California State Fire Marshal
Flammability Standards for Building Insulation Materials

March 21, 2014 Draft

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Table of Contents **– to be added**

<To be added later>

CSFM Flammability Standards for Building Insulation Materials
Working Group Analysis and Recommendations

FOREWORD

The Office of the State Fire Marshal convened a working group (see Appendix A) for the review of flammability standards for building insulation materials that was brought through AB 127 of 2013 by Assembly member Skinner that addressed Fire safety, fire retardants in building insulation. The intent of the working group is to review published data and technical information, examine peer reviewed scientific studies and information, and determine recommendations, that may include alternatives to current methodologies, to the SFM to identify what conditions flame retardant chemicals may be omitted from building insulations without compromising and or reducing fire safety of the building, building occupants and firefighters. ~~The Office of the State Fire Marshal convened a working group (see Appendix A) to review and examine the following areas using current or relevant studies, reports, and scientific data. This was done as a result of recent passage of AB 127~~, 2013, . After reviewing the information, the working group reported on the following key issues, and provided recommendations to the State Fire Marshal as noted below. Relocate this sentence?

The working group was requested to focus their efforts on the following areas, which are consistent with new requirements in Health and Safety Code §13108.1:

1. Review the California flammability standards for building insulation materials, including whether the flammability standards for some insulation materials can only be met with the addition of chemical flame retardants.
2. Determine if updated insulation flammability standards should be adopted that maintain overall building fire safety and ensure that there is adequate protection from fires that travel between walls and into confined areas, including crawl spaces and attics, for occupants of the building and any firefighters who may be in the building during a fire.

SOURCES OF DATA

The working group was asked to review current research, testing, published reports, codes, standards and regulations to form a basis for the observations, conclusions and recommendations. These documents had to include data and observations that are applicable to modern technologies, concerns and building construction practices. Anecdotal data would be considered by the committee, but not given as much weight as the technical data described above.
The referenced documents that the working group selected to use as a basis for their work are included in Appendix B. In many cases data and findings cited in this report include footnotes references to the source document.

1. ISSUES AND ANALYSIS (Phase 1)

Fire performance in California Building Standards Codes. The International Building Code and International Residential Code, which form the basis for the California building and residential codes are developed by a government consensus process. Among other objectives, the purpose of these codes is to establish requirements to safeguard life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations. (R1HH)

(MF/LR) add California Fire Tests (LR Doc) consider adding Table as an appendix.

Fire test standards. These codes require specific levels of fire safety based on risks associated with the specific occupancy and building type. In many cases this is done by requiring building materials and assemblies to comply with specific fire test standards that are adopted by reference in the code. Examples of such fire test standards are ASTM E84, NFPA 265 and UL 790. In general these fire test standards consist of specific performance standards that evaluate the fire performance of the materials and assemblies being tested, and their ability to resist unacceptable fire growth. These standards do not include requirements that specify that materials (such as flame retardants) must be used in products to achieve a specific fire rating. The addition of flame retardants is strictly at the discretion of the manufacturer of the product, who may use it to achieve a specific fire rating. (MF/LR to revise, is “fire” or “flammability” the correct word~~)~~

Building code requirements for insulation - <Short summary based on LR presentation, with a reference to Appendix C for text of current California requirements?> (LR to provide)

Is this section applicable?
Toxicity and building materials. Building and residential codes, and fire test standards do not include requirements that restrict the use of toxic materials in building materials. Toxicity is a concern in today’s built environment, but bans against using specific chemicals and formulations in California are handled through the legislative process, in conjunction with CAL EPA. (pt 12 12-1563 (Warren Alquest Act) verify applicability)

Look to combine and revise the following items
Firefighter toxicity considerations – During firefighting operations firefighters are exposed to toxic gases and byproducts of combustion. Minimize risk of adverse health effects is accomplished by using personal protective equipment

