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The Case against Candle Resistant TVs

(Updates will be posted at http://greensciencepolicy.org/standards.shtml)

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A proposed amendment to International Electrotechnical Commission (IEC) Standard 60065 for candle resistance of television enclosures has an unproven fire safety rationale as well as a large potential to cause harm to human health and the environment.

This report contains significant new information about the health and environmental hazards of the chemicals that are likely to be used to meet such a requirement. It should be read as a supplement to our previous paper, "The Case against Candle Resistant Electronics" available at http://greensciencepolicy.org/files/standards/MASTERWhitepaper.pdf .

During the recent vote on 108/276/CDV for IEC 62638, many of the IEC T108 National Committees submitted comments that the Clause 7 candle flame resistance requirement should not be implemented until current health, environmental, and fire data were evaluated. This paper will show that this statement is similarly true for Clause 21 of 108/295/FDIS for IEC 60065-A2 Ed 7.0 and CENELEC EN 60065, pr. which would mandate similar external ignition requirements for televisions.

These principal points are discussed in more detail below.

1. Television enclosures and furniture are primary sources of toxic fire retardants found in dust in U.S. homes.
2. These fire retardant chemicals are also found in people, with children having the highest levels.
3. When studied, many flame retardants have been shown to cause an alarming array of adverse health effects including thyroid problems, reduced sperm count, infertility, hyperactivity, and cancer. There is not adequate health and environmental information for the chemicals that currently are likely to be used in television housings.
4. Levels of toxic fire retardants are much lower in European dust and people, apparently because European countries do not have flammability requirements for electronics housings and furniture. If these standards are implemented, more fire retardant chemicals are likely to be used in televisions worldwide and more will find their way into people and animals.
5. The peer-reviewed scientific literature shows that decaBDE, which has been used as the primary fire retardant in TV housings, is found in humans, wild animals, and the environment; causes negative health effects in several species of experimental animals; and converts to more toxic smaller molecules.
6. Antimony trioxide (ATO), used at high levels as a synergist in TVs to increase the effectiveness of brominated and chlorinated fire retardants, has been classified as a possible human carcinogen by the IARC (International Agency for Research on Cancer), the European Union, and the U.S. EPA.
7. Many of the brominated chemicals that are likely to be used to fire retard TVs could eventually contaminate sediments in rivers, lakes, and estuaries.
8. Brominated fire retardants are found in increasing levels in ten species of wild animals.

9. A valid current fire safety rationale for the candle resistance of televisions has not been demonstrated. The fire data that is cited is outdated and lacks relevance to the current televisions. Furthermore, comparisons between EU and U.S. data are problematic.
10. Consumer television technology has changed greatly over the past three decades leading to a decreased fire hazard.
11. New ASTM standards in the U.S. and European Committee for Standardization (CEN) standards address the root causes of candle fires and lessen the potential for candle-initiated fires in TV enclosures without introducing harmful chemicals into the environment.
12. The inclusion of a variety of fire retarding chemicals in consumer product housings will make responsible recycling of electronics more expensive and difficult.

Even though these standards are at the FDIS Final Draft International Standard (FDIS) state, which is extremely late in the process, a vast body of new research on the persistence, bioaccumulation, and/or toxicity of many fire retardant chemicals is currently being published in the peer-reviewed scientific literature. The timing of this FDIS is such that much of this information was unavailable at the time when 108/251/ CDV (Committee Draft for Vote) regarding IEC 60065-A2 Ed 7.0 was being voted on in January 2008.

We urge TC108 National Committees to vote "NO" on this proposed standard and additionally comment to remove the mandatory candle flame ignition requirement in Clause 21 of 108/295/FDIS as well as all related language and reference.

More detailed information of special relevance to the TV candle flammability standard follows.

1. **Televisions and furniture are the primary sources of the brominated fire retardants in U.S. house dust.** Joe Allen, as part of a group led by Tom Webster at the Boston University School of Public Health, published a peer-reviewed paper in *Environmental Science & Technology* on April 30, 2008 demonstrating that the **bromine levels in TVs can be related to decabromodiphenyl ether (decaBDE) levels in dust in homes.**[2] The association was stronger for homes with more residents, suggesting an effect of usage of the TVs. TV usage could impact dust concentration by elevating the temperature of the plastic and increasing the rate at which the decaBDE migrates from the TV into the dust. For the main living area, a relation was found between an approximation for television usage and the level of decaBDE in dust. Allen's scientific study was reported in recent news accounts with titles such as "Harmful chemical wafts off your TV."[3]

2. **The fire retardant chemicals from consumer products end up in people, with children having the highest levels.** U.S. citizens harbor levels of fire retardant chemicals that are much higher (between 7.1 and 35 times) than those of Europeans.[4] The reason for this can be linked to the fact that furniture manufactured for sale in California must comply with TB117 (a small open flame standard for foam) and TV manufacturers add fire retardants to TV enclosures to achieve compliance with UL-94 V0 flammability requirements for the US market. Fire retardants are not required in TV housings and furniture in Europe.

