Flammability Standards – A Major Role in Flame Retardant Exposure? Televisions as a case study.

By

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Abstract

Flame retardants (FRs) are added to materials to enhance the fire safety level of readily combustible polymers. Although they have been purported to aid in preventing fires in some cases, they have also become a significant cause for concern given the vast data on environmental persistence and human and animal adverse health effects. Evidence since the 1980s has shown that Canadian, American and Europeans have detectable levels of FRs in their bodies. North Americans in particular have high levels of these chemicals due to stringent flammability standards and the higher use of polybrominated diphenyl ethers (PBDEs) in North America as opposed to Europe. FRs have been detected in household dust and some evidence suggests that TVs could be a significant source of exposure to FRs. It is imperative to re-visit the flammability standard (UL94V) that allows for FR use in TVs plastic materials by providing a risk versus benefit analysis to determine if this standard provides a fire safety benefit and if it plays a major role in FR exposure. This report first examined the history of televisions and the progression to the UL94V flammability test standard to understand why FRs were first added to polymers used in the manufacturing of TVs. It has been demonstrated to be due to fire hazards resulting from the use of plastic materials in cathode-ray tube (CRT) TVS that had an “instant-on” feature and high voltage and operating temperatures. In providing a risk versus benefit analysis, this paper presents the argument that 1) by providing a market survey the current flammability test standard (UL94V) is outdated and lacks relevance to current technology as flat, thin, energy efficient Liquid Crystal Displays (LCDs) dominate over traditionally used heavy, bulky and energy-intensive CRTs; 2) FRs do not impart fire safety benefits considering that there is a lack of valid fire safety concern, such as reduced internal and external ignition and fire hazard, and a lack of valid fire data and hazard for television fires in general and finally; 3) the standard is overly stringent as it does not consider the risk due to exposure to FRs in household dust due to the proliferation and greater use of televisions in households. Therefore, this report argues that the UL94V standard has become trapped in history and needs to be updated as it may play a major role in FR exposure.
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<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
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<td>ASTM</td>
<td>American Standard Test Methods</td>
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<td>BFRs</td>
<td>Brominated flame retardants</td>
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<td>BEARHFTI</td>
<td>Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation</td>
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<td>CCFL-LEDs</td>
<td>Cold Cathode Fluorescent Lighting - LEDs</td>
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<td>CPSC</td>
<td>Consumer Product Safety Commission</td>
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<td>CRTs</td>
<td>Cathode Ray Tubes</td>
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<tr>
<td>CSA</td>
<td>Canadian Standards Association</td>
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<td>Deca-BDE</td>
<td>Decabromo diphenyl ether</td>
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<td>EPA</td>
<td>Environmental Protection Agency</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>FPDs</td>
<td>Flat panel displays</td>
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<tr>
<td>HD</td>
<td>High definition</td>
</tr>
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<td>HFR</td>
<td>Halogenated flame retardants</td>
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<td>HRR</td>
<td>Heat release rate</td>
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<td>IEC</td>
<td>International Electronics Commission</td>
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<td>ISO</td>
<td>International Standards Organization</td>
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<td>LCDs</td>
<td>Liquid crystal displays</td>
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<td>LED-LCDs</td>
<td>Light-emitting diodes LCDs</td>
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<td>Octa-BDE</td>
<td>Octabromo diphenyl ether</td>
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<td>OLEDs</td>
<td>Organic light emitting diodes</td>
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<td>PBDEs</td>
<td>Pentabromo diphenyl ether</td>
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<td>PDPs</td>
<td>Plasma display panels</td>
</tr>
<tr>
<td>Penta-BDE</td>
<td>Pentabromo diphenyl ether</td>
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<td>POPs</td>
<td>Persistant organic pollutants</td>
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<td>PUF</td>
<td>Polyurethan foam</td>
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<td>REACH</td>
<td>Registration, Evaluation, Authorization of Chemicals</td>
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<tr>
<td>SCC</td>
<td>Standards Council of Canada</td>
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<tr>
<td>TB117</td>
<td>Technical Bulletin 117</td>
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<td>TB117-2013</td>
<td>Technical Bulletin 117-2013</td>
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<tr>
<td>TSCA</td>
<td>Toxic Substances Control Act</td>
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<td>UL</td>
<td>Underwriters Laboratory</td>
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<td>UNEP</td>
<td>United Nations Environmental Programme</td>
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Chapter 1

FLAMMABILITY STANDARDS TRAPPED IN HISTORY: REVISITING THE TV FLAMMABILITY STANDARD

Flame retardants (FRs) provide an important example of how challenging it can be to balance the goal of reducing the number of people harmed by a risk (i.e., fire), while also trying to ensure that the number of people harmed by the measures taken to reduce the risk (i.e., FRs), is minimized (Fire safety and environmental risk: What next?, 2014). Manufacturers develop and adopt flammability standards to reduce a fire hazard, which at times requires the use of FRs, whereas government regulated chemical plans in Canada (Chemical Management Plan, CMP), the United States (US) (Toxic Substances Control Act, TSCA) and the European Union (EU) (Registration, Evaluation, Authorization of Chemicals, REACH), evaluate the safety of individual FRs. These agendas perpetuate the use of FRs and at times, may act in a counter-productive way from an environmental and human health perspective.

FR Risks?

Although chemical FR use in Canada, the US and the EU stemmed from the need to reduce catastrophic fire occurrences in the 1970s by implementing flammability standards, the associated risks of exposure to FRs on human and environmental health were not anticipated. Required flammability standards have led to the expanded use of FRs and Canadians, Americans and Europeans have detectable levels of FRs in their bodies (Klasson Wehler, 1997; Darnerud et al 1998; Sjödin et al., 1999; Meironyte et al., 1999; Hites 2004). Interestingly, North Americans have significantly higher levels of polybrominated diphenyl ethers (PBDEs) than Europeans (Hites, 2004), which has been attributed to stricter flammability standards (Trudel et al. 2011).
and the higher use of PBDEs in North America as compared to Europe (Birnbaum & Staskal, 2004; Trudel et al. 2011).

Today, some of these FR chemicals, such as pentabromo diphenyl ether (pentaBDE) and octabromo diphenyl ether (octaBDE), are recognized as global contaminants. While toxicology studies on some FRs used in products have demonstrated the potential for adverse human and animal health effects (Chapter 3, Section II describes the concerns of PBDEs in relation to the routes of exposure, body burden and toxicity of PBDEs), a valid fire safety rationale and benefit for the use of FRs has been difficult to demonstrate, in some cases making their use questionable.

FR Benefit?

There has been an overall decrease in fire mortality, injuries and incidences in the past few decades in both Canada (Fire Losses in Canada, 2002) and the US (The U.S. Fire Problem, 2016). These decreases resulted from a combined effort of a number of fire prevention measures such as FR use, building codes, improved electrical product safety standards, educational campaigns focused on smoking, smoke detectors and behavioral and lifestyle changes such as declines in smoking rates (Cordner & Brown, 2011; Cordner & Brown, 2016). It is unknown to what degree these measures individually have contributed to the overall decline of fire incidences. Specific to FRs, there is no evidence in existing fire data that would allow researchers to isolate the effects of FRs on fire safety, however, it is worth mentioning that fire death rates have declined by similar levels in various States within the US with and without strict flammability standards (Blum, 2007; Cordner & Brown, 2016) indicating FR use may not have a substantial influence on decreasing fire deaths as is typically purported.
Flammability Standards: A Major Role in FR Exposure?

The evidence of human and environmental harm regarding FR exposure is increasing while it has been difficult to isolate effects of FRs have on fire safety. In Canada and the US, policy makers have rarely discussed the trade off between the risks versus the benefit for FR use. Babrauskas et al. (2011) states it is necessary to consider the “net outcome associated with FR agents, instead of only evaluating their improvement on fire safety” therefore, including an evaluation of the human and environmental health adverse affects is necessary. According to Babrauskas et al. (2011), going forward requires a “complex weighing of alternatives, which lack a common basis for comparison, e.g., death or injury due to fire versus damage to the environment or long-term health effects associated FR exposure” however in some cases, this may not be necessary “where no fire safety benefit or data associated with a particular usage exists” (Babrauskas et al. 2011).

This line of reasoning extends to flammability standards and the role they may play in exposing humans and the environment to FRs. The risk versus benefit trade off for flammability standards are also rarely discussed in this context and yet, such stringent standards can be regarded as a human and environmental health risk given the use of FRs to meet them and the known risks associated with FR exposure. Therefore, it is vital to challenge this issue head on and confront whether flammability standards and FRs can reasonably provide a fire safety benefit and try to elucidate if they perpetuate the risks of FR exposure.
California’s Furniture Flammability Standard Technical Bulletin 117 (TB117)

An example in which a flammability standard provided no demonstrable fire safety benefit is that of California’s Furniture Flammability Standard Technical Bulletin 117 (TB117). In 1975, California set the more stringent furniture flammability standard in the US and is currently the only state with fire safety regulations for upholstered furniture. TB117 required polyurethane foam (PUF) in juvenile products and upholstered furniture to withstand a small open flame for 12 seconds without igniting. Halogenated FRs (HFRs) were used by the PUF industry to meet this requirement, such as pentaBDE (Babrauskas et al., 2011). Compliance with TB117 was mandatory for all products sold in California and TB117 became the de facto national standard (Flame Retardants in Furniture, n.d.). Many national furniture manufacturers were using this standard for all of their furniture sold across the US and in Canada to avoid “maintaining double inventory and for defense against liability claims (Babrauskas et al. 2011; Flame Retardants in Furniture, n.d).

TB117 has been greatly contested as being a significant human and environmental health risk while no significant fire safety benefit could be demonstrated. It was determined that TB117 compliant materials did not significantly reduce the severity of fire when compared to non-TB117 compliant foam in identically constructed furniture (Babrauskas, 1983; Schuhmann & Hatzell, 1989) indicating the levels of FRs in TB117 foam were not effective. Although “advanced foam” not found in residential furniture (higher density and higher levels of FRs than TB117 compliant foam) did have a significantly lower peak heat release rate (HRR) as compared to TB117 foams (Schuhmann & Hartzell, 1989) indicating that FRs may work when substantially added to materials beyond levels in TB117 compliant materials.
Further, as fires start in the exterior fabric and not the PUF filling, a fault of TB117 test was that only a small piece of foam was exposed to a small burner flame and not the composite piece of furniture, which if considered, would assess the behavior of the actual composite (Babrauskas et al. 2011) and would be a better indication of a real life fire situation. But according to Babrauskas et al. (2011), studies mentioned in their analysis on benefits and risks of FRs in furniture foam, have demonstrated that “TB117 foam did not make a significant difference in ignition or flame spread” and that the foam “did not offer any benefit to resisting smoldering ignition from cigarettes” when upholstered fabric were tested. Further, Babrauskas et al. (2011) examined a study conducted by the US Consumer Product Safety Commission (CPSC), which concluded that “TB117 component results were not predictive of full scale performance,” indicating that it may not reduce the risk of a small flame ignition.