including SCBA gear. The nature and concentration of the generated smoke depends on a variety of factors. These include the quantity of the product that is burning, whether the product is flaming or pyrolyzing, the ventilation in the area, and distance from the fire. Thus, smoke toxicity is not a singular property of a product. Almost all polymeric materials, both natural (e.g., wood) and synthetic (e.g., polyurethane or nylon), can undergo pyrolysis and/or combustion. Products of combustion from the burning of natural or synthetic materials are likely to contain carbon dioxide, carbon monoxide, hydrogen cyanide, halogen acids, organic irritants and other gases and aerosols, in various concentrations. (R2HH)
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(VS) There is a possible link between exposure to the by-products of flame retardant combustion and certain cancers experienced at high rates in firefighters. Studies show that firefighters have higher rates of cancers associated with dioxin exposure, including multiple myeloma, non-Hodgkin's lymphoma, prostate and testicular cancers (Bates 2007; IARC 2010; LeMasters et al. 2006). Hexabromocyclododecane (HBCD), the flame retardant used in polystyrene, produces from 160 to 5000 ng brominated dioxins per kg of polystyrene when burned, depending on the conditions (Desmet, Schelfaut, and Sandra 2005; Ebert and Bahadir 2003). Firefighter exposure to dioxins can occur in the course of their work, both during and after an active fire, and brominated dioxins are of particular concern (Ebert and Bahadir 2003; Weber and Kuch 2003; Shaw et al. 2013). It is unknown how HBCD-generated dioxins contribute to the total dioxin toxicity experienced by firefighters. Given the high rates of dioxin-associated cancers in this population, reduction of dioxin exposures is desirable where feasible. (R1VS)
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(WR) Toxicity of smoke and combustion by-products is not in doubt. However, the sources cited below support that HBCD in EPS foam insulation does not appreciably affect the overall nature of combustion by-products.

Professor Wichman examined the combustion by-products of seven polystyrene polymers and concluded that "decomposition products of [the materials] were not unusually toxic when compared to the toxicity of other natural and synthetic materials and that the addition of flame retardants did not significantly alter combustion by-product toxicity. Material flammability, combustion, toxicity and fire hazard transportation. Indrek S. Wichman, Progress in Energy and Combustion Science 29 (2003) 247-299

Wichman's findings are consistent with Mario Rossi's earlier study which found that the presence of HBCD in EPS foam insulation does not appreciably change the combustion by-products. He further found that fire retardants delay the ignition of EPS foam while the retardants did not significantly modify the production of smoke and carbon monoxide. Characterization of smoke in expanded polystyrene combustion. Mario Rossi, Polymer Degradation and Stability 74 (2001) at 508.

JB to revise

History of foam plastics in building codes - The presentation provided the history relating to the regulations for foam plastic insulation in the Building Codes in the United States and a summary of the current Code requirements in the CBC. The presentation described the early issues with describing the flammability of foam plastics, the resultant Federal Trade Commission Consent Cease and Desist Order, and the Industries' research to develop new tests that are applicable to the application and assembly to be used in construction as well as the introduction of Code requirements into the Code for the regulation of foam plastics. The presentation then provided an overview describing the various test requirements and their applications in the current CBC which form the basis for the appropriate use of foam plastic insulation in construction. The presentation is located HERE.

Code considerations related to ASTM E84 – (HH) Several code sections require insulation in the building envelop to comply with flame and smoke developed indexes that are established by E 84 Steiner tunnel testing. Considerations related to these testing requirements are as follows:
< This section to document the issues in a fairly concise fashion, probably with pros and cons of each point.>

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- Synapsis/intent of AB 127, use data from transcripts of testimony?
- Intent of existing codes and regulations – Jess B.
- Material test methods versus assembly test methods

Building Envelope – The OFSM AB127 Working Group's scope is insulating materials used for either thermal or acoustic insulation within the building envelope:
1) On the building exterior, including but not limited to insulation in Structural Insulated (or Insulating) Panels (SIP), Exterior Insulation and Finish Systems (EIFS), External Wall Insulation System (or EWIS) and similar systems (typically continuous insulation) .
2) Inside the building's exterior walls cavities
3) Inside the building's interior walls cavities
4) Between floors (i.e. above the ceiling of the lower floor and the floor of the next level)
5) Between ceiling and attic spaces

6) Between the ceiling and roof (e.g., between rafters in a cathedral ceiling, between roof joists or ceiling joists)
7) As part of a roof or deck structure (e.g. between joists or rafters, or insulation applied as part of the outer layers of the roof/deck)
8) In crawl spaces
9) Insulation in doors
10) As part of a cold room/freeze room structure within a building
11) As part of below grade insulation and related thermal breaks.
(see e.g.http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_0263/0901b80380263fdc.pdf?filepath=styrofoam/pdfs/noreg/178-00132.pdf&fromPage=GetDoc
and
http://homeenergypros.lbl.gov/group/bestpracticesresidential/forum/topics/designing-for-high-performance-slab-on-grade-part-i-controlling?xg_source=activity)

The working group intentionally excluded from consideration insulation used for mechanical equipment, ductwork, piping, appliances and other installed equipment.