   Webster's group published the first research to definitively link pentaBDE concentrations in house dust with concentrations in the people living in those homes.[5] PentaBDE levels in house dust were also associated with levels in breast milk of nursing mothers. Children take in approximately 7 times more pentaPBDE each day than adults.[6]

3. **When studied, many flame retardant have been shown to cause an alarming array of adverse health effects including thyroid problems, reduced sperm count, infertility, hyperactivity, and cancer. There is not adequate health and environmental information for the chemicals that currently are likely to be used in television housings.**

   In animal studies, brominated flame-retardants such as decaBDE have been reported to cause thyroid disease, reproductive and developmental problems, and cancer**.** Neurological impacts include decreased memory and learning, behavioral disorders, and hyperactivity.

   According to an American Public Health Association Consensus Resolution, virtually all organochlorides that have been studied exhibit one or more serious toxic effects, including endocrine dysfunction, developmental impairment, birth defects, reproductive dysfunction, immunosuppressant effects, and cancer, often at extremely low doses.

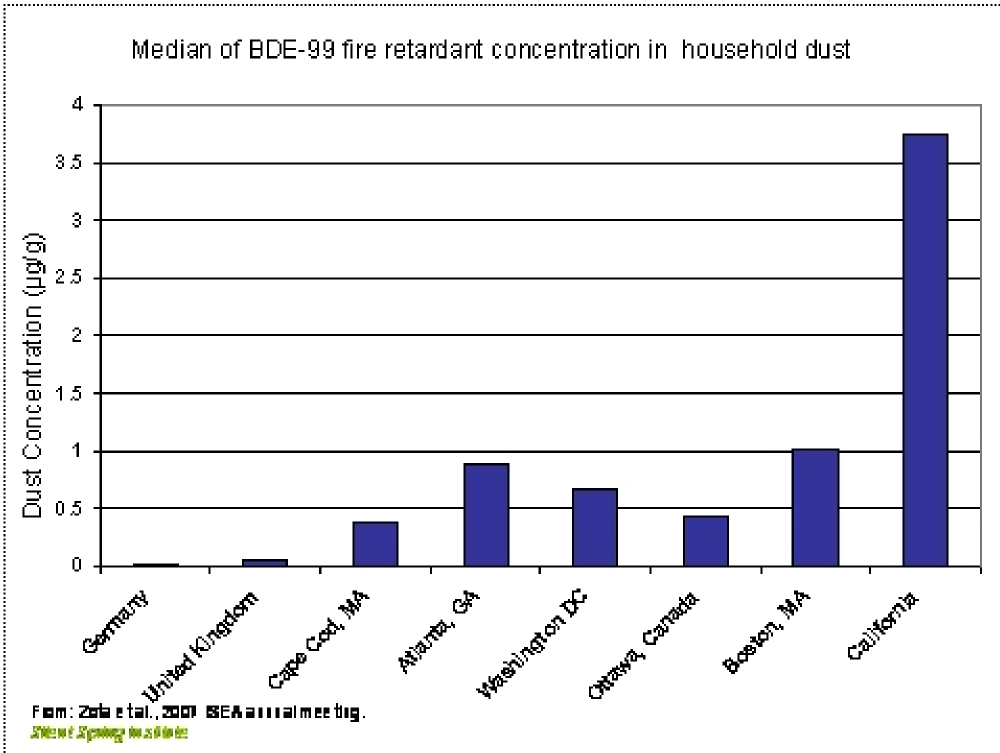
   DecaBDE replacements listed on industry websites include a number of brominated chemicals and others that lack adequate neurological, reproductive, cancer, or other health data. The brominated replacements could have similar toxicity problems to those of decaBDE and include Tetradecabromodiphenoxy benzene, Ethane-1,2-bis(pentabromophenyl), Ethylene bis-tetrabromophthalimide, Ethylene bis-tetrabromophthalimide, Tetrabromobisphenol A.

