of formal risk assessments by recognized national authorities reinforce our view that the Petition should be denied on its merits.

The Canadian Environmental Protection Act requires the Minister of the Environment and the Minister of Health to conduct screening assessments of substances of potential concern to determine whether they present or may present a risk to the environment or to human health.[44] Following an extensive review of available hazard and exposure data for TBBPA, TBBPA bis(allyl ether), and TBBPA bis(2-hydroxyethyl ether), they concluded that the three substances
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- *"[A]re not entering the environment in quantities or concentrations or under conditions that constitute or may constitute a danger in Canada to human life or health . . ."[45] and*

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[44] Government of Canada. 1999. Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33). Available at URL: http://laws-lois.justice.gc.ca/eng/acts/C-15.31/index.html. Accessed Jan. 16, 2016.
[45] Environment Canada and Health Canada. 2013. Screening Assessment Report Phenol, 4,4'-(1-methylethylidene) bis[2,6-dibromo-, Ethanol,2,2' [(1-methylethylidene)bis[(2,6-dibromo-4,1-

- *"[A]re not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity or that constitute or may constitute a danger to the environment on which life depends."*[46]

In 2006, the ECB published a risk of assessment of TBBPA.[47] *The analysis examined multiple endpoints—acute toxicity, irritation, corrosivity, sensitization, repeated dose toxicity, mutagenicity, carcinogenicity, and reproductive toxicity—from inhalation, ingestion, dermal exposure routes. The Bureau's conclusions were as follows:*

- *Regarding human health, "No health effects of concern have been identified for TBBPA."*[48]
- *Regarding workers, "No health effects of concern to adults have been identified." Furthermore, "There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already."*[49] *This conclusion applied "in relation to all endpoints and for all exposure scenarios."*[50]
- *Regarding consumer exposure, "consumer exposure is negligible" and the findings were identical to those for workers for all endpoints.*[51]

In 2011, the European Commission directed EFSA's CONTAM Panel to deliver a scientific opinion on potential risks from TBBPA and its derivatives in food. The panel produced a comprehensive aggregate assessment that also included consideration of exposure to breast-fed infants with average or high milk consumption, as well as exposure to TBBPA in dust in homes, classrooms, and cars. They concluded that:

- *For consumers of fish and consumers of cow's milk (i.e., infants and small children), the margin of exposure (MOE) in the worst case exposure scenarios was several orders of magnitude below the default margin of exposure (100), "indicating that current dietary exposure to TBBPA for these population groups in the EU does not raise a health concern."*[52]

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phenylene)oxy]]bis, Benzene, 1,1'-(1-methylethylidene)bis[3,5-dibromo-4-(2-propenyloxy)-, Available at: http://ec.gc.ca/ese-ees/BEE093E4-8387-4790-A9CD-C753B3E5BFAD/FSAR_TBBPA_EN.pdf. Page 6.

[46] *Id.* at 43.

[47] European Chemicals Bureau. 2006. European Union Risk Assessment Report. 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol (tetrabromobisphenol-A or TBBP-A) Part II – human health, Available at URL: http://echa.europa.eu/documents/10162/32b000fe-b4fe-4828-b3d3-93c24c1cdd51.

[48] *Id.* at VI.

[49] *Id.*

[50] *Id.*

[51] *Id.*

[52] CONTAM (European Food Safety Authority Panel on Contaminants in the Food Chain). 2011. Scientific Opinion on Tetrabromobisphenol A (TBBPA) and its derivatives in food. EFSA Journal 9(12):2477. Page 54.

- *More generally, given the extremely low levels of TBBPA in food (below the level of quantification), "it is unlikely that current dietary exposure of the general population to TBBPA raises a health concern."*[53]
- *Regarding breast-fed infants, "Exposure of breast-fed infants to TBBPA via human milk also shows very high MOEs . . . and therefore does not raise a health concern."*[54]
- *And finally, "combined exposure to TBBPA from food and dust, particularly for children, is unlikely to raise a health concern."*[55]

The European Chemicals Bureau's (ECB) 2008 assessment of Tris (1-chloro-2-propyl) phosphate (TCPP) examined multiple endpoints—acute toxicity, irritation, corrosivity, sensitization, repeated dose toxicity, mutagenicity, carcinogenicity, and reproductive toxicity—from inhalation, ingestion, dermal exposure routes. For TCPP, ECB found:

- *Regarding risk to the environment, "There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already."*[56] *The study also noted that TCPP meets neither the bioaccumulation nor toxicity criteria for persistent, bioaccumaltive, and toxic (PBT) designation.*
- *ECB made the same conclusion with respect to potential risk to workers, consumers, humans exposed via the environment. The conclusion held even when ECB combined consumer and environmental exposures.*[57]

Commissioner Joseph Mohorovic

1. Would you support the Commission adopting California's TB117-2013 as a national mandatory standard for upholstered furniture?

We understand the furniture industry's interest in the adoption of uniform, national fire safety standards, and we look forward to working with the furniture sector on these efforts.

According to the National Fire Protection Association (NFPA), upholstered furniture can be a major fuel source during fires, so it is important that the CPSC implement a national standard that fully addresses fire safety, including fires that initiate from an open flame.

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[53] *Id.* at 4.
[54] *Id.* at 55.
[55] *Id.*
[56] European Chemicals Bureau. 2008. European Union Risk Assessment Report Tris(2-chloro-1-methyl ethyl) phosphate (TCPP). Page 8. Available at: http://echa.europa.eu/documents/10162/6434698/orats_summary_tris2-chloro-1-methylethylphos_en.pdf (accessed Jan. 7, 2016).
[57] *Id.* at 14.

In the comments regarding the proposed changes to California's furniture flammability standard TB 117, the NFPA made the following statement: "Reflecting these statistics, NFPA feels strongly that a fully comprehensive fire safety regulation of upholstered furniture must address the full spectrum of major fire scenarios including the open flame scenarios." Similar comments can be found in the TB 117 record from Underwriters Laboratories, the Consumer Product Safety Commission and at least 20 other fire scientists and fire safety experts.

It is important to also note that in adopting the revised TB-117 standard, California recognized the significance of open-flame sources and is actively evaluating open flame testing as part of its ongoing fire safety research for implementing TB-117 2013.

It is critical that the CPSC carefully evaluate the relevance of the open-flame test in developing any flammability standards for furniture. As the Commissioners know well, the CPSC is currently evaluating appropriate fire safety standards including the applicability of appropriate open flame testing.