TB117 has been challenged and the details of the battle between scientists and the activist community and the FR industry are greatly documented in Cordner et al. (2013). A four –part investigative series on FRs was published in the Chicago Tribune in May 2012 and has been regarded as playing a substantial role in facilitating a revision to TB117. In 2012, the Governor of California directed the Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI) to revise the standard and California enacted an updated furniture standard, TB117-2013 (“Flame Retardants In Furniture”, n.d). This standard calls for a smolder ignition test, which is consistent with fire data showing that smoldering, rather than open fire, is the leading cause of furniture fires in the US (“Flame Retardants in Furniture”, n.d). The TB117-2013 standard can now be met without the use of FR chemicals added to PUF with improved fire safety, though the regulation does not specifically ban the use of FRs (“Flame Retardants In Furniture”, n.d).
TB117-2013 was a success in that the standard was scrutinized and subsequently revised on the basis of the risk (human and environmental harm) versus benefit (fire safety benefit from FR use) trade off. Specifically, it was revised based on consideration of no demonstrable fire safety benefit for FRs and as a collective standard as well as the significant risks to human and environmental health from the use of additive FRs. Further, it was revised to a standard for which there was sound-scientific evidence (smoldering being the leading cause of furniture fires in the US) giving an alternative to FR use and fire safety regulation that would likely be a significant fire safety benefit reducing the fire hazard.

It is critical that flammability standards are based on sound-scientific evidence, given that FR use poses substantial adverse affects to humans and the environment. Revisiting flammability standards and FR use, evaluating the “net outcome associated with FR agents” (Babrauskas et al. 2011) for other household or consumer products would be an important step to ensuring the risks of FR exposure are minimized. The essential component is to explore if there is a reasonable fire safety benefit warranting FR use and if the standard has been effective in reducing fires. In some cases where no fire safety benefit is demonstrated, it is essential to consider alternatives such as fire barriers for which there is evidence showing a fire safety benefit. Thus, this paper will revisit the use of FRs in televisions (TVs) given that, besides furniture, TVs are the primary sources of exposure to FRs in households.

*FRs in TVs*

TV fires resulted from the trend towards the use of combustible plastic polymers as well as the high operating voltages and temperatures (Robertson, 1976). Specifically, in the US, TV fires in the late 1960s and early 1970s were “preliminarily determined” to be an “unreasonable
risk” of injury to the public as cathode ray tube (CRT) TVs with an “instant-on” feature and high voltage and operating temperatures were implicated as being the influencing factors in many fires (Coen & Hoffman, 1984; Grand & Wilkie, 2000; Hoffman, 2006) which was regarded as a significant internal fire hazard. There was also an external fire hazard given the large surface of CRT TVs where people would place candles or plants. This led to a reactive-response to a fire concern and as a result, the stringent UL94V standard, which require the use of FRs, was adopted for CRT TV plastic materials, such as the plastic in printed circuit boards and enclosures, with the intention of reducing fire hazard and casualties.

However, today CRT TVs are no longer the dominant form of technology, as Flat Panel Displays (FPDs) have surpassed them (Kheng et al., 2012). The switch from CRTs resulted in modern technology that consists of significantly reduced operating voltages and temperature and thin, flat, mount-able TVs (Blum, 2014), begging the question if an internal or external fire hazard persists and if FR use is necessary. As Dr. Vyto Babrauskas, a fire scientist from California, stated, “TVs are held to a very different standard than other electronics” in that those certain TV components such as external cabinetry casings, are UL94V rated (the more stringent flammability standard requiring FRs to meet it), where as other electronic housings are UL94HB rated (which do not require the use of FRs).

What’s more, with technological advances and the proliferation of the TV industry, the number of TVs in households and viewing hours has significantly increased over the decades, which becomes a concern given that TVs are one of two (the other being furniture) primary sources of FRs found in household dust (Allen et al., 2008; Li et al. 2015). Again, this is concerning given the vast data indicating that humans have FRs in their bodies and data indicating a toxicological adverse affects (examined further in Chapter 3, Section II). However,
Despite these advances and concerns, the UL94V flammability standard for plastic materials in TVs has not changed since its inception. Therefore, this paper will revisit the UL94V flammability standard for TV plastic materials, which is currently in use in Canada and the US under CSA/UL 62368-1 standard. This paper will explore the risk versus benefit trade off to determine if there is a fire safety benefit to FR use in TVs and if UL94V is effective in reducing fires while also exploring the risks associated with using FRs to meet this standard.

The current TV flammability standard in regards to UL94V rated plastic material (which again, requires the use of FRs) is: 1) outdated and lacks relevance to current technology as flat, thin, energy efficient LCDs dominate over traditionally used heavy, bulky and energy-intensive CRTs; 2) does not impart fire safety benefits considering there is a lack of valid fire safety concern (due to the reduced internal and external ignition) and fire hazard, and a lack of valid fire data on TV fires in general and; 3) overly stringent as it does not consider the possibility of increased risk due to exposure to FRs due to the proliferation and greater use of TVs. Therefore, this paper will argue that the UL94V standard has become trapped in history and needs to be updated as it may play a major role in FR exposure.
Chapter 2

METHODS

In order to acquire the information on FRs, their role in materials (polymer combustion, mechanism of action), their use worldwide and in North America, the extent of their contamination in the environment and in human bodies, their routes of exposure and their toxicity, various online databases were searched electronically for both primary scientific journal articles, reviews and books using Google Scholar, Web of Science, Environmental Science & Technology using various search strategies. In researching background information in Chapter 3 section II specifically; no data limit was applied for some information in order to achieve a historical context. However, there was a date limited for some searches, such as a minimum of the year 2000 for toxicity or routes of exposure given that this is still a rapidly evolving area of research and more updated discoveries were needed. Key words used to find information included but were not limited to: FRs, Brominated FRs (BFRs), PBDEs, polymer combustion, FR mechanism of action in polymers, BFR mechanism of action, global production of PBDEs, PBDEs in Sweden, PBDEs or FRs route of exposure, PBDEs or FRs in food, PBDEs or FRs in households, PBDEs or FRs in furniture and TVs, PBDEs in fish/birds/rodents and mice/humans, etc.

In addition to literature searches, governmental sources were searched such as the US Statistical Abstract from the US Census Bureau for TV statistics, and websites such Green Policy Science Institute and United Nations Environmental Programme (UNEP), Underwriters Laboratories (UL), Canadian Standards Association (CSA) for flammability standards, regulation and chemical regulation.
Changes in TV technology is complex and beyond the scope of this paper. The scope in reviewing the history of TV focused on some of the major technological advances that occurred in relation to those that were implicated as influencing factors in TV fires in the 1970s (such as color TVs, “instant-on” feature, etc) while also recounting the decade in which these factors were widely adopted. Subsequently, the changes in flammability standards were also explored. As well, the changes in TV technology since the 1970s to current day were also explored. As such literature searches and books were utilized to develop the historical context using databases such as Google Scholar and IEEE, and the online Summon search engine for books. Key words used included but were not limited to: history of TVs, TVs in the 1940s/1950s/1960s/1970s, fires in TVs in the 1960’s/1970s, influencing factors on TV fires in 1960’s, TV flammability standard, CRTs versus FPDs, plasma display panels (PDPs), liquid crystal display (LCDs), market survey, etc. A limit on the date was necessary for some searches in order to obtain relevant information closer to those historical dates.

This paper used key informant interviews with Dr. Richard Hull, Professor of Chemistry and Fire Science at the University of Central Lancashire, and Dr. Vyto Babrauskas, a leading US fire scientist and authority in fire safety science and fire protection engineering. A general interview guide approach was used ensuring that relatively the same areas of information were collected with a semi-structured approach to obtained detailed insights on FR effectiveness in materials, flammability standards such as UL94, history of TVs and fires, etc. Their expert opinions served as a guide and as evidence for arguments regarding fire safety of TVs and FR effectiveness in TVs.
Chapter 3

BACKGROUND INFORMATION: LITERATURE REVIEW

I. Aspects of Fire Science and Safety Measures

The Council of Canadian Fire Marshals and Fire Commissioners reports fire losses in Canada with the most recent information from 2002 (taking into account all provinces and territories) indicating that there were nearly 54,000 fires reported, with a $1.5 billion in property losses, and just over 300 fire deaths that year. According to the National Fire Protection Association in the United States, in 2014, there were 1,298,000 fires reported, which caused 3,275 civilian deaths, 15,775 civilian injuries, and $11.6 billion in property damage. Although these reports seem high, fire incidences have largely decreased over the past few decades due to implemented fire safety measures, such as flammability standards requiring the use of flame retardants (FRs) in order to lessen the combustibility of materials (Birnbaum & Staskal, 2004; Haynes, 2015) as well as a number of other fire safety measures such as smoke alarms.

This section will examine polymer characteristics and polymer combustion, the proposed FR mechanisms of action with particular emphasis on HFRs and as well as the flammability standard that requires the use of FRs in plastic materials found in television (TV) parts.

Polymer Characteristics and Polymer Combustion

Polymers are macromolecules that have repeated subunits of carbon and hydrogen and can either be homopolymers, consisting of one subunit, or co-polymers, that contains two different subunits (Horrocks & Price, 2001). Polymers can contain heteroatoms such as chlorine, nitrogen, fluorine, and oxygen (Horrocks & Price, 2001). Classification of polymers can either
be natural or synthetic (or synthetic modifications to natural polymers) or based on physical and mechanical properties like elasticity or degree of elongation (Horrocks & Price, 2001). There are a number of different classifications of polymers, for example they can be classified based on their chemical structure, which in terms of fire science “gives an important indication of their reactivity, including their fire performance, and the tendency to produce smoke when they burn” (Horrocks & Price, 2001). Although polymers are extremely widely used and provide us with many advantages, some polymers such as textiles and plastics, have high flammability due to their combustible carbon-hydrogen backbone, which is problematic in terms of fire safety (Waaijers et al., 2012).

Combustion is a “catalytic exothermic reaction that releases energy stored in chemical bonds in the presence of oxygen and is maintained by internal generation of free radicals and heat” (Horrocks & Price, 2001). The mechanisms of polymer combustion are complex, however, there are four phases: heating, pyrolysis, ignition and flame spread. In the case of a fire, organic polymers, both natural and synthetic, are exposed to a heat source, raising the surrounding temperature causing the polymer to thermally decompose. This process is known as pyrolysis, which yields volatile gases, solid carbonaceous char and smoke (Mouritz & Gibson, 2006).