   The fire retardant chemical industry has a history of not providing adequate toxicological information in advance of the sale of its products. Polybrominated biphenyls (PBBs), polychlorinated biphenyls (PCBs), Tris, Halon, asbestos, and PBDEs are all fire retardant materials which have turned out to have serious long-term negative effects on our health and/or environment. These effects were documented only following extensive use. In many cases, their use resulted in expensive and often unsuccessful clean-up projects as discussed in Section 7 below.

4. **If these standards are implemented, more fire retardant chemicals are likely to be used in televisions worldwide and more will find their way into people and animals**. Many dozens of peer reviewed scientific papers demonstrate that chemical fire retardants that could be used to meet such standards migrate out of consumer products into dust, humans, and animals. For example, the state of California has a more rigorous fire safety standard for furniture than other states in the US, which in turn results in the use of more fire retardants in furniture than is used in other states and Europe. California household dust has higher levels of fire retardant chemicals than other states, which in turn have much higher levels than Europe as can be seen in Figure 1 below.

   Please note that health information can only be obtained after chemicals have been used for a significant period of time. The most information currently available is for pentaBDEs which has been used in a variety of consumer products since the 1980s. Although banned in the EU and several states in the US, pentaBDE continues to migrate from products in consumers' home. Similar studies are currently being conducted on decaBDE levels in dust and people.

   Figure 1. Comparison of the fire retardant chemical BDE-99 in dust samples from two locations in Europe and six locations in the US.[7]



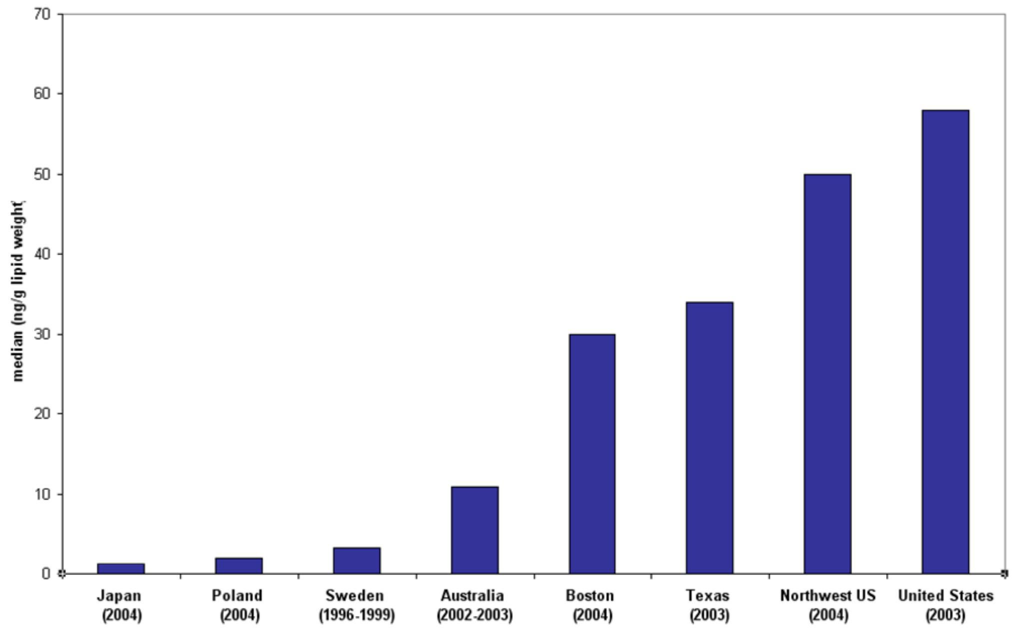
The US has a much higher level of toxic pentaBDE congeners such as BDE-99 in dust, breast milk and body fluids than does Europe. In the US, median human pentaBDE levels in breast milk range from 30 to 58 nanograms PBDE per g lipid weight which can be compared to levels of 1.3 in Japan, 2.0 in Poland, and 3.2 in Sweden in similar studies as shown in Table 1 and Figure 2.[8]

Table1. Recent studies of PBDE levels in human breast milk

Study (US)	Year collected	Population	Number of subjects	Median ng/g lipid weight	Range ng/g lipid weight
Schecter et al	(2003)	Texas	47	34	(6.2- 419)
Lunder, Sharp	(2003)	US	20	58	(9.5 to 1,078)
She et al	(2004)	NW US	40	50	(6 to 321)
Wu et al	(2004)	Boston	40	30	(4.3 to 264)
(Outside US)					
Eslami et al	(2004)	Japan	105	1.3	(0.01-23.0)
Jaraczewska et al	(2004)	Poland	22	2.0	(0.8-8.4)
Lind et al	(1996-99)	Sweden	93	3.2	(0.9-28.2)

Figure 2. A comparison of the sum of PBDE congeners in breast milk from regions around the world shows higher levels in the United States compared to Europe and Japan[9]. Regions, from the left, are Japan, Poland, Sweden, Australia, Boston, Texas, Northwest U.S, and the U.S.