2. **During the hearing you cited a study that shows the human exposure to the flame retardant TBBPA is 7 million times below the level associated with potential health effects. Is the study you cited the "Development of toxicity values and exposure estimates for tetrabromobisphenol A: application in a margin of exposure assessment," accepted for publication in the Journal of Applied Toxicology on January 19, 1995 and funded by the North American Flame Retardant Alliance Panel of the American Chemistry Council? Has this study been refuted in any way?**

Our reference in the hearing was to "Wikoff et al. 2015. Development of toxicity values and exposure estimates for tetrabromobisphenol A (TBBPA): Application in a margin of exposure assessment. Journal of Applied Toxicology".[58] *This comprehensive evaluation of TBBPA exposure and toxicity found that margin of safety (MOS) estimates were sufficiently large. Using the most conservative estimates of exposure and toxicity, the total lifetime average daily exposure would have to be increased ~80 times or greater for adverse health effects to occur. Specifically, the study evaluated the available toxicity data and human exposure information using the maximum exposure concentrations of TBBPA in the diet, breast milk, soil/dust, and water and reported that the* ***resulting exposures were many orders of magnitude below*** *any reported adverse effects seen in research animal studies.*

The article has been available on line since March 2015, and to our knowledge there has been no critical response to it. While we reference this recent comprehensive study, our comments are based on the weight of the scientific evidence. Although several studies have assessed certain hazard characteristics of TBBPA, when taking into account actual

[58] Wikoff et al. 2015. Development of toxicity values and exposure estimates for tetrabromobisphenol A (TBBPA): Application in a margin of exposure assessment. Journal of Applied Toxicology 35(11):1292-1308..

exposure, the substance has been determined to not present a risk to human health. Consideration of both hazard and actual exposure to understand risk is a fundamental tenant of effective chemical management.

It is for this reason that risk assessments in Canada and the European Union concluded TBBPA does not present a risk to human health. EPA is currently conducting an assessment of TBBPA, and we are confident that if exposure information is accurately considered that this review will also confirm that TBBPA exposures do not present a risk to human health or the environment.

3. **Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.**

   Flame retardants are used in a broad range of products. Our response to Question 8 below provides additional information on the use of flame retardants.

4. **Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.**

   Attachment 1 accompanying these responses outlines company specific examples of how flame retardants are applied. If the Commission is interested, we would be happy to provide additional detailed, information on how flame retardants are applied including demonstrations of how flame retardants are incorporated into certain plastic materials.

5. **Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.**

   As NAFRA stated it is written comments, its oral and written testimony and in meetings with the CPSC, the exact scope of the petition is not clear, and, by the Petitioners own admission, the precise number of substances that would be covered by their proposed ban is not known. Also, it is important to note that NAFRA members do not manufacture all of the non-polymeric, additive organohalogen flame retardants that could be covered by the petition.

   NAFRA members operate in a global regulatory environment and are required to develop and share a broad range of environmental, health and safety information on their chemicals. Extensive information on a chemicals properties, intended use and potential exposure are required for the registration and production of chemicals in many countries. Attachment 1 accompanying these responses outlines publicly available resources for information on these chemicals.

   Section IV of NAFRA's comments filed in the docket for Petition HP 15–1 provides additional information and examples of toxicity information.

6. **Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.**

It is important to emphasize that NAFRA members do not manufacture all of the non-polymeric, additive organohalogen flame retardants that would be covered by the petition.

NAFRA members operate in a global regulatory environment and are required to develop and share a broad range of environmental, health and safety information on their chemicals. Extensive information on a chemicals properties, intended use and potential exposure are required for the registration and production of chemicals in key countries. Attachment 1 accompanying these responses outlines publicly available resources for information on these chemicals.

Section IV of NAFRA's comments filed in the docket for Petition HP 15–1 provides additional information and examples of toxicity information.

7. **Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.**

Section III of NAFRA's comments filed in the docket for Petition HP 15–1 provides an extensive overview of the benefits of flame retardants. Key highlights are also outlined in our response to Question 1 from Chairman Kaye.

8. **Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?**

Flame retardants are used in a broad range of products, examples of which are described below.

Electronics and Electrical Devices
- *Television and other electronic device casings*
- *Computers and laptops, including monitors, keyboards and portable digital devices*
- *Telephones and cell phones*
- *Refrigerators*
- *Washers and dryers*
- *Vacuum cleaners*
- *Electronic circuit boards*
- *Electrical and optical wires and cables*
- *Small household appliances*
- *Battery chargers*

Building and Construction Materials

- *Electrical wires and cables, including those behind walls*
- *Insulation materials (e.g., polystyrene and polyurethane insulation foams)*
- *Paints and coatings which are applied to a variety of building materials, including steel structures, metal sheets, wood, plaster and concrete*
- *Structural and decorative wood products*
- *Roofing components*
- *Composite panels*
- *Decorative fixtures*

Furnishings

- *Natural and synthetic filling materials and textile fibers*
- *Foam upholstery*
- *Curtains and fabric blinds*
- *Carpets*

Transportation (Airplanes, Trains, Automobiles)

- *Overhead compartments*
- *Seat covers and fillings*
- *Seats, headrests and armrests*
- *Roof liners*
- *Textile carpets*
- *Curtains*
- *Sidewall and ceiling panels*
- *Internal structures, including dashboards and instrument panels*
- *Insulation panels*
- *Electrical and electronic cable coverings*
- *Electrical and electronic equipment*
- *Battery cases and trays*
- *Car bumpers*
- *Stereo components*
- *GPS and other computer systems*

NAFRA members do not manufacture consumer products and cannot speculate on the percentage of CPSC-regulated products potentially covered by the petition. We would anticipate that a broad range of products would be impacted by the petition, particularly given the inclusion of electronics.

As noted in our comments to the docket, the CPSC will need to evaluate each individual product using additive non-polymeric organohalogen flame retardants. The broad range of the petition, which would also include any new non-polymeric additives that have not even been developed, will make it difficult for the CPSC to implement a rulemaking under the FHSA as requested by the petition and for manufacturer compliance.

Attachment 1

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Supporting Attachment to Responses from the
American Chemistry Council's North American Flame Retardant Alliance

The following outlines examples of publicly available resources for information on flame retardant chemicals, including relevant non-published data and information on how flame retardants are applied. This information is being highlighted in response to some of the Commissioners' questions and to inform the CPSC's review of Petition HP 15-1.

Examples of Available Information Resources on Chemicals

Government Regulatory Resources

- US EPA ChemView
- European Chemicals Agency Registered Substances Database
- European Chemicals Agency Classification and Labeling Database
- OECD eChemPortal
- OECD Existing Chemicals Database

Industry Resources

- http://www.flameretardantfacts.com/flame-retardant-resources/
- http://www.cefic-efra.com/
- http://www.bsef.com/

Company Resources

- http://albemarle.com/_filelib/FileCabinet/Literature_Library/Performance_Chemicals_Literature/Fire_Safety_Advocacy/Product_safety_profile_S8010.pdf
- http://albemarle.com/_filelib/FileCabinet/Literature_Library/Performance_Chemicals_Literature/Fire_Safety_Advocacy/Product_safety_profile_TBBPA.pdf
- Albemarle Product Resources and Product Selector
- http://www.chemtura.com/msd/external/e/search/msds_main_fs_1.jsp?P_LANGU=E&P_SYS=6
- http://www.greatlakes.com/
- http://www.greatlakes.com/deployedfiles/ChemturaV8/GreatLakes/Flame%20Retardants/FR%20Brochures/Flame%20Retardants%20Overview.pdf
- http://icl-ip.com/products/

Matthew S. Blais, Ph.D.