In particular, flammable volatiles are produced and diffuse and mix with oxygen in the “flame zone”, acting as fuel and leading to final combustion products and release of heat (Mouritz & Gibson, 2006). Ignition occurs in the presence of an external flame, flash ignition, or if temperatures are high enough, auto-ignition (Horrocks & Price, 2001). As illustrated in Figure 1, a self-sustaining cycle exists in which the organic polymer continues to undergo pyrolysis due to increasing temperatures and heat fed-back to the decomposing area; organic volatiles accumulate, interacting with oxygen leading to flame spreading (Horrocks & Price, 2001;
Mouritz & Gibson, 2006). It is important to note that individual polymers are different in structure and composition and therefore, have different decomposition temperature ranges and mixtures of polymers behave differently (Horrocks & Price, 2001).

Figure 1: Self-sustaining cycle of polymer combustion (Mouritz & Gibson, 2006).

**Fire Safety: Proposed FR Mechanism of Action**

FRs added to a polymer material is one approach used for fire safety. There are a number of factors that are taken into account to understand the behavior of a polymer in a fire risk situation. Polymers and mixtures of polymers differ in chemical structure and composition and therefore possess different characteristics in terms of fire science, such as decomposition
temperature ranges (Horrocks & Price, 2001). Therefore, this influences which type(s) of FRs are used with which polymer. The various physical and chemical modes of actions include:

Depending on the mode of action, FRs can act at any of the four steps involved in polymer combustion, and can act chemically and/or physically in the solid, liquid or gas phase (Troitzsch, 1998) and can prevent or limit the occurrence of fires (Alaee et al., 2003). The various chemical and physical modes of action in which FRs act include:

1) **Physical action:** a) additives, such as Aluminum hydroxide, trigger endothermic processes cool the substrate to a temperature below that required for sustaining combustion; b) compounds such as phosphorus or boron can form a protective layer, where a solid or gaseous protective layer that shields the condensed combustible layer from gaseous phase and; c) inert substances and additives, such as Aluminum hydroxide, are incorporated and evolve as inert gases on decomposition dilutes the fuel in solid and gaseous phases, lowering ignition limit of the gas mixture (Troitzsch, 1998);

2) **Chemical action:** a) HFRs undergo a chemical reaction in the gas-phase of combustion, where a free radical mechanism taking place in the gas phase is interrupted by the FR thus stopping the exothermic process and cooling the system down and; b) chemical reaction in the solid phase, where the FR, such as phosphorus compounds, can cause a layer of carbon to form on the polymer surface, forming carbonaceous layer cyclizing and cross-linking (Troitzsch, 1998).

The key challenge to ensuring flame retardancy is to “find a suitable compromise between the performance of the polymer and fulfilling flame retardancy requirements” (Waaijers et al., 2012). There are reactive, additive or combination FRs that work within the condensed and gas phases of polymer combustion (Green, 1996; Troitzsch, 1998). Reactive FRs, as the name suggests, react with the polymer and retard migration of the FR from the polymer (Troitzsch,
Additive FRs are incorporated prior to, during or more frequently, following polymerization of plastics, acting as either fillers or plasticizers if they are compatible with a plastic material. Additive FRs are more likely to migrate from the polymer than reactive FRs because they are not chemically bound to the polymer whereas reactive FRs are (Troitzsch, 1998). Combination FRs are both additive and reactive FRs, which can produce additive, synergistic or antagonistic effects (Troitzsch, 1998).

In particular, the synergistic system (FR/synergist) has been common use because it is less expensive than only using an individual FR (Troitzsch, 1998). As an example, BFRs have very good technical properties and are used in many polymers and in most cases with antimony trioxide as a synergist, which is used to enhance the mechanism of action of the FR (Troitzsch, 1998). The halogen (e.g., bromine) and antimony can function in the vapour phase through a free radical mechanism by capturing free radicals produced during combustion and thus interrupting the exothermic process and suppressing combustion as free radicals are essential in order for the flame to propagate by capturing free radicals that are produced during the combustion process, which are essential elements for flame propagation (Green, 1996; Alaee et al., 2003).

All four halogens are effective in capturing free radicals, however, not all halogens are suitable for use in FRs. For example, as explained in Alaee et al. (2003), “fluorinated compounds are very stable and decompose at much higher temperatures than most organics burn, delivering their halogens too late to be effective as FRs”, whereas “iodinated compounds are not stable and decomposes at slightly elevated temperatures. Therefore, leaving organobromines and organochlorines are used as FRs (Alaee et al., 2003). Organobromine compounds were more widely used than organochlorine compounds given their ability to efficiently capture free
radicals and decompose at lower temperatures (Alaee et al., 2003). Figure 2 demonstrates how organobromine and organochlorine FRs work to suppress flame spread.

First the flame retardant breaks down to

$$RX \rightarrow R^\cdot + X^\cdot$$  \hspace{1cm} (1)

where $X^\cdot$ is either Cl$^\cdot$ or Br$^\cdot$.

The halogen radical reacts to form the hydrogen halide:

$$X^\cdot + RH \rightarrow R^\cdot + HX$$  \hspace{1cm} (2)

which in turn interferes with the radical chain mechanism:

$$HX + H^\cdot \rightarrow H_2 + X^\cdot$$  \hspace{1cm} (3)

$$HX + OH^\cdot \rightarrow H_2O + X^\cdot$$  \hspace{1cm} (4)

The high-energy H$^\cdot$ and OH$^\cdot$ radicals are removed by reaction with HX and replaced with lower-energy X$^\cdot$ radicals. The actual flame retardant effect is thus produced by HX. Previously the decisive stage of inhibition was believed to take place according to Eq. (4) but more recent studies suggest the reaction according to Eq. (3) to be responsible.

Figure 2: Mechanism of action for organobromine FRs; Hull & Stec, 2014.

Flammability Standards: UL 94

FRs are used to meet flammability codes, regulations and standards, which are regulatory requirements adopted by government agencies or voluntarily adopted by manufacturers.

Standard bodies such as the International Standard Organization (ISO), International Electronics Commission (IEC), US Underwriters Laboratory (UL), American Standards for Testing and Materials (ASTM), Canadian Standards Association (CSA) and Canadian UL, develop flammability standards. The design of the flammability standard determines a material’s
performance and acceptability for use in a commercial product. In particular, manufacturers that produce resins, FRs, and plastic products are required to perform tests confirming that regulatory standards are met. This includes the materials reaction-to-fire performance and understanding how a material or a product responds to heating or to a fire (Babrauskas &., 1992).

Of particular relevance to this paper and the use of TVs as a case study, is the Standard for Safety entitled UL94: Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, which includes “requirements covering tests for flammability of polymeric materials used for parts in devices and appliances. They are intended to serve as a preliminary indication of their acceptability with respect to flammability for a particular application. According the UL94 standard, “the final acceptance of the material is dependent upon its use in complete equipment that conforms with the standards applicable to such equipment. The flammability classification required of a material is dependent upon the equipment or device involved and the particular use of the material”. The standard that requires plastic materials to conform to the UL94 classification in TVs is CSA/UL 62368-1.

UL94 tests are widely used and the ratings based on these tests are used to classify plastic materials based on a number of different factors such as how they burn depending on position and how quickly they self extinguish after ignition (Hull & Stec, 2014). Six tests come under UL 94: Horizontal Burning Test (HB), 50W (20mm) Vertical Burning Test (V-0, V-1, V-2), 500W (125 mm) Vertical Burning Test (5VA, 5VB), Radian Panel Flame Spread Test, Material Vertical Burning Test (VTM-0, VTM-1, VTM-2) and the Horizontal Burning Foamed Material Test (HBF, HF-1, HF-2). According to the UL94 standard, the methods employed in these tests involve a standard size specimen and are intended to measure and describe the flammability properties of materials in response to a small open flame or radiant heat source under laboratory
conditions. In other words, there is a piece of plastic of a specific size, which is held in different planes according to the test (e.g., vertical for the Vertical Burning Test) at a specified distance away from a burner flame comprising a specific height.

Of particular interest is the UL94HB test, which is the lowest fire-safe classification and the UL94V test that is more stringent. Both tests are used for plastics and rubbers and are based on the use of a small gas flame but have different specifications that materials must meet (Refer to Table 1, Figure 3 and Figure 4 for more information on the specifications of these tests). HB rated plastic does not require the use of FRs in order to pass the test whereas V rated plastics do in order to pass the level of test requirements.

Table 1: Summary of UL94 flammability ratings for 94V and 94HB tests (highest to lowest: most to least flame retardant). Modified from Hull & Stec, 2014

<table>
<thead>
<tr>
<th>Rating</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-0</td>
<td>20 mm flame applied for 10s to the base of 5 vertical test bars. Burning must stop within 10s for first flame application and within 30s after second flame application (both flaming and afterglow). Total burn time must not be greater than 50s. Specimens must not burn to the upper clam or generate burning drips.</td>
</tr>
<tr>
<td>V-1</td>
<td>As for V-0 but burning shall stop within 3s for first application, and flaming plus afterglow within 60s after second application. Total burn time must not exceed 250s. Specimens must not burn to upper clam or generate burning drips.</td>
</tr>
<tr>
<td>V-2</td>
<td>As for V-1 except generation of burning drips is allowed, igniting the cotton wool below.</td>
</tr>
<tr>
<td>HB</td>
<td>For specimens 3mm thick or less, burning over a 75mm distance must be less than 75mm/min. For specimen between 3 and 13 mm thick, burning rate must be less than 40 mm/min, or less than 100mm from the end of the specimen in the flame.</td>
</tr>
</tbody>
</table>
Figure 3: UL94HB test specifications; Hull & Stec, 2014

Figure 4: UL94V test specifications; Hull & Stec, 2014
II. FRs and the Cause for Concern

FRs refer to a large group of chemicals that are incorporated into polymeric materials such as textiles and plastics in order to meet flammability standards with the goal of enhancing the fire safety level of the combustible materials (Alaee et al. 2003). There are more than 175 FRs on the market consisting of four major classes: inorganic, halogenated organic, organophosphorus and nitrogen-based FRs (Alaee et al., 2003). In particular, HFRs are a large group that has been extremely widely used. Some HFRs such as polybrominated diphenyl ethers (PBDEs), belonging to the group of BFRs, have been extensively studied for their effects on the environment and humans. In particular, decabromo diphenyl ether (decaBDE) has been one FR of choice for use in some plastic materials in TVs, such as in the external cabinetry casing. Therefore, PBDEs will be a focus in this chapter.

In North America, HFRs, such as BFRs, are used in electronics, building materials such as insulation, transportation vehicles (from automobiles to airplanes and trains), and home furnishings (Shaw et al., 2010). The levels in each product differ significantly. For example, HFR are commonly used in PUF and polymeric insulation at 5-20% by weight of the polymer (Shaw et al., 2010). BFRs are additive FRs and were the dominant HFR used until recent restrictions on the use of some compounds. In 2000, BFRs accounted for 38% of the global demand share of bromine, a considerable increase compared to 1975 where BFRs accounted for only 8% (Birnbaum & Staskal, 2004).