PBDEs in Breast Milk: Comparisons of Regional Studies



Chemically similar fire retardants are likely to be used if Clause 21 is implemented, and could similarly end up in dust, human and animal bodies and breast milk.

5. The primary fire retardant chemical currently being used in TVs is decaBDE. Although the bromine industry states that hundreds of studies show decaBDE does not pose a significant environmental or human health risk, a survey of the literature yields a contrary result. **Most of the peer-reviewed scientific literature on decaBDE demonstrates accumulation of the fire retardant chemical in humans, wild animals, and the environment; negative health effects in experimental animals and humans; and debromination resulting in conversion of decaBDE into more toxic smaller molecules.** While decaBDE is highly persistent in the environment, it does not have a long half-life in animals or people. This is due to the fact that it can be rapidly metabolized to lower and more toxic brominated congeners as well as to oxidative metabolites which can bind to macromolecules.
   Pub Med, a service of the U.S. National Library of Medicine that includes over 17 million citations, is the established source for biomedical literature. In a recent search of their database completed on May 15, 2008 for the term "for decabromodiphenyl ether," 106 articles were found, with publication dates ranging from January 1980 through May 2008.

   - 20 studied health effects in laboratory animals. Findings included induced DNA damage and decreased sperm count. Exposure studies during pregnancy indicated that decaBDE can be absorbed across the placenta and may be a developmental neurotoxicant, an endocrine disrupter during development and may have other adverse effects on the immune function of the exposed offspring. Two papers submitted by Albemarle Corporation, a major producer of decaBDE, reported no potential adverse effects nor need for further study.

- 3 were related to human health, with reported negative health effects including cell death and potential carcinogenic effects.
- 9 were related to levels of decaBDE found in humans. In particular, children were found to have higher levels of decaBDE in their bodies.
- In 5 wild animal studies, decaBDE or its congeners were detected in all of the animals or associated sediments studied.
- 16 studies found decaBDE in a variety of environments, with one study showing significantly high levels found in air from the dismantling hall of a recycling plant.
- 25 studies were related to debromination and degradation, both environmental and metabolic, where decaBDE degraded into lower brominated diphenyl ether congeners, which are more bioaccumulative and more toxic.
- 12 were related to analytical techniques.
- 8 were related to miscellaneous topics and 8 were in languages other than English or did not have an abstract or paper available for review.

6. **Antimony trioxide (ATO), which is used at a high level in electronic applications to increase the effectiveness of brominated and chlorinated flame retardants, has been classified as a possible human carcinogen by the IARC (International Agency for Research on Cancer), the European Union and the U.S. EPA**. Brominated and chlorinated fire retardants are usually mixed with up to 50 percent ATO when used in TV housings. The ATO could pose an additional threat to worker and consumer health.

7. **Once the brominated flame retardants (BFRs), such as those listed above in Section 3 that could be used to fire retard TVs, go out into the world, we cannot call them back. BFRs are being identified as emerging contaminants in sediments in rivers, lakes, and estuaries. They are likely to possess many of the same properties as polychlorinated biphenyl compounds (PCBs) and could eventually cause similar environmental problems.**[10]

   Today, more than thirty years after PCBs were banned from production, we struggle to clean up the legacy from PCB use and disposal. Many other halogenated chemicals are similarly bioaccumulative, toxic, and persistent in the environment. Sediments in rivers, lakes and estuaries often become the final repository for these chemicals, from which the compounds are then transferred through the food web to humans and other animals.

