Note Regarding This Document:

This document was submitted to the Office of the State Fire Marshal after the Flammability Standards for Building Insulation Materials Working Group finalized their report and recommendations. This document was not reviewed by the Working Group. The thirty questions and answers contained within *Section 3* of this document were, at one time, partially contained within an early draft version of the Working Group Report. Due to the Working Group not being able to reach a consensus on the information contained within the thirty Questions and Answers, the thirty Questions and Answers were removed from the Working Group Report. At the time of removal, it was agreed that the thirty Questions and Answers would be posted as a reference document on the Flammability Standards for Building Insulation Materials Working Group Webpage.

Questions and Answers on Issues Raised During CA AB 127 Working Group

Summarized from Working Group Input

by

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1. Background

The California State Fire Marshal convened a working group to consider ways to implement the requirements of CA AB 127[1], which are summarized as shown below.

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 proposed 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.

The working group was asked to review information published in reports or scientific publications and presentations, as well as current research and test results, potentially unpublished, and relevant codes, standards and regulations to form a basis for the working group's observations, conclusions and recommendations. All the documents to be considered 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. Moreover, the California State Fire Marshal explained to the working group at the start of the first meeting that she was interested in meaningful data and not necessarily measurable data.

Initially, the group was tasked to address the use of thermal insulation materials in construction. Such insulation materials include, but are not limited to, the following: foam plastics (including, typically, expanded polystyrene or EPS, extruded polystyrene or XPS, rigid polyurethane or PUR, spray polyurethane or SPF, polyisocyanurate or PIR, polyimide, phenolic, melamine, polyolefin, and others), cellulose loose-fill, fiberglass, mineral wool, reflective, straw bale, cementitious foam and recycled denim. Some of these insulation materials do not typically need flame retardants to meet code requirements (for example fiberglass, mineral wool or polyimide foam) but many others do. However, the group was directed, later in the process, to focus on foam plastic insulation.

The working group was faced with a key question, which is: what metric is to be used to ensure that the fire safety of buildings is maintained, as the bill requires. Thus, what criteria are to be used to determine/measure that the level of fire safety is maintained, so as to match the intent of the bill? Also, the working group considered whether it is essential to determine a way to judge the economic impact of any recommendations. No decisions were made.

The International Building Code[2] (IBC) and the International Residential Code[3] (IRC), which form the basis for the California Building and Residential codes, are developed by the International Code Council by using a government consensus process (meaning that only governmental members vote on the final code changes). 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. The IBC and IRC codes require specific levels of fire safety based on the fire hazard and fire risk 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. These fire test standards evaluate the fire performance of the materials and assemblies being tested, and their responses to certain fire exposures. In some cases the fire test standards include pass/fail requirements, but many of them simply describe a procedure to be followed. The codes reference these fire test standards and include requirements for certain specific fire performance requirements in each fire test, if the fire test standard does not include the criteria (as is often the case). Examples of such fire test standards that are applicable to most insulation materials, depending on the application, are NFPA 286[4], ASTM E84[5] (or UL 723[6]), ASTM E108[7] (or UL 790[8]), ASTM E119[9] (or UL 263[10]), NFPA 268[11], NFPA 259[12], and NFPA 285[13]. There are also some fire test standards that are applicable only to some specific insulation materials. For example, cellulose loose-fill insulation must comply with US Consumer Product Safety Commission (CPSC) regulation, which includes passing two fire tests included in 16 CFR 1209[14] and being labeled in accordance with 16 CFR 1404[15]. None of these fire test standards include requirements that specify that flame retardants must be added to the products being tested to achieve a specific fire test response characteristic or a fire resistance rating. The addition of flame retardants is a fire safety tool that is used, strictly at the discretion of the manufacturer of a product, to achieve a specific improved fire performance.

Some of the many materials used as building insulation rely upon the addition of flame retardants to meet the fire test requirements included in the code or some additional requirements. For example, cellulose loose-fill insulation relies upon flame retardants, such as boric acid, borax, other borates or ammonium sulfate, to meet not just the code requirements but also the legal requirements imposed by CPSC. In the case of some other insulation materials, such as expanded polystyrene or extruded polystyrene, they must comply with standard specifications, such as ASTM C578[16], which requires that the materials meet an oxygen index (or LOI, based on ASTM D2863[17]) higher than can be achieved by the material without the use of flame retardants. Finally, the code requires that all foam plastic insulation materials be listed and labeled by a nationally recognized testing laboratory and the listing requirements also include the requirement for fire testing of the insulation. In fact, thus, the manufacturers of any insulation material produce products for use in construction that must meet a variety of requirements (beyond just fire performance) and they comply in the manner that is most appropriate and commercially viable.

Flame retardants (or flame retardant chemicals) will not be addressed individually for the purpose of this working group. Moreover, the issue of the inherent toxicity of the flame retardants used for foam plastic insulation materials was considered to be outside the scope of this working group, because it is not a fire safety issue.

Appendix A details the history relating to the regulations for foam plastic insulation in Building and Residential Codes in the United States and a summary of the current Code requirements in the California Building Code (CBC). The appendix describes early testing and issues associated with inadequate descriptions of the flammability of foam plastics. These issues resulted in a Federal Trade Commission Consent (FTC) “Cease and Desist Order”, in the 1970s and a requirement for research by the foam plastics industry, in conjunction with various organizations (including Underwriters Laboratories, UL, and National Institute of Standards and Technology, NIST) to develop new tests applicable to foam plastics. This includes both material tests and assembly tests, to be used in construction. The result was the introduction of Code requirements into the Codes (starting with the 1976 Uniform Building Code, UBC[18]) for the regulation of foam plastics that are similar to those in use today. Those code

requirements, which still include both material fire tests and assembly fire tests today, form the basis for the appropriate construction use of foam plastic insulation. Appendix B contains a list of the CBC fire test standards, and the associated requirements, applying to foam plastic insulation and cellulose loose-fill insulation.

2. Concerns expressed

2.1 Source of concerns: A publication by Babrauskas et al.[19] summarized concerns by some parties that are directly relevant to CA AB 127. The five key points made in the publication are shown below. Note that the summary provided by the authors is not necessarily an adequate literature review, and the results from the referenced studies need to be examined in detail.

- The Steiner Tunnel test is invalid for plastic foams. It states that, in the unusual case of a cavity constructed in violation of the codes without proper fire-stopping, the Steiner Tunnel test rating for insulation materials does not influence fire propagation.
- If buildings are constructed in violation of the codes, 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.
- 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.

2.2 Questions and Answers: The remainder of this document contains a series of 30 questions that were raised during the deliberations by the Working Group and technical approaches to answering the various questions, as summarized by those members of the Working Group listed on the cover page.

3. Questions and technical answers addressing the concerns

The concerns can be discussed in detail and addressed by considering the following 30 questions and technical factual answers.

3.1 Are assembly fire tests adequate enough to determine fire safety in the built environment without the added material fire tests?

As discussed in Appendix B, the codes require a combination of assembly testing and material testing. In the case of foam plastic insulation contained in cavity walls and separated from a habitable compartment, the codes require that foam plastic insulation be: (a) tested to ASTM E84 and obtain a flame spread index ≤ 75 and a smoke developed index ≤ 450 and (b) either be separated by a thermal barrier or comply with the requirements associated with room corner testing (to NFPA 286). The thermal barrier must have been approved by testing via NFPA 275[20], where there are two tests: a reaction to fire test (with the thermal barrier and the foam plastic insulation tested together) and a fire

resistance test, for 15 minutes. The required material testing ensures that an "entry level" of fire performance of the insulation is available before it is submitted to assembly tests.

NFPA 275 (thermal barrier test) requires that the thermal barrier be tested together with the insulation in the reaction-to-fire test and to control flashover, heat release and smoke release. The permitted reaction-to-fire tests are: UL 1040[21] (Standard for Fire Test of Insulated Wall Construction), UL 1715[22] (Standard for Fire Test of Interior Finish Material) or FM 4880[23] (Approval Standard for Class I Fire Rating of Insulated Wall or Wall and Roof/Ceiling Panels, Interior Finish Materials or Coatings and Exterior Wall Systems), each with the pass/fail criteria included in the standard and NFPA 286 (with the pass/fail criteria included in NFPA 275, namely no flashover, a peak heat release rate ≤ 800 kW, total smoke released ≤ 1,000 m^2 and no flame spread to the extremities of wall or ceiling). The fire resistance test is conducted in accordance with the same time-temperature curve as the ASTM E119 test but for a period of 15 minutes and with a smaller sized specimen.

In 1928, Simon Ingberg, of the National Bureau of Standards, published a paper on the severity of fire in which he equated the gross combustible fuel load (combustible content in mass per unit area) to the potential fire exposure in terms of duration of exposure to a fire following the standard (ASTM E119) fire curve[24]. This means that Ingberg demonstrated that the standard ASTM E119 fire curve was representative of the typical severity of the fires associated with combustible contents present in buildings in the 1920's (i.e. their fire load). Recent studies by UL (Kerber et al., 2008)[25] where full scale experiments were conducted to examine the changes in fire development in modern room's contents versus that that may have been found in a house in the mid-20th century. The modern rooms utilized synthetic contents that were readily available new at various retail outlets, and the legacy rooms utilized contents that were purchased used from a number of second hand outlets. The rooms measured 12 by 12 ft., with an 8 ft. ceiling and had an 8 ft. wide by 7 ft. tall opening on the front wall. Both rooms contained similar types and amounts of like furnishings. Both rooms were ignited by placing a lit candle on the right side of the sofa and allowed to go to flashover and maintain flashover for a period of time before being extinguished. The fire in the modern room transitioned to flashover in 3 minutes and 30 seconds while the fire in the legacy room did the same (with a slightly lower peak temperature) after 29 minutes and 30 seconds. It is clear that modern rooms result in hotter fires that go to flashover faster, so that the time temperature curve of the ASTM E119 fire test (which is based on the fire growth in legacy rooms) is less likely to be representative of the actual fire hazard. Therefore protection required in the 21st century must be at least as high as that required in the 1970s.

Note that the codes do not require that penetrations (such as those for wires and cables, pipes or conduits) through the thermal barrier be fire-stopped, meaning that heat, flames and combustion products can penetrate the thermal barrier and enter the habitable environment. This is a critical concern if the insulation behind the thermal barrier were not flame retarded because it could lead to the faster development of heat, smoke and combustion products than with present materials.

3.2 Are the current fire test methods used in the codes the correct test methods to provide the correct level of fire safety?

The fire safety record of foam plastic insulation, when installed in accordance with modern codes, has been excellent, while there have been abundant examples of tragedies associated with the use of inappropriately used foam plastic insulation. The most severe examples have been three cases of

nightclub fires where foam plastic insulation was used exposed (without a thermal barrier) resulting in multiple fatalities. These were the Station Nightclub in West Warwick, RI (100 fatalities in February 2003), the Cromagnon nightclub in Buenos Aires, Argentina (194 fatalities, December 2004) and the Kiss nightclub in Santa Maria, Brazil (242 fatalities in January 2013). This and other examples of foam plastic fire experience have been studied recently, both for the US, by Evans and Hirschler[26], and internationally, by White[27].

It is of interest, in this connection, that NFPA fire statistics (e.g. M. Ahrens, 2011[28]), show that insulation within a structural area was not a key factor in causing fire fatalities or fire injuries because the fire safety measures implemented are working well. The statistics (2006-10) show that insulation within a structural area was the primary item contributing to flame spread in only less than 2% of US home structure fires, due to its proper protection. These numbers translate also to less than 1% of all fire fatalities and of all fire injuries from home fires.

3.3 Should ISO 9705 be used as the room-corner fire test instead of NFPA 286?

Note that ISO 9705[29] is a room-corner test, similar to NFPA 286, used in Europe for assessing when materials go to flashover but not used in US codes. The difference between NFPA 286 and ISO 9705 is that the former uses incident heat sources of 40 kW and 160 kW while ISO 9705 uses heat sources of 100 kW and 300 kW. Moreover, in US codes the room-corner test is used to assess ***whether*** a material or product reaches flashover (plus other criteria, see Appendix B), while ISO 9705 is used to assess simply ***after what time period*** a tested specimen goes to flashover.

3.4 Is there a correlation between the required fire test results and the actual fire safety that the codes need to address?

