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On: 14 March 2014, At: 11:31

Publisher: Routledge

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Building Research & Information

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/rbri20>

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Published online: 26 Nov 2012.

To cite this article: Vytenis Babrauskas, Donald Lucas, David Eisenberg, Veena Singla, Michel Dedeo & Arlene Blum (2012) Flame retardants in building insulation: a case for re-evaluating building codes, Building Research & Information, 40:6, 738-755, DOI: [10.1080/09613218.2012.744533](https://doi.org/10.1080/09613218.2012.744533)

To link to this article: <http://dx.doi.org/10.1080/09613218.2012.744533>

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INFORMATION PAPER

Flame retardants in building insulation: a case for re-evaluating building codes

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US building codes balance the consideration of hazards to public safety, health and general welfare. Current codes require foam plastic insulation materials to have both protection by a thermal barrier and compliance with Steiner Tunnel test requirements. The Steiner Tunnel test is met by adding flame-retardant chemicals to the foam. Studies demonstrate that the Steiner Tunnel test does not give reliable fire safety results for foam plastic insulations. Foams that meet the Steiner Tunnel test still pose a fire hazard if used without a code-mandated thermal barrier. Insulations protected by a thermal barrier are fire safe and the use of flame retardants does not provide any additional benefit. Evidence is examined of the health and ecological impacts from the added flame-retardant chemicals. Changing the building codes could prevent health and environmental harm from the toxicity of these substances without a reduction in fire safety. Plastic foam insulations that are protected by a thermal barrier should be exempted from the Steiner Tunnel test and the need to use flame retardants. This change would align US codes with code regulations in Sweden and Norway and ensure the fire safety as well as improve health and environmental impacts.

Keywords: building codes, fire safety, flame retardants, flammability, insulation, public health, Steiner Tunnel, thermal barrier, toxicity

Les codes de construction américains prennent en compte de manière équilibrée les dangers pour la sécurité publique, la santé et le bien-être général. Les codes actuels exigent que les matériaux d'isolation en mousse de plastique possèdent à la fois une protection assurée par une barrière thermique et une conformité aux exigences des tests en tunnel Steiner. Il est satisfait à l'essai en tunnel Steiner par l'ajout à la mousse de produits chimiques retardateurs de flamme. Les études démontrent que l'essai en tunnel Steiner ne donne pas de résultats fiables en matière de sécurité incendie concernant les isolations en mousse de plastique. Les mousses qui satisfont à cet essai présentent encore un risque incendie en cas d'utilisation sans une barrière thermique prescrite par un code. Les isolations protégées par une barrière thermique sont ignifuges et l'utilisation de retardateurs de flamme n'apporte aucun avantage supplémentaire. Sont examinés les éléments probants relatifs aux incidences sur la santé et l'environnement des produits chimiques retardateurs de flamme qui sont ajoutés. La modification des codes de construction pourrait prévenir les dommages en matière de santé et d'environnement dus à la toxicité de ces substances sans réduction de la sécurité incendie. Les isolations en

mousse de plastique qui sont protégées par une barrière thermique devraient être dispensées de l'essai en tunnel Steiner et de la nécessité d'utiliser des retardateurs de flamme. Ce changement alignerait les codes américains sur les règles des codes en vigueur en Suède et en Norvège et garantirait la sécurité incendie tout en améliorant les incidences sur la santé et l'environnement.

Mots clés: codes de construction, sécurité incendie, retardateurs de flamme, inflammabilité, isolation, santé publique, Tunnel Steiner, barrière thermique, toxicité