BFRs were the dominant choice because they do not significantly alter the polymer’s characteristics, have been reported to be effective in low amounts at reducing heat evolved in combustion and reduce the release of volatile organic compounds (VOCs) from decomposing polymers, and are very economical (Horrocks & Price, 2001; Waaijers et al., 2012). In particular,
three polybrominated diphenyl ethers (PBDEs) commercial mixtures, pentabromodiphenyl ether (pentaBDE), octabromodiphenyl ether (octaBDE) and decabromodiphenyl ether (decaBDE), were among the most widely used BFRs (Birnbaum & Staskal, 2004).

It has been estimated that approximately 85% of the total global pentaBDE was used in North America (Alcock et al. 2003). The total global consumption for octaBDE was estimated at ~110 000 tonnes whereas for decaBDE, the total global production was estimated at ~1 100 000 to 1 250 000 tonnes from 1970 to 2005 (UNEP, 2002). By 2005, production was expected to exceed 60,000 tonnes per year with over 40% of total global production used in North America (UNEP, 2002), which may be attributable to restrictions placed on penta- and octa-BDE (Abbasi et al., 2015).

Specific to the US and Canada, it was estimated by Abbasi et al. (2015) that the time-dependent stocks of PBDEs in in-use products of penta- and octaBDE peaked at 17 000 and 4000 tonnes in 2004, respectively, and at 140 000 tonnes in 2008 for decaBDE. Further, it was found that the total consumption of penta-, octa-, and decaBDE from 1970 to 2020 in products considered was estimated at ~46 000, ~25 000, ~380 000 tonnes, respectively, making decaBDE the most extensively used of the three commercial mixtures (Abbasi et al., 2015). DecaBDE has been extensively used in a range of electrical and electronic equipment (EEE) such as personal computers and TVs (Abbasi et al. 2015).

**PBDE Contamination and Body Burden**

Concerns were raised about the human and environmental adverse effects resulting from FR use, as research on PBDEs began documenting widespread environmental and human exposure since the 1980s. PBDEs have relatively low reactivity, high hydrophobicity,
persistence, and have the ability to bioaccumulate in animal tissue. Swedish researchers documented BFR contamination in the environment (Jansson, 1987; Sellström et al., 1993) and in human blood (Klasson Wehler, 1997; Sjödin et al., 1999), and breast milk (Darnerud et al 1998; Meironyte et al., 1999). In addition, an increasing temporal trend in the levels of PBDEs, specifically in milk from Swedish mothers, has been noted which was attributable to the coinciding increase in the usage of products containing PBDEs, such as electronics, from 1972 to 1997 (Meironyte et al., 1999).

Furthermore, PBDEs continue to be detected in more recent studies where they have been detected in air (Venier & Hites, 2004; Melymuk et al., 2012), sediments (Zhu & Hites, 2005) water, snow and rain (Ueno et al., 2008), fish (Christensen et al., 2002; Boon et al., 2002; Brown et al., 2006), birds and bird eggs (Sellstroem et al., 2001; Voorspoels et al., 2006), and marine mammals (de Boer et al., 1998; Alaee et al., 1999; Boon et al., 2002, She et al., 2002) and in human tissues (Hites, 2004) such as human breast adipose tissue (She et al., 2002).

More, a meta-analysis by Hites (2004) showed that up until 2004, biota and humans in North America had much higher levels of PBDEs compared to Europe, with levels doubling every 4-6 years. The higher levels of PBDEs in North American populations have been attributed to stricter flammability standards (Trudel et al., 2011) and the higher use of PBDEs as compared to Europe (Hites, 2004). As previously reported, in 2001, North America was the largest consumer of PBDEs at approximately 50% of the global demand (Birnbaum & Staskal, 2004; Trudel et al. 2011). As a result of PBDE properties, their widespread use and ability to accumulate in the environment and in animal tissue, routes of exposure and toxicity have also been extensively studied.
Routes of Exposure

Exposure to FR may occur during their incorporation into manufactured materials, such as PUF and plastic polymers, and from commercial products such as furniture and electronic equipment during assembly, use and subsequent disposal (Jones-Otazo et al., 2005; Rauert & Harrad, 2015). For humans in particular, possibilities for routes of exposure can be through either one or a combination of the following: ingestion and inhalation of FR-containing dust, diet, dermal uptake, and hand-to-mouth transfer (Lorber, 2008; Trudel et al., 2011).

Human exposure through dietary intake has been studied and predictably it appears to be influenced by geographic location. Dorso et al. (2010) concluded that poultry and meat consumption constituted a major PBDE exposure pathway for humans in North America, whereas in European and Asian countries, fish consumption contributed significantly to PBDE body burden. Trudel et al. (2011) found food to be the dominant pathway of human exposure to FRs given that PBDEs can be found in considerable amounts in foods consumed regularly. They also found that ingestion of dust might be another important pathway of FR exposure.

Since humans spend over 90% of their time indoors, of which 70% is spent at home (Matz et al, 2014), indoor environments are believed to be important sources of FR exposure. Dorso et al. (2010) reported that indoor levels of BFRs in house dust have increased significantly throughout the years, which is likely due to household and consumer products which are reservoirs for FRs. Jones-Otazo et al. (2005) considered individual exposure to PBDEs in particular and found that inadvertent ingestion of house dust was the largest contributing route of exposure for toddlers through to adults.
BFRs are incorporated into consumer products as additives, which are loosely bound to the product and as such, can migrate and settle into household dust (Rauert & Harrad, 2015). Specific to higher molecular weight PBDEs like BDE-209, migration seems to be influenced more strongly by abrasion and direct migration pathways versus volatization with subsequent migration to dust (Rauert & Harrad, 2015). Rauert & Harrad (2015) stated these findings are likely to be different for lower molecular weight compounds, compounds with higher volatility and reactive FRs where one or a combination of transfer mechanisms can be utilized (e.g. volatization and subsequent migration to dust, abrasion and direct migration, etc). Therefore, more research is needed to further substantiate the mass transfer of a range of organic FRs into household dust. More information on migration of PBDEs into household dust specific to electronics and TVs will be presented in Chapter 5.

**PBDE Toxicity**

In addition to documentation of widespread use and exposure to PBDEs, studies have raised concerns about the toxicity of these chemicals given their similarity in structure to polychlorinated biphenyls (PCBs), a highly toxic environmental pollutant. According to a review by Shaw et al. (2010), *in vitro* and *in vivo* studies have shown that PBDEs have the potential to cause endocrine disruption in animals such as amphibians, birds, fish, mice and rats. Further, epidemiological evidence has found associations between prenatal and/or postnatal exposure to PBDEs and a number of neurodevelopmental health issues, altered thyroid hormone levels and reproductive function (Abbasi et al., 2015).
Fish

Specifically, fish studies have show that PBDEs can alter behavior such as delaying hatching, depressing rates of swimming and feeding (Timme-Laragay et al., 2006) and induce morphological abnormalities such as neural defects and impair cardiovascular function such as inducing cardiac arrhythmia (Lema et al., 2007). It has also been found that parental exposure to PBDEs can be transferred to offspring causing adverse effects on neurodevelopment in zebrafish offspring such as significantly altered acetylcholinesterase (AChE) activity, downregulated genes of the central nervous system development, and decreased locomotion activity (Chen et al., 2012).

Birds

In relation to birds, studies have shown that in ovo and post-hatch exposure of captive American kestrels to environmentally relevant PBDEs alter thyroid, retinol and oxidative stress measures (Fernie et al., 2005) with behavioral changes such as modified quality of the pair-bond and reproductive behavior of both sexes (Fernie et al., 2007). Other studies have found that in some of the birds examined, there were higher concentrations of PBDEs in the brains of birds than in adipose tissue examined (e.g. sparrow hawks, etc) suggesting important interspecies and individual differences to the susceptibility for accumulation of PBDEs in the central nervous system (Naert et al., 2007).
Rodents

There are laboratory experiments using rodents that have found associations with exposure to PBDEs to a variety of adverse effects. In particular, Eriksson et al. (2002) found that neo-natal exposure to PBDEs could result in impairment to motor skills, learning and memory. Hallgren & Darnerud (2002) found that PBDE exposure can lead to endocrine disruption altering thyroid hormone levels. Further, Stroker et al. (2004) found that exposure to PBDEs can lead to reproductive development impairment (Stroker et al., 2004).

Humans

Little human hazard to PBDE exposure information is known given that PBDE commercial mixtures have varying composition, which makes toxicological characterization difficult (Roth & Wilks, 2014). However, the animal studies mentioned above suggest potential adverse effects in humans and epidemiologic studies can be useful in demonstrating associations to adverse effects and exposure. Exposure to PBDEs has been particularly concerning given the potential disruption to thyroid hormone homeostasis especially during development, which is a sensitive period of time where any disruption in maternal and fetal thyroid homeostasis can cause neurologic impairments (Roth & Wilks, 2014). Thus a primary concern for the toxic effect of PBDEs is the for potential neurodevelopmental toxicity.

An epidemiologic study conducted by Herbstman et al. (2010) examined prenatal PBDE exposure and neurodevelopment in children at various ages and found that neurodevelopmental effects, such as performance IQ, correlated with cord blood PBDE concentrations. Another epidemiologic study by Eskenazi et al. (2013) investigated the relationship between in utero and
child PBDE exposure to neurobehavioral development in a California cohort (Exposure to PBDEs in California children is among the highest worldwide) and found that prenatal and childhood PBDE exposures were associated with a number of neurobehavioral effects such as poorer attention and cognition. Further, in relation to postnatal exposure, it has been demonstrated that exposure to low levels of PBDEs can lead to an increased risk of symptoms on the attention deficit subscale of Attention Deficient Hyperactivity Disorder (ADHD) symptoms and a higher risk of social competence symptoms (Gascon et al. 2011).