Recent work by Hirschler[30, 31] showed that heat release rate (HRR) can be reduced, and time to ignition (TTI) increased, if sufficient levels of the appropriate flame retardant systems are used. This is a recent comprehensive survey that built on the work done by NIST (called National Bureau of Standards, or NBS, at the time) in 1988[32].

The NBS work showed how adding flame retardants lower heat release and significantly increased time available for escape and rescue, while not increasing smoke obscuration and significantly decreasing the degree of toxicity without changing its characteristics (in the words of the report: "The results showed that none of the test specimens produced smoke of extreme toxicity. The smoke from both the FR and NFR products was similar in potency and comparable to the potency of the smoke produced by materials commonly found in buildings."). The NBS work addressed five commercial products not containing flame retardants and the equivalent five products containing some flame retardants. The report states that the flame retarded formulations were chosen to represent ones which are (or were, at the time) commercially available and in common use, but which were anticipated to represent high quality performance. None of the systems was designed to provide exceptional fire performance. The five products assessed were: (a) television housings, (b) business machine housings, (c) upholstered chairs, (d) electric cable arrays, and (e) laminated electronic circuit boards.

It is fairly common that combinations of flame retardant systems may be necessary to get the appropriate improvement in fire performance for each system. The fact is that the pairing of a flame retardant

system and a substrate is the result of conducting research that ensures that the flame retardant systems used (types and amounts) are suitable for both the substrate and to meet the fire safety requirements.

An important consideration is whether standard commercial insulation products have HRR and TTI values that are substantially and meaningfully different from those of the corresponding materials that do not contain flame retardants. Data obtained for heat release of rigid polyurethane foam and polyisocyanurate foam in the cone calorimeter heat release test (ASTM E1354[34]) demonstrate very significant levels of improvement on heat release rate. In the case of rigid polyurethane foam the improvement in heat release rate (shown in Appendix C as Table 1) is 40%, while it is 46% for polyisocyanurate foam (shown in Appendix C as Table 2). Data on heat release of solid polystyrene in the cone calorimeter also show high improvements in the range of 40-60% in heat release rates depending on the system, using a variety of different flame retardant additive systems (shown in Appendix C as Tables 3-8). Data on heat release in small scale tests (like the cone calorimeter) is very difficult to obtain for polystyrene foam because of its physical properties (the way it melts and shrinks). However, limited data, on foamed EPS, showed some 20% improvement (shown in Appendix C as Table 9).

More important, the positive effect of flame retardants on the fire performance of polystyrene foam is demonstrated by the fact that improvements are found by using different tests, including both ASTM E84 (in the US) and the combination of the Single Burning Item test (EN 13823[34]) and the small burner test (ISO 11925-2[35]) in the European Union, based on work by Blomqvist et al.[36]. Similar results have been found with other foam plastic insulations (polyurethane and polyisocyanurate). In all cases the fire performance of the flame retarded foam plastic insulation material is improved over that of the non-flame retarded material.

Additional information on the effect of flame retardants on polyurethane foam (flexible foam) can be found in data from an analysis of the Station Nightclub fire by NIST (Grosshandler et al.[37]). Table 4.2 from this NIST report is shown in Appendix D.

3.5 Specifically, does the ASTM E84 fire test accurately predict the performance of foam plastic insulation under real-world fire conditions?

According to the 2012 paper by Vytenis Babrauskas et al.[19] referenced earlier affirms that the ASTM E84 test does not accurately predict the fire performance of foam plastic insulation under real-world fire conditions. It states that the Steiner tunnel fire test results for flame spread index (FSI) do not correlate well with other fire test results, such as room-corner tests. It states that materials with low FSI (< 25) values can show very short times (< 2 min) to flashover. It also states, conversely, that some materials with high FSI (> 60) values appear to have flashover times as long as 15 minutes. As such, it states that ASTM E84 tests for polymeric foams do not accurately predict expected fire performance. These assertions are not correct.

In fact, some low flame spread index results can be associated with poor fire performance but high flame spread index results are always associated with poor fire performance. Moreover, note, that information based on other fire tests demonstrates that foam plastic insulation materials that are flame retarded (and perform better in the ASTM E84 test) also exhibit better fire performance in other tests. For example, all foam plastic insulation materials are required by their listings and, often also by their specifications

(such as ASTM C578 for polystyrene), to meet a fire test (such as ASTM E84 and, in some cases also ASTM D2863 or the oxygen index, or LOI) before they can be placed on the market. All commercial polystyrene foam materials must comply with the ASTM C578 standard specification, which requires them to exhibit an LOI of 24 (higher, meaning better fire performance, than the LOI of non-flame retarded polystyrene, which is 17). Also, cone calorimeter testing[30-32] and European fire testing[36] (as discussed above and shown in Appendixes C and D) have demonstrated that flame retarded foam plastic insulation materials exhibit better fire performance than the non-flame retarded equivalents. Interestingly a publication from UL stated that "a strong empirical relationship was observed between room-corner flashover behavior and Steiner tunnel flame spread index.[38] Thus, compliance with ASTM E84 requirements is simply a tool to ensure that the foam plastic insulation has sufficiently acceptable fire performance to be included in the assembly fire test.

3.6 Does the code require assembly fire tests or material fire tests or both?

As shown in the summary of fire test requirements in the code in Appendix B, the code requires a combination of a material fire test (usually ASTM E84) and an assembly fire test. Foam plastic insulation is not permitted, by code, to be used without an approved thermal barrier in the habitable environment (cavity walls, roofs, etc.). Standard half inch gypsum board is an approved thermal barrier, acceptable for use with listed foam plastic insulations (which are flame retarded). Other thermal barriers are approved as a result of testing to NFPA 275, in conjunction with the foam plastic insulation intended for use, which is always flame retarded. The thermal barrier is necessary and sufficient to prevent foam from igniting in the event of a room fire until well after flashover has occurred. Note that 23/32 inch wood structural panel has been added to the IRC residential code as an approved thermal barrier, in spite of being a combustible material that fails the NFPA 275 test. It has not been added to the California code.

The codes require that foam plastic insulation materials comply with a flame spread index of ≤ 75 and a smoke developed index of ≤ 450 (Class B) in accordance with ASTM E84 (or UL 723) in order to be able to be qualified for conducting the following fire tests as an assembly: ASTM E108 or UL 790 (roofing), ASTM E119 or UL 263 (fire resistance), FM 4450 (roofing), FM 4880 (interior finish), NFPA 275 (thermal barrier), NFPA 285 (multi-story facades), NFPA 286 (room-corner), UL 1256[39] (roofing) and UL 1715 and UL 1040 (interior finish). A whole range of International Code Council Evaluation Services (ICC-ES) evaluation reports associated with foam plastic materials all require testing of the foam plastic insulation to ASTM E84 (or UL 723) as a material test: AC 04[409], AC 05[41], AC 12[42], AC 71[43], AC 161[44], AC 214[45], AC 239[46], AC 263[47], AC 309[48], AC 315[49] and AC 377[50] Most of them are associated with ASTM specifications for the corresponding foam plastic materials, including ASTM C578[16], ASTM C591[51], ASTM C1029[52] and ASTM C1289[53].

3.7 Are thermal barriers adequate to prevent ignition of the foam plastic insulation installed behind the thermal barrier?

The question has been raised as to whether commercial flame retarded foam plastic insulation products will lead to room flashover if when exposed to a large fire source in the absence of a thermal barrier. In fact, undoubtedly, the most widely used foam plastic insulation materials, such as EPS, XPS, SPF and PIR, are all likely to cause flashover when exposed to the ignition source of NFPA 286 (a 40 kW burner followed by a 150 kW burner) in the absence of a thermal barrier complying with NFPA 275, even when

they have been flame retarded. Some other, more specialized, foam plastic insulation materials will not reach flashover under those conditions.

The second part of this question is whether an approved thermal barrier prevents the flame retarded foam plastic insulation materials from being ignited, when exposed to the same ignition source. It is not known whether or not standard fire resistant gypsum board or other NFPA 275 compliant thermal barriers are sufficient to prevent foam plastic insulation materials from igniting in the event of a room fire until well after flashover has occurred, because that is not a required criterion for approval of a thermal barrier. A thermal barrier is approved if it meets two criteria (as shown above): it meets the corresponding pass-fail criteria when tested to NFPA 286, UL 1715, UL 1040 or FM 4880 in conjunction with the listed foam plastic insulation (reaction-to-fire test or integrity fire test in NFPA 275) and it meets the temperature rise criteria when tested to the fire resistance (or temperature transmission) fire test in NFPA 275 (based on the ASTM E119 time temperature curve). None of these criteria involve assessing whether the foam plastic insulation ignites. The key issue is whether the system generates too much heat release. The members of the working group are not aware of any fire tests that have been conducted to assess whether or not a thermal barrier would prevent a foam plastic insulation material that is not flame retarded from igniting when exposed to a certain ignition source.

Thus, there is no answer to the question that has been asked as to whether, if the thermal barrier prevents foam plastic insulation (whether flame retarded or not), from igniting, the added flame retardants added to the foam plastic insulation improve fire safety. In fact, all listings of foam plastic insulation and of thermal barriers are based on tests conducted with foam plastic materials that comply with the code requirements for ASTM E84 testing. Furthermore, the primary issue is not preventing ignition of the insulation but ensuring that the fire does not spread into other compartments.

3.8 Do the flame retardants in commercial foam plastic insulation materials prevent the foam insulation materials from burning?

Foam plastic insulation materials are combustible materials. A combustible material is often defined as "a material that, in the form in which it is used and under the conditions anticipated, will ignite and burn" or "a material that does not meet the definition of noncombustible material". Thus, combustible materials will burn, depending on the conditions of exposure, if exposure conditions are severe enough. The addition of flame retardants to combustible materials will not transform them into noncombustible materials. Consequently, the flame retardants in commercial foam plastic insulation materials will not prevent the foam insulation materials from burning, depending on the conditions of exposure.

3.9 Are thermal barriers required in all areas in the construction environment?

Thermal barriers are not always required to protect for foamed plastic insulation materials (see Appendix B for the list of requirements for insulation materials in codes). Ignition barriers are often required in lieu of thermal barriers in certain occupancies, in code requirements. The following wording is extracted from the recommendations by Spray Polyurethane Foam Alliance (SPFA)[54] for information: "Ignition barriers do not afford as high a degree of protection from fire as thermal barriers but are considered acceptable for attics and crawl spaces where entry is limited. Building code authorities may accept alternative ignition barrier materials and/or alternative assemblies based on large-scale tests such as outlined in ICC -ES Acceptance Criteria 377[50], Appendix X."

The residential code recognizes the following eight ignition barrier materials to protect foam plastic insulation materials in attics and crawl spaces where entry is limited only for the purposes of repair or maintenance:

1. ½ inch thick (38 mm) mineral fiber insulation,
2. ¼ inch thick (6.4 mm) wood structural panels,
3. 3/8 inch (9.5 mm) particleboard,
4. ¼ inch (6.4 mm) hardboard,
5. 3/8 inch (9.5 mm) gypsum board,
6. corrosion-resistant steel having a base metal thickness of 0.016 inch (0.406 mm),
7. 1 ½ inch thick (38 mm) cellulose insulation
8. ¼ inch (6.4 mm) fiber-cement panel, soffit or backer board.

3.10 What is the difference between a thermal barrier and an ignition barrier?

As discussed above, thermal barriers are materials that comply with the requirements of NFPA 275 (including both a reaction-to-fire and a fire resistance test) in conjunction with an approved or listed foam plastic insulation material (which, in turn, complies with requirements based on ASTM E84). Two other materials are accepted by codes as thermal barriers: ½ inch gypsum board and, in the 2015 IRC, 23/32 inch (18.2 mm) wood structural panel. On the other hand, ignition barriers are eight types of material, as listed above (in 3.9). Ignition barriers are only allowed in attics and crawl spaces where entry is limited only for the purposes of repair or maintenance and are not expected to protect the foam to the same degree as thermal barriers.

3.11 If ASTM E84 does not provide meaningful fire test data for foam plastic insulation materials, should this test continue to be required as a certification test for such materials?