- Is it possible to use thermal barriers in lieu of insulation materials with FR chemicals?

What flame retardants are of particular concern, are all included in one bucket, evaluate one by one? Can they be grouped or individually identified? (WR)

Some of the many materials used as building insulation other than polystyrene foam include cellulose, fiberglass, mineral wool, cotton and cementitious foam. These materials rely upon flame retardants such as ammonium sulfate, boric acid, borate and borax.
[NOTE: The working group should seek health and safety information on all of the flame retardants used in insulation set out above.]

EPS (expanded polystyrene) foam presently uses primarily hexabromocycledodecane at a concentration of approximately 0.7% to meet fire performance standards. HBCD is integral to the resin feedstock used to make rigid foam insulation and is bound within the polymer matrix of finished expanded polystyrene. The EPS industry is transitioning to a new polymeric flame retardant, butadiene styrene brominated copolymer, which has been assessed by the U.S. EPA as having “low hazard designations for all human health endpoints due to its high molecular weight and limited potential for absorption.”
Sources:
Flame Retardant Alternatives for Hexabromocyclododecane, EPA Design for the Environment, 2013.
EPA Pollution Prevention and Toxics, ChemView Database

Risk Assessments have been performed on HBCD and the conclusions are summarized as follows:

Canada “HBCD [is] not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.” Screening Assessment Report on Hexabromocyclododecane, at p. 50.

Australia “ . . . release of [HBCD] to the environment over the product’s [polystyrene insulation panels] life is expected to be very small . . .” Priority Existing Chemical Assessment Report No. 34, Hexabromocyclododecane at p.75

European Union “ . . . the exposure from [polystyrene construction boards] is considered insignificant and therefore not brought forward to the risk characterization.” Risk Assessment, Hexabromocyclododecane, at p. 381

- Are the current test methods the right test methods to provide the correct level of fire safety? Is there a link between the required test results and the actual need in the codes?

<HH Suggestion – Move references in the following to Appendix B, possibly include these points under the above E 84 heading, or other new headings>

(PW) What data rebuts the following assertions and/or the supporting information?

Assertion 1: The E84 test does not accurately predict the performance of foam polymer insulation under real-world fire conditions.

Assertion 2: Assembly tests are necessary to certify foam insulation for many applications, as cited in http://osfm.fire.ca.gov/codedevelopment/pdf/wgfsbim/CaBldgCodeInsulFireTests20140225.pdf and the related discussion the 25 February 2014 meeting

Assertion 3: Thermal barriers (NFPA 275) are necessary and sufficient to prevent foam ignition until after flashover conditions occur, regardless of whether the foam has flame retardant added or not. Absent a thermal barrier, flame retardant foams will ignite upon flashover, if not before. (For example see the corner test comparing various insulating materials at https://www.youtube.com/watch?v=snlhECzj1E8&noredirect=1)

Assertion 4: Because the flame retardants in the commercial products do not prevent the foam insulation from burning, fire safety requires that insulating foams in occupied areas must be in an assembly protected by thermal barriers.

Assertion 5: Since all foam insulations must be protected from ignition by a thermal barrier or ignition barrier in the assembly, the appropriate fire safety test must be based on the performance of the assembly, not on E84. In fact, E84 test results showing a low FSI for foams might mislead users as to the foam's actual fire risks.

Assertion 6: Since E84 does not provide meaningful data for insulating foams, this test should not be required as a certification test for insulating foams.

Support for the assertions is found in:

1) The 2012 paper by Vytenis Babrauskas et al
(http://dx.doi.org/10.1080/09613218.2012.744533)
What evidence rebuts the points (below) made in this paper?

a) The Steiner Tunnel Test results for Fire Spread Index (FSI) do not correlate well with other fire test results, such as corner tests (plots and references on p. 742.) Low FSI (< 25) samples can show very short times (<2 min) to flashover. Conversely, some high FSI (> 60) samples appear to have flashover times as long as 15 minutes. As such, E84 tests of polymer foams do not accurately predict expected fire performance.

b) Commercial FR foam insulation contributes significantly to the fire when there is no thermal barrier.

c) Standard fire resistant gypsum board or other NFPA 275-compliant thermal barrier is necessary and sufficient to prevent foam from igniting in the event of a room fire until well after flashover has occurred. Since unprotected commercial FR foams will lead to room flashover if uncovered, and the thermal barrier keeps FR-free foam from igniting, it is unclear that added FR improves fire safety.

d) Fire propagation in the wall cavity is primarily a function of cavity geometry and size - and that FSI does not play a significant role (p.741)

If no evidence rebuts these points, then why require E-84 testing for insulation foams?