Southwest Research Institute

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

<u>Matthew Blais, Southwest Research Institute</u>

Chairman Elliot F. Kaye

1. Dr. Blais, do you believe that American consumers can expect the same *functional* level of fire safety that currently exists if the chemicals in the scope of the petition are regulated by the CPSC for the specific products mentioned in the petition? Why or why not?

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organohalogen flame retardants are in what products? And if so, please provide.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?

U.S. Consumer Product Safety Commission
Questions for the Record
Public Hearing on the Petition Regarding
Additive Organohalogen Flame Retardants

Matthew Blais, Southwest Research Institute

Chairman Elliot F. Kaye

1. Dr. Blais, do you believe that American consumers can expect the same *functional* level of fire safety that currently exists if the chemicals in the scope of the petition are regulated by the CPSC for the specific products mentioned in the petition? Why or why not?
    a. I believe removing this class of chemicals will decrease fire safety of consumer products, specifically for electronics and furniture. The bromo and Halo organic FR attack fire in the vapor phase and interrupt the chemical reaction of fire by acting as radical scavengers. Work is progressing in the development of polymeric/reactive FRs as replacements but to date most if not all have shown negative materials properties in these two applications. This will likely be overcome in the future but many applications do not currently have an acceptable Polymeric or Reactive FR replacement.
    b. I just finished editing a modeling paper this morning from the Czech Republic for the Journal of Fire Science that points to the single most significant factor in fire growth in vehicle fires that are ignited inside of the vehicle as the composition of the Upholstery and whether it has FR or not.
    c. Apparently, after my testimony a video was shown of 5 sheets of newspaper igniting a couch that had passed BS 5852. What the presenters failed to point out was that this is equivalent to the 19 kW ignition source of the CAL TB 133 standard used for high occupancy space furniture. This is a much larger ignition source than the small open flame sources used in the tests that certify products for consumer use. These ignition sources typically range from 50 to 500 W and are 380 to 38 times smaller, respectively, than the newspaper ignition shown in the video.

2. Supposing that the Commission takes this action and bans these chemicals in these four product categories under the Federal Hazardous Substances Act (FHSA), how do we identify and avoid the unintended consequences of alternatives that may be used in place of these chemicals? Can you foresee issues about which the Commission should know now?
    a. Some consumer products do not have acceptable alternative FR to meet the existing IEEE requirements of passing UL 94 with a V1 rating. This may result in major impacts to manufacturers in bringing items to market. The amount of testing required for new case materials for flat panel display televisions is likely to increase dramatically. While this is a good

thing for my testing laboratory, it is not a good thing for consumers who demand product availability.

b. In a recent paper we published in the Journal of Fire Technology, we noted that not all items listed as passing UL 94 V1 passed the testing in our laboratory. Specifically we looked at the casings for Flat Panel Televisions. On manufacture in particular was a borderline failure for a HIPS casing and when challenged as a part of our testing burned vigorously with a 500 W ignition. In addition we noted that the stands provided with the televisions were not FR protected and were not UL 94 compliant. The stands had sufficient energy to overcome the FR of the FPT.

c. My recommendation would be to actually increase the flame resistance requirement for consumer products, requiring a V0 rating for casing and stand to increase public safety. This should be done in a time phased approach to give manufacturers time to develop the need materials.

d. Numerous studies have been completed on the safe dose of various organo-halogen FRs that indicate the environmental exposure is many orders of magnitude below safe exposure limits, while I am not a toxicologist, I am a Ph.D. chemist and understand the difference between hazard and risk. This action seems unwarranted based on the scientific data available on risk compared to the benefit that is measurable for this family of compounds.

e. I can provide copies of two recent journal articles that highlight the efficacy of Fire Retardants, one for upholstered furniture and the other on FPT. These are peer reviewed and published in the Journal of Fire Technology. These papers also point out an important fact: ignition source size does matter, as I said in my presentation. Do not be fooled by unscientific demonstrations, materials tested to a standard are done under very controlled conditions that are repeatable as demonstrated by inter laboratory studies. The precision of the tests has been validated by organizations like ASTM. My laboratory is ISO 17025 certified and we are audited frequently to ensure the quality of the data we produce. We are a reliable source fire safety information.

Commissioner Joseph Mohorovic

1. Do you have data on what non-polymeric additive organo-halogen flame retardants are in what products? And if so, please provide.
    a. Most of the data we produce is proprietary in nature and belongs to the companies that pay for the testing under contract. However, we have performed two recent studies for publication in the Journal of Fire Technology where we analyzed the test samples for FR content and measured their performance under controlled conditions. I will provide these two articles as an attachment to this response. These papers are on upholstered furniture and flat panel televisions.

2. Do you have data on how non-polymeric additive organohalogen flame retardants are applied? And if so, please provide.
    a. The response to this question is the same as the last question. It is important to note that we routinely perform fire tests, on the order of 3 to 4000 per year but we do not routinely measure the FR content. Manufacturers keep their formulations secret as proprietary information. The best way to get this information is to go to the OEMs and ask them for the FR content of specific items.
    b. This information is included in the two reports cited in the previous question

3. Do you have data on the toxicity of all of the non-polymeric additive organohalogen flame retardants included in the petition? And if so, please provide.
    a. We have data on a couple of FR in this category as published in the two papers attached, we measured PAH, acid gas, halo-dioxin and furan, and EPA TO-15 indoor pollutant production. These are all concentrations in air as a result of fires involving the materials tested.
    b. We directly measure the products of combustion of lots of materials in our labs. We use FTIR following ATSM E-800 and other test standards. We have not created a compendium of data that looks at all of the materials and their FR content and combustion gas production, however, there are many studies in the scientific literature that measure this. Most are cited in the papers I am attaching.

4. Do you have data on the exposure to different populations of non-polymeric additive organohalogen flame retardants? And if so, please provide.
    a. We do not perform exposure studies to populations, we just perform the studies on the ability of the materials to resist fire and studies that quantify the gases and other products incomplete combustion produced during controlled fire scenarios.

5. Do you have any studies on the benefits of non-polymeric additive organohalogen flame retardants? And if so, please provide.
    a. See Attached Studies, also many of the references cited are of similar work produced by SP and other reputable fire testing labs, both government and private.

6. Of the approximate 16,000 products that CPSC regulates, provide an estimate of percentage of those products that would be impacted by a ban on non-polymeric additive organohalogen flame retardants?
    a. Home furnishings and electronics are the two biggest groups impacted, I am not aware of others but I am not thoroughly knowledgeable in what CPSC regulates, nor do I know where all of the non-polymeric additive organo-halogen compounds are used.