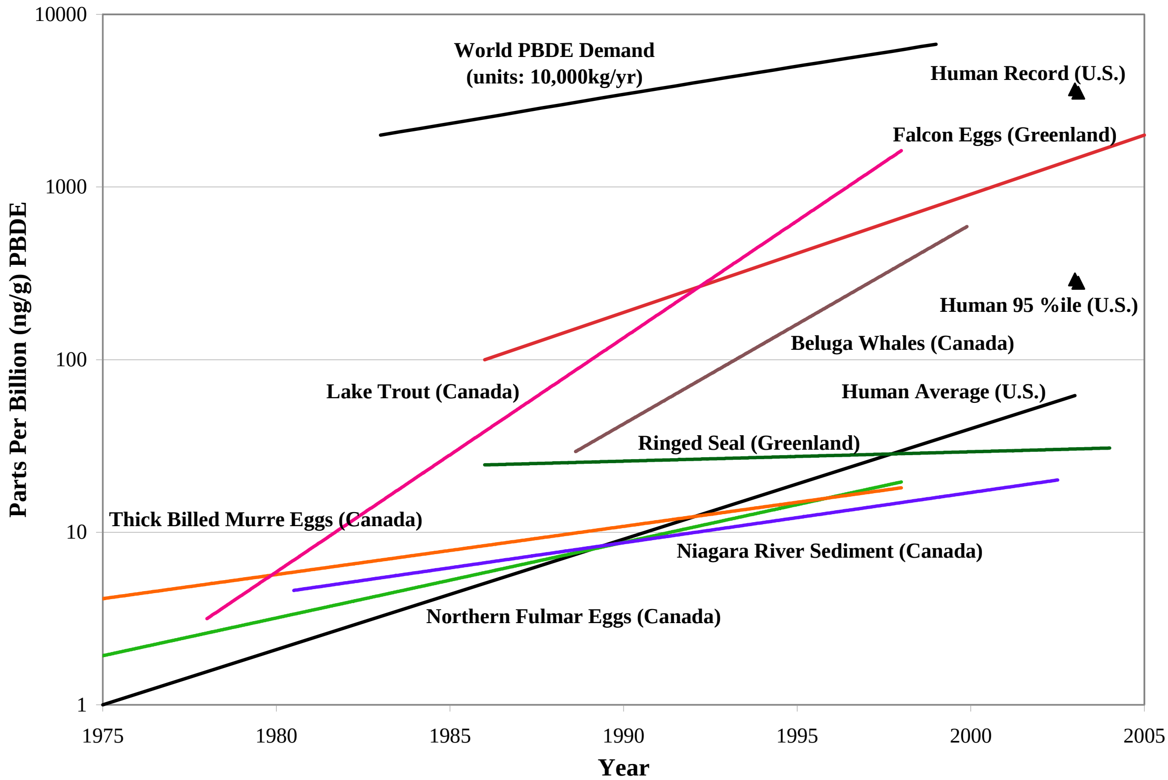
   The clean up of contaminated sediments can be challenging and costly. The costs for dredging the Hudson River to try to remove PCB contamination, for example, will be hundreds of millions of dollars, or possibly more. Also, a study of the National Research Council released in 2007 highlighted some of the challenges with sediment dredging such as the difficultly in meeting cleanup goals and dealing with residual material left after dredging. Further, the disposal of toxic dredged sediment is costly and controversial. Hence, we can expend large amounts of effort and money without assurance of success.

   We can learn from the PCB experience that once released into the environment, many halogenated flame retardants eventually could require very challenging and expensive cleanup measures.

8. The rapid increase in amounts of PBDEs in the environment can be seen from the levels in ten species of wild animals as shown in Figure 2. **The increasing body burden of these fire retardant**

chemicals in wildlife aligns with the increased usage of the chemicals. Though the magnitude of the body burden varies in different animals, the chart below shows the trend is similarly increasing across the eleven studies included in this survey.[11]

Figure 2. Logarithmic graph of the rapid recent increase in PBDE levels in 10 species of wild animal compared with world demand for PBDEs. [11] (Note that the world demand needs to be multiplied by the number on the Y axis.[12])



9. **A valid current fire safety rationale for the candle resistance of current televisions has not been demonstrated.**
Much of the TV fire data cited as a rationale for this standard is more than ten years old and refers to all TV fires rather than external small open flame ignitions. The majority of TV fires result from internal electrical malfunction; these should not be included in the analysis. Candle fires (or any other external small open flame) account for a small share of appliance housing fires and appliance housings as first items ignited account for a small share of candle fires. [13] [14]

It is important to distinguish between overall fire death rates, which are relatively accurate and consistently captured, and death rates from relatively infrequent causes such as TV fires and candle fires. At that level of detail, fire data coding systems and collection methods are likely to vary from country to country and large sampling errors are inevitable. Fire data collected in different studies in Europe is difficult to compare with each other or with the U.S. as can be seen from the large variability between Grand and Wilkie data and Poortere's results as compared in Table 2 below.

In their book published in 2000, Grand and Wilkie found European TV fire incidence and death rates similar to those reported for the US.[15] In contrast, a paper by Poortere, Shonbach, and Simonson reports a significantly higher rate of TV fires and related injuries and deaths.[16] The Poortere *et al.*

research was funded by the European Brominated Flame Retardants Industry Panel and was based on a single suburb of Stockholm with an extraordinarily large number of TV fires in the 1990s. Please refer to our previous paper “The Case against Candle Resistant Electronics” pages 13-14 for further discussion of the Poortere *et al.* analysis.