2) Reports on facade structure fires show that flame retarded polystyrene foams are a significant fuel source for fast spreading fires. References accessed 14 March 2014:

http://magazine.sfpe.org/fire-investigation/monte-carlo-exterior-facade-fire http://www.fireengineering.com/articles/2010/05/modern-building-materials-are-factors-in-atlantic-city-fires.html

Do these reports support the hypothesis that using a FR in the polymer is insufficient on its own, and so the thermal or ignition barrier is a critical component of the sub-assembly or building system?
Do these reports support the hypothesis that once a fire is intense enough to breach the thermal barrier controls, the FR does not significantly reduce the fire growth or spread?
Does E84 testing predict real world performance, or is assembly testing necessary to assess actual fire performance?

3) Papers submitted by Marcelo Hirschler show that Heat Release Rate (HRR) can be reduced, and Time to Ignition (TTI) increased, if sufficient levels of flame retardants are added. However, most of these data appear to be from experiments using high levels of flame retardants, and often mixtures of different flame retardants. QUESTION: Do the standard commercial insulation products have HRR and TTI values that are substantially and meaningfully different than the flame retardant free materials? Please provide data.

3a) HRR appears to show some relationship to ignition source energy flux (e.g. http://osfm.fire.ca.gov/codedevelopment/pdf/wgfsbim/HirschlerFAM2242FlameRetardantsHeatRelease2FireMaterials2014.pdf, table 3, or table 16. Table 16 suggests that higher ignition energy flux results in increased HRR. What is the energy flux range (kW/m2) expected at flashover? At flashover conditions does the FR create a meaningful difference? Again, what data supports the answer?

4) A series of reports indicate that improperly applied Spray Foam Insulation can spontaneously ignite during the exothermic curing process, or during spraying if an ignition source is present. References accessed 14 March 2014:
http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/three-massachusetts-home-fires-linked-spray-foam-installation

http://www.capecodonline.com/apps/pbcs.dll/article?AID=/20110211/NEWS/102110323 (last paragraph)
http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/nze-project-tragic-fire-and-will-rebuild
These reports raise the following questions regarding industry claims that the flame retardant protects during transport and construction:
a) What studies, if any, have been conducted on the flammability of the two SFI components?
b) What do these studies tell us about the comparative safety of the FR and non-FR versions during transport and construction?

(Note - as has been pointed out, the fire code does not address transport and construction phases, but since the industry claims this benefit it would be useful to see the actual data supporting the assertion.)

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- What is the criteria used to determine/measure that the level of fire safety is maintained? Match the intent of the bill?

- Way to judge economic impact? Is this needed? (may be addressed during drafting of recommendations)

- Impact on sprinklered versus non-sprinklered buildings?

- Will insulation products burn or ignite “greater” without compliance to ASTM E84? (Placeholder PW to revise question)

- Is there an alternative to ASTM E84 to create compliant insulation products?

- Are there situations that ASTM E84 does not provide meaningful data regarding the suitability of material application/use assembly…?

- What are the fire safety impacts on existing building undergoing construction.

CURRENT STATE REGULATIONS AND LOCAL ORDINANCES

California regulations covering insulation are included in Health and Safety Code, Sections _______. (KR)

- List of fire tests in the California codes (provide reference to (LR presentation doc unless this is included as Appendix C)

2. OBSERVATIONS AND CONCLUSIONS (Phase 2)

Based on a review of the data provided, some of the more significant observations and conclusions that supported the working group recommendations are as follows:

ISSUES LACKING CONSENSUS < This is from the smoke alarm task group and may not be applicable for our group. need to review and revise?>

~~The task force worked effectively together to compile this report and for the most part agreed on the content, with some exceptions. The task force wanted to make sure that any recommendations provided to the State Fire Marshal represent a strong consensus of voting members. We therefore required each recommendation included below to obtain a 2/3 majority vote~~. To be revised to reflect working groups

3. RECOMMENDATIONS (Phase 3)

In order to address concerns raised in AB 127, the working group recommends that the following recommendations be considered. While they capture the intent of the working group, we recognize that ultimate execution of each may require changes in regulations, codes, standards, and even legislation. As a result, it is expected additional work will be needed to develop enforceable language and precise definitions of terms.