No fire test, whether on a material alone or an assembly, precisely predicts fire performance in a real fire, nor will any two fire tests correlate perfectly with each other. By their very nature, fire tests are performed under controlled conditions, whereas "real world" fire conditions are unpredictable. There is no data to confirm that foam plastic insulation materials without flame retardants can successfully meet the requirements of the existing code requirements for thermal barrier fire tests, or that the foam plastic insulation materials would be adequately protected by current ignition barriers, which are generic and do not require testing. If flame retardants were removed from foam plastic insulation materials, the majority of existing systems would be invalidated. Moreover, the most widely used commercial foam plastic insulation materials require the addition of flame retardants in order to meet the ASTM E84 requirements in codes. On the other hand some specialized foam plastic insulations exist that can meet the code requirements based on the NFPA 286 room-corner test and be used without thermal barriers, in some cases without using flame retardants. Finally, as discussed above, multiple other fire tests have demonstrated that foam plastic insulation materials exhibit better fire performance when they have been adequately treated with flame retardants.

All foam plastic insulation materials are required by their listings and, often also by their specifications (such as ASTM C578 for polystyrene), to meet a fire test (such as ASTM E84 and, in some cases also ASTM D2863 or the oxygen index) before they can be placed on the market. As discussed above some specialized foam plastic insulation materials can meet the code requirements of NFPA 286 and do not

need the thermal barrier. All foam plastic insulation materials must have been tested to ASTM E84, irrespective of whether they need the thermal barrier or not. Undoubtedly the protection afforded by ignition barriers is much less than that afforded by thermal barriers and that is why they are permitted only in attics and crawl spaces where entry is limited.

3.12 Do reports on facade structure fires show that polystyrene foams are a significant fuel source for fast spreading fires?

The vast majority (if not all) the cases studied where there have been façade fires involving foam plastic insulation with fast flame spread have been shown to be cases where the type of fire protection required by US codes was absent. Two recent studies have looked at such fires, both in the US (Evans and Hirschler[26]) and internationally (White[27]). Two of such exterior fires, both in casinos in the US, were very prominent and were investigated in detail and it was found that the fire was not associated with code compliant construction.

One of the fires investigated was the Monte Carlo casino façade fire in Las Vegas, NV, in 2008 (Beitel and Evans[55]). This was a fire that occurred in the façade of a large casino in Las Vegas on January 25th 2008 and took over 1 hour to bring under control; no fatalities or injuries. The fire was caused by welding on a catwalk on the roof parapet wall - a 30 ft. (9 m) high screen wall. The exterior cladding materials first ignited on the left side (as viewed from the exterior) of the central core area. The fire then progressed laterally. The adjacent materials on the right and left of the central core facade began to burn and the fire continued to propagate laterally over these decorative materials and cladding materials. Over time, the fire on the west tower moved laterally approximately 80 ft. The detailed investigation of this fire showed that the façade had two types of combustible material: an EIFS (Exterior Insulation and Finish System, complying with the code) and "decorative non-EIFS materials used for ornamentation". These decorative materials included the horizontal band at the 29th floor, the horizontal band at the top of the 32nd floor, the railing at the top of the parapet wall and are believed to include the medallions between the windows on the 32nd floor, and the primary contributor to the progression of the fire was the combination of materials in the decorative band at the top of the wall, the decorative band at the top of the 32nd floor (EPS with a polyurethane resin coating) and the undetermined materials in the medallions. Flaming droplets and burning pieces of EPS and/or polyurethane caused ignition of the large decorative band at the 29th floor, where this decorative band was composed of EPS and had a non-EIFS coating.

The other key fire that is often mentioned is the Water Club Tower fire at the Borgata Casino in Atlantic City, NJ, in 2007 (Foley[56]). The fire, on September 23, 2007, involved a tower under construction that was a separate building from the existing casino. There were no fire fatalities or injuries. According to reports of the construction workers, the flames were 30 feet above the roof on the 41st floor. As firefighting crews were organized and assigned, the fire began to subside, as all of the available fuel was being rapidly consumed. Within 10 to 15 minutes, the bulk of the fire had subsided, and only burning window frames and spot fires remained on the 35 stories of charred structure. The investigation revealed that white aluminum composite panels were used in the exterior wall of the structure as a decorative finish (composite panels with 1/8 inch Aluminum sheets with ¼ inch polystyrene foam in the center). The panels were intended to appear like a sail on the side of the new high-rise tower. There was a concrete shear wall 6 ft. behind these exterior panels that prevented major fire extension into the interior of the building. There were no direct openings into the interior portion of the void space other than on the third floor and the roof on the 41st floor. An investigation by the Atlantic City fire department built

wall panels set into aluminum frames and covered, at the rear, by ¾ inch foamed polystyrene insulation with no fire barrier. The polystyrene foam insulation was flame retarded. To ensure that the same polystyrene foam insulation product was used for the tests as was used on the building in question, the fire marshal acquired samples from the contractor and conducted full-scale fire testing at the Atlantic County Fire Academy. Vertical burn tests of the polystyrene verified that this material was not the one that accelerated the fire 38 stories in minutes. The polystyrene material would shrink and produce carbon particulate, but it was not the primary or secondary fuel source in this fire. The wall panels themselves were then acquired and erected at the fire academy in the burn building and subjected to fire exposure from small to large heat sources to determine how much energy was necessary to get the panels to ignite. After extensive small-scale testing of the panel, it was discovered that the only way to involve the panels was to apply significant heat quickly to the panel, causing the polystyrene to liquefy and burn like a flammable liquid. In the tests conducted on a full-scale panel, a bale and a half of dry hay were necessary to replicate the burn effects the fire department witnessed at the fire scene that day. This fuel source was sufficient enough to cause the aluminum to deform and the polystyrene to liquefy and delaminate from the aluminum facings. Further small-scale and large-scale fir tests were conducted at the ATF (Bureau of Alcohol, Tobacco and Firearms) laboratory in Beltsville, MD. ATF results indicated that to ignite the panel, would require "at least 250 to 400 MW/m^3 of heat applied to the panel surface", a very considerable heat input. The International Code Council (ICC) approved the exterior panels involved in this fire and which are used all over the world. Typically in exterior wall construction, these panels would be protected by fire-resistant drywall on the interior side, once construction is complete. The potential danger involves fire exposure from an adjacent structure. A later confidential investigation found that the exterior panels involved in the fire were actually 4 mm thick panels constructed with thin aluminum facers over a solid plastic polyethylene core. The exterior panels were described in the reference report as meeting the Code requirements; however, the actual exterior panels used would not meet the Code requirement for NFPA 285 compliance.

3.13 Do Steiner Tunnel (ASTM E84) fire test results for flame spread index (FSI) correlate well with other fire test results, such as corner tests? Are there situations where ASTM E84 does not provide meaningful data regarding the suitability of the material tested?

In fire testing it is very rare for the results of one fire test to correlate with those of another fire test. The most notable exception to this rule is the case of tests at two different scales that assess the same property, such as heat release rate. For example, it has been shown that heat release in the cone calorimeter (a small scale test) often correlates with heat release in some (but not all) large scale tests, especially when the geometry is similar (such as in the case of vertical or horizontal surfaces).

However, it is often the case that materials or products that show improved fire performance in one fire test will also show improved fire performance in other fire tests, even if the results do not necessarily correlate with each other. In the case of foam plastic insulation materials, multiple fire tests have indicated that the addition of flame retardants improves the fire performance. As discussed above, no correlations but similar improvement trends for foam plastic insulation materials have been found with the Steiner tunnel test, ASTM E84, the cone calorimeter, the oxygen index (ASTM D2863) and the European Union fire tests.

Work conducted at the time that the room-corner test (NFPA 286) was incorporated into the building code demonstrated that, in general, materials that perform well in NFPA 286 also perform well in

ASTM E84. Similarly, materials that perform badly in ASTM E84 perform badly in NFPA 286. However, it is also well known (and discussed above) that some materials (especially those that very thin, those that are very light weight and those that melt and drip before the flame front has reached the test specimen) can give adequate results in the ASTM E84 and poor results in NFPA 286.

Note that the codes do not require that foam plastic insulation materials exhibit exceptional fire performance but simply that they achieve a flame spread index of ≤ 75 (Class B). Thus, it is to be expected that most materials that exhibit such a flame spread index will fail the code requirements based on NFPA 286. Thus, a direct correlation between the tests, based on code requirements, is not meaningful.

3.14 Do commercial flame retarded foam insulation materials contribute significantly to a fire when there is no thermal barrier?

Foam plastic insulation materials are not permitted to be used without an approved thermal barrier in the habitable environment, unless they meet the requirements based on NFPA 286 or another one of the accepted large scale tests (UL 1040, UL 1715 or FM 4880). Thus, those commercial foam plastic insulation materials that meet the large scale fire test requirements will not contribute significantly to a fire while those that require a thermal barrier will burn more vigorously if installed under conditions not accepted by the codes.

3.15 Is standard fire resistant gypsum board or other NFPA 275-compliant thermal barrier necessary and sufficient to prevent foam from igniting in the event of a room fire until well after flashover has occurred?

It is not known whether or not standard fire resistant gypsum board or other thermal barriers complying with NFPA 275 are sufficient to prevent foam from igniting in the event of a room fire until well after flashover has occurred. That is not what the code requires. The code requires that all approvals of foam plastic insulation and of thermal barriers be based on tests conducted with foam plastic materials that comply with the code requirements for ASTM E84 testing. Furthermore, the primary issue is not preventing ignition of the insulation but ensuring that the fire does not spread into other compartments.

3.16 Is fire propagation in the wall cavity primarily a function of cavity geometry and size and, thus, does the flame spread index play any significant role?

Fire propagation in any fire scenario is affected to a very large degree (probably more than anything else) by the heat release rate of the combustible materials and it has been shown that flame retardants decrease heat release rate. Babrauskas and Peacock[57] demonstrated, in 1992, that it is heat release rate that controls most other fire properties.

3.17 In view of the fact that heat release rate is a function of incident heat flux (since higher incident heat fluxes generate higher heat release rates), do flame retardants create a meaningful difference at flashover?

It is well known that heat release rate increases with incident heat flux; this has been demonstrated for all materials (for example Hirschler, 1992[58]). The key fire safety interest is in preventing flashover

and/or delaying high heat release in rooms away from the room of origin after flashover, because once flashover has occurred survival in that room is impossible. Data described above shows that flame retardants decrease heat release rates in polymeric material0073.

3.18 What heat fluxes are to be expected at flashover?

NFPA 286 uses as one of the criteria for flashover a heat flux to the floor of 20 kW/m^2. On the other hand, heat fluxes to the ceiling and to the walls will probably have to be higher than those for flashover to occur. It is not possible to have a firm heat flux that is associated with flashover because that would be a function of the surface to be investigated.

The NFPA Glossary of Terminology uses a definition for the term "flashover" that reads as follows and originates in NFPA 555[59] (Guide on Methods for Evaluating Potential for Room Flashover): "A stage in the development of a contained fire in which all exposed surfaces reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space." Thus, the concept of flashover is associated with burning of all exposed surfaces rather than with a specific heat flux.

3.19 Since a series of reports appear to indicate that improperly applied spray foam insulation can spontaneously ignite during the exothermic curing process, or during spraying if an ignition source is present, is information available regarding the flammability of the separate components of spray foam insulation and what does this information tell us about the comparative safety of the flame retarded and non-flame retarded versions during transport or construction? What studies, if any, have been conducted on the flammability of the two spray foam insulation components?

Several newspaper articles published online (examples are those by Gouveia, 2011[60] and Holladay, 2011[61]) report that improperly applied spray polyurethane foam (SPF) insulation has spontaneously ignited during the exothermic curing process, or during spraying if an ignition source is present. The newspaper stories referenced talk about fires that occurred in which spray foam insulation contributed to the fire. Like many other building materials, SPF is a combustible material, and its improper application can lead to the potential for ignition and fire.

SPF is transported in two liquid components to the job site. These liquids are typically stored and dispensed in a trailer or truck outside of the building. During application, the A-side isocyanate and the B-side polyol blend are heated and aerosolized and then mixed in a 1:1 ratio on-site during the application process. The reaction and curing process of closed-cell medium density SPF can generate high exothermic temperatures which can ignite the foam and surrounding structures when improperly installed. Self-ignition from high exothermic temperatures with closed-cell SPF is a direct result of the applicator significantly exceeding the manufacturer's recommended maximum pass thickness for the product - typically 1.5" to 2.0" for most closed-cell SPF products. The high exothermic heat increases internal temperatures concentrating in the center of the pass. This retention of heat is reinforced by high thermal resistance and high density (high thermal capacity) of closed-cell foam. Additional passes of closed-cell SPF, without allowing the previous pass to cool, can exacerbate heat retention. Open-cell SPF also generates elevated exothermic temperatures during reaction and curing, however the lower thermal conductivity and density (thermal capacity) of open-cell foam does not retain exothermic temperatures high enough to self-ignite open-cell foam. As a result, the manufacturer's installation

instructions for open-cell SPF typically do not specify maximum pass thickness limits or cooling time between passes.