Table 2 Comparison of reported TV fire data per million TVs.

	Per Million TVs		
Region (Source)	TV Fires	Fire Deaths	Fire Injuries
US (Hall, 2002)	10	0.13	0.65
Europe (Grand and Wilkie, 2000)	12	0.07	0.91
Europe (Poortere, Shonbach, & Simonson, 2000)	165	1.00	N/A

Public relations campaigns, financed by the fire retardant industry, may have contributed to the statistically unproven perception that Europe has a large fire problem that urgently needs to be solved. On the contrary, Western European fire death rates are lower than the U.S., rather than higher. The published comparative national data on Western European fire death rates show death rates per 100,000 for Western Europe ranged from 0.43 (Switzerland) to 2.12 (Finland).[17] The average Western European rate of 1.1 can be compared with a U.S. death rate of 1.6 during the mid-90's.[18]

10. **Consumer television technology has changed greatly over the past three decades**. After the earlier transition from vacuum tube to solid state technology occurred, cathode ray tube (CRT)-based TVs have become nearly extinct, and are being replaced by LCD panel and plasma display based technologies. These new technologies have resulted in:

- reduced and contained high voltage
- lower power
- shallower products; new TVs cannot function as shelves, nor can materials easily be placed to lean against them.
- more capability to wall-mount
- lower weight

Fire retardant chemicals were first added to TV enclosures in the mid-1970s to protect against internally-initiated fires. The likelihood of such fires was far greater with the 15,000V to 25,000V required by CRT technology, generated by a large flyback transformer, and transmitted to the CRT anode by an insulated wire. Air can break down at 10,000V to 20,000V per inch (4,000V to 8,000V per centimeter) based on humidity levels, so these voltages were significant arcing risks, particularly if the transformer, wire, or connection to the CRT failed. Today's technology eliminates this hazard. High voltages are now self-contained in the ballast of fluorescent lamps that backlight the LCD display (these can briefly reach several hundred volts), or within the individual cells of a plasma display (normally around 200V). These voltages are so low that arcing is not a potential hazard.

This new technology eliminates hazards such as internal heat sources like the tube filaments, rectification and plate voltages that could reach as high as several hundred volts, and related high currents that were required in the printed circuit boards to deliver (particularly) filament power. Currently, in the US, TVs are essentially required to have fire-retardant enclosures due not to externally initiated ignition threats, but due to internally initiated ignition threats. The dramatic reduction in and containment of what was extremely high voltage, significant reduction of power requirements, as well as decades of improvement in the technology of other high power circuitry (and the fact that high power is, again, very limited in new technology TVs) suggests that TV manufacturers interested in improving environmental performance of their products, without impacting fire safety, should consider revisiting whether design changes can be made to eliminate the necessity for fire retardants in the enclosures.

11. **Regarding candle flame ignition of TVs, new ASTM and European Committee for Standardization (CEN) standards for candle design address the root causes of candle fires and substantially reduce the potential for candle-initiated fires in TV housings.** Candles can no longer be placed on many of the new TVs; they are now very shallow and can no longer function as a shelf to put candles and other items on. Also, consumers have an increased awareness of the risks of placing open flames near electronics. Manufacturers are producing candles with a maximum wick length and warning labels, without combustible decorative materials, that will self extinguish without incident when they have burned down, and that are designed to not tip over.

12. **In addition, the inclusion of a variety of fire retarding chemicals in consumer product housings will make responsible recycling of electronics more expensive and difficult. Brominated and chlorinated fire retardants form highly toxic dioxins and furans during the controlled and uncontrolled combustion that is still the unfortunate end-of-life fate for much of the world's electronics.** See Appendix I for a detailed rebuttal with references to industry claims to the contrary.

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The content and support for "The Case against Candle Resistant Electronics" came from distinguished chemists, biologists, engineers, and physicians from Stanford, University of California at Berkeley and Davis, Carnegie Mellon, the University of Pittsburgh, the University of Pittsburgh Cancer Institute, and other renowned education institutions. In addition, it has support from numerous health, environmental, consumer, and citizens groups worldwide. Many of the same scientists, physicians, and NGSO's are contributing and support this document, "The Case against Candle Resistant TVs."