Fire Technology

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Combustion Characteristics of Flat Panel Televisions With and Without Fire Retardants in the Casing

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Abstract. A series of flat panel television burns were performed with incrementally increasing ignition sources in a single burning item apparatus. A comparison study was performed of like model televisions for the United States, Mexican and Brazilian markets. Heat release rate, smoke, combustion gas, TO-15 vapor, and halo-dioxin and furan generation were measured. A total of 18 televisions were ignited and their burning behavior studied to examine the impact of materials of construction and the presence of fire retardants in the casing of the televisions on fire growth. US market televisions required more than 500 W with greater than 180 s exposure to ignite and in four out of the 6 trials these televisions did not achieve sustained ignition. In the two cases where sustained ignition for the US market televisions occurred, it was not the flat panel display television itself which ignited, but the stand and mounting bracket which lead to fire growth. Mexican and Brazilian market televisions ignited easily with 60 s exposure to a 50 W flame. US market televisions did produce brominated dioxins or furans but the mass loss of these televisions was much lower.

Keywords: Flat panel televisions, SBI testing, Smoke toxicity, Calorimetry, pHHR, Dioxins and furans

1. Introduction

Modern televisions have changed dramatically in design and materials of construction from those of just 15 years ago. Flat panel designs now dominate the marketplace. Large screen flat panel display televisions, ≥30 inches, represent the vast majority of televisions sold internationally. Previous studies on televisions studied consol type and or cathode ray tube (CRT) systems with smaller screens and different materials of construction [1–3]. However data on modern FPD televisions combustion as described here has not been previously published in peer reviewed journals. Because polymeric materials are used in modern FPD televisions, these devices can contribute to fires as either the first item ignited, either by internal or external sources, or by becoming a second item ignited and adding to the overall fuel load. International markets also have different requirements for

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resistance to fire with the United States having the strictest standards for ignitability [4]. The statistical analysis of Hall points to the V rating from UL94 standard fire testing for the television housing as a driver for the better performance of televisions in the US market as compared to their European counterparts [5]. For these reasons a study was performed using small flame, external ignition sources applied to televisions that were procured during 2013 in Brazil, Mexico and the United States. Matching sizes and models were used to do a comparison of the response to ignition. Flame spread, heat of combustion, smoke production and toxic constituents of smoke were all measured in this study [6].

Underwriters Laboratories, UL, has released a comparative video [7] that shows fire loading from furnishings in modern household living rooms has increased dramatically compared to legacy rooms from the 1970s. Kerber's study also does an excellent job of describing the impact of fuel growth of modern materials in residential fire [8]. The high energy content of modern rooms can lead to flashover conditions in as little as three to 4 min as compared to 29 min to 30 min in the legacy room. The use of polymeric materials in our homes is a significant contributor to this increased fire load. Most polymers decompose to low molecular weight vaporous components during pyrolysis [9] which burn with a large amount of energy release leading to rapid fire growth. For this reason, many modern polymers incorporate fire retardants (FR) that inhibit ignition while not significantly altering the mechanical and physical properties of the material [10–12].

Incorporation of FR in the cabinets of televisions has sparked controversy because of claims of potential health hazards. The proponents of the health hazard claims are pushing for the removal of the external ignition testing requirements for materials used in the construction of these televisions [13, 14]. Further, these groups are pushing manufacturers to cease the use of plastics with FR and to design the televisions so that potential ignition sources within the television are contained with inherently fire safe construction. The wisdom of eliminating ignition resistant plastics is questionable given media reports and product recalls related to incidences of plasma and LCD television fires that have breached the casing of the television and caused loss of life and many thousands of dollars in damages to homes [15–19].

Fire protection works best when approached from a layered perspective. Use of sprinklers, smoke detectors and inherently fire safe furnishings all increase the probability of preventing or surviving fires and minimizing property damage [20]. Human behavior is the one variable that is hardest to control. Numerous fires have started by placing ignition sources such as candles or heaters next to readily ignitable items made of plastics. Among the reasons that some claim that external flame source testing is not required is based on the assumption that all flat panel television are hung on walls and there is not an opportunity to come in contact with external small ignition sources. This ignores the fact that many of these televisions are mounted on stands sitting on entertainment centers, credenzas, tables and even carpeted floors. This is especially prevalent in apartment complexes where modification of the walls may not be permitted and hotels.

In this study, 18 televisions of three different models of similar sizes and weights were ignited using progressively larger open flame ignition sources of 50 W and

Table 1
Sample Television Composition and Characterization

TV Brand— Manu. Country	Television 1— Brazil (1B)	Television 2— Brazil (2B)	Television— Mexico (3M)	Television 1— U.S. (1US)	Television 2— U.S. (2US)	Televion 3— U.S. (3US)
SC						
Br (ppm)	612	235	1460	9.04 wt%	9.67 wt%	9.20 wt%
FTIR						
Polymer	HIPS	ABS	HIPS	HIPS	ABS	HIPS
FR content	No FR	No FR	No FR	FR-245 (major); 8010 (minor)	FR-245	FR-245 (major); 8010 (minor)
XRF						
Br (ppm)	–	–	808	10.08 wt%		
Sb (ppm)	–	–	77	2.33 wt%		
ICP						
Sb (ppm)	<11	<8.5	<260	2.39 wt%	1.67 wt%	1.97 wt%
UL-94	Fail	Fail	Fail	V-1	Fail	V-1

500 W. Half of the televisions studied were manufactured for the US market and the remaining for the Brazilian and Mexican markets. Televisions were ignited in a single burning item (SBI) apparatus as described in EN 13823: 2010 appendix E and the heat release rate and smoke generation were measured. Mass loss as a result of combustion, combustion gas generation, in-door air pollutant and chlorinated—and brominated—dioxins and furans were also measured.

2. Experimental

2.1. Materials

The composition and performance of the test items used in this study are summarized in Table 1. The polymer composition of the back case remained the same for the same model of televisions from the different markets excluding FR addition. Analysis of components was performed by Schoeniger Combustion (SC), Fourier