Restrictions on PBDEs

The human and environmental health concerns for PBDEs have increased dramatically over the years since their widespread environmental persistence has become known. Production and use of major BFRs have been restricted in Canada, the European Union (EU), US and Japan (van der Veen & de Boer, 2012). In 2004, the US Environmental Protection Agency (EPA) brokered a voluntary agreement with three US PBDE manufacturers to cease production of penta- and octaBDEs (Abbasi et al. 2015). In 2006, the Canadian Environmental Protection Act (CEPA) listed the homologues in c-penta- and c-octaBDE as toxic agents and were banned from production and use in new products in 2009 (Abbasi et al. 2015). In 2009, the United Nations Environmental Programme (UNEP) listed penta- and octaBDE as persistent organic pollutants (POPs) subject to control under the Stockholm Convention (van der Veen & de Boer, 2012). DecaBDE however, continued to be used although in 2008 the EU banned its use in EEE and in the US, industry committed to a voluntary phase out of this chemical by 2013 (Ma et al., 2013; Abbasi et al. 2015). DecaBDE continues to be produced and used in China.
Alternatives to PBDEs

Given the restrictions on PBDEs, organophosphorus FRs (PFRs) have re-emerged as alternatives to BFRs since they were presumed to be less environmentally persistent than some of the previously used BFRs (Ma et al., 2013). Similar to BFRs, many of the PFRs are additives and not chemically bonded to the polymeric materials, which results in similar migration from the polymers to which they were added and subsequent exposure to humans and the environment as BFRs. Although PFRs are different from BFRs, evidence is emerging indicating detectable levels in household dust (Stapleton et al., 2009; Hoffman et al., 2015), in infant bodies (Hoffman et al., 2015) and in pregnant women (Hoffman et al., 2014) as well early studies indicating the toxicity of some PFRs to animals such as zebrafish (Dishaw et al., 2014). As well, some PFRs are persistent and able to under long-range transport to remote locations (Zhang & Suhring et al., 2016; Suhring et al., 2016).
Chapter 4

A RECOUNT OF EVENTS THAT LED TO FR USE IN CANADIAN AND US TVs

In order to examine the risk versus benefit trade off, it is instructive to first look at how FRs came to be in TVs sold in both Canada and the US by examining the history of TVs and the progression of corresponding flammability standards in the US. The US will be the country of focus given that concern over TV fires in the US initiated the corresponding voluntary action by the UL for a mandatory standard in 1976, UL 1410 (which required UL94V rated plastic materials in TVs as one fire safety requirement), at the request of the US Consumer Product Safety Commission (CPSC). These historical events are relevant to Canada because plastic components in Canadian TVs follow the UL94V standard requirement and thus contain FRs in the most recent standard encompassing TVs entitled, CSA/UL 62368-1.

1940s

TV manufacturing started before the onset of World War II but slowed down as other higher priority projects became more pertinent. The War created an explosion of electronic technologies, which used the same basic technologies as TVs and as a result advanced TV receiver technology (O’Brien & Monroe, 1999). After the war, the production and sales of black-and-white TV receivers commenced.

The Radio Corporation of America (RCA) was the leading force in the area of radio and TVs. They had a line of CRT TVs that became the standard in the early 1940s with the help of the Federal Communications Commission (FCC) (Shapiro & Varian, 1999). At the time, RCA shared their technology with other TV manufacturers as it was realized that a uniform TV
standard was needed for the success of the industry (Shapiro & Varian, 1999). Other technological advances during this time included an increase in size and change of shape for TV picture tubes. The size of TV receivers grew from 7- and 10- inch picture tubes in 1947, with picture tubes ranging up to 19 inch in diameter two years later (O’Brien & Monroe, 1999). By 1950, rectangular picture tubes had been introduced and soon became the preferred type of display (O’Brien & Monroe, 1999).

Standards for Safety kept pace with the progression of radio and TV technology. Specifically, the Standard for Safety for Power-Operated Radio Receiving Appliances (UL 492) was first issued in 1928 and was originally intended to cover construction requirements for radios which included wood or metal enclosures, supply circuit components, and fuses, etc (Coen & Hoffman, 1984). Over the years, this standard grew to include new construction requirements to address risks, such as fire. The 6th edition of the standard was revised in 1942 to include TV receivers. While this standard had few requirements with respect to TVs, “noncombustible” enclosures were defined with respect to type and thickness of materials use, number and size of openings and volume of enclosures (Coen & Hoffman, 1984).

Around the time of World War II, black-and-white TV receivers were very expensive and thus a luxury item. The prices of TVs at the time ranged from $200 for smaller TVs to $400-500 for the larger TVs (Morton, 1999). In addition, these TVs required constant maintenance given the large number of vacuum tubes (an electron tube containing a near-vacuum that allows free passage of electric current) they contained. However, towards the end of the 1940s, TV receiver sales were growing in the US. In 1947, 178,500 receivers were built, 875,00 in 1948, 3 million in 1949 and 7.5 million in 1950 (O’Brien & Monroe, 1999).
The methods of production for TVs and electronic equipment changed drastically, becoming much more efficient as TV manufacturers made use of printed circuit boards and automated assembly, which reduced the cost of TVs by nearly 50% by the early 1950s (Morton, 1999). By 1955, 35 million of an estimated 46 million US households had TVs (Morton, 1999).

During the early 1950s, the thermoplastic industry was gaining prominence and thermoplastic enclosures were used in TVs, as opposed to metal or wood enclosures that were used previously. As a result, requirements and conditions were needed for approving these materials for support of live parts and to determine whether enclosures increased risk of injury from fire (Coen & Hoffman, 1984). Tests were required to judge the mechanical strength and temperature stability of polymeric enclosures with back covers of pressed-board materials. For example, thermoplastic enclosures were required to withstand an impact test and a bending moment test (Coen & Hoffman, 1984).

The concern of TV fires became evident and was reflected in the number of safety requirements that manufacturers had to meet. Safety standards progressed to include requirements to reduce the risk of injury from fire in terms of fire *containment* (Coen & Hoffman, 1984). Some of the requirements included that: high-voltage components, such as the fly-back transformer, were required to be in a non-combustible enclosure, usually a metal cage; the size and number of openings in the enclosure were required to be limited in order to restrict the escape of flames in the event of fire; fuses which were relied upon to reduce the risk of fire in TV receivers; and TV receivers needed to be marked with caution for the user or serviceman that fuses should be replaced only with fuses having the same voltage and current rations (Coen & Hoffman, 1984).
Further, implosion tests were necessary to judge the protection of high-vacuum cathode-ray tubes (CRTs) with requirements such as limiting the openings in enclosures (Coen & Hoffman, 1984). The aim was to protect against the glass throw in the case of an implosion (Coen & Hoffman, 1984). In the early 1950s TVs were covered in a separate publication and deleted from the scope of the standard. In 1957, this separate publication was incorporated into the ninth edition of the existing standard and renamed to the *Standard for Radio and Television Receiving Appliances* (Coen & Hoffman, 1984; Hoffman, 2003).

### 1960 and 1970s

The 1960s to 1970s marked an era of drastic technological advances that resulted in TVs becoming a commonplace product. The many advances improved “overall picture quality, performance stability, product performance uniformity, end product safety and reliability, and reduction of input power consumption” (Lemke, 1984). All these advances led to wider acceptance of TVs in households where by before 1980, 97% of US households invested in TV (US Census Bureau, 2000).

By 1960, black-and-white TV programing and reception was well established. Consumers did not want to invest in color TV given the “reliability and service issues, marginal performance levels, lack of significant color programing and high receiver cost” (Lemke, 1984). This lack of acceptance was evident in 1963, when only about 3% of TV households had color sets, which “remained three to five times as expensive as black-and-white sets” (Shapiro & Varion, 1999). The premier of “Walt Disney’s’ Wonderful World of Color” was regarded as the “killer app” that enabled households to start investing in color sets (Shapiro & Varion, 1999).
By the mid-1960’s, color sets became more reliable and less expensive leading to a surge in color TVs in the marketplace. Consumers began investing in color receivers at an accelerating rate and by the 1970s; the entire broadcasting industry was converted to color (O’Brien & Monroe, 1976). Sales of color TVs dramatically increased from 120,000 units in 1960 to 2,646,000 units in 1965 (US Census Bureau, 1972). By 1969, color TVs began to surpass black-and-white TVs in sales (Refer to Figure 5).

![Figure 5: Sales of TVs from 1960 to 1971 demonstrating black-and-white TV supremacy up until 1969 when color TV sales started increasing and being the dominant technology. Data obtained from the U.S. Statistical Abstract from the U.S. Census Bureau (US Census Bureau, 1972).](image)

A goal in the color TV industry was towards developing a receiver capable of being viewed “instantly” after turning on (Admiral Corp, 1967), which was a desirable characteristic for customers (Figure 6). This required supplying a constant, reduced power to the vacuum tube filaments while the receiver was off, allowing the filaments to be maintained in warm conditions...
so the cathodes could emit electrons immediately when the receiver was turned on (Admiral Corp, 1967). In CRTs, the vacuum tube amplifiers, or valves, needed to remain hot in order to function correctly, so most of the power was released to air as heat from the valves and dropper resistors (Admiral Corp, 1967). This heat represented a considerable risk of fire in TV sets as it further necessitated the high power consumption in color CRTs with the “instant-on” features. This would soon be implicated as one of the factors influencing TV fires.

Figure 6: Advertisement for “Instant-On” TVs (1960 – 1969 TV Set Advertising US, n.d)

As the standard contained upgraded requirements for TV components from the standpoint of flammability and resistance to ignition and arc tracing (Coen and Hoffman, 1984), government pressure increased to produce TVs with lower power consumption. Power consumption of TVs began to fall in 1967 as transistors began to replace vacuum tubes, and fell significantly when vacuum tubes ceased to be used around 1970. The conversion from vacuum
tubes to transistors “set the stage for further technological expansion of performance, reliability and productivity improvements that allowed for continued economic viability” (Lemke, 1984)

Fires in Color CRT TVs with “Instant-On” Feature and High Voltages and Temperatures

Around the 1970s, there were “120 million TV sets in the US with some 20,000 TV fires per year and 800 life-threatening fires per year” (Grand & Wilkie, 2000). TV fires prompted the TV industry, UL and CPSC to consider the possibilities of fires resulting from arcing or overheating components in combination with flammable materials used in the construction of the set, especially TV enclosures. In particular, the TV industry, US CPSC and UL became aware of fire incidents that were occurring predominantly in color TVs (Coen & Hoffman, 1984).

Field investigations were carried out to gain a better understanding of the factors leading to TV fires and the severity. These investigations indicated that several characteristics of TVs were possible contributing factors. It was found that “on-off” switches, across-the-line capacitors and high voltages were among the factors influencing TV fires (Coen & Hoffman, 1984). CPSC held hearings to investigate the safety of TV receivers, particularly color TV during 1969 and 1970. During these hearings, the TV industry and UL discussed the problems they identified in field investigations.

In the mid 1970s, the CPSC subpoenaed documents from TV manufacturers from the 1970 to mid-1974 that reported on accidents and safety-related incidents (Robertson, 1976). Robertson (1976) stated that over 10,000 reports were received from manufacturers during this time period, all of which were reviewed. The analysis of these reports showed that of 7620 of the incidents, 83% were fire or fire related, 52 of the fires involved fatalities, and there was a higher incidence of fires that occurred in damp climates than dry climates (Robertson, 1976).
This analysis found that the incidence of fire for each year of manufacture was always “significantly greater in color sets, averaging two times that of black-and-white sets” and that a fire was “over 6 times as probable in a set equipped with an instant turn on feature by which filaments kept the picture tube energized even while the set was turned off” (Robertson, 1976). This figure was based on 861 fires in “instant-on” TVs, in which the presence or absence of an “instant-on” feature was known (Robertson, 1976). In 3103 fires, the origin of fire could be identified: 36.4% cited high voltage and while the incidence of picture tube implosions during fire is not known, implosions were indicated to have occurred in “306 of the reported fires as they were a factor in the spread of fire through the scattering of hot or burning particles or drops of burning molten plastic” (Robertson, 1976). The higher incidence of fire could be related to operating temperatures and voltages: color CRT TVs could operate at electric potentials up to 30 kV with operating temperatures in the 43 to 46 degree Celsius range whereas black-and-white CRT TVs up to 16 kV (Robertson, 1976).