Much of the support for the candle ignition requirement comes from the world's four major producers of brominated flame retardants – based in the US, Israel and Japan. See page 23 of "The Case against Candle Resistant Electronics" for further details about the connection between the fire retardant chemical industry and the U.S. National Association of State Fire Marshals who have proposed and vigorously promoted a series of the candle resistance standards for electronics through the IEC, Underwriter's Laboratory in the U.S., and the Canadian Standards Association in Canada.

In summary, the arguments for a mandatory candle flame ignition requirement for TVs are based on old data regarding CRT-based TVs and primarily on old internal ignition problems in these TVs. This argument has little bearing on current and future TV technology. Adding chemicals, with the potential for harm to human health and the environment, to televisions to deal with an unsubstantiated present and future fire hazard is not a judicious course of action.

Although we do not advocate elimination of current measures to fire retard TV enclosures in the U.S., we urge manufacturers to review this historic approach to fire safety and carefully consider whether it continues to remain of value given the new TV technology.

Without this candle ignition requirement, TV manufacturers will have more flexibility in the future to look at design and material alternatives that could achieve fire safety without potentially toxic chemicals. TV manufacturers might choose to investigate whether they can eventually meet UL 60065 without the use of added flame retardant chemicals in enclosures.

We urge TC108 National Committees to vote "NO" on this proposed standard and additionally comment to remove the mandatory candle flame ignition requirement in Clause 21 of 108/295/FDIS as well as all related language and reference.

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Appendix I

Rebuttals to fire retardant chemical industry statements in italics with regard to recycling in "The Case against Candle Resistant Electronics"

"The paper gives reference to the recyclability of flame retarded plastics. In fact, several studies have shown that it is feasible to recycle plastics containing flame retardants."

Although it is possible to recycle flame retarded plastics, the presence of flame retarding chemicals can be problematic for several reasons, including that the flame retardants can reduce the mechanical properties of the materials, requiring additional treatments and additives to compensate for unpredictable or degraded properties.[19] This problem is more pronounced with phosphorus-based additives.[20] Unpredictable properties of recycled materials reduce the value of the materials in the market, and reduce the economic viability of recycling.

"The variety of different plastics and the use of a number of different additives is more problematic to the recycling and the economics of recycling [than the use of a single class of chemicals]."

- We make the identical argument as a reason to not introduce new open flame requirements (p17, number 2). Further fragmenting the market for recycled material by introducing a variety of flame retarding chemicals reduces the financial incentives for recycling.
- Neither increased use of BFRs nor the use of several different additives is desirable with respect to recycling.

"Large E&E OEMs and resin producers are very pleased by the use of plastics flame retarded among others by BFRs as they can easily recycle them to produce new equipment with a high value; this would not be possible with plastics not using BFRs."

Most large electronics original equipment manufacturers (OEMs) have made commitments to remove BFRs from product housings and other components, so recycled plastics containing BFRs cannot be used to "produce new equipment with a high value" for these companies because of the requirement to have a maximum concentration level of 1000ppm PBDEs/PBBs under RoHS,[21] or 900ppm Br under certain "halogen free" requirements, or similar voluntary restrictions.

"Moreover such current practice in Japan saves a lot of energy and eliminates large volumes of electronic waste."[22]

The development cited is not related to mechanical recycling of plastics. It is a gasification method that can recover metals. Halogenated compounds must still be neutralized. In addition, it is quite new and can hardly be considered "current practice" in Japan.

"Projects conducted by academic institutes show that recycling operations made under severe and extreme conditions as well as incineration tests made with plastics containing BFRs do not produce noticeable toxic smoke. On the contrary the academic studies indicate very significant reduction of the toxicity of smoke once FRs in general and BFRs in particular are used when compared with the much more toxic smoke produced by the equivalent non FR plastic, or beech wood used as a reference."
Brominated dioxins and furans (PBDD/Fs) can be formed according to chemical routes similar to their chlorinated PCDD/F analogues in thermal treatment of BFR containing polymers.[23 24 25 26 27] The immediate human health effect of acute toxicity from a combustion event may be different from the toxicity associated with a chemical's environmental fate, which has been shown to be problematic, especially for BFR containing polymers. [28 29]

Finally, it should be noted that although the chemical industry and their associates refer to **"The Case against Candle Resistant Electronics,"** as the Greenpeace paper, Greenpeace neither contributed to nor signed on to that paper.

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Appendix II

Trade-off Analysis of the Impacts of the IEC TV standard on multiple stakeholders

A class of graduate and undergraduate students studying "Sustainability in Theory and Practice" in the Department of Civil and Environmental Engineering at Stanford University completed an assignment to read **"The Case against Candle Resistant Electronics,"** and obtain data on the use of FRs in TV housings, fire statistics, and impact of implementing the IEC TV standard on recycling, human and animal health in Europe. Using this data they each performed a trade-off analysis of the impacts of the proposed IEC TV standard in Europe.