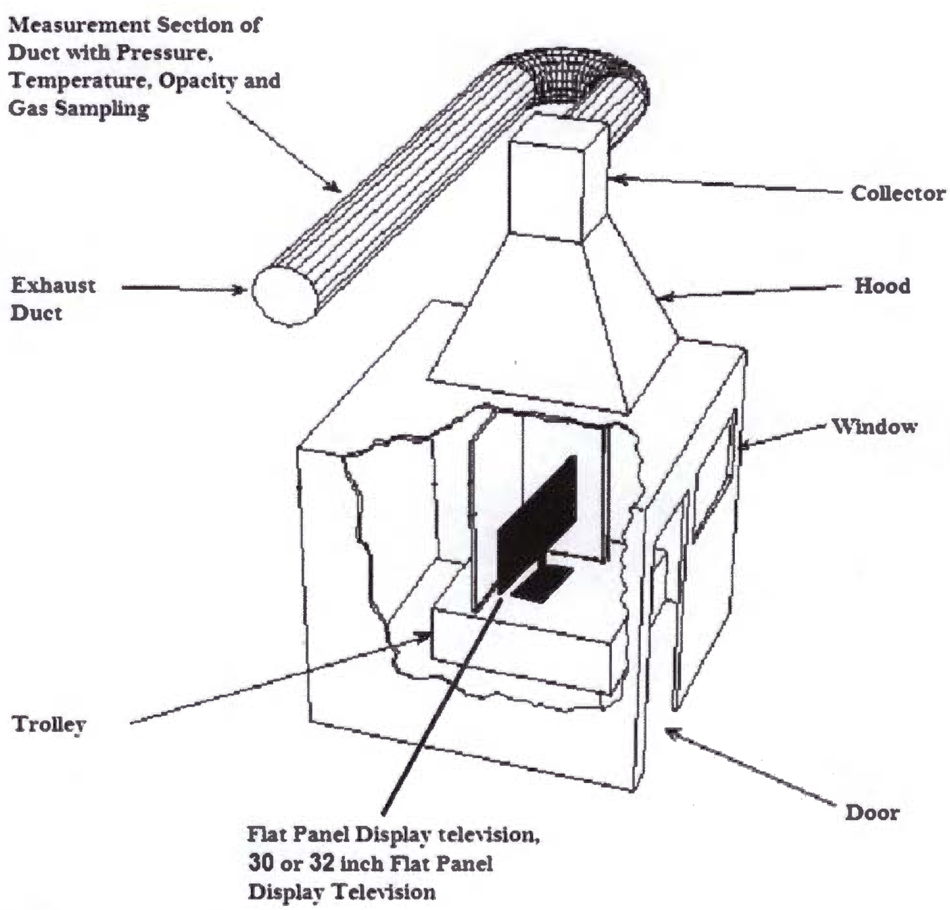

Figure 1. SBI test apparatus schematic.

Transform Infra-Red spectroscopy (FTIR), X-ray Fluorescence (XRF) and Inductively Coupled Plasma (ICP). Sections of the back casing were tested in accordance with UL-94 and the results are also reported in the table. FR-245 is tris(tribromophenoxy) triazine and FR8010 is Ethane—1,2-bis(pentabromophenyl). Analysis was performed by Mr. Brett Wallet of Albemarle, Baton Rouge, LA.

All televisions were mounted on the manufacturer supplied stands. Items 2B and 2US had identical bases with methyl methacrylate (MMA) and acrylonitrile–butadiene–styrene (ABS) with halogen free phosphate and aromatic brominated compounds added but were not fire test rated. The bases for 3M and 3US televisions were composed of MMA ABS containing halogen free phosphate and aromatic brominated compounds but were not fire test rated. The stand for 1US had a UL 94 V0 rated high impact polystyrene (HIPS) cover while the 1B stand cover did not have a fire rating but was also composed of HIPS.

2.2. SBI Apparatus Tests

A standard SBI test apparatus as described in EN 13823 appendix E was used for all television burns. Figure 1 shows a schematic drawing of the SBI test apparatus as used with the location of the television indicated in the drawing. Smoke density was measured via opacity in the exhaust duct. Heat release was measured as a function of oxygen consumption and carbon monoxide and carbon dioxide production. The sampling rate for the data acquisition system was 1 Hz.

2.3. Gas Sampling and Analysis System

An isokinetic sampling probe was positioned centroid to the SBI exhaust duct. A heated sample transfer line was attached to the duct probe. An EPA Method 23A sample train was attached to the heated line and the system was used to analyze for chlorinated and brominated dioxins and furans. Dioxin and furan analysis was performed by high resolution gas chromatography and high resolution mass spectrometry based on EPA Method 8290. A Summa Canister™ was also attached to sample for EPA method TO-15 to measure 98 standard volatile organic indoor pollutants as well as tentatively identified compounds via mass spectroscopy. The sample line was also attached to a Thermo Fischer Nicolet 6700 FTIR equipped with a 2-m gas cell, potassium bromide windows and gold reflectors to perform analysis of combustion gases in based on a partial least squares calibration of nine combustion gasses with a detection limit of 5 ppm or less. Sample gases were drawn through the gas cell at constant pressure of 756 mm Hg and a flow of approximately 1.5 SLPM which resulted in a concentration rise time of less than 30 s as verified during calibration.

Plastic composition and FR content determination was performed by an external laboratory and is reported in the sample description of the materials section.

3. Procedures

One of each type of television mounted on the manufacturers supplied stand was put through progressively increasing ignition source intensity and duration. The

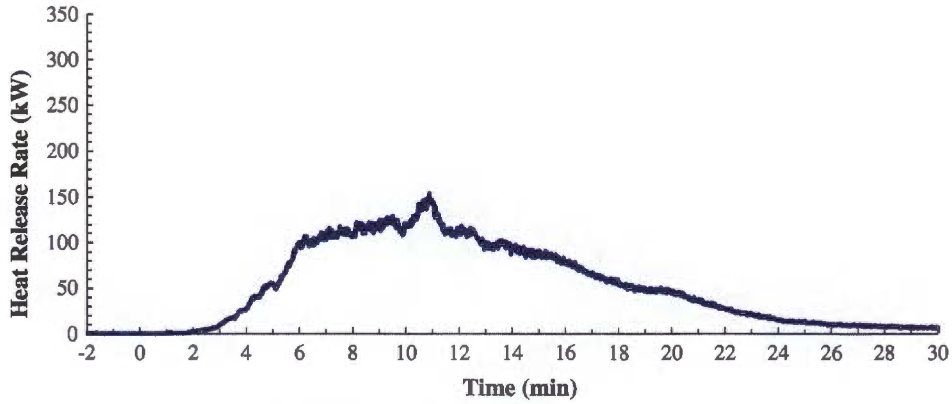

Figure 2. Heat release for Test 1 Television 1B.

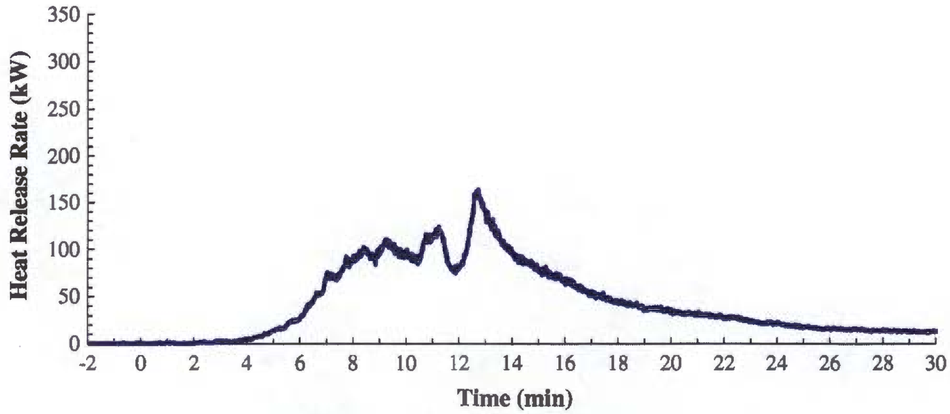

Figure 3. Heat release for Test #2, Mexican Market M3.