Therefore, in order to greatly minimize the potential for it catching fire, SPF should be applied by a professional installer, according to the manufacturers' installation instructions, industry best practices, and the instructions from ICC ES[54].

There are no published studies available on fire testing of the components of spray polyurethane foam as they are not actual building materials. For construction applications, SPF products are tested as finished products, not as separate components. Spray polyurethane foam is not transported as such but the two components (an isocyanate and a polyol) are combined on site during application. Thus transport of the SPF foam is not relevant, particularly since the codes do not address the transport phase. Codes do address construction and renovation, particularly the International Existing Building Code[62] (IEBC) and there is abundant evidence that fire hazard is greatest during construction and renovation and it is the time when the highest level of precautions needs to be taken.

3.20 Will foam plastic insulation materials burn more vigorously or ignite more easily if they do not comply with the requirements based on ASTM E84?

The key parameter that assesses whether a material burns "more vigorously" is the peak heat release rate (as demonstrated by Babrauskas and Peacock[57]). As discussed above, properly flame retarded materials exhibit lower peak heat release rate than their non-flame retarded versions. In many cases the addition of flame retardants does slow the ignition process but that is not always the case. Note, however, that compliance with ASTM E84 alone is not sufficient for foam plastic insulation materials to be installed in the habitable environment.

3.21 Is there an alternative to ASTM E84 to create foam plastic insulation materials that comply with code requirements?

The fire safety of the insulation presently used in the built environment, when the building complies with the code, is adequate and has prevented and minimized the effects of fires, thus saving lives and protecting property. Therefore it is probably necessary that any type of insulation used in the built environment should undergo a fire test. At present, no other fire test has been developed and completed the consensus process in order to ensure that fire test results with the alternate fire test are at least equivalent to those with ASTM E84. It is probable that an alternate fire test could be developed and standardized to replace ASTM E84 but it is not available at present. It is important that the insulation be subjected to a fire test irrespective of whether the insulation is protected by a barrier (ignition barrier or thermal barrier) because such barriers are usually not noncombustible materials. Note that virtually all thermal barrier materials (and even gypsum board) fail the test for determining that a material is a noncombustible material, namely ASTM E136[63]).

3.22 What are the fire safety impacts of foam plastic insulation without flame retardants on new buildings undergoing construction or on existing buildings undergoing renovation or reconstruction?

As discussed above, both the IBC and the IEBC address the fire safety of buildings under construction and/or renovation and evidence shows that those are periods when the potential for serious fires is greatest and that special precautions are needed.

3.23 What would be the impact on fire safety of a trade-off allowing for non-flame retarded foam plastic insulation when buildings are fully sprinklered?

In California all new residential construction is required to be sprinklered. Therefore, such a trade-off is not significant because all new buildings will be sprinklered.

3.24 What insulation materials need to be addressed by this working group?

CA AB 127 addressed all insulation materials but the Working Group has been focusing primarily on foam plastic insulation materials, and particularly those that are most commonly used in residential construction, which generally necessitate the addition of flame retardants to comply with code requirements. Another category of insulation materials of particular interest, for example, are cellulose loose-fill insulation materials. Those materials, as shown above, must comply with US Consumer Product Safety Commission regulation, which includes passing two fire tests included in 16 CFR 1209 and being labeled in accordance with 16 CFR 1404. The fire tests involve assessing a critical radiant flux and not spreading fire via smoldering; such fire performance is achieved only through the addition of flame retardant systems. This limitation in scope is an important deviation from the original regulation.

3.25 What is the effect of the flame retardants added to foam plastic insulation on the acute toxicity of fire atmospheres? What are the hazards associated with toxic chemicals found in the smoke produced during structural building fires?

The toxicity of smoke in a fire is a function of four factors; the amount of materials burnt; the distribution of combustion products within the smoke; the individual toxic potencies of each combustion product found in the vapor phase; and the duration of exposure. Clearly, the greater the amount of material burnt the greater the toxicity of the smoke. In fact although roughly two-thirds of fire victims die from the effects of smoke inhalation, it is extremely rare for the root cause of their deaths to be that the smoke comes from a specific very toxic material. Fire fatalities are usually the result of inhaling too much smoke of average toxicity. More than 83% of fire deaths in building fires in the United States occur in fires that have become very large so that they extend beyond the room of origin, and thus generate too much toxic smoke (Gann et al. 1994[64]). This means that very few people actually die in fires that are small and that fire deaths are rarely due to burning or heat effects, even in small fires. All combustible materials release carbon monoxide (CO), an asphyxiant, when they burn. Once a fire has reached flashover, roughly 20 percent of the mass lost from the combination of any material has been converted into carbon monoxide (CO). This is almost irrespective of fuel composition or ventilation. Most fire fatalities occur only after flashover. A pair of studies made in the United States involving more than 5,000 fatalities (Debanne et al. 1992[65] and Hirschler et al. 1993[66]) demonstrated that there is an excellent correlation between fire fatalities and levels of carbon monoxide absorbed in the blood as carboxyhemoglobin (COHb) and that the distribution of COHb concentrations was identical (when comparing populations of the same type) between fire and non-fire deaths (e.g. defective space heater). The studies also showed that whenever high levels of hydrogen cyanide (another asphyxiant) were found

in blood, high levels of COHb were also found, indicating that hydrogen cyanide is of minor consequence in the overall study of fire fatalities. The studies also showed that fatalities can be linked to COHb levels as low as 20 percent and that it is likely that any COHb level above 30-40 percent is lethal. The overall conclusion of this work, the most extensive ever conducted, is clear: fire fatalities are overwhelmingly associated with the carbon monoxide generated when fires become big, and all other causes of fire deaths are of much lower importance. Similar conclusions were obtained earlier by other authors, with smaller data bases.

Thus, the most immediately dangerous chemicals produced during all fires are those that behave as chemical asphyxiants such as carbon monoxide, which is responsible for most deaths in fires, and hydrogen cyanide along with irritants such as hydrogen halides or oxides of nitrogen.

3.26 What is the effect of the flame retardants added to foam plastic insulation on the long-term (chronic) toxicity of fire atmospheres?

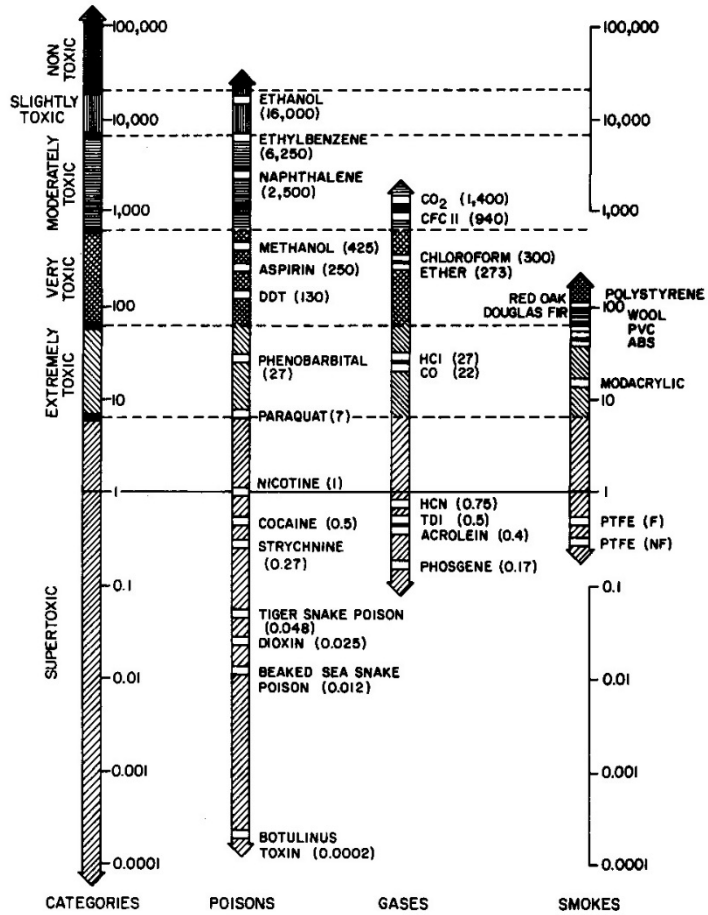
Firefighters are, justifiably, most concerned not about the acute exposures in fires but about the chronic or repeated exposures to those carcinogenic chemicals and particulate matter that are found, at low levels, during the overhaul phase after the primary fire is extinguished or "knocked down". According to an International Agency for Research on Cancer (IARC) monograph[67], nine known human carcinogens (Group 1), four probable human carcinogens (Group 2A), and 21 possible human carcinogens (Group 2B), or a total of 34 known and possible human carcinogens, have been detected in smoke from experimental and actual building fires reported in the literature. The nine known human carcinogens include arsenic, asbestos, benzene, benzo[a]pyrene, 1,3-butadiene, cadmium, formaldehyde, 2,3,7,8-tetrachloro dibenzo-para-dioxin, and sulfuric acid. Notably, all burning materials also produce significant concentrations of polynuclear aromatic hydrocarbons (PAH), including benzo[a]pyrene [BAP], many of which are carcinogenic. In fact, BAP is the one combustion product with the highest level of toxic carcinogenicity.

Formation of trace amounts of polychlorinated dioxins and furans (PCDD/F) or polybrominated dioxins and furans (PBDD/F) occurs during high temperature production or during recycling of plastics that contain halogenated flame retardants and the levels of dioxins and furans are highest when halogenated aromatic flame retardants are present (Ebert and Bahadir, 2003[68] and Bahadir et al., 1999[69]). Since some halogenated dioxins fall into the category of known human carcinogens, some researchers have analyzed smoke and soot residues to determine their concentrations during and after fires. Wobst et al., 1999[709], analyzed surface residues found in two different private residences where a small kitchen fire occurred with minor damage in one case and a large fire destroyed the entire residence in the second case. They found that the particulate residues contained 96 to 5,000 $\mu g/m^2$ of polycyclic aromatic hydrocarbons (PAH) but only 4 to 1300 ng/m^2 of PCDD/F. This means that the particulates contained approximately 4000 to 8000 times more PAH than PCDD/F were present in the small kitchen fire residues. For the large fire, they found 858 to 59,000 $\mu g/m^2$ of PAH but only 9 to 89 ng/m^2 of PCDD/F, meaning that there are over 60,000 more PAH than PCDD/F. Ruokojarvi et al., 2000[71], conducted simulated house fires in two rooms of a two story apartment in order to collect gas and surface samples to measure dioxin and PAH levels and also found higher levels of PAH compounds but with smaller relative ratios since the amount of furnishings and maximum temperatures were lower than a real fire scenario. Finally, Troitzsch, 2000[72], published an analysis of pollutant data gathered from two well-documented German catastrophic fires (Bahadir et al.[69]) and found that PAH levels were thousands of times higher than those

of PCDD/F. Added to this is the fact that the toxicity of PAHs is much higher than those of PCDD/F or PBDD/F. Essentially, all reports to date indicate that polyhalogenated dioxins and furans pose only a very minor exposure risk to firefighters while the risk of exposure to known human carcinogenic components of PAH is extremely high and unaffected by the presence of halogenated compounds in a fire.

3.27 Are the levels of toxic chemicals in today's structural building fires higher than they were before the widespread use of modern plastics?

During the 1970'S and 1980's there was a belief that burning plastic materials produced smoke that was far more toxic than smoke from burning natural products such as wood, wool, or cotton. A number of studies have been done to compare the amount of carbon dioxide, carbon monoxide, and hydrogen cyanide produced by natural and synthetic materials under flaming and nonflaming conditions in order to model smoke toxicity. This resulted in the development of multiple small scale test methods, all of which gave varied rankings. In summary, however, it has since become clear that the smoke toxicity of virtually all materials is almost identical, within the margin of error (for example Hirschler, 1990, 1994, 2006 and 2013[73-76]). The Figure below[75] shows ranges of toxicity and illustrates that smoke toxicity is virtually the same for all types of burning materials.