A summary of these results will be available and included in subsequent versions of this report.

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[1] With thanks to Michael Kirschner, Dick Luthie, Peter Brigham, Sara Schendler, Elana Fishman, Natalya Blumenfeld, Judy Levin, Ralph Hall, DC Jayasundera, and Nick Enge and Rebecca Schwartz and the other students in Sustainability in Theory and Practice in the Department of Civil and Environmental Engineering at Stanford University, and many others who contributed to the text and/or editing of this report.

[2] Allen JG, McClean MD, Stapleton HM, Webster TF. Linking PBDEs in House Dust to Consumer Products using X-ray Fluorescence (XRF). *Environ Sci Technol* 2008. In press. [Online April 30, 2008].
doi: 10.1021/es702964a

[3] Harmful chemical wafts off your TV, By Scott Streater, Fort Worth Star-Telegram
http://seattletimes.nwsource.com/html/health/2004406134_dust11.html

[4] Environmental Health Perspectives Volume 116, Number 5, May 2008, Unwelcome Guest: PBDEs in Indoor Dust
http://www.ehponline.org/members/2008/116-5/focus.html

[5] Wu et al, EST, 2007 Environ Sci Technol. 2007 Mar 1;41(5):1505-6. Human exposure to PBDEs: associations of PBDE body burdens with food consumption and house dust concentrations.

[6] M. Lorber, J. Exposure Sci. Environ. Epidemiol., published online 11 April 2007 (PMID: 17426733).

[7] Zota AR, Rudel RA, Morello-Frosch RA, Camann DE, Brody JG. 2007. Regional variation in levels of indoor polybrominated diphenyl ethers may reflect differences in fire safety regulations for consumer products. 17th Annual Conference of the International Society of Exposure Analysis, Research Triangle Park, NC.

[8] Total PBDE congener levels in Table I and Graph 2 are based on the studies below. These results are qualitative as congeners are summed in these studies.

1. Schecter M.P.Vuk, O. Papke, J.J. Ryan, L. Birnbaum, R. Rosen,, Polybrominated diphenyl ethers (PBDEs) in US mothers' milk. Environmental Health Perspectives, 111, (14), 1723-1729(2003).
2. S. Lunder, R. Sharp, Mothers' Milk: Record levels of toxic fire retardants found in American mothers' breast milk. Environmental Working Group. www.ewg.org/reports/mothersmilk/ (2003)
3. She J. et al. 2007. Polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in breast milk from the Pacific Northwest. Chemosphere, 2007 Apr;67(9):S307-17 .
4. N. Wu, T. Herrmann, et al. "Human exposure to PBDEs: associations of PBDE body burdens with food consumption and house dust concentrations." Environmental Science and Technology 41(5): 1584-9(2007).
5. Eslami, B. et al. 2006. Large-scale evaluation of the current level of polybrominated diphenyl ethers (PBDEs) in breast milk from 13 regions of Japan. Chemosphere, 63 (4): 554-61.
6. Jaraczewska, K., J. Lulek, A. Covaci. et al. 2006. Distribution of polychlorinated biphenals, organochlorine pesticides and polybrominated diphenyl ethers in human umbilical cord serum, maternal serum and milk from Wielkopolska region, Poland. Sci Total Environ, 372 (1): 20-31.
7. Lind Y. et al. 2003. Polybrominated diphenyl ethers in breast milk from Uppsala County, Sweden. Environ Res. 2003 Oct; 93(2):186-94.

[9] Thanks to Ruthann Rudel, of the Silent Spring Institute, Newton, Massachusetts for the bar graph of the data above.

[10] Thanks to Dick Luthy, Chair of the Department of Civil and Environmental Engineering at Stanford University, who provided the information for this discussion of the environmental remediation of halogenated hydrocarbons.

[11] Thanks to Nick Enge and Rebecca Schwartz, students in the class *Sustainability in Theory and Practice*, Department of Civil and Environmental Engineering, Stanford University, for summarizing data from references listed below in Figure 2:

1. Vorkamp, K.; Thomsen, M.; Falk, K.; Leslie, H.; Møller, S.; Sørensen, P. B. *Temporal development of brominated flame retardants in peregrine falcon (Falco peregrinus) eggs from South Greenland (1986-2003).* Environ. Sci. Technol. 2005, 39, 8199-8206.
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