ignition source was applied to the back, bottom edge of each television. A summary of the individual tests is presented in the results section. The initial ignition source was a 12 mm needle flame which is equivalent to a small candle flame as described in IEC 60695-11-5. Exposure times of 60 s and 180 s were used to try and achieve sustained ignition. The next progressive ignition source was a 50 W, 20 mm flame as described in UL 94 section 8 applied twice for 10 s intervals, then 60 s, and 180 s, The largest ignition source applied was a 500 W, 125 mm flame as described by UL 94 section 9. Successive exposures of 2 at 10 s, then 60 s and 180 s were used until sustained ignition was achieved. The data obtained from the progressive ignition source test determined the ignition sequence for the follow-on tests of the same item type. Subsequent tests used the largest ignition source with the longest duration condition required to ignite the test items of like manufac-

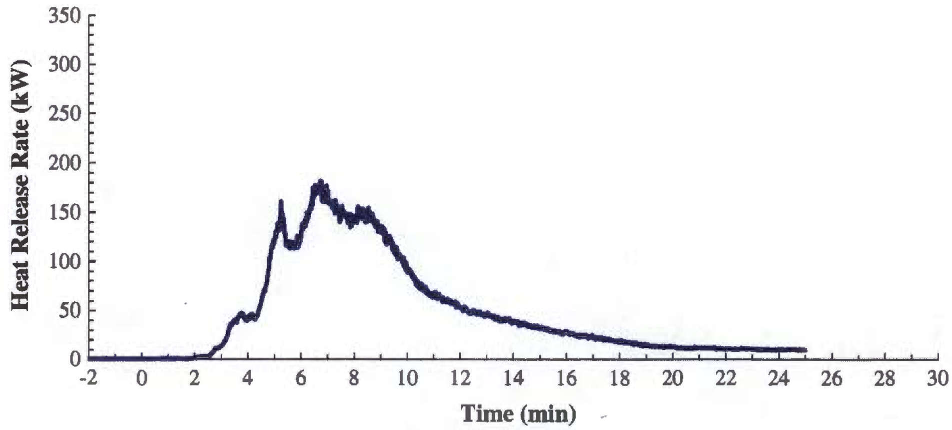

Figure 4. Test #3 Brazilian Market television 2B, 32″ heat release rate.

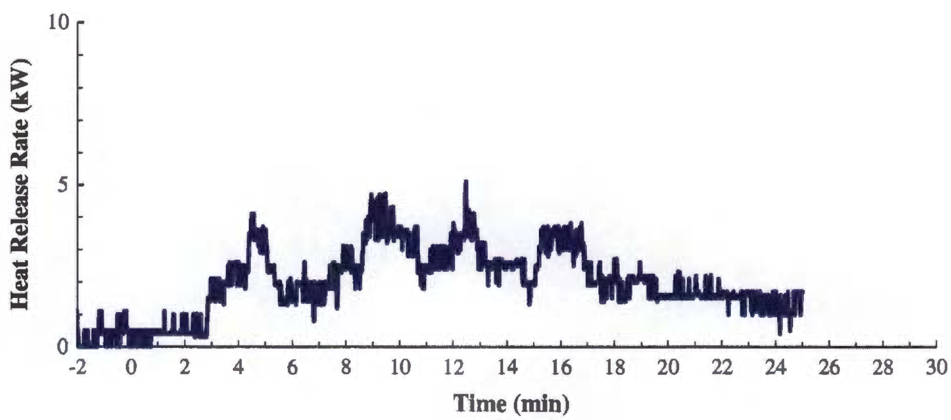

Figure 5. Test #4, US market television 1US.

ture. The data was also used to determine the collection time for the Summa™ canisters. Canisters were collected at pHRR and peak smoke generation times to determine EPA TO-15 indoor air pollutants concentrations. In the second and third tests for each television type, sampling was performed for dioxins and furans over the duration of the entire test.

4. Results

In the progressive ignition portion of the testing for test #1, the Brazilian market television 1B ignited with a 60 s exposure to the needle burner. The fire produced sooty black smoke with the first flaming drops occurring at 24 s. The television stand collapsed at 316 s with a resulting rapid increase in heat release as seen in Figure 2. The flame propagation covered the entire back surface of the television as well as the front screen and the interior components.

In test #2, the Mexican market television 3M was ignited with a 60 s exposure to the needle burner. The first burning droplets fell onto the stand with the result of the stand also catching fire at 102 s. The fire produced black sooty smoke with the stand collapsing at 510 s. Figure 3 shows the heat release rate for this test.

In test #3 a 32 inch Brazilian market television 2B was ignited after exposure to the needle burner for 60 s. The first flaming droplets were noted at 111 s resulting in the stand catching fire and collapsing at 320 s. Figure 4 shows the heat release rate for test #3. The rapid increase in energy release corresponds to the base catching fire. The first flaming drips were seen between 5 min and 6 min with the subsequent rapid increase corresponds to the collapse of the TV stand.

In test #4 the first of the US market television 1US was subjected to the needle burner for 60 s with the result of a guttering flame that extinguishes at 87 s. The needle burner was then applied for 180 s with flames extinguishing at 192 s. A 50 W flame source was then applied to the television for 2 s to 10 s intervals, a 60 s interval and a 180 s interval all with no ignition. The 500 W flame was then applied to a previously burned area for 60 s without result followed by an additional 180 s which breached the casing and resulted in a very slow fire with a peak heat release rate of 5 kW and very little overall mass loss for the television. Figure 5 shows the heat release rate for this test with the Y axis scale expanded to show more detail.

In test #5, a US market television 3US was also subjected to the progressive ignition regime with very similar results as obtained in Test # 4. The needle burner was applied for 60 s with the result of a guttering flame that extinguishes at 96 s. Flaming drops were noted at 81 s that extinguished on impact with the floor. The needle burner was then applied for 180 s with flames extinguishing upon removal of the burner. The casing material melted during this process and retreated from the flame. A 50 W flame source was then applied to a different

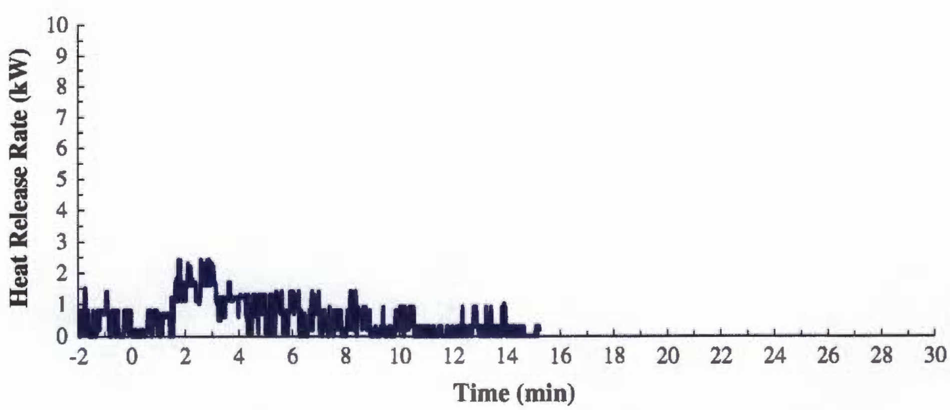

Figure 6. Test #5 Heat Release rate US Market television 3US.