The total number of fires that resulted from CRT TVs with the “instant on” feature in the US during this time is unclear, however, these occurrences generated attention and led to increased public concern for fires resulting from TVs. Figure 7 refers to a newspaper article that documents cases of fires from color TVs with an “instant-on” feature. The deputy fire marshal of Virginia described receiving at least 3 or 4 reports each month from fires that resulted from TVs with more that likely go unreported. One man in particular, who served on the National Fire Protection Association, recounted his scare at the CPSC (assumed to be thee hearings held during 1969 and 1970) hearing where a Philco-Ford color TV with an “instant-on” feature caused a fire in his hotel room. Thousands of similar sets were recalled for adjustment as a result.
Figure 7: Newspaper article chronicling events from fires resulting from “instant-on” color TVs. “Instant-on” features one factor in television fires in the mid 1960’s and early 1970s.

Another TV set recall includes an immediate consumer release from the US CPSC warning consumers of the “possible fire hazard in 12,000 Zenith 19-inch table model color TV sets (CPSC, 1973). According to the CPSC release, Zenith commented that the “possible fire hazard in the sets is a result of an improperly located high voltage capacitor” (CPSC, 1973).

Although the number of fires resulting from either of these TVs manufacturers that were recalled and the number of fires resulting from these components is unknown, it is evident that key components of color CRT TVs with an “instant-on” feature and high voltage components were
the cause for fires during this time which led CPSC to “preliminarily determine” that these TV receivers presented an “unreasonable risk of injury to the public” (Coen & Hoffman, 1984).

In 1974, CPSC began the development process for a consumer product safety standard addressing hazards such as fire, explosion and mechanical hazards of TV receivers and issued the bid to the UL to formulate the standard (Coen & Hoffman, 1984; Hoffman, 2003). In producing the standard the UL worked with various committees which included “technically-oriented and use-oriented representatives of ultimate consumers and consumer groups including: TV receiver manufacturers; component manufacturers; retailers and others, including representatives of insurance interests, inspection authorities, TV servicemen organizations, safety experts, fire marshals, utilities and testing laboratories” (Coen & Hoffman, 1984).

Initially, polymeric materials that were used in TV cabinet enclosures were first required to meet the fire safety standard UL94-HB rating (effective July 1974), but this rating increased to UL94V-2 rating in 1975, to V-1 rating in 1977 and finally to a V-0 rating for major parts of an enclosure in 1978 in the 15th edition (Hoffman, 2003). As will be explored in Chapter 3, section I, the UL94V-0 rating is the more stringent flammability test standard requiring the use of FRs to meet it as opposed to the UL94 HB rating which does not require the use of FR for compliance.

In 1976, UL 492 became superseded by the 15th edition of the standard and became UL 1410, the Standard for Television Receivers and High-Voltage Video Products. At this time the UL 1410 standard became a separate standard from radio and audio equipment (UL1270) and video equipment except TV receivers (UL1490). This final draft was presented to the CPSC and included a number of changes that had been identified as problems during field investigations, in addition to the UL94 ratings aimed at reducing the energy requirements of TVs and ensuring
reduction in the heat produced by the TV when in use (Coen & Hoffman, 1984; de Poortere, 2000).

Based on the proposed changes, Coen and Hoffman (1984) stated that there was “a general change in philosophy in the field from relying upon containment of fire, to preventing a fire from starting, as less emphasis was placed on component enclosures and more emphasis placed on the components themselves and better use of less flammable material”. Thus, relative to the standards during the 1940s and 1950s, the final draft of the 1976 standard specified that combustible plastic materials needed to conform to the V0 classifications of the UL 94 standard whereby FRs were used to result in the use of less flammable material.

**Plastic Materials and FRs Used**

Adopting the UL94V-0 rating led to the use of very high fire performing plastic materials to meet the requirements that a vertical test specimen would not combust after being in contact with the flame of a gas burner (as per UL94V test requirements) (de Poortere, 2000). In order to achieve such high fire performance, HFRs, which were regarded highly effective and relatively inexpensive, were introduced into the plastic polymers (de Poortere, 2000), particularly, BFRs. High impact polystyrene (HIPS) was used for TV cabinets, typically used in electronic housings with decaBDE along with antimony trioxide whereas tetrabromobisphenol A (TBBPA) was used in epoxies for printed circuit boards (Green, 1997). DecaBDE was used well into the 2010’s in Canada and the US as the FR of choice, although, decaBDE was voluntarily phased out by the chemical industry in 2013.
Reduction in TV Fires as a Result of UL94V Rated Materials

As the UL standards for TVs became more stringent (UL rating changes noted above), CPSC continued to monitor the perceived hazards. According to Hoffman (2003), in 1979 CPSC performed a statistical analysis from 1975 to 1977, which found there were approximately 34.4 fires per million color TVs with cabinets of UL95HB plastics (432 fires total) and 4.6 fires per million color TVs with cabinets of V-0 rated plastics (46 fires total) manufactured between 1970 and 1977. The CPSC concluded that while these numbers could be attributed in part to a decrease in the overall number of fires and a decrease in the use of UL94HB plastic, according to Hoffman (2003), CPSC stated that “even if the data are restricted to 1975-1977 fire incidence in 1975-1977 produced sets, the relative risks of fire in TV sets with [UL94] HB plastic is four times higher than the risk with [UL94] V-0 cabinets”. With all the influencing factors that resulted in the fires that took place during this time, it seemed vital to adopt the most stringent V0 classification of UL94 in order to reduce the number of fires hazards from TVs.

The Change in Flammability Standards Since 1976

Since 1976, the UL 1410 standard has been supplanted by other standards although it is important to note that the UL 1410 equivalent in Canada at the time was unknown but it is likely to have been implemented given that Canadian standards appear to typically default to US standards. In 2003, the UL adopted an identical version of IEC 60065 (Standard for Audio, Video and Similar Electronic Apparatus) entitled ANSI/UL 60065 with its equivalence CAN/CSA-C22.2 No. 60065-2003 in Canada. Most recently, in 2010, separate standards covering audio/video including radio and TV equipment and computer and “information technology”
equipment were consolidated under one standard, International Electronics Commission (IEC) 62368-1 (*Standard for Audio/Video, Information and Communication Technology Equipment*). The UL adopted this standard in 2012 as CSA/UL 62368-1, replacing the UL 60065. The second edition of this standard has been published in both Canada and in the US as of December 1, 2014 and was approved by the Standards Council of Canada (SCC) and the American National Standards Institute (ANSI) (Edition No. 2 of CSA/UL 62368-1 published in Canada & U.S. on December 1, 2014, n.d) and is expected to take a few years to be implemented. Despite these changes, UL94V rated plastic materials remains apart of the over arching fire safety standard for TVs.
CHAPTER 5
TRAPPED IN HISTORY: OUTDATED AND OVERLY STRINGENT FLAMMABILITY STANDARD LACKS RELEVENCE TO CURRENT TV TECHNOLOGY

TV technology has advanced significantly from 1976 when UL 1410 was implemented with UL94V rated plastic materials requiring the use of BFRs, such as decaBDE. However, despite these changes, the standard has remained the same. This chapter will argue that the UL94V test standard, which has been a requirement in the many renumbered standards since 1976, has become trapped in history in that it is outdated, lacks valid fire safety data or benefit and is overly stringent, as it does not coincide with developments that have taken place since its inception.

First a market survey will be presented that shows the widespread adoption of flat, thin “TV on the wall” technology with improved energy efficiency; then an explanation concerning the differences between traditional CRT TVs and current FPDs in the context of fire hazard and risk will be provided; then an examination of the fire safety benefit of the FRs in plastic materials and the UL94V flammability standard in light of technological changes in TVs will be demonstrated; and finally it will be argued that the standard does not take into account the proliferation and penetration of TVs into US households, leading to increased human exposure to FRs.

Thus, the aim of this chapter is to demonstrate the risk versus benefit trade-off for FR use and UL94V flammability standard requirement and will argue that this standard does not impart a fire safety benefit and instead, the human and environmental health risks have come to significantly out-weight the fire safety benefits. Raising this question will require careful data-
driven analysis and the end goal is to encourage standard and policy makers to view this standard as playing a major role in FR exposure.

I. Standard is Outdated as TV Technology Has Changed

This section will demonstrate that TV technology has evolved from bulky, heavy CRTs with high-energy requirements to current FPDs that are thin, flat, with low energy requirements providing a market survey to demonstrate this change. Also, the quest for higher energy efficient products means that there has likely been a reduced fire hazard resulting from internally initiated ignition (will be explored further in Section II) and which will likely continue to be the case into the future.

Market Survey and Technology Advances

CRT TVs were the ultimate emissive display with technology that “matched the human visual system very closely, providing a highly realistic and film-like image,” (Mentley, 2002) at a remarkably low price. However, CRTs were heavy, very bulky, consumed a lot of resources and toxic chemicals such as the leaded front glass, and they required very high voltages and high temperatures to operate.

These limitations were recognized and led to the dream of flat, thin “TV on the wall” technology with greater energy efficiency (Parker et al., 1999, Kreng & Wang, 2009; Kreng et al., 2012). The demand for bigger TV screens in households, as well as the commercial market, was fuelled by HD Digital TV services, which led to the development of new display technologies (Cho et al., 2015). The start of the 2000’s saw the introduction of FPD technologies
such as LCDs and PDPs, which offered “screens of unprecedented size, brightness and contrast approaching or surpassing the quality afforded by the CRTs” (Eden, 2006) with significantly lower energy requirements.