Introduction

For improved energy efficiency and to reduce global climate change, the use of plastic insulation materials with high R-values such as polystyrene, polyisocyanurate and polyurethane is increasing in buildings and especially in 'green' buildings. In the United States, the International Code Council (ICC), ASTM International (formerly known as the American Society for Testing and Materials – ASTM) and the National Fire Protection Association (NFPA) set flammability requirements for plastic foam insulations and other building materials. These requirements are found in building codes, insurance requirements and other fire regulations for building materials. To meet these performance requirements for plastic insulation materials, flame-retardant chemicals – usually halogenated organic compounds with chlorine or bromine bonded to carbon – are added at per cent levels to the insulation. Flame retardants whose primary use is in building insulation are found at increasing levels in household dust, human body fluids and in the environment. These substances have been associated with neurological and developmental toxicity, endocrine disruption, and potential carcinogenicity (Covaci *et al.*, 2006; Marvin *et al.*, 2011; van der Veen and de Boer, 2012). It is argued that highly energy-efficient buildings are likely to contain potentially harmful flame-retardant chemicals in their insulation.

Given the additional cost of adding flame retardants to foam building insulation and their potential adverse health and ecological impacts, an important question is whether their use leads to an improvement in fire safety. To address this, an examination is presented of (1) the provisions in US building codes leading to requirements for both a thermal barrier and a flame spread rating for foam insulation, as well as (2) evidence that the thermal barrier alone is equally effective in providing fire safety. Though the goals of fire safety and long-term human and ecological health might appear to be competing, consideration is given to the potential elimination of flame retardants in plastic foam building insulation without a reduction in overall building fire safety.

Background

Until 2000, the United States had three separate building code bodies and three separate 'model' building codes. 'Model' means that the codes are published by

private organizations and they only acquire a regulatory status when public authorities (states, counties or municipalities) enact them into regulation. The three organizations merged to form the ICC which issued the International Building Code (IBC) and International Residential Code (IRC) in 2000. The ICC reissues their codes every three years, and most US jurisdictions use some version of the IBC and the IRC, occasionally supplemented by local provisions. The current ICC provisions governing foam plastic insulation in buildings are essentially unchanged from the predecessor building codes that had been in place for over five decades.

Code provisions regulating plastic insulations in buildings were first introduced in the early 1960s (International Conference of Building Officials (ICBO), 1961). These included a requirement for ASTM E 84 testing, known as the Steiner Tunnel test (ASTM, 2012). Though the goal of these provisions was to ensure that insulations did not show rapid flame spread over their surface, Steiner Tunnel testing did not result in foams with acceptable flame spread behaviour. In the 1970s, serious fires occurred when exposed foam plastic insulation was installed in unfinished basement rooms, garages and other habitable spaces.

To address this issue, the 1976 Uniform Building Code (UBC) introduced Section 1717, regulating foam plastics with some new provisions (ICBO, 1976) as described by Williamson and Mowrer (2004). According to this section, foam plastics are required to be separated from the interior of a room by a 'thermal barrier,' usually 0.5 inch (12.7 mm) thick gypsum wallboard, which protects the foam underneath from the heat of a fire. The UBC did allow foams to be used uncovered if they met certain large-scale (corner, or room fire test) test requirements, but such foams are expensive and will not be found in exposed use in general-purpose buildings. When the thermal barrier requirement was introduced in 1976, the UBC code maintained the 1960s' requirement for Steiner Tunnel testing of the foam (ICBO, 1976). The dual set of requirements for both a thermal barrier and Steiner Tunnel test were incorporated into other model building codes and every subsequent edition of both the IBC and the IRC (ICC, 2000a, 2000b, 2003a, 2003b,

2006a, 2006b, 2009a, 2009b, 2012a, 2012b). The current wording in the 2012 IBC is:

foam plastic insulation and foam plastic cores of manufactured assemblies shall have a flame spread index of not more than 75 and a smoke-developed index of not more than 450 when tested in the maximum thickness intended for use in accordance with the ASTM E 84 or UL 723.

(ICC, 2012a:
2012 IRC Section R316.3;
2012 IBC Section 2603.3)

It is important to note that the codes do not specify that chemicals be added to foam plastic insulation, but in practice organohalogen flame-retardant compounds are added to meet the Steiner Tunnel test requirements. Also, 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. Thus, since 1976 in the United States, foam plastic insulations have met both the Steiner Tunnel requirements and have been protected from fire by a thermal barrier. The code provisions in other countries are not discussed in detail here, but the same principles will apply to codes which mandate both flame-spread ratings and thermal barriers for foam plastic insulations.