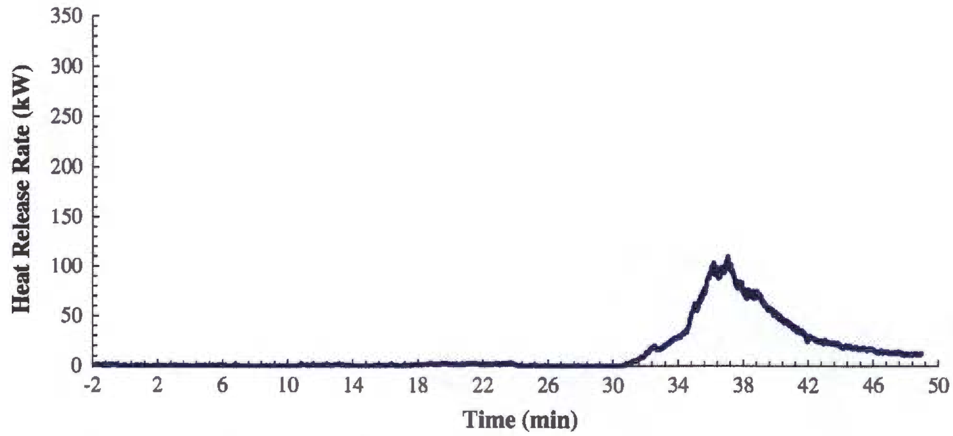

Figure 7. Test #17, Heat release for US market television 2US.

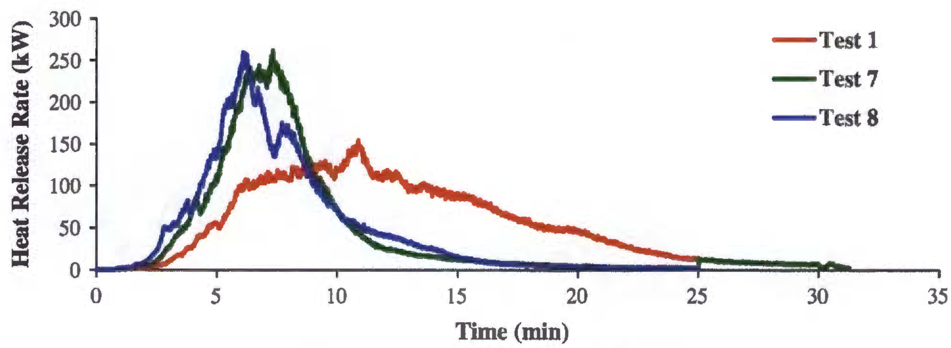

Figure 8. Combined Heat Release Rate Plots for 3 Brazilian Market Model 1B Televisions.

area of the television for 2 s to 10 s intervals, a 60 s interval and a 180 s interval all with no ignition. The 500 W flame was then applied to a previously burned area for 60 s without result followed by an additional 180 s but melting drops extinguished the burner at 105 s. The Burner was relit and the exposure continued for the remaining time. At 150 s into the exposure flaming drops were produced. A 180 s exposure was then performed on a previously tested part of the surface which produced a breach in the case and produced a slow fire that produced flaming drops. The fire self extinguished at 14 min 30 s. A pHRR of 2 kW was obtained as shown in Figure 6.

The last of the progressive ignition tests was planned to be test #6 however the ignition source was applied to the stand mounting bracket instead of the television case. The stands were determined to be a different material and were not UL-94 fire test rated. Test #17 using US market television 2US was the final progressive ignition experiment and was determined to be very similar to test 4 and 5. The

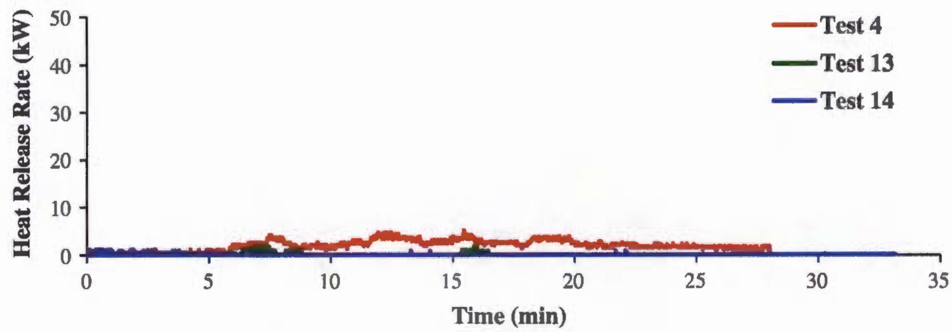

Figure 9. Combined Heat Release Rate Plots for 3 US Market Model 1US Televisions.

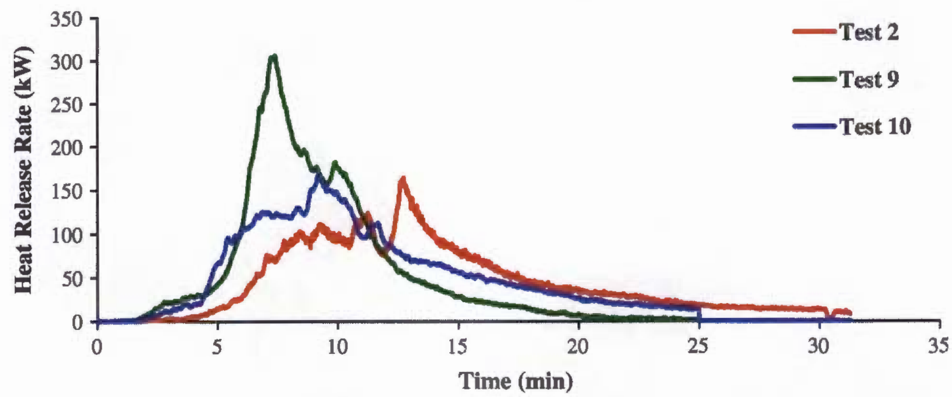

Figure 10. Combined Heat Release Rate Plots for 3 Mexican Market Model 3M Televisions.

television was subjected to the needle flame for 60 s with the result of immediately extinguishment on removal of ignition source. The needle flame was then applied for 180 s with flames extinguishing at 180 s. A 50 W flame source was then applied to the television for 60 s with the flame extinguishing in 62 s. It was then was then applied for 180 s with flames extinguishing at 180 s. The 500 W flame ignition source was then applied for 10 s without ignition followed by a 60 s exposure which breached the casing and resulted in a very slow fire over a period of 46 min with a peak heat release rate of 110 kW. Figure 7 shows the heat release rate for test #17.