Regulations and Legislation

Other Organizations

Education and Messaging

Future Stakeholder Interactions

APPENDIX A

CSFM FLAMMABILITY STANDARDS FOR BUILDING INSULATION MATERIALS WORKING GROUP

This information was added using best available information and needs a review

- Kevin Reinertson - Chair CAL FIRE – Office of the State Fire Marshal

Working Group Members

- Eric Banks - BASF Corp., representing the Spray Foam Coalition of the Center for the Polyurethanes Industry (CPI)
- Jesse Beitel - Hughes Associates, representing the American Chemistry
- Council (ACC)
- Tonya Blood - Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI)
- George Combs- Bayer Material Science LLC
- Gordon Damant - Damant & Associates
- Barb Fabian- Owens Corning
- Michael D. Fischer - Kellen Company, representing the Polyisocyanurate Insulation Manufacturers Association (PIMA)
- Gene Gantt - California State Firefighters Association
- Dr. Marcelo M. Hirschler - GBH International, representing the North American Flame Retardant Alliance (NAFRA)
- Howard Hopper - UL LLC
- Avery Lindeman - Green Science Policy Institute
- Donald Lucas - Environmental Energy Technologies Division - Lawrence
- Berkeley National Laboratory
- Jim McGowan - California Building Standards Commission
- Robert Raymer - California Building Industry Association (CBIA)
- Walter Reiter - Expanded Polystrene (EPS) Industry Alliance
- Lorraine A. Ross - Intech Consulting Inc., representing the Extruded Polystyrene Insulation Manufacturers Association (XPSA)
- Veena Singla - Natural Resources Defense Council
- Adria Smith - Fountain Valley Fire Department, representing Cal Chiefs /
- SoCal Fire Prevention Officers Association
- Joel Tenney - ICl-IP America Inc., representing Israeli Chemicals
- Paul Wermer, Paul Wermer Sustainability Consulting, representing the U.S. Green Building Council of California
- Kevin White - California Professional Firefighters
- Mike Wilson - California Department of Industrial Relations, representing California Labor & Workforce Development Agency (LWDA)

Working Group Alternates

- James Carver – City of El Segundo, representing CalChiefs, Southern California Fire Prevention Officers
- Carrie Cathalifaud - Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI)
- Tim Earl - GBH International, representing the North American Flame Retardant Alliance (NAFRA)
- John Ferraro- Extruded Polystrene Foam Association (XPSA)
- Steve Fischer - Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI)
- Justin Malan - ECO Consult, representing the U.S. Green Building Council
- of California
- Jerry Phelan- Bayer Material Science
- Greg Pruden, Department of Consumer Affairs
- Steve Risotto - American Chemistry Council
- Tim Shestek - American Chemistry Council
- Jeff Sickenger - KP Public Affairs, representing the American Chemistry Council
- Don Wheat- ?
- John Woestman- Extruded Polystyrene Foam Association

APPENDIX B

REFERENCED DOCUMENTS

The referenced documents that the working group selected to use as a basis for their work are included below. These are limited current research, testing, published reports, codes, standards and regulations. These documents are limited to current applicable subjects that are directly related to U.S. codes, standards and research.

R1HH – Based on IBC Section 101.3.

R1VS

Bates, Michael N. 2007. "Registry-Based Case – Control Study of Cancer in California Firefighters." American Journal of Industrial Medicine 344: 339–44. doi:10.1002/ajim.20446.

Desmet, Koen, Marc Schelfaut, and Pat Sandra. 2005. "Determination of Bromophenols as Dioxin Precursors in Combustion Gases of Fire Retarded Extruded Polystyrene by Sorptive Sampling-Capillary Gas Chromatography–mass Spectrometry." Journal of Chromatography A 1071 (1-2): 125–29. doi:10.1016/j.chroma.2004.12.019.

Ebert, J, and M Bahadir. 2003. "Formation of PBDD/F from Flame-Retarded Plastic Materials under Thermal Stress." Environment International 29 (6): 711–16. doi:10.1016/S0160-4120(03)00117-X.

IARC. 2010. "IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: FIREFIGHTING". Lyon: International Agency for Research on Cancer.

LeMasters, Grace K, Ash M Genaidy, Paul Succop, James Deddens, Tarek Sobeih, Heriberto Barriera-Viruet, Kari Dunning, and James Lockey. 2006. "Cancer Risk among Firefighters: A Review and Meta-Analysis of 32 Studies." Journal of Occupational and Environmental Medicine / American College of Occupational and Environmental Medicine 48 (11): 1189–1202.