In 2003 and 2009, respectively, the intent statements of the IBC and the IRC were expanded:

The purpose of this code is to establish minimum requirements to safeguard public safety, health and general welfare...from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

(ICC, 2003a, 2009a:
2012 IRC Section R101.3;
2012 IBC Section 101.3)

This expanded scope covers firefighters and emergency responders and recognizes a larger range of hazards, suggesting a reconsideration of code provisions in order to reduce the use of materials with negative health or ecological impacts.

Evaluating building codes for foam insulation

Are both the thermal barrier and Steiner Tunnel requirements necessary? A number of factors need to be examined to assess this question:

- adequacy of the thermal barrier
- validity of the Steiner Tunnel test for plastic foams

- fire propagation into a cavity constructed in violation of codes
- behaviour of exposed foam insulations installed in violation of codes
- potential value of a more accurate test

Adequacy of the thermal barrier

During a room fire under pre-flashover conditions, gypsum wallboard can essentially withstand indefinitely long fire exposure. After flashover has occurred, a gypsum board barrier will keep fire, heat and ignition sources originating in the room from impinging on the foam insulation for at least 15 min. The concept of a thermal barrier being able to withstand a post-flashover fire for a certain length of time is termed a 'finish rating'¹ in the building codes. According to the 2012 IBC Section 2603.4 and IRC Section R316.4, after 15 min the temperature at the interface of the thermal barrier and foam (back of thermal barrier/front of foam) cannot exceed the criteria of NFPA 275 (NFPA, 2009): 121°C (250°F) average with 163°C (325°F) at one peak value thermocouple. This is far below the auto-ignition temperature of plastic foams, which is in excess of 400°C for polystyrene and polyurethane (Babrauskas, 2003). Gypsum wallboard of 0.5 inch (12.7 mm) or greater thickness is accepted by the codes as a complying thermal barrier. Materials such as concrete and soil are also accepted as compliant thermal barriers. For other materials, the codes require testing according to NFPA 275, with the time and temperature criteria identified above (IRC Section R316.4, IBC Section 2603.4).

Research supports this code requirement. On the basis of conducting ASTM E 119 fire tests (which simulate a post-flashover fire), Zicherman and Eliahu (1998) showed that 0.5-inch (12.7 mm) gypsum wallboard barriers obtained from diverse manufacturers provide 15–20 min finish ratings, meeting the intent of the codes. At the end of that time period, the gypsum board layers had not cracked or fallen off, and the back face temperature rise values were so low that no combustibles (*e.g.* foam) behind the barrier would have been capable of igniting. Similarly, Mehaffey *et al.* (1994) documented times of 16–24 min. D'Sousa *et al.* (1981) ran a full-scale room corner test where a 0.5-inch (12.7 mm) gypsum barrier protected expanded polystyrene (EPS) foam insulation for 30 min, as judged by the temperature criterion and absence of fire involvement of foam.

These times are far longer than an individual could survive if a room fire goes to flashover, and even properly attired fire fighters can only safely endure post-flashover exposure very briefly. This indicates that even if foams behind the barrier were tested and

regulated to be, in some sense, fire resistive, such a requirement would be superfluous.

Validity of the Steiner Tunnel test for plastic foams

The Steiner Tunnel test (ASTM E 84) is a test for measuring the fire propagation over surfaces of materials in the early stages of the fire, when a fire is still small and flashover has not been reached. While it produces useful results for other materials such as wood products, research has shown that the Steiner Tunnel test is unreliable in assessing the hazard of plastic foams (Babrauskas *et al.*, 1997). Factory Mutual, now FM Global, one of the largest organizations in the United States engaged in fire safety research and testing, issued an advisory notice stating:

Flame spread ratings by ASTM E 84 tunnel test should be disregarded for foamed plastics.
(Factory Mutual, 1974, 1978)

Additionally, Section 1.4 of ASTM E 84 itself states:

testing of materials that melt, drip, or delaminate to such a degree that the continuity of the flame front is destroyed, results in low flame spread indices that do not relate directly to indices obtained by testing materials that remain in place.
(ASTM, 2012)

The most important reason for the inaccuracy of the Steiner Tunnel test is related to the mounting geometry. The specimen is placed on the ceiling of a long, tunnel-shaped apparatus, with an exposure flame directed from one end (Figure 1).