In all subsequent tests, a 500 W ignition source was applied for 180 s to the back of each television. A total of two of each type of television was challenged under this technique. In all of the non-US market televisions this resulted in higher peak heat release rates in much shorter times. Comparing the 1B and 1US television, same model, gives the greatest contrast as shown in Figures 8 and 9. The Brazilian version reaches 295 kW in as little as 365 s while US versions fails

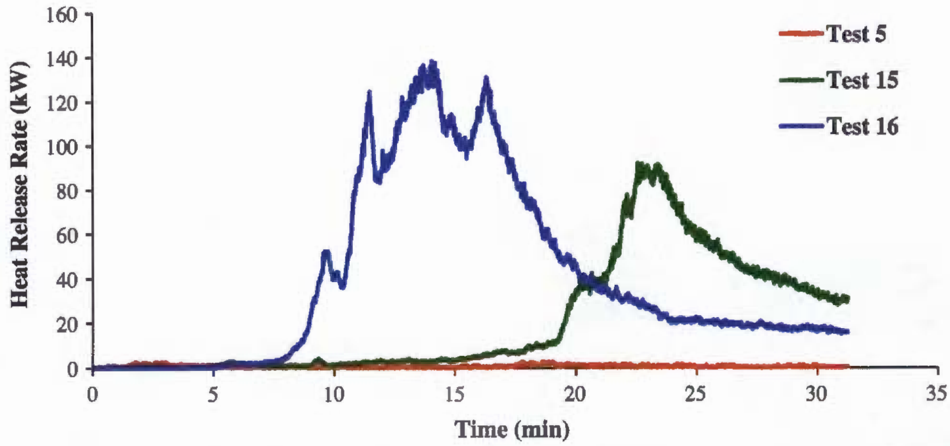

Figure 11. Combined Heat Release Rate Plots for 3 US Market Model 3US Televisions.

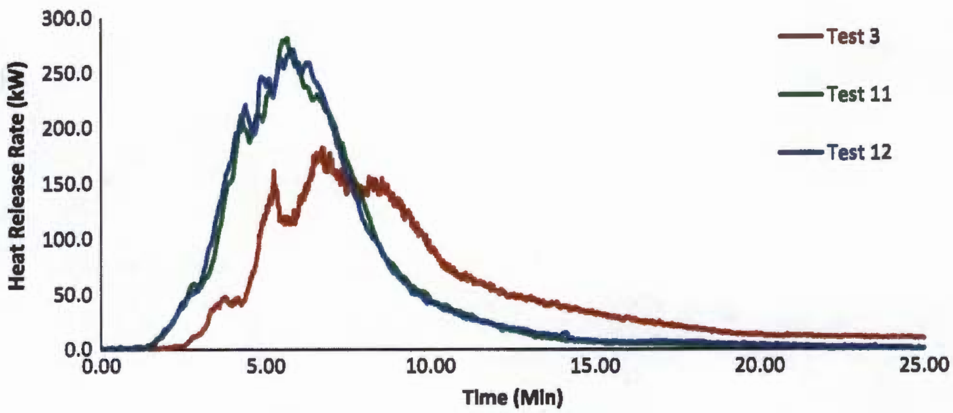

Figure 12. Combined Heat Release Rate Plots for 3 Brazilian Market model 2B televisions.

to achieve sustained ignition. It is important to note that the red line in Figure 8, test 1, represents ignition with a needle flame while tests 7 and 8 used the 500 W burner. The minor differences in the tests 7 and 8 are more a function of the normal variability in flame spread on the surface.

The 3M and 3US televisions show the same trend but not as dramatically and there is more variability in the performance for both the US and Mexican market televisions as shown in Figures 10 and 11. This is primarily due to the design and composition of the television stands of this model. None of the stands were rated for fire and were significantly involved in the early stages of the fire in tests 9 (2 min), 10 (2 min), 15 (3 min) and 16 (4 min). The major difference between tests 15 and 16 is that the front face of the television becomes involved in the fire early

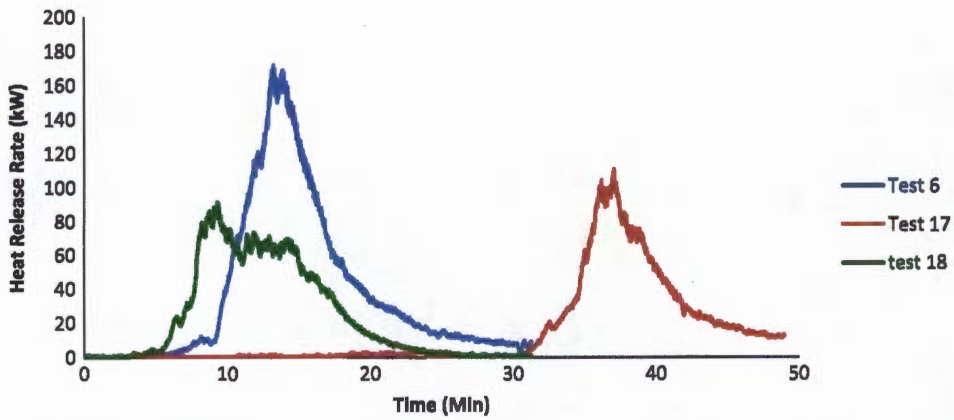

Figure 13. Combined Heat Release Rate for 3 US Market model 2US televisions.

in test 16 and not at all in test 15. In test 5 the stand was not involved in the fire and this television failed to achieve sustained ignition and test number 2 used the smaller, needle flame ignition source.

The 2B and 2US televisions were smaller in size than the other televisions tested in this program being a 32 inch model however the mass of plastics in the rear casing was actually higher than the 40 inch models. All of the tests for the 2B and 2US televisions can be found in Figures 12 and 13. The Brazilian televisions burned faster and with greater peak heat release rate than those comparable to the US market using the same ignition source. Test 3 and 6 were ignited with the needle flame. In test 6, the needle flame came in direct contact with the stand which ignited and resulted in near complete combustion of the television. It did require an extended time to achieve a rapid combustion, approximately 10 min. In the 500 W ignition source fires the non-FR televisions reached pHRR of near 280 kW at between 3 and 6 min. In test 17, the stand for the television was not involved in the fire, by selective location of the ignition source, and this television required approximately 30 min to achieve free burning with a steep rise in heat release rate as shown in Figure 13.

The summary of the heat release and smoke generation data is presented in Table 2. Events with multiple ignition attempts have an asterisk adjacent to pHRR time. Comparing the non-FR television from Brazil and Mexico to the US market televisions shows that the non-FR televisions were easily ignited on their back cases with a small candle flame and that they reach their pHRR in between 6.67 and 13 min. The US market television required much larger ignition sources of longer duration to achieve ignition. Using the larger ignition source on the Brazilian and Mexican television to provide a direct comparison of identical conditions to the US televisions shows that the pHRR for the Brazilian and Mexican televisions nearly doubles and/or the time required to reach pHRR decreased significantly. For Tests 7 through 16 and test 18, all performed under identical condition, the US market televisions either failed to sustain ignition or burned very