Up until the early 2000’s, CRTs were the dominant technology. Kreng et al. (2012) used a product competition diffusion model to determine the tripartite competitive relationship amongst CRT, LCD and PDP TVs globally in the scope of 30- to 45-inch TVs. Their data was obtained from DisplaySearch, which published quarterly shipments of CRT, LCD and PDP TVs from 2001 to 2007, globally. The market share of 30- to 45-inch TVs in 2003 was 93.55% for CRT TVs while LCD TV took up only 2.37% of the market and PDP TV 4.09%. However, in 2007, the market share of CRT TVs had plummeted to 6.41% while that of LCD TV had grown considerably to 80.7%, while PDP TVs increased slightly to 13.52% (Kreng et al., 2012). The high penetration of LCD TVs resulted from the increased output of the next generation production line and cutting costs and price in manufacturing (Kreng et al. 2012). LCD TV possessed better competitive advantage than CRT and PDP TVs (Kreng et al. 2012; Figure 8). PDPs were similar to CRTs, in that they remained power hungry and heavy, unlike LCDs, which require less power than CRTs (Eden, 2008; Figure 8).
Specific to LCDs, in recent years there has been a transition from Cold Cathode Fluorescent Lamp (CCFL)-LCDs to Light Emitting Diode (LED)-LCD in LCD technology, which has emerged as a dominant design in the TV market (Cho et al. 2015). Adoption of LED-LCD offered improvements in energy efficiency, screen size and thin profile and the market share was expected to grow worldwide from 2010 to 2015 (Cho et al. 2015). According to Cho et al. (2015), DisplaySearch predicted that LCD TVs would account for more than 85% of the global TV market through 2012, where CCFL-LCD TVs would account for ~29%, where as LED-LCD TVs would account for ~60% (Cho et al. 2015). Currently, flexible Organic Light Emitting Diode (OLED) TV has emerged as the next generation of TV technology. The major drivers of this technology development are market demand for thin profile, bigger screen sizes, and the needs of energy efficiency (Cho et al. 2015). In recent years, OLED technology has been taking off substantially and has successfully penetrated the TV market, where by 2015 it was expected that sales of OLED TVs would reach 2.7 million units, according to DisplaySearch (Cho et al. 2015).
In terms of power consumption, Cho et al. (2015) presented data showing power consumption of TVs by screen size and technology which showed that the larger the screen, the higher energy consumption and cost per month and per year for both LED-LCD TVs and PDPs, however, the cost was substantially more for PDPs TVs than LED-LCD TVs at comparable sizes (Figure 9). Further, as a comparative, LED-LCD TVs consume less power at about 70% compared to PDP, and 40% power as compared to traditional CCFL-LCD. Although Cho et al (2015) stated that this analysis is only an estimate, with many other factors associated with it; it appears that LED-LCD TVs are more energy efficient and happen to be the dominant form of TV technology currently.

![Figure 9: Energy cost per year and per month for LED and Plasma TVs indicating as screen size increases, energy consumption and cost increases and that LED are still much more energy efficient and cost efficient than PDPs. Taken from Cho et al. 2015.](image)

Taken together, the UL94V standard is outdated given that the standard was implemented to protect against internally initiated fires associated with high voltage and operating temperatures in CRT TVs. However, as demonstrated by the market survey, CRTs are no longer
the dominant technology as LCD technology has taken over the market since 2007. Particularly, energy efficient LED-LCD TVs have surpassed sales of traditional CCFL-LEDs with OLED technology projected to take up a larger market share in the future, demonstrating that the desire for higher energy efficiency requirements has been a big driver in the development of TV technology and will likely continue to be the case into the future. This is relevant because given that the quest for higher energy efficient TVs up until this point (and likely into the future) and the low voltage and operating temperatures in current TV technology, there longer seems to be a high risk for an internally initiated fire. However, the following Section II will explore this in more detail.

II. Lack of Valid TV Fire Hazard and Fire Safety Data Imparting Concern

Just to reiterate, Chapter 4 described that high voltage and operating temperatures in CRT TVs were a fire hazard, which led to the mandatory standard (UL 1410), which required UL94V rated plastic material and FR use in order to be compliant. However, as presented in Section I above, TV display technology has changed from CRT TVs to FPDs such as LCDs, becoming much thinner and lighter, with lower energy requirements. Therefore, this section explores the relevance of the UL94V flammability standard in the context of fire hazard and concern in light of technological changes in TVs.
FPDs vs. CRTs: Reduced Fire Hazard

Internal Fire Hazard

In comparing the voltages of CRTs to current technology, Dr. Vyto Babrauskas stated that, “TVs today all have lower voltages because LEDs and LCDs use a few hundred volts rather than a few thousand volts”. As mentioned in Chapter 4, color CRTs operated at electric potentials up to 30 kV and operating temperatures in the 43 and 46 degree Celsius range, and black-and-white CRTs up to 16 kV (Robertson, 1976). The high voltages were generated by the fly-back transformer and were transmitted to the CRT anode by an insulated wire (Blum, 2014). Because of these high voltages, there was a greater likelihood of an internally initiated fire. As an example, based on humidity levels, air can break down at 10 kV to 20kV per inch, so these high voltages were significant arcing risks if the transformer, wire or connection to the CRT failed (Blum, 2014).

However, with LCDs and PDPs, voltages are now self-contained in the ballast of fluorescent lamps that backlight LCD display or within the individual cells of a plasma display, that normal reach around several hundred volts (Blum, 2014). The current technology also reduces hazards such as internal heat sources like tube filaments, rectification and plate voltages that could reach as high as several hundred volts, and related high currents that were required in printed circuit boards to deliver filament power (Blum, 2014).

Given that advances in current TV technology have resulted in a significant reduction in voltage, as compared to CRTs, there is no longer an internal arcing hazard. UL94V was implemented to prevent against internally initiated fires and given the low energy requirements of current TV technology, the argument for the UL94V rated materials and FR use in TVs to
meet this standard no longer appears to be justifiable. However, FR effectiveness in TV components will be explored in more detail in section II of this chapter.

*External Fire Hazard*

Dr. Richard Hull explained that in the 1960s, TVs were large and bulky with a wooden casing and consumed a lot of energy, which had the potential for heating up the TV, drying everything up and igniting. He went on to explain that TVs were the main piece of furniture in people’s living rooms, and had a big surface area that people would typically place candles or plants on top of which presented a fire hazard. For example, if the candle would fall over or if people would water the plants the water could drip into the TVs. However, Dr. Hull stated that if you look at modern TVs, they are much thinner and lighter than in the past, leaving barely enough space to put candles or plants on top of.

Dr. Hull has put into perspective the external ignition factors that once were present for CRT TVs and explains that these external ignition factors are no longer a concern because TVs are flatter, thinner and are usually out of reach of candles and plants given some people choose to mount their TVs. And so, with the change in TV technology reducing the external fire hazard, the rationale of FR use in TV components such as external cabinet housings and the relevance of UL94V flammability test become questionable. Again, the following section II will examine FR effectiveness in certain components of TVs more closely.

Further, there has been an initiative from the FR industry focusing on external small flame ignitions like candles in an attempt to introduce an international “candle standard” for all electronics. Given that audio/video including radio and TV equipment and computer and “information technology” equipment were consolidated under one standard internationally (IEC
62368-1) and in Canada and the US (CSA/UL 62368-1), a “candle standard” would require all plastic cabinetry casings (or housings) to be resistant to external ignition from an external open flame which would further necessitate the use of FRs in TV housings in Canada and the US, as well as introduce FRs into all electronics casings.

Central to the FR industries argument is that external ignition is a significant fire hazard in TV fires. Margaret Simonson, a research manager at the SP technical Research Institute of Sweden has proposed significant fire safety benefit from FR use in UL94V-0 rated cabinet casings in the US, which has been frequently cited in proposals for a new requirement (Section 7 of IEC 62368). The FR industry is calling for a standard for open-flame resistance of TV sets, which would result in substantial use of FRs in all electronics (de Poortere et al., 2000; Simonson et al., 2002, Simonson et al., 2004; per Blomqvist et al., 2004). These proposals have been turned down numerous times internationally citing a “lack of proven fire safety benefit as well as health, environmental and recycling concerns” (Blum, 2014).

Tom Muir, an independent scientist and former employee of Environment Canada (retired), argues that the numbers of fire casualties that are asserted in the Simonson papers are cited with “neither evidence nor legitimate basis” (Muir, 2014). Further, Blum (2014) stated that the TV fire data presented by Simonson is “more than 10 years old and refers to all TV fires rather than external small flame ignitions” (Blum, 2014) which gives substantial inaccuracies when demonstrating an external fire hazard, which in this case has been reported as being substantially greater than it really is.

Dr. Babrauskas has asserted that external ignition from candles as “an insignificant societal problem”. As he explained, “there is a greater likelihood that there is an internal electrical defect in a TV than a child putting a candle to the exterior of a TV”. From an internal
fire hazard perspective on FRs in TV housings, Dr. Babrauskas mentioned, “even if they [chemical industry] focus their attention [to an internal fire hazard], there is still no where near enough FRs, even with UL94V rated materials, to withstand an internal fire that has somehow gotten started, so the [FR] effectiveness is not there”. This calls into question the effectiveness of UL94V standard and FR use as a whole with current technology.

To further substantiate the fact that an external fire hazard does not exist Dr. Hull stated, “incorporating FRs into the outer casings of TVs would have been appropriate when TVs had large heated surface area. But a large flat screen is completely different [because there is no space to hold a candle or plant]”. In relation to the UL94V and no valid external fire hazard, Dr. Hull went on to state that it is necessary to make regulations appropriate rather than to say TVs should follow an outdated standard as people know that you can not balance a candle on a [flat, thin] TV because they know it would fall over. Moreover, the candle industry now produces candles with maximum wick length, warning labels, no combustible decorative materials that would self-extinguish, and are designed not to tip over (Blum, 2014), in efforts to reduce the fire hazard of candles which can be seen as further reducing the TV fire hazard.

No Valid Fire Safety Data or Rationale for FR Effectiveness or UL94V Benefit

No Demonstrable Data on FR Effectiveness

Dr. Babrauskas provided a conceptual analysis of the effectiveness of FRs, which is “qualitatively based on a ratio between the loading of chemicals over the volume of flame it is attacking”. As an example, if there is a heavy loading of a FR chemical and a few cubic mm of a flame, he explains, “you stand a good chance of stopping the fire dead in its tracks”. However, if
you have a few cubic feet of a flame, he further states, that it won’t be effective unless you have a substantial amount of FRs and in that case the FRs become notable. In these statements he points out that FRs *can* work in some cases, but in others, there is not nearly enough FR loadings in order to prevent ignition. As an example, recalling the TB117 studies noted above citing “advanced foam” and FR effectiveness (Schuhmann & Hartzell, 1989).

In discussing FRs and the effectiveness in certain TV components, he went on to explain that there is *no data* showing that FRs in UL94V-0 rated printed circuit boards plastic materials are effective. However, looking at the physics allows one to speculate that “this probably is useful because there is a good ratio in that whatever the loading of the chemical is, the volume of the flame is going to be minuscule because this will be a place of insipient fire genesis”, so what that means is that if there is anyway to nip a fire in the bud, this would be the right place to do it. Again, this can only be regarded as a potentially effective use of FRs because there has not been any statistics or testing that has indicated a positive fire safety benefit from incorporating FRs into the UL94V-0 rated printed circuit boards.

Further, Dr. Babrauskas mentioned that he does not think this line of reasoning extends to FRs in TV external cabinet casings. Dr. Babrauskas states that, “TVs are held to a very different standard than other electronics in North America”. He is referring to the fact that TV cabinet casing plastic material is UL94V-0 rated requiring the use of FRs to meet it whereas most other casing plastic materials in other electronics are UL94-HB rated and do not require the use of FRs (Blum, 2014). “Fire enclosures” hold the requirement for a UL94V-0 rating, and this does not necessarily extend to the external cabinet casings although typically in the US and Canadian market, external cabinet casings have historically had V-0 rating. The rationale for this may be
that product casings are required to have higher flame ratings if they act as part of the “protective enclosure” in the case of an internal fault (or internally initiated fire) (Blum, 2014).