Under the test conditions, thermoplastic foams tend to melt and the liquid residue flows onto the floor,



Figure 1 The Steiner Tunnel, showing the flame being applied to the ceiling. Source: Intertek Testing Services Inc, Elmendorf, TX.

out of reach of the burner flame. Since the burner does not apply a flame to the floor, the test results are registered as no flame spread having occurred, even though the same product would show extreme fire spread if exposed to a more realistic flame. This problem was recognized long ago in Canada, where a special variant of the Steiner Tunnel, CAN/ULC-S102.2, is used with foams in the floor position (Higginson, 1979; Underwriters Laboratories of Canada (UL-CA), 2010). In other cases the foams produce so much smoke that observation of flame front position becomes impossible (Rose, 1971). Some foams also intumesce so much as to change completely the expected air flow in the tunnel (Rose, 1975). Further research details that support this conclusion are considered below (see the section entitled 'Behaviour of exposed foam insulations installed in violation of codes').

Fire propagation into a cavity constructed in violation of codes

Were the Steiner Tunnel test to produce results which are actually indicative of the flame spread hazard of foams, it would be necessary to examine the question of a potential benefit if fire propagates into a wall or ceiling cavity. However, (1) the Steiner Tunnel test is invalid for foams, (2) US building codes contain stringent fire-stopping provisions which require the openings to or from such cavities are closed, and (3) research shows that fire propagation in cavities is not influenced by the Steiner Tunnel rating of the materials, as discussed below.

Researchers have conducted tests to determine under what circumstances insulation materials will allow fire that enters a cavity to sustain continued propagation. Choi and Taylor (1984) ran large-scale tests at the National Research Council of Canada (NRC) and concluded that in the absence of proper firestopping, fire can spread vertically inside wall cavities. However, they found that this behaviour was dependent on the thickness of the gap between the insulation and the inner surface of the interior wall finish material (assuming the insulation fails to fill the cavity fully). Gaps of more than 1 inch (25 mm) showed propagation, while smaller ones did not. They demonstrated that the size of the gap was the determining factor influencing the propagation of the fire and that:

the flame spread rating of the materials used in the tests was not a significant factor.
(Choi and Taylor, 1984, p. 185)

Thus, having a lower Steiner Tunnel flame spread test result for the insulation does not improve the fire safety of the cavities.

Behaviour of exposed foam insulations installed in violation of codes

Finally, there may be a situation when, in violation of the codes, an individual constructs a building with foam plastic insulations exposed to the room interior without a thermal barrier. Would the use of flame retardant-treated foams that meet the Steiner Tunnel requirement – a flame spread index (FSI) < 75 – make these constructions fire safe? As discussed above, the fact that prior to 1976 severe fires occurred when foams that met the Steiner Tunnel requirement were used without a thermal barrier suggests the answer is no, and there is extensive scientific research on this topic. Several studies have examined whether it is safe to use foam insulation with FSI < 75 uncovered on room walls and ceiling surfaces. Williamson and Baron (1973) demonstrated that rigid polyurethane insulation with FSI < 25 applied uncovered on the walls and ceiling could undergo extremely rapid, severe fire development within a room. The most extensive study on this topic was published by Underwriters Laboratories (UL) in 1975 (Castino *et al.*, 1975). UL ran Steiner Tunnel tests and accompanying full-scale room tests, along with open room/corner tests similar to Williamson and Baron's, and some additional geometry tests. In this series of tests, UL obtained some extremely severe results. Using extruded polystyrene foam (XPS) having FSI = 3 (*sic*) caused a serious room fire with most (91%) of the walls and ceiling surfaces being burned out. Although some foams in their tests performed much better, there was no correlation between FSI and the room fire hazard (Figure 2). Additional studies provided very similar results. The NRC conducted corner tests on a variety of exposed foams and concluded that