In the United States, ASTM E1678[77] and NFPA 269[78] (virtually the same test) are used to provide lethal toxic potency values (also known as LC_{50} values) for use in modeling pre-flashover fire hazard conditions by heating test materials with a radiant flux of 50 kW/m^2. Note that a lower LC_{50} value corresponds to a higher smoke toxicity. This bench test data has been compared to room scale fire tests under post-flashover conditions by Babrauskas et al. (1991)[79] in a NIST study and found to be accurate within a factor of three with an adjustment for the very high carbon monoxide post-flashover values that cannot be replicated in the bench test, meaning that there is no statistical difference between the smoke toxicity of materials. It is noteworthy that the NIST data shows that the LC_{50} value for Douglas Fir is >70 mg/l and the value for the rigid foam tested is 30-40 mg/l for the real scale room test while their respective values in the NBS cup furnace bench tests are 41-51 for Douglas fir and 10-13 for the rigid foam. Others have done bench scale tests to compare rigid foam to natural products using the German DIN 53436[80] toxicity test method and found that the LC_{50} for rigid foam is about the same as wool but slightly higher than wood or cotton by a factor of two to three, well within the variance cited by the NIST study, further confirmation that all these variations are not statistically significant (Ruokojarvi et al.[71] and Kimmerle and Prager[81]). For instance, Prager et al. 1994[82] report that the LC_{50} for Douglas fir with a density of 31 pounds per cubic foot (pcf) is 28 gm/m^3 and that of a rigid foam with a density of 2.5 pcf is 7 gm/m^3 when measured at equal mass, but respective values become 54 cm^3/m^3 for the wood sample and 165 cm^3/m^3 for the foam sample when measured at equal volumes (because the foam insulation has lower density than the wood). So the acute toxicity of smoke from rigid foam is not toxicologically different from that of natural products used in buildings and furnishings.

With regard to potential chronic exposure to volatile organic compounds (VOC's) generated at municipal fires, Austin et al. 2001[83] reported analyses of air and smoke samples collected in special stainless steel canisters from inside burning buildings at nine municipal fires by firefighters. The samples were taken at times during which the firefighters thought that some coworkers might remove their self-contained breathing apparatus (SCBA) masks. There were seven mixed occupancy fires, one electronics industry fire, and one structural fire that had smoldered for nine days. Fourteen substances accounted for 77% of the 123 VOCs found in the samples. Benzene (0.12-10.76 ppm), toluene (0.05-5.52 ppm), 1,3-butadiene (0.03-4.84 ppm), naphthalene (0.01-2.14 ppm), and styrene (0.003-2.01 ppm) accounted for 31% of the total VOCs from the fires. Benzene and 1,3 butadiene are known human carcinogens (Group 1) with OSHA established 15 minute short term exposure limit values of 5 ppm while toluene, naphthalene, and styrene are possible human carcinogens (Group 2B) with respective OSHA 8 hour time weighted average values of 200 ppm, 10 ppm, and 100 ppm. These same five compounds were also the predominant components of experimental fires analyzed by Austin and coworkers[83] where spruce wood, mattresses, sofa foam, plywood, cardboard, and white foam insulation were burned. Thus, most modern plastics generally produce the same types and levels of carcinogenic VOCs than do wood products in fires.

3.28 Does the use of halogenated flame retardants in foam plastics result in smoke that is more toxic being produced in building fires?

Data has already been presented[72] regarding the extremely minor contributions to carcinogen concentration in smoke and soot that polyhalogenated dioxins and furans may make relative to the extremely large contributions from PAH. Also, evidence has been cited that the smoke toxicity of foam plastic insulation is comparable to that of natural products as is the level of carcinogenic VOCs. Toxicologists use a toxicity classification scale for inhalation that places LC_{50} values of 10 to 100 in the

highly toxic category and values of 10 or less in the extremely toxic category. Since smoke toxicity studies have demonstrated that the smoke potency values must differ by more than a factor of 3 to be considered statistically significantly different, one would have to find literature values where the smoke LC_{50} value for an FR foam would have to have an extremely low value (outside the typical scale, see Figure above) to move to the next higher hazard class.

3.29 How do the effects of fires affect firefighters in particular?

It is undoubtedly true that firefighters should have special concerns because the rates of many chronic diseases, including cancers, are higher among firefighters than among the general population. However, there is little, if any, evidence that this is associated with the flame retardants used in foam plastic insulation materials. In fact, there is significant evidence[72] that the added effect of the combustion or thermal decomposition products of flame retardants have an insignificant added effect on toxicity.

3.30 Is it safe to use thermal barriers covering non flame retarded insulation materials in lieu of the combination of thermal barriers and insulation materials containing flame retardants?

The answer is: probably not. There is no information available on this because all thermal barriers have been approved (or listed or labeled) based on testing in conjunction with a commercial foam plastic insulation material and all commercial foam plastic insulation materials that are used in the US and need a thermal barrier contain flame retardants, as they are required to comply with the appropriate specification and/or certification. In order to know the answer to this question fire testing would have to be done. All approved thermal barriers have been approved as a result of composite testing with flame retarded foam plastic insulation materials.

The only way to ensure that thermal barriers will not allow penetration into the habitable environment is if all openings (used for the penetration of electrical connections, conduits, pipes, or other construction materials) are fire-stopped adequately. The way to assess fire-stopping is to use sealing materials to cover these penetrations that comply with the requirements of ASTM E814[84] for at least 15 minutes. Unfortunately that is neither common practice not required by the codes.

Therefore, as discussed above, the fact that thermal barriers are not required to be fire-stopped means that heat, flames and combustion products will be able to penetrate through the thermal barrier and enter the habitable environment. As stated earlier, this is a critical concern since it has been demonstrated that foam plastic insulation that is not flame retarded will lead to the faster development of heat, smoke and combustion products than would result from present materials. Thus, the use of foam plastic insulation materials that are not flame retarded will result in higher heat and smoke penetrating the thermal barrier.

4. Summary

The concerns expressed regarding the use of flame retardants in foam plastic insulation are misguided, for the following reasons, and the use of foam plastic insulation that is not flame retarded will result in a lowering of fire safety.

1. Materials that get high flame spread index results in the Steiner Tunnel test (ASTM E84) will be associated with poor fire performance in real fires. Also, multiple fire tests, including tests for

heat release (the key fire property) have shown that flame retarded foam plastic insulation has better fire performance than the non-flame retarded equivalent insulation. Moreover, the ASTM E84 fire test is very widely used in codes to assess fire performance of building materials. Moreover, thermal barriers are not fire-stopped, without violating the codes, so that an insulation material that is not flame retarded would cause more severe fire propagation into the habitable environment.

2. Buildings have rarely been constructed in violation of the codes, with exposed insulation, since the code requirements came into effect, as evidenced by the extremely low fire losses associated with insulation within a structural area, when using flame retarded foam plastic insulation.
3. Commercial grades of common foam plastic insulation materials in the US all contain added flame retardants to meet the material fire test required. Specifications for foam plastic insulations require that foams meet not just requirements based on ASTM E84 but also requirements based on ASTM D2863 (LOI). Codes and evaluation services demand that the foams meet the specifications as well as the additional requirements (including barriers) that limit their use to ensure building fire safety.
4. The code provisions for thermal barriers alone cannot provide sufficient fire safety due to the lack of assurances that the thermal barrier (or the ignition barrier) provides sufficient protection from fire, particularly in view of the dual facts that: (a) modern fires are hotter than those commonly found at the time that the time-temperature curves were developed and (b) thermal barriers are not fire-stopped. Moreover, many code applications do not require the use of a thermal barrier. Finally, thermal barriers are approved based on testing using flame retarded foams and would need to be revisited to determine their effectiveness with foams that are not flame retarded.
5. The problem of using foam plastic insulation materials that are not flame retarded is particularly severe during construction or demolition, for two major reasons: (a) thermal barriers and other protections (including compartmentation, sprinklers and smoke alarms) are not in place, and (b) the presence of various types of insulations at a construction site (meaning both flame retarded and non-flame retarded versions) could lead to potential confusion when installing the materials in their assigned application.
6. It is clear that any possible additional health effects caused by flame retardants (or their decomposition products) on the serious health effects caused by all other fire products is insignificant.

5. References

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Abbreviations

AC: ICC Evaluation Services Acceptance Criteria
ASTM: ASTM International
BAP: Benzo[a]pyrene
CBC: California Building Code
CEN: Committee Européen de Normalisation (European Committee for Standardization)
CO: Carbon monoxide
COHb: Carboxyhemoglobin
CPSC: Consumer Product Safety Commission
DIN: Deutsches Institut für Normung (German Standards Organization)
EIFS: Exterior Insulation and Finish Systems
FTC: Federal Trade Commission
EIFS: Exterior Insulation and Finishing System
EPS: Expanded polystyrene foam
EWIS: External Wall Insulation Systems
FM: FM Global, formerly Factory Mutual Corp.
IARC: International Agency for Research on Cancer
IBC: International Building Code
ICC: International Code Council
ICC ES: ICC Evaluation Services
IEBC: International Existing Building Code
IRC: International Residential Code
ISO: International Organization for Standardization
LC_{50}: Concentration lethal to 50% of exposed subjects
LOI: Limiting oxygen index
NBS: National Bureau of Standards (now NIST)
NFPA: National Fire Protection Association
NIST: National Institute of Standards and Technology
OSHA: Occupational Safety and Health Administration
PAH: Polynuclear aromatic hydrocarbons or polycyclic aromatic hydrocarbons
PBDD/F: Polybrominated dioxins and furans
PCDD/F: Polychlorinated dioxins and furans
PIR: Polyisocyanurate foam
SCBA: Self-contained breathing apparatus
SIPs: Structural Insulated (or Insulating) Panels
SPF: Spray polyurethane foam
SPFA: Spray Polyurethane Foam Alliance
UL Underwriters Laboratories
VOCs: Volatile organic compounds
XPS: Extruded polystyrene foam

Appendix A

History of Foam Plastic Regulation in Codes

Jesse J. Beitel
(Hughes Associates)

Appendix A

History of Foam Plastic Regulation in Codes

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HISTORY OF FOAM PLASTICS IN THE BUILDING CODES

By
Jesse J. Beitel

Presented to
CALFIRE Working Group Meeting (AB127)
February 25, 2014

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

LEARNING FROM THE PAST

- Understand the basis for current code requirements for foam plastic products
- Educate new entrants/personnel in the foam plastic industry on our fire testing history
- Prevent inappropriate uses of foam plastic products
  - Rhode Island Nightclub fire that used packaging foam as interior finish materials

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OVERVIEW

- History of Foam Plastics in the Codes
- Current Code Requirements For Foam Plastics

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HISTORY OF FOAM PLASTICS IN THE CODES

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MARKET INTRODUCTION OF FOAM PLASTIC INSULATION

- Late 1960s and early 1970s
  - Response to a developing Energy Crisis
  - Roof and Wall Construction
  - Agricultural, Industrial, Commercial and Residential Buildings
- Questions on assessing the fire performance of these products

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EARLY FIRE TESTING

- ASTM D1692 Method of Test for Rate of Burning or Extent and Time of Burning of Cellular Plastics Using a Specimen Horizontal
  - Introduced in 1959
  - Small-scale test
    - Sample size: 6"long x 2"wide x 0.5" thick
    - Fire source: Bunsen Burner
    - Test Results: Burning, Non-burning or self-extinguishing
- **Standard withdrawn in 1976**

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EARLY FIRE TESTING

- ASTM E84 Standard Test Methods for the Surface Burning Characteristics of Building Materials
  - Introduced in 1941, promulgated by ASTM in 1950 to assess cellulosic materials for walls & ceilings and used for other interior finish materials
  - Also known as the "Steiner Tunnel"

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EARLY FIRE TESTING: ASTM E84

- Small-scale test
  - Sample size: 24 ft. long x 2 ft. wide x product thickness (4" max.)
  - Fire source: Gas burner at one end of tunnel for ten minutes
  - Test Results: Flame Spread based on time and distance and smoke developed index measured optically
- **Standard still in use today**

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FEDERAL TRADE COMMISSION (FTC) ACTIONS

- 1972 Investigations of fires involving cellular plastics
  - "Childress fire" – residential fire – exposed foam insulation – deaths of 2 small children
- Alleged misuse of small-scale fire tests in promotional materials
  - "Small scale tests are neither reliable nor accurate tests for determining, evaluating, predicting or describing the burning characteristics of plastic products under actual fire conditions."