However, as explained above, internally initiated fires are no longer a risk given the substantial reduction in voltages from CRTs in current technology. Further, as described by Dr. Babrauskas, Dr. Hull and Blum (2014) external fire hazards no longer exist given that the current technology is thin, flat and wall-mountable, and typically out of reach of candles.

No Useful Data on Fires Resulting from TVs

Determining fires, deaths or injuries resulting from TV fires are very difficult to validate. Dr. Hull explained a scenario in that as TVs can overheat, suddenly turning off, people don’t typically go through the trouble of getting their TV fixed or finding out that they may have been on the verge of a fire or determining if the FR may have saved their life. He went on to explain that typically, the fire brigade does not get called in such cases and as such there is no accurate evidence of a potential fire or that the FR helped prevent the fire. He stated there is no data and there will likely never be any data to say what proportion of TVs break down as a result of component failure that would have resulted in a fire or did not result in a fire had it not been for the FR. Further, he stated, on the other hand, fire investigations are a pretty inexact science. He went on to explain the difficulties in investigating the start of fires and stated that, when firefighters go in to determine the fire origin, if they see signs of an ashtray, smoking materials or candles they automatically put that down. But this doesn’t necessarily mean that that is what caused the fire indicating the level of difficulty in assessing fire origins.

Taken together, from a fire safety benefit perspective, the effectiveness of using FRs in TV components is uncertain given that there are no statistics to prove a benefit. Further, in a real
fire situation, there is no data to reliably and accurately demonstrate whether UL94V is effective in reducing the number of fire casualties. Therefore, the fire safety benefit of UL94 and FR use as a result, is not demonstrable and both their existence current day is not based on sound scientific evidence.

III. Standard is Overly Stringent as it Does Not Take Into Consideration The Proliferation and Penetration of TVs

TVs have greatly proliferated as an industry, which has resulted in US and Canadian households containing more than one TV set and people watching TV for longer hours. However, as previously stated TVs and furniture are the primary sources of FR exposure in household dust (Allen et al., 2008; Blum, 2014). This is concerning because inhalation of household dust and hand-to-mouth-contact are large routes of FR exposure, adding significantly to body burden and potentially causing serious adverse affects to human (and environmental) health (Chapter 3, Section II). As such, this section will give TV statistics from the US (which is assumed here to be a similar case for Canada) and present the argument that there is a considerable risk to FR exposure given penetration of TVs into households with increased viewing hours potentially exacerbating FR migration into household dust. Thus, it is argued here that the standard is overly stringent and doesn’t take into consideration these concerns.
UL94V Plays a Major Role in Human Exposure to FRs Migrating from In-Use TVs

*Increase in TVs per Household and Viewing Hours*

As evident from Chapter 4 and Chapter 5 section I, recent technological advances have made TVs more reliable, more economical, more aesthetically appealing, and more energy efficient. As such, the number of TVs in US households has increased throughout the decades. According to the US Statistical Abstract (Figure 10), the number of TVs has increased from an average number of 1.13 sets per household in 1960 to an average number of 2.9 sets in households in 2008 (US Census Bureau, 2011). The increase in TVs in the US is also discussed by Hoffman (2003) who quoted from Nielson Media, that of 102 million TV homes in the US, approximately 35% have two TVs in their homes while 41% have 3 or more. In addition, the time people watch TV has increased over time. According to the US Statistical Abstract (Figure 11), the average viewing hours per household has doubled from 4.6 hours per day in 1950 to 8.2 hours per day in 2008 (US Census Bureau, 2011).

![Figure 10: Penetration of televisions into households table. Data obtained from the U.S. Statistical Abstract from the U.S. Census Bureau (US Census Bureau, 2011).](image-url)
Figure 11: Average viewing hours per day per household in the US. Data obtained from the U.S. Statistical Abstract from the U.S. Census Bureau (US Census Bureau, 2011).

DecaBDE in Household Dust from TVs

Focusing on human exposure to FRs in household dust, people spend 90% of their time indoors, of which 70% is spent at their homes (Matz et al., 2014). It has been found that FRs accumulate in dust and inadvertent ingestion of dust is a large exposure route from toddlers to adults (Jones-Otazo et al. 2005) and that hand-to-mouth contact with products containing FRs is also another route of exposure for adults (Butke, 2013). There are many studies that have focused on the number of EEE products such as TVs in households and the concentration of FRs in dust and humans.

Substantial variability of FR concentrations can be detected in rooms where there is a change in room contents. Specifically, Harrad et al. (2009) examined the variations in FR levels
and found that the presence of FRs detected declined dramatically with increasing distance from a TV source. Similarly, Muenhor and Harrad (2012) found similar results where there were variations in the levels of FRs detected in rooms due to the introduction and removal of FR sources such as TVs and a bed. The variations in the levels of FRs sampled and detected in indoor dust can be explained by the presence of electronics such as TVs indicating that the number of electronic devices in a house can lead to high levels of FR exposure. This is relevant to the TV discussion given that households have more than one TV resulting in FRs likely to be detected at high levels in each room of the house.

Allen et al. (2008) found that TVs largely drive decaBDE levels in household dust and that bromine levels in TVs predict decaBDE in household dust which was affected by the number of residents in a home, indicating a potential association for TV usage. Further, Li et al. (2015) conducted a study where a strong positive correlation was found between power consumption of electronics and PBDE levels in a large room, which they attributed to heat generated from in-use electronics. Dr. Hull described one potential mechanism of migration for FR escape during TV use and stated that organic FRs tend to be relatively volatile in the hot environment of a TV that is turned on, whereas in a cool environment when the TV is turned off, FRs will likely to be stable for a long time. When discussing how FRs can escape from internal components, he mentioned once TVs heat up and pyrolysis occurs, FRs may seep out of the grills at the back of the set by hot air forcing their expulsion. This is relevant because usage may impact dust concentrations by elevating temperatures of TVs, thereby potentially increasing emission rates or increasing abrasion.

The risk of FR exposure (i.e adverse affects) has been documented in Chapter 3, Section II and has raised concerns about FR use and detection in household dust. It has been demonstrated
here that electronics such as TVs are major contributors to decaBDE release during use (i.e. volatization) or through abrasion or direct migration pathways. And so with the increase in the number of TVs in US households and the increased hours of usage, the concern is that people are exposed to substantially high amounts of FRs daily. In regards to the UL94V standard, it has been argued here that the standard is overly stringent only considering the unsubstantiated fire safety benefit and does not take these concerns into consideration which at this point are far too great to further ignore.
Chapter 6

CONCLUSIONS AND RELEVANCE TO SUSTAINABILITY

Regulation seems to follow when there are emerging issues such as the fires resulting largely from color CRTs with plastic materials, the “instant-on” feature and high voltage and operating temperatures that occurred in the late-1960s and mid-1970s. As previously mentioned, chemical FR use in the US (and in Canada) stemmed from necessary fire safety regulations in the 1970s (Brown & Cordner, 2011) and in regards to TVs, the UL94V flammability test standard (along with the overarching TV safety standard UL1410) came into effect when TV fires were high and were “preliminarily determined” to be an “unreasonable risk” of injury to the public (Grand & Wilkie, 2000). In a reactive-response to a large fire concern, the stringent UL94V standard was adopted for TV plastic components, requiring the use of FRs, to aid in reducing fire hazard, and this standard still holds strong today.

However, this paper has presented the argument that despite the fact that the risk of internal or external fire hazard has decreased (due to the replacement of voluminous, high temperature and voltage CRTs with flat, thin, low temperature and low voltage FPDs) and that regardless of a lack of valid data on FR effectiveness and UL94V fire safety benefit for current TV technology, FRs are still incorporated into TV plastic components because of an outdated flammability standard which does not offer a fire safety benefit. More, it has been argued that the standard is overly stringent, and it does not take into consideration the proliferation and penetration of TVs into households, which increases human exposure to FRs in household dust.

Therefore, in this risk versus benefit analysis, the “net outcome” is that the UL94V flammability standard presents a major role in FR exposure. With no demonstrable evidence of fire safety benefit from FR use in current TVs or a demonstrable fire safety benefit for UL94V,
the risk from increased FR exposure given proliferation of TVs and viewing hours in households outweighs the “potential” mechanisms of FRs and UL94V. As quoted in Cordner & Brown (2013), a FR industry representative argued, “our FRs industry lives and dies by regulation, because people wouldn’t have FRs in their products unless someone told them they had to be there”. And so it is urged and recommended that standard and policy makers in Canada and the US should take into consideration the risk versus benefit trade off demonstrated here and revise this standard.

The Need for Sustainable Flammability Standards

According to Eckley & Selin (2004), “a pitfall that often plagues decision-making on issues characterized by risk and uncertainty is that the existence of uncertainties can lead to a legislative standstill that results in undesirable harm to the environment and human health”. Further, uncertainties delay policy action and as such, there is “usually a lengthy process in environmental policy-making between early scientific warning signs of potential risks to the environment and human health and subsequent action to mitigate the risk” (Eckley & Selin, 2004).

This has been the case for FRs. FRs have been in use since the 1970s and in the 1980s, Swedish researchers started documenting the environmental persistence of PBDEs and their ability to accumulate in animal and human tissues. Nearly four decades of extensive research has brought an understanding of PBDE routes of exposure, detection and persistence in soil, water and air, bioaccumulation in biota and humans and the potential adverse toxicological effects to both humans and animals. The intrinsic physico-chemical properties fundamentally render the use of these chemicals unsustainable (Santillo & Johnston, 2003) and it wasn’t until the mid-2000’s
that restrictions were finally placed on PBDEs, citing them as POPs subject to control under the Stockholm Convention.

In order for fire safety to be sustainable, flammability standards and the use of FRs need to examined using “net outcome associated with FR agents, instead of only evaluating their improvement on fire safety” (Babrauskas et al. 2011) therefore, including an evaluation of the human and environmental health adverse affects is necessary, as it has not been historically considered (Babrauskas et al. 2011). In some cases, “where no fire safety benefit or data associated with a particular usage exists” (Babrauskas et al. 2011), then the flammability standards requiring FR use must be re-evaluated or considered based on sound-scientific evidence. In the cases where no fire safety benefit is demonstrated, achieving fire safety can be accomplished in a sustainable way where in some cases; an alternative to FR can be selected. However, in some cases, alternatives to FRs may also pose a potential hazard and so Santillo & Johnston (2003) outlined some guiding principles to decision making such as, “always seek to select the alternative possessing the least hazardous properties and re-evaluate the selection on a periodic basis”, etc.

This paper on TVs can contribute to sustainable flammability standard development by using what Dr. Babrauskas’ “net outcome” associated with a risk versus benefit analysis using sound scientific evidence. Using this process is one way to lead to more sustainable fire safety and chemical use and more informed policymaking which would ensure that human and environmental health is considered.
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