Shaw, Susan D, Michelle L Berger, Jennifer H Harris, Se Hun Yun, Qian Wu, Chunyang Liao, Arlene Blum, Anthony Stefani, and Kurunthachalam Kannan. 2013. "Persistent Organic Pollutants Including Polychlorinated and Polybrominated Dibenzo-P-Dioxins and Dibenzofurans in Firefighters from Northern California." Chemosphere 91 (10): 1386–94. doi:10.1016/j.chemosphere.2012.12.070.

Weber, Roland, and Bertram Kuch. 2003. "Relevance of BFRs and Thermal Conditions on the Formation Pathways of Brominated and Brominated-Chlorinated Dibenzodioxins and Dibenzofurans." Environment International 29 (6): 699–710. doi:10.1016/S0160-4120(03)00118-1.

DL (summaries and references)

Babrauskas, V. et al. (2012) Flame retardants in building insulation: a case for re-evaluating building codes, Building Research and Information, 40:6, 738 – 755

Note: This review paper asks questions that directly respond to AB 127. The questions were answered by a thorough scientific review of the literature, with over 100 papers cited. A brief summary of this paper is given below, along with summaries from the most relevant papers cited. Note that this summary is not a proper literature review, and the results from these studies need to be examined in detail.

The Steiner Tunnel test is invalid for plastic foams. In the unusual case of a cavity constructed in violation of codes without proper firestopping, the Steiner Tunnel test rating for insulation materials does not influence fire propagation. If buildings are constructed in violation of code with exposed insulation, meeting the Steiner Tunnel test requirements still does not provide for acceptable behavior of these materials. Furthermore, research does not support the view that the change should be to replace the Steiner Tunnel with a more accurate test. If this were done, all economically viable foams would end up being precluded from use. Such a step is not necessary, as the code provisions for thermal barriers alone provide adequate fire safety benefits, i.e. the thermal barrier provides a 15-min finish rating, effectively protecting insulation from fire. (743)

US Building Codes do not regulate materials usage during construction or demolition, and all requirements refer only to the condition as found after completion of construction. (740)

Babrauskas, V. (2003): Ignition Handbook, Fire Science Publ. and Society of Fire Science Engineers, Issaquah, WA.

The auto-ignition temperatures of polyurethane and polystyrene are greater than 400ºC.

National Fire Protection Association (NFPA) (2009): Standard method of fire tests for the evaluation of thermal barriers (NFPA 275), NFPA, Quincy, MA.

This test ensures that barriers which pass the test will protect underlying foams for at least 15 minutes after flashover, as simulated by the standard fire resistance test. After 15 minutes, the temperature at the interface of the thermal barrier and the foam cannot be greater than 121ºC (on average), and the maximum allowable temperature at any one thermocouple is 163ºC. The values are greatly below the ignition temperatures of insulation foams and thus provide a safety factor, not just a bare minimum.

Zicherman, J.B. and Eliahu, A. (1998): Finish ratings of gypsum wallboards. Fire Technology, 34, 356-362.

The authors tested half-inch gypsum wallboard from a number of manufacturers and found that they provided 15- to 20-minute finish ratings; at the end of the test period, all samples tested had retained structural integrity. Foam would not have been ignited behind these materials.

D'Sousa, M.V. et al (1981): Performance of protective linings for polystyrene insulation in a corner wall test. Fire Technology, 17(2), 85-97

In a full-scale room-corner test, a 0.5-inch gypsum barrier protected expanded polystyrene (EPS) foam insulation for 30 minutes.

Mehaffey, J.R. et al (1994): A Model for predicting heat transfer through gypsum-board/woodstud walls exposed to fire. Fire and Materials, 18(5), 297-305.

Gypsum wall board samples were tested using the criteria in NFPA275. All samples achieved finish ratings of 16 – 24 minutes.

Babrauskas, V. et al (1997): Testing for surface spread of flame: new tests to come into use. Building Standards, 66(2), 13-18

The Steiner Tunnel test (ASTM E84) is unreliable for evaluating fire hazard of plastic foams.

Factory Mutual (1974): Foamed Polystyrene for Construction (Data Sheet 1-58), Factory Mutual, Norwood, MA.

Factory Mutual (1978): Foamed Polystyrene for Construction (Data Sheet 1-58), Revision, Factory Mutual, Norwood, MA.

"Flame spread ratings by ASTM E84 tunnel test should be disregarded for foamed plastics."