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FEDERAL TRADE COMMISSION (FTC) FINDINGS

- Recognition that plastics burn differently than "conventional materials", such as wood or cotton
  - Flame spread was more rapid and likelihood of flashover was increased
  - Plastic products liberated more BTUs per pound than conventional materials
  - Greater amounts of dense smoke were produced
  - Toxic or flammable gases were release more quickly
  - Polystyrenes tended to melt or drip and contribute to spread of fire
  - Certain types of polyurethanes could self-ignite if improperly formulated or applied.

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1974 FTC CONSENT CEASE & DESIST ORDER

- Issued November 4, 1974
- Signed by Respondents for settlement purposes, not as an admission that the law had been violated.
- Focused on the use of small-scale combustibility tests
  - Cease using "non-burning", "Self-extinguishing" or non-combustible" when describing foam plastic products
  - Any reference to numerical flame spread ratings based on small scale tests, such as ASTM E84 contain a disclaimer:
    - "This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions."

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1974 FTC CONSENT CEASE & DESIST ORDER

- Notification of the Terms of the Order
  - Previous purchasers of the plastic products, government bodies & officials, insurance underwriters, building code bodies and members of ASTM.
- Establishment of a Research Program
  - 5 year, $5 million program to
    - Determine the "safest" method of using foam plastics
    - Develop guidelines for safe and effective use of the products
    - Develop tests or standards
      - including large-scale tests to provide an accurate and reliable determination of the burning characteristics of the products under actual fire conditions

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1974 FTC CONSENT CEASE & DESIST ORDER

- Compliance Reporting to the FTC for 5 years
- 1974 Proposed Trade Regulation Rule to govern cellular plastic products
  - Withdrawn in 1980 due to widespread compliance with the terms of the Consent Order.

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FOAM PLASTICS INDUSTRY COMPLIANCE EFFORTS

- Society of the Plastics Industry (precursor to current trade associations) took a leadership role on Education & Notification of the terms of the Order
  - Technical Bulletins
  - Issuance of Advisory Letters
- Development of Code requirements/language
- Establishment of the Products Research Committee
  - SPI/ National Bureau of Standards (now NIST) research associate program
  - Development of large scale corner wall tests
  - Programs to validate such tests with small-scale work
  - Development of combustion toxicity studies

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PRODUCTS RESEARCH COMMITTEE RECOMMENDATIONS

- Educational efforts by the foam plastic industry
- Foam plastics should be covered with a thermal barrier unless there is a pass of large scale fire tests without the thermal barrier
- Continue development of full-scale fire tests
- Continue refinement of predictive models
- The Steiner Tunnel should be detailed and validated
- Evaluation of other combustion tests methods and apparatus
- Continued work on combustion toxicity, including correlating work from small-scale tests to full-scale fires.

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SUNSET OF THE FTC ORDER

- January 2, 1996: Automatic "sunset" of FTC Order
- Signatories to the Order could no longer be cited for violating the Order

BUT

The FTC still view claims inconsistent with the Order as "false and misleading"

Therefore: Comply with the intent of the Order

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BUILDING CODES ADDRESS FOAM PLASTICS

- 1976 Uniform Building Code
  - Complete new section (Section 1717) devoted to Foam Plastics
  - Required E84 testing
  - Required a 15 min. thermal barrier – typically ½" gypsum board – covering the foam insulation
  - Full-scale fire tests for foam plastic insulation were still under development
- Other Model Codes followed

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CURRENT CODE REQUIREMENTS FOR FOAM PLASTICS

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CODE DEFINITIONS

- **FOAM PLASTIC INSULATION**. A plastic that is intentionally expanded by the use of a foaming agent to produce a reduced-density plastic containing voids consisting of open or closed cells distributed throughout the plastic for thermal insulating or acoustic purposes and that has a density less than 20 pounds per cubic foot (320 kg/m3).
- Other definitions for other foam plastic applications and other types of plastics (light transmitting, etc.)

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CBC SECTION 2603 & CRC SECTION R316

- Basic Requirements for both the CBC and CRC
  - Labeling & Identification
  - Surface Burning Characteristics - ASTM E84 or UL723
    - < 75 flame spread index
    - < 450 smoke developed index
  - Thermal Barrier Requirements
    - Typically 0.5" gypsum wall board

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CBC SECTION 2603.2

- **Labeling and identification.** Packages and containers of foam plastic insulation and foam plastic insulation components delivered to the job site shall bear the label of an approved agency showing the manufacturer's name, the product listing, product identification and information sufficient to determine that the end use will comply with the code requirements.

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LABELING OF FOAM PLASTIC

The requirement for labeling involves an approved agency (UL, etc.) that requires:

- QC manual be developed & compliance
- Unannounced inspections to verify manufacturing process & compliance
- Use the FSI & SDI results to determine compliance with the Code

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CBC – SECTION 2603.3

Surface burning characteristics. Unless otherwise allowed in this section, all foam plastic or foam plastic cores used as a component in manufactured assemblies used in building construction shall have a flame-spread index of not more than 75 and shall have a smoke-developed index of not more than 450 when tested in the maximum thickness intended for use in accordance with ASTM E84 or UL 723. Loose fill type foam plastic insulation shall be tested as boardstock for the flame spread index and smoke developed index.

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E84 / UL723

- Studies by ULI in mid-1970s showed a "rough" correlation between the E84 results and vertical wall tests.
  - Work involved various materials
- Require foam plastic to have FSI better than wood (B versus C)

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EXCEPTIONS TO SECTION 2603.3

- Interior Trim – SDI is exempt, but not FSI
- Cold storage buildings – Tested & sprinklers
- Roofing – but meet other tests
- Greater than 4 inches in thickness – test in full-scale test.
- Interior signs in malls – meet other tests

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CBC SECTION 2603.4

Thermal barrier. Unless otherwise allowed in Section 2603.4.1 and Section 2603.10, foam plastic shall be separated from the interior of a building by an approved thermal barrier of minimum ½-inch (12.7 mm) gypsum wallboard or a material that is testes in accordance with and meets the acceptance criteria of both the Temperature Transmission Fire Test and the Integrity Fire Test on NFPA 275. Combustible concealed spaces shall comply with section 718.

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WHY IS A THERMAL BARRIER REQUIRED?

- **To isolate the foam plastic from an ignition source**
- **To delay fire growth if the foam plastic ignites**

‘‘Fire Research on Cellular Products Plastics: The Final Report of the Products Research Committee’’ ~Becker et al. 1980

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THERMAL BARRIER INFORMATION

- Provides protection to the underlying foam for a **finite** period of time when exposed to a **moderate** fire.
- The ½-inch thick gypsum wallboard was selected based on full-scale testing by ULI and others.
- Other materials are in use (Spray-applied Fire Resistive Materials, Cellulosic insulation, etc.)
- 2015 IRC will allow wood

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EXCEPTIONS TO THERMAL BARRIER REQUIREMENT BASED ON SPECIFIC USE OR TESTING

- Masonry & concrete – 1-in. minimum
- Cooler & Freezer walls – <25 FSI, meet other reqmts & AS
- Walk-in coolers – coverings, size limits
- Exterior walls – 1 story Bldg - <25 FSI, coverings, AS
- Roofing – Wood structural panel or meet other tests
- Attics/crawlspaces – Cover with ignition barrier
- Doors – No Fire-Resistance (F-R), then covered
- Garage doors – No F-R, coverings or full-scale test
- Siding backer board – limit on amount, separate from interior
- Interior trim – meet other requirements
- Interior signs – meet other requirements
- Sill & Headers – Type V – ,25 FSI, limits on size, density

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CBC – SECTION 2603.5

Exterior walls of buildings of any height. Exterior walls of buildings of Type I, II, III or IV construction of any height shall comply with Sections 2603.5.1 through 2603.5.7. Exterior walls of cold storage buildings required to be constructed of noncombustible materials, where the building is more than one story in height, shall also comply with the provisions of Sections 2603.5.1 through 2603.5.7. Exterior walls of buildings of Type V construction shall comply with Sections 2603.2, 2603.3 and 2603.4.

Continues on next slide……..

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CBC SECTION 2603.5 EXTERIOR WALLS OF BUILDING OF ANY HEIGHT

- **2603.5.1 Fire-resistance-rated walls.**
  - Where the wall is required to have a fire-resistance rating, data based on tests conducted in accordance with ASTM E 119 or UL 263 shall be provided to substantiate that the fire-resistance rating is maintained.
- **2603.5.2 Thermal barrier.**
  - Any foam plastic insulation shall be separated from the building interior by a thermal barrier meeting the provisions of Section 2603.4, unless special approval is obtained on the basis of Section 2603.9.
    - Exception: One-story buildings complying with Section 2603.4.1.4.

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CBC SECTION 2603.5 EXTERIOR WALLS OF BUILDING OF ANY HEIGHT

- **2603.5.3 Potential heat.**
  - The potential heat of foam plastic insulation in any portion of the wall or panel shall not exceed the potential heat expressed in Btu per square feet (mJ/m2) of the foam plastic insulation contained in the wall assembly tested in accordance with Section 2603.5.5. The potential heat of the foam plastic insulation shall be determined by tests conducted in accordance with NFPA 259 and the results shall be expressed in Btu per square feet (mJ/m2).
    - Exception: One-story buildings complying with Section 2603.4.1.4.

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CBC SECTION 2603.5 EXTERIOR WALLS OF BUILDING OF ANY HEIGHT

- **2603.5.4 Flame spread and smoke-developed indexes.**
  - Foam plastic insulation, exterior coatings and facings shall be tested separately in the thickness intended for use, but not to exceed 4 inches (102 mm), and shall each have a flame spread index of 25 or less and a smoke-developed index of 450 or less as determined in accordance with ASTM E 84 or UL 723.
    - Exception: Prefabricated or factory-manufactured panels having minimum 0.020-inch (0.51 mm) aluminum facings and a total thickness of 0.25 inch (6.4 mm) or less are permitted to be tested as an assembly where the foam plastic core is not exposed in the course of construction.

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CBC SECTION 2603.5 EXTERIOR WALLS OF BUILDING OF ANY HEIGHT

- 2603.5.5 Vertical and lateral fire propagation.
  - The wall assembly shall be tested in accordance with and comply with the acceptance criteria of NFPA 285.
    - Exception: One-story buildings complying with Section 2603.4.1.4.
- 2603.5.6 Label required.
  - The edge or face of each piece of foam plastic insulation shall bear the label of an approved agency. The label shall contain the manufacturer's or distributor's identification, model number, serial number or definitive information describing the product or materials' performance characteristics and approved agency's identification.

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2603.5 EXTERIOR WALLS OF BUILDING OF ANY HEIGHT

- 2603.5.7 Ignition.
  - Exterior walls shall not exhibit sustained flaming where tested in accordance with NFPA 268. Where a material is intended to be installed in more than one thickness, tests of the minimum and maximum thickness intended for use shall be performed.
    - Exception: Assemblies protected on the outside with one of the following:
      1. A thermal barrier complying with Section 2603.4.
      2. A minimum 1 inch (25 mm) thickness of concrete or masonry.
      3. Glass-fiber-reinforced concrete panels of a minimum thickness of 0.375 inch (9.5 mm).
      4. Metal-faced panels having minimum 0.019inch-thick (0.48 mm) aluminum or 0.016-inchthick (0.41mm) corrosion-resistant steel outer facings.
      5. A minimum 0.875 inch (22.2 mm) thickness of stucco complying with Section 2510.

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CBC SECTION 2603.6

2603.6 Roofing. Foam plastic insulation meeting the requirements of Sections 2603.2, 2603.3 and 2603.4 shall be permitted as part of a roof-covering assembly, provided the assembly with the foam plastic insulation is a Class A, B or C roofing assembly where tested in accordance with ASTM E 108 or UL 790.

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CBC SECTION 2603.7

2603.7 Interior finish in plenums. Foam plastic insulation used as interior wall or ceiling finish in plenums shall comply with one or more of the following:

1. **Use thermal barrier, FSI≤75, SDI≤450**
2. **Has FSI≤255, SDI≤50 & meet NFPA 286 (room/corner test)**
3. **Cover by steel or Al & FSI≤75, SDI≤450**

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CBC SECTION 2603.8

2603.8 Interior trim in plenums. Foam plastic insulation used as interior trim in plenums shall comply with the requirements of Section 2603.7

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CBC Section 2603.9

2603.8 Protection against termites. In areas where the probability of termite infestation is very heavy in accordance with Figure 2603.8, extruded and expanded polystyrene, polyisocyanurate and other foam plastics shall not be installed on the exterior face or under interior or exterior foundation walls or slab foundations located below grade. The clearance between foam plastics installed above grade and exposed earth shall be at least 6 inches (152 mm).

Exceptions:

1. Buildings where the structural members of walls, floors, ceilings and roofs are entirely of noncombustible materials or preservative-treated wood.
2. An approved method of protecting the foam plastic and structure from subterranean termite damage is provided.
3. On the interior side of basement walls.

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CBC SECTION 2603.10

2603.10 Special approval. Foam plastic shall not be required to comply with the requirements of Sections 2603.4 through 2603.8, where specifically approved based on large-scale tests such as, but not limited to, FM 4880, UL 1040, NFPA 286 or UL 1715. Such testing shall be related to the actual end-use configuration and be performed on the finished manufactured foam plastic assembly in the maximum thickness intended for use. Foam plastics that are used as interior finish on the basis of special tests shall also conform to the flame spread requirements of Chapter 8. Assemblies tested shall include seams, joints and other typical details used in the installation of the assembly and shall be tested in the manner intended for use.

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CBC SECTION 2603.10.1

2603.10.1 Exterior walls. Testing based on section 2603.10 shall not be used to eliminate any component of the construction of an exterior wall assembly when that component was included in the construction that has met the requirements of Section 2603.5.5.

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PURPOSE OF SECTION 2603.10

- Allows alternatives to previous Sections (i.e., eliminate thermal barrier, etc.)
- Allows new/modified applications when appropriately evaluated in a full-scale test
- Use existing full-scale fire tests
- Use other tests but test shall be reflective of actual end-use & sample configuration must be reflective of actual use, thickness, geometry, seams, joint treatments, coverings, etc.

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CBC SECTION 2604 - INTERIOR FINISH & TRIM

- Interior finish requires full-scale test
- Interior trim – Control density, thickness, area and FSI≤75.

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SUMMARY

Proper compliance with the Code requirements has shown that foam plastic insulations have an excellent fire performance history and provides an excellent basis for the safe use of foam plastic insulations.

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Appendix B – Fire Tests for Insulation in California Codes

Fire Tests for Insulation in California Codes:
2013 California Building Code (CBC)
CBC Chapter 7, Section 720 Thermal and Sound-Insulating Materials

Products	Insulating materials, fiberglass, mineral wool, cellulose, including facings and all layers of single and multilayer reflective foil insulation (except Foam insulation shall comply with Chapter 26, and Single and Multilayer reflective plastic core insulation shall comply with CBC Section 2613)
Uses	Wall, roof, ceiling, attic, crawl spaces
Fire test requirements - applicability	Nationwide applicability: California Codes are based on the International Code Council (ICC) model codes: International Building Code (IBC), International Residential Code (IRC)
Concealed installation	Except cellulose: flame spread index and smoke developed index (CBC Section 720.2): Flame spread index ≤ 25 / Smoke-developed index ≤ 450 • ASTM E84 (2007) - Test Method for Surface Burning Characteristics of Building Materials, or • UL 723 (2003) - Standard for Test for Surface Burning Characteristics of Building Materials – with Revisions through May 2005 Facings are exempt from the flame spread and smoke developed index if they are in contact with the unexposed surface of the ceiling, wall, or floor finish. Cellulose loose fill insulation, that is not spray applied – no limit on flame spread index, but must comply with ≤450 smoke-developed index and (CBC Section 720.6) • CPSC 16 CFR Part 1209 (1979) - Interim Safety Standard for Cellulose Insulation; and • CPSC 16 CFR Part 1404 (1979) - Cellulose Insulation
Exposed installation	Flame spread index and smoke developed index (CBC Section 720.3): Flame Spread Index ≤ 25 / Smoke-developed Index ≤ 450 • ASTM E84 (2007) - Test Method for Surface Burning Characteristics of Building Materials, or • UL 723 (2003) - Standard for Test for Surface Burning Characteristics of Building Materials – with Revisions through May 2005 Cellulose loose fill insulation that is not spray applied: no limit on flame spread index, but must comply with smoke developed index of ≤ 450 On Attic floors (CBC Section 720.3.1): • Cellulose loose fill insulation in attic floors must comply with a critical radiant flux of ≥ 0.12 W/cm^2 when tested in accordance with ASTM E970

	• ASTM E970 (2000) - Test Method for Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant Heat Energy Source
Loose fill insulation	For materials that cannot be mounted in the ASTM E84 apparatus, Flame spread index and smoke developed index (CBC Section 720.4): Flame Spread Index ≤ 25 / Smoke-developed Index ≤ 450 • CAN/ULC S102.2 (1988) - Standard Method of Test for Surface Burning Characteristics of Flooring, Floor Coverings and Miscellaneous Materials and Assemblies – with 2000 Revisions Except cellulose, which must comply with the details for concealed or exposed applications, AND with the CPSC requirements in CBC Section 720.6

CBC Chapter 26 Plastics, Section 2603 Foam Plastic Insulation
Applies to all types of foam insulation: Extruded Polystyrene (XPS), Expanded Polystyrene (EPS), Rigid Polyurethane (PUR), Polyisocyanurate (PIR), Spray Polyurethane Foam (SPF)

Products	XPS, EPS, PU, PIR, SPF
Uses	Walls, roofs, crawl spaces, attics, below grade, exposed commercial interiors, coolers, freezers, entry doors, garage doors, metal panels, Exterior Insulation Finish Systems (EIFS)
Fire test requirements - applicability	Nationwide applicability: California Codes are based on the ICC model codes: International Building Code (IBC), International Residential Code (IRC)
Basic fire test	Flame spread index and smoke developed index (CBC Section 2603.3): Flame Spread Index ≤ 75 / Smoke-developed Index ≤ 450 • ASTM E84 (2007) - Test Method for Surface Burning Characteristics of Building Materials, or • UL 723 (2003) - Standard for Test for Surface Burning Characteristics of Building Materials – with Revisions through May 2005 ASTM E84 or UL 723 is also used as quality control for the labeling requirements in CBC Section 2603.2 ASTM E84 or UL 723 is also referenced in CBC Section 2603.4.1.13 (Type V Construction), and Section 2603.5.4 (Foam used on exterior walls in Type I, II, III, IV construction of any height) – here the foam Flame spread index is limited to ≤ 25 and the smoke –developed index is ≤ 450
	Foam roof insulation – Exterior flame spread (CBC Section 2603.6): • ASTM E108 (2007a) – Test Methods for Fire Tests of Roof Coverings or • UL 790 (2004) - Standard Test Methods for Fire Tests of Roof Coverings

In addition to ASTM E84, additional fire tests or prescriptive installation details are required for specific uses of foam insulation:	Foam roof insulation – Interior (under steel deck) flame spread – fuel contribution (CBC Section 2603.3 – Exception 3, 2603.4.1.5): • ANSI/FM 4450 (1989) - Approval Standard for Class 1 Insulated Steel Deck Roofs – with Supplements through 1992 or • UL 1256 (2002) - Fire Test of Roof Deck Construction – with Revisions through January 2007 Wall, roof/ceiling, floor/ceiling assemblies containing foam insulation – hourly fire resistance ratings (CBC Section 2603.5.1 if required for Exterior walls of Type I, II, III, IV of any height) • ASTM E119 (2007) - Test Methods for Fire Tests of Building Construction and Materials or • UL 263 (2003) - Standard for Fire Test of Building Construction and Materials Garage Doors with foam insulation (CBC Section 2603.4.1.9) • ANSI/DASMA 107 (1997; R2004) - Room Fire Test for Garage Doors Using Foam Plastic Insulation (garage doors) Siding backer board (CBC Section 2603.4.1.10) Potential Heat • NFPA 259 (2013) – Standard Test Method for Potential Heat of Building Materials Exterior walls, one-story buildings: Flame Spread Index ≤ 25; Smoke-developed Index ≤ 450 (CBC Section 2603.4.1.4) and Exterior walls of Type I, II, III, IV of any height: Flame Spread Index ≤ 25; Smoke-developed Index ≤ 450 (CBC Section 2603.5.4); • ASTM E84 (2007) - Test Method for Surface Burning Characteristics of Building Materials, or • UL 723 (2003) - Standard for Test for Surface Burning Characteristics of Building Materials – with Revisions through May 2005 Exterior walls Type I, II, III, IV over 1 story - Potential Heat (CBC Section 2603.5.3) • NFPA 259 (2013) – Standard Test Method for Potential Heat of Building Materials Exterior Walls Type I, II, III, IV of any height - Ignitability (CBC Section 2603.5.7) • NFPA 268 (2007) – Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using A Radiant Heat Source Exterior Walls Type I, II, III IV of any height - Vertical and lateral flame propagation – (CBC Section 2603.5.5) • NFPA 285 (2006) - Standard Method of Test for the

	Evaluation of the Flammability Characteristics of Exterior Nonload-bearing Wall Assemblies Containing Combustible Components Special approvals (CBC Section 2603.10), test must reflect actual end use configuration; typically used to qualify exposed interior wall/ceiling finish, elimination of ignition barriers for attics, crawl spaces, etc. • NFPA 286 (2006) - Standard Method of Test for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth (includes specific acceptance criteria: no flashover, peak heat release rate ≤ 800 kW, total smoke released ≤ 1,000 m^2 and no flame spread to the extremities of wall or ceiling) • ANSI/FM 4880 (2005) - American National Standard for Evaluating Insulated Wall or Wall and Roof/Ceiling Assemblies, Plastic Interior Finish Materials, Plastic Exterior Building Panels, Wall/Ceiling Coating Systems, Interior and Exterior Finish Systems (exposed foam in interior walls, also various assemblies as described, elimination of the thermal barrier), or • UL 1040 (1996) - Fire Test of Insulated Wall Construction – with Revisions through January 2001 (CBC Sections 2603.4, 2603.9 – exposed foam in interior walls, elimination of the thermal barrier), or • UL 1715 (1997) – Fire Test of Interior Finish Material – with Revisions through March 2004 (CBC Sections 2603.4, 2603.9, exposed foam on interior walls)

Chapter 26 Plastics, Section 2613 Reflective Plastic Core Insulation

Products	Reflective Plastic Core Insulation
Uses	Walls, roofs, crawl spaces, attics, exposed commercial interiors, coolers, freezers
Fire test requirements - applicability	Nationwide applicability: California Codes are based on the ICC model codes: International Building Code (IBC), International Residential Code (IRC)
Basic fire test	Flame spread index and smoke-developed index (CBC Section 2613.3) Flame Spread Index ≤ 25 / Smoke-developed Index ≤ 450 • ASTM E84 (2007) - Test Method for Surface Burning Characteristics of Building Materials, or • UL 723 (2003) - Standard for Test for Surface Burning Characteristics of Building Materials – with Revisions through May 2005
In addition to ASTM E84, if exposed	• NFPA 286 (2006) - Standard Method of Test for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth (includes specific acceptance criteria in CBC Section 803.1.2.1)

	• UL 1715 (1997) – Fire Test of Interior Finish Material – with Revisions through March 2004 (CBC Sections 2603.4, 2603.9, exposed foam on interior walls)

Note: the dates following each reference to a fire test standard are the dates mentioned in the 2013 California codes and not the latest editions of the corresponding standards.

Appendix C – Tables on Heat Release and Flame Retardants (from "Flame retardants and heat release: review of data on individual polymers", by M.M. Hirschler (Article published online, Fire and Materials, 03/11/2014, DOI: 10.1002/fam.2242)

Table 1 – Effectiveness of Flame Retardants on Heat Release of a Rigid Polyurethane Foam				
Cone @ 25 kW/m^2	TTI (s)	Pk HRR	Improvement	FPI
Rigid PU foam	s	(kW/m^2)	%	(m^{2}skW^{-1})
Control	26	890	0	0.03
with alkyl aryl phosphate	41	548	38	0.07
with Fyrol RDP	65	910	2	0.07
with Fyrol RDP + Zn stearate	33	720	19	0.05
with Zn stannate & Zn stearate			46	0.02
with Zinc stannate	31	424	52	0.07
with Zn hydroxystannate	36	471	47	0.08

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in Pk HRR based on the untreated material.