Note: According to Vyto Babrauskas, PhD, "This was the conclusion by one of the nation's most respected fire research establishments. Nothing has changed in the procedures of ASTM E84 testing that would justify changing that conclusion." (personal communication, March 13, 2014)

ASTM (2012): Standard Test Method for Surface Burning Characteristics of Building Materials (ASTM E84 – 12a), ASTM International, West Conshohocken, PA.

"Testing of materials that melt, drip, or delaminate to such a degree that the continuity of the flame front is destroyed, results in low flame spread indices that do not relate directly to indices obtained by testing materials that remain in place." (Section 1.4)

Rose, A. (1971): Flammability of lining and insulating materials (Canadian Building Digest DBD-141), National Research Council of Canada, Ottawa, ON.

Some foams tested could not be evaluated using ASTM E84 because of excessive smoke production which made observation of the flame front impossible.

Rose, A. (1975): Fire testing of rigid cellular plastics (IR-422), National Research Council of Canada, Ottawa, ON.

Some foams tested intumesced to such a degree that air flow in the Steiner Tunnel is no longer reflective of the prescribed test conditions.

In corner tests of exposed foams, insulation materials with code-allowed FSI values between 18 and 65 led to room flashover in as little as 0.5 minutes.

Choi, K.K. and Taylor, W. (1984): Combustibility of insulation in cavity walls. Journal of Fire Sciences, 2(3), 179-188:

Fire propagated rapidly when a gap of 1 inch or larger was present between insulation and the interior face of the wall. Smaller gaps did not display rapid propagation of flames.

“The flame spread rating of materials used in the tests was not a significant factor [of fire propagation in the wall cavity].” (185)

Williamson, R.B. and Baron, F.M. (1973): A corner fire test to simulate residential fires. Journal of Fire and Flammability, 4, 99-105.

Low flame spread index rigid polyurethane foams can undergo extremely rapid fire development if used uncovered. The materials tested had FSI values < 25.

Castino, T.G. et al (1975): Flammability Studies of Cellular Plastics and Other Building Materials Used for Interior Finishes. Subject No. 723, Underwriters Laboratories, Northbrook, IL.

There is no correlation between Flame Spread Index and fire safety: low FSI does not imply a long time to flashover, nor does it imply a small amount of specimen destroyed in a fire.

Lee, B.T. (1985): Standard room fire test development at the National Bureau of Standards, in Fire Safety: Science and Engineering (ASTM STP 882), ASTM, Philadelphia, PA, pp. 29-44.

In full-scale room fire tests, uncovered polyisocyanurate and polystyrene foams with FSI < 25 resulted in very rapid times to flashover.

Dillon, S.E. (1998): Analysis of the ISO 9705 Room/Corner Test: Simulations, Correlations and Heat Flux Measurements (NIST-GCR-98-756), National Institute of Standards and Technology, Gaithersburg, MD.

Exposed, flame retardant-treated foams were studied in large-scale burn tests. Extruded polystyrene (XPS) produced flashover in only 1.5 minutes, and expanded polystyrene (EPS) produced flashover in only 1.4 to 1.8 minutes.

Babrauskas, V. (1996): Wall insulation products: full-scale tests versus evaluation from benchscale toxic potency data, in Interflam 1996, Interscience Communications, London, pp. 257-274.

Foam plastic insulation materials meeting the current flammability standards for foam insulation (Steiner Tunnel test) do not perform acceptably in ISO 9705, considered to be a reliable test for assessing the fire hazard of exposed wall/ceiling surfaces.

Ahrens, M. (2011): Home Structure Fires, National Fire Protection Association, Quincy, MA.

Insulation within a structural area was the primary item contributing to flame spread in only 2% of US home structure fires. Foam insulation very rarely presents a fire safety issue when it is properly protected behind a thermal barrier. This amounted to zero deaths and only 40 injuries (1% of fire injuries for the entire US).

Posner, S. et al (2010): Exploration of Management Options for HBCD, Swerea IVF, Mölndal,
Sweden.

“Using thermal barriers it is possible to fulfill fire safety requirements in most of the uses in constructions and buildings with EPS and XPS without a fame retardant.” (40)

“The national fire safety requirements are achieved by the building codes specifying the different uses of insulation products in buildings and construction, through the use of thermal barriers. In Scandinavian countries like Norway and Sweden buildings are constructed to prevent the spread of fire and additionally the
buildings should not pose and health and/or environmental hazard to residents and
the local environment.” (46)

Molyneux, S. et al.(2013) The effect of gas phase flame retardants on fire effluent toxicity.
Polymer Degradation and Stability:

The presence of halogenated flame retardants may increase toxicity of fire effluents under certain combustion conditions.

Ebert, J. and Bahadir, M. (2003): Formation of PBDD/F from flame-retarded plastic materials
under thermal stress. Environment International, 29(6), 711-716.

Formation of dioxins has been observed during incorporation of brominated flame
retardants and processing (e.g. extrusion cycles) of plastic foam insulation. Dioxin
byproducts from manufacturing processes can be found in the commercial insulation product and in workplace air. Dioxins can be produced when halogenated flame retardants burn either in accidental fires or during intentional incineration.

Polystyrene containing HBCD can produce brominated dioxins when burned. The amount produced will depend on the conditions of combustion.

Weber, R. and Kuch, B. (2003): Relevance of BFRs and thermal conditions on the formation
pathways of brominated and brominated-chlorinated dibenzodioxins and dibenzofurans.
Environment International, 29(6), 699-710.

Brominated and brominated-chlorinated dibenzodioxins and dibenzofurans are produced during thermal processing of products containing brominated flame retardants, including during accidental fires of intentional incineration.

World Health Organization (WHO) (1998): Polybrominated Dibenzo-p-dioxins and
Dibenzofurans (EHC 205), WHO, Geneva.

Human exposure to chlorinated dioxins has been associated with adverse health effects including some types of cancer, liver problems, impairment of immune, endocrine, or reproductive function, and disruption of nervous system development.

“PBDDs/PBDFs are contaminants that are more or less similar to PCDDs/PCDFs in their persistence and toxicity. Therefore, humans and the environment should be protected from them… Brominated flame retardants and their precursors appear to be a main source of PBDDs/PBDFs.”

“Owing to the accumulating and toxic potential of some PBDDs/PBDFs, every effort should be made to prevent exposure of humans to, and pollution of the environment by, these compounds. Brominated flame retardants should not be used where suitable replacements are available, and future efforts should encourage the development of further substitutes.”

Van den Berg, M. et al. (2006) The 2005 World Health Organization reevaluation of human and
mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicological
Sciences, 93(2), 223-241.

Development of human exposure guidelines for brominated dioxins has been identified as a high priority by the World Health Organization.

Birnbaum, l. S. et al. (2003): Health effects of polybrominated dibenzo-p-dioxins (PBDDs) and
dibenzofurans (PBDFs). Environment International, 29(6) 855-860.

Brominated dioxins can have similar effects to those associated with chlorinated dioxins. Brominated dioxins could be contributing to the total dioxin toxicity experienced by humans.

“Essentially all of the classic effects demonstrated for TCDD and the other chlorinated dioxins and furans…have been observed in the limited studies with PBDDs and PBDFs.” (857)

Desmet, K. et al (2005): Determination of bromophenols as dioxin precursors in combustion
gases of fire retarded extruded polystyrene by sorptive sampling-capillary gas chromatographymass
spectrometry. Journal of Chromatography A, 1071(1-2), 125-129.

Polystyrene containing HBCD can produce brominated dioxins when burned. The amount produced will depend on the conditions of combustion.

Hsu, J.F. et al (2011): An occupational exposure assessment of polychlorinated dibenzo-p-dioxin
and dibenzofurans in firefighters. Chemosphere, 83(10), 1353-1359.

Serum samples from fire service professionals showed higher polychlorinated dibenzo-p-dioxin and dibenzofuran (PCDD/F) exposure than the general population, suggesting occupational exposure to these chemicals.

Bates, M.N. (2007): Registry-based case-control study of cancer in California firefighters.
American Journal of Industrial Medicine, 344, 339-344.

In a statistical analysis of cancers registered in California, firefighting was associated with increased rates of testicular cancer, melanoma, brain cancer, esophageal cancer, and prostate cancer.

LeMasters, G.K. et al (2006): Cancer risk among firefighters: a review and meta-analysis of 32
studies. Journal of Occupational and Environmental Medicine/American College of
Occupational and Environmental Medicine, 48(11), 1189-1202.

A meta-analysis of 26 studies on cancer occurrence in firefighters reveled that firefighters are at higher risk for multiple myeloma, non-Hodgkin lymphoma, prostate, and testicular cancer.

APPENDIX C

Related California Laws and Regulations <Add sections from the California Building and Residential Codes, or the table from LR presentation?>