Table 2 – Effectiveness of Flame Retardants on Heat Release of a Polyisocyanurate Foam					
Cone @ 40 kW/m^2	TTI	Pk HRR	FPI	Av HRR	THR
Polyisocyanurate foam	s	kW/m^2	(m^{2}skW^{-1})	kW/m^2	MJ/m^2
40 kW/m2					
Untreated	4.3	161	0.03	69	11
Plus TCPP	4.6	87	0.05	19	5
Improvement%	7	46	98	72	55

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; Avg HRR: average heat release rate during test in cone calorimeter test; THR: total heat released during test in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in relevant property based on the untreated material. TCPP: Tris (1-chloro-2-propyl) phosphate.

Table 3 – Effectiveness of Halogen-containing Nanocomposites and Antimony Oxide as Flame Retardants on Heat and Ignitability Properties of Polystyrene Materials				
Cone calorimeter	TTI	Pk HRR	FPI	THR
35 kW/m^2	s	kW/m^2	(m^2skW^{-1})	MJ/m^2
Polystyrene				
Untreated	59	1242	0.05	100
Plus FR1	43	1065	0.04	77
Improvement %	-27	14	-15	23
Plus FR1 + ATO	41	590	0.07	50
Improvement %	-31	52	46	50
Plus FR2	33	707	0.05	62
Improvement %	-44	43	-2	38
Plus FR2 + ATO	42	541	0.08	45
Improvement %	-29	56	63	55
Plus FR3	34	967	0.04	71
Improvement %	-42	22	-26	29
Plus FR3 + ATO	43	813	0.05	51
Improvement %	-27	35	11	49
Plus FR4	34	813	0.04	75
Improvement %	-42	35	-12	25
Plus FR4 + ATO	44	875	0.05	61
Improvement %	-25	30	6	39

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; THR: total heat released during test in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). FR1: butyric acid pentabromobenzyl ester; FR2: pentabromobenzyl ester polyacrylate; FR3: methacrylate acid pentabromobenzyl ester; FR4: and acrylic acid pentabromobenzyl ester; ATO antimony oxide. Improvement %: percentage improvement in relevant property based on the untreated material.

Table 4 – Effectiveness of Brominated Additives (with and without antimony oxide) as Flame Retardants on Heat and Ignitability Properties of High Impact Polystyrene					
Cone @ 40 kW/m^2	TTI	Pk HRR	Av HRR 3 min	Eff. Ht Comb	FPI
	s	kW/m^2	kW/m^2	MJ/kg	(m^{2}skW^{-1})
HIPS	60	968	621	30.7	0.06
HIPS + SbO	62	910	580	28.6	0.07
HIPS + Deca	55	708	470	17.0	0.08
HIPS + Deca + SbO	72	360	255	10.1	0.20
HIPS + DBE	54	782	487	18.6	0.07
HIPS + DBE + SBO	78	393	302	10.8	0.20
HIPS + BT93	54	768	509	19.6	0.07
HIPS + BT93 + SbO	88	423	293	12.2	0.21
HIPS + HBCD	72	885	710	23.2	0.08
HIPS + HBCD + SbO	80	766	423	13.2	0.10
Improvement % SbO	3	6	7	7	10
Improvement % Deca	-8	27	24	45	25
Improvement % Deca + SbO	20	63	59	67	223
Improvement % DBE	-10	19	22	39	11
Improvement % DBE + SbO	30	59	51	65	220
Improvement % BT93	-10	21	18	36	13
Improvement % BT93 + SbO	47	56	53	60	236
Improvement % HBCD	20	9	-14	24	31
Improvement % HBCD + SbO	33	21	32	57	68
Brominated additives at 12%; antimony oxide at 4%					
Sb: antimony oxide					
Deca: decabromodiphenyl oxide					
DBE: Decabromodiphenyl Ethane					
BT93: Ethylenebis(tetrabromophthalimide)					
HBCDE: hexabromocyclododecane					

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; Avg HRR 3 min: average heat release rate during the 3 minutes following ignition in cone calorimeter test; Eff. Ht Comb: effective heat of combustion in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test).

Table 5 – Effectiveness of Synthetic Micas as Flame Retardants on Heat and Ignitability Properties of Polystyrene Materials					
Cone @ 50 kW/m^2	TTI	Pk HRR	FPI	Ht Comb	THR
Synthetic Micas	s	kW/m^2	(m^{2}skW^{-1})	MJ/kg	MJ/m^2
Polystyrene	65	1294	0.05	30.6	111
PS + 1 (18.6 wt% Mica O)	51	513	0.10	27.9	94
PS + 2 (9.3 wt% Mica O)	49	428	0.11	27.1	98
PS + 3 (1.9 wt% Mica O)	63	911	0.07	29.4	111
PS + 4 (10 wt% Mica N)	41	995	0.04	30.8	113
PS + 5 (5 wt% Mica N)	43	1146	0.04	31.7	117
PS + 6 (1 wt% Mica N)	52	1201	0.04	31.9	117
Mica O: dimethyl, di(hydrogenated tallow) ammonium treated sodium fluorinated synthetic mica					
Mica N: Sodium fluorinated synthetic mica					
Improvement % 1	-22	60	98	9	15
Improvement % 2	-25	67	128	11	12
Improvement % 3	-3	30	38	4	0
Improvement % 4	-37	23	-18	-1	-2
Improvement % 5	-34	11	-25	-4	-5
Improvement % 6	-20	7	-14	-4	-5

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; THR: total heat released during test in cone calorimeter test; Ht Comb: effective heat of combustion in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in relevant property based on the untreated material.

Table 6 – Effectiveness of Sodium Montmorillonites as Flame Retardants on Heat and Ignitability Properties of Polystyrene Materials					
Cone @ 50 kW/m^2	TTI	Pk HRR	FPI	Ht Comb	THR
Sodium montmorillonite	s	kW/m^2	(m^{2}skW^{-1})	MJ/kg	MJ/m^2
Polystyrene	65	1294	0.05	30.6	111
PS + 1 (16.2 wt% MMT O)	52	446	0.12	26.9	97
PS + 2 (8.1 wt% MMT O)	58	555	0.10	26.6	98
PS + 3 (1.6 wt% MMT O)	66	1080	0.06	29.9	111
PS + 4 (10 wt% MMT N)	40	792	0.05	29.2	106
PS + 5 (5 wt% MMT N)	41	993	0.04	29.5	111
PS + 6 (1 wt% MMT N)	57	1106	0.05	29.8	110
MMT O: dimethyl, di(hydrogenated tallow) ammonium treated montmorillonite (Cloisite 15A)					
MMT N: sodium montmorillonite (Cloisite Na+)					
Improvement % 1	-20	66	132	12	13
Improvement % 2	-11	57	108	13	12
Improvement % 3	2	17	22	2	0
Improvement % 4	-38	39	1	5	5
Improvement % 5	-37	23	-18	4	0
Improvement % 6	-12	15	3	3	1

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; THR: total heat released during test in cone calorimeter test; Ht Comb: effective heat of combustion in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in relevant property based on the untreated material.

Table 7 – Effectiveness of Phosphonium Synthetic Micas as Flame Retardants on Heat and Ignitability Properties of Polystyrene and Associated Materials					
Cone @ 50 kW/m^2	TTI	Pk HRR	FPI	Ht Comb	THR
Phosphonium treated synthetic micas	s	kW/m^2	(m^{2}skW^{-1})	MJ/kg	MJ/m^2
Polystyrene	65	1294	0.05	30.6	30.6
PS + 1 (styrene/maleic anhydride)	64	1280	0.05	30.8	30.8
PS + 2 (PS + 1 + 8.3 wt% Mica P)	65	557	0.12	26.5	26.5
PS + 3 (8.3 wt% Mica P)	64	586	0.11	26.6	26.6
Mica P: Triphenyl, n-hexadecyl phosphonium treated sodium fluorinated synthetic mica					
System 1: Addition of styrene/maleic anhydride					
Improvement % 1	-2	1	0	-1	-1
Improvement % 2	0	57	132	13	13
Improvement % 3	-2	55	117	13	13

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; THR: total heat released during test in cone calorimeter test; Ht Comb: effective heat of combustion in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in relevant property based on the untreated material.

Table 8 – Effectiveness of Layered Double Hydroxides as Flame Retardants on Heat and Ignitability Properties of Polystyrene				
Cone @ 35 kW/m^2	TTI	Pk HRR	FPI	THR
	s	kW/m^2	(m^{2}skW^{-1})	MJ/m^2
Polystyrene	88	813	0.11	138
PS + 5 wt% LDH-DBP	72	616	0.12	133
Improvement %	-18	24	8	4
PS + 5 wt%5 LDH - SMM 30 min DBP	65	517	0.13	133
Improvement %	-26	36	16	4
PS + 5 wt% LDH - SMM 60 min DBP	66	621	0.11	131
Improvement %	-25	24	-2	5
PS + 5 wt% LDH-syntal DBP	59	627	0.09	129
Improvement %	-33	23	-13	7
PS + 10 wt% LDH-DBP	74	444	0.17	127
Improvement %	-16	45	54	8
PS + 15 wt% LDH-DBP	95	402	0.24	125
Improvement %	8	51	118	9
DBP: 3,4-dihydroxybenzophenone				
LDH: layered double hydroxides				
SMM: surface modification				
LDH syntal: commercial material				

Notes: TTI: time to ignition in cone calorimeter test; Pk HRR: peak heat release rate in cone calorimeter test; THR: total heat released during test in cone calorimeter test; Ht Comb: effective heat of combustion in cone calorimeter test; FPI: fire performance index (ratio of time to ignition and peak heat release rate, in cone calorimeter test). Improvement %: percentage improvement in relevant property based on the untreated material.

Table 9 – Effectiveness of Flame Retardant Systems on Heat and Ignitability Properties of Foamed Expanded Polystyrene (EPS)			
Foamed EPS	TTI	Pk HRR	FPI
35 kW/m^2	s	kW/m^2	MJ/m^2
EPS	77.7	310.5	0.25
EPS Plus Commercial FR	81	230.6	0.35
Improvement % FR	4	26	40
Foamed EPS	TTI	Pk HRR	FPI
30 kW/m^2	s	kW/m^2	MJ/m^2
EPS	73	299	0.24
EPS Plus Commercial FR	77	238	0.32
Improvement % FR	5	20	33
Foamed EPS	TTI	Pk HRR	FPI
40 kW/m^2	s	kW/m^2	MJ/m^2
EPS	28	394	0.07
EPS Plus Commercial FR	40	321	0.12
Improvement % FR	43	19	75
Foamed EPS	TTI	Pk HRR	FPI
50 kW/m^2	s	kW/m^2	MJ/m^2
EPS	18	407	0.04
EPS Plus Commercial FR	24	379	0.06
Improvement % FR	33	7	43
Note: Data at 35 kW/m^2 was determined by the authors, while data at 30, 40 and 50 kW/m^2 was obtained by comparison of published data from other authors			

APPENDIX D

NIST Cone Calorimeter Data on Flexible Polyurethane Foam

Table 4.2 Peak HRR, time to sustained Ignition, and time to Peak HRR

polyurethane foam sample ID	External Radiant Flux, kW/m^2	Time to Sustained Ignition, Average,* seconds	Time to Peak Heat Release, Average,* seconds	Peak Heat Release Rate, Average,* kW/m^2
NIST				
PUF-FR	35	13	36	453
PUF-NFR-A	35	7	30	605
PUF-NFR-B	20	14	45	450
	35	6	30	586
	40	4	29	820
	60	3	24	1154
	70	3	21	970
ATF [24]				
Polyether PUF	20	9	37	260
Polyether PUF	40	3	31	297
Polyether PUF	60	1	26	415

* Average values include all individual test runs at each specific external thermal flux. Data from individual test runs are provided in Appendix A.

The full NIST report is available at:
http://www.fire.nist.gov/bfrlpubs/fire05/PDF/f05032.pdf