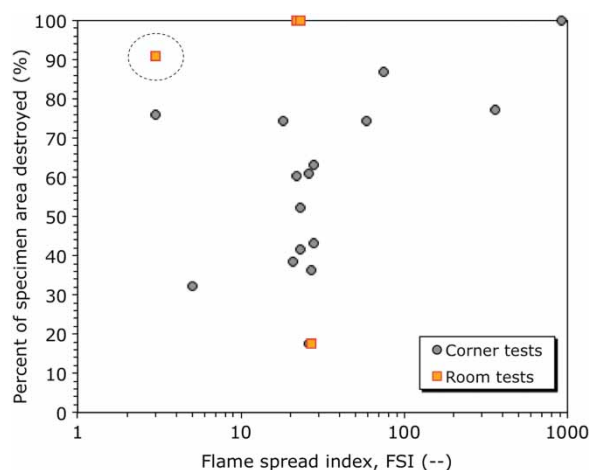


Figure 2 Results of the Underwriters Laboratories (UL) study on foams in corner and room test geometries. A lower flame spread index (FSI) does not correlate with a smaller per cent of area destroyed. The lowest FSI tested (indicated by the dotted circle) had one of the highest per cent areas destroyed. Source: Graph created from data in Castino *et al.* (1975)

foams with FSI = 18–65 would lead to room flashover (the most extreme kind of room fire) in as little as 0.5 min (Figure 3) (Rose, 1975).

The US National Bureau of Standards (now the National Institute of Standards and Technology (NIST)) similarly showed that uncovered polyisocyanurate and polystyrene foams having FSI < 25 showed very rapid flashover times when tested in full-scale room fire tests (Lee, 1985). Later NIST studies produced very similar findings for uncovered flame retardant-treated foams: XPS foams produced room flashover in 1.5 min, while EPS foams produced flashover in 1.4 and 1.8 min (Dillon, 1998). Thus, these large-scale studies indicate that:

- The Steiner Tunnel (ASTM E 84) test is unreliable in characterizing the fire hazard properties of foam plastics. The evidence presented above points to the same conclusion.
- Foam plastic insulation that is not protected by a thermal barrier has an unacceptable level of fire hazard, irrespective of the use of flame retardants. Foams complying with the building code requirement (FSI ≤ 75) can produce hazardous fire conditions if used in violation of codes without a thermal barrier. Even foams of much lower FSI values than the code criterion cannot be used uncovered without creating a fire hazard.

Potential value of a more accurate test

If the Steiner Tunnel test gives inaccurate results for foam plastic insulations, is there a test that would be appropriate for assessing flame spread ratings for these materials? There are methods that would be

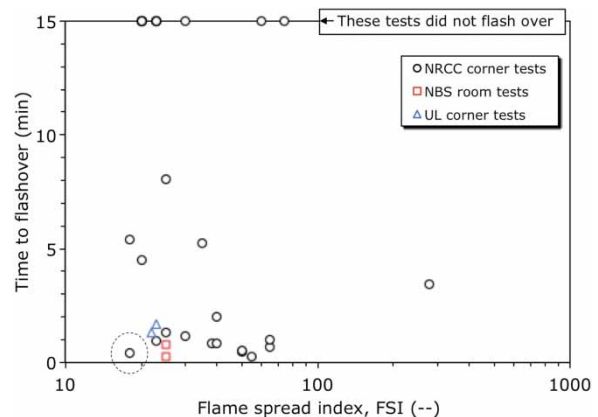


Figure 3 Relationship between flashover time and flame spread index (FSI) for several test series. A lower FSI does not reliably increase the time to flashover. The lowest FSI tested (indicated by the dotted circle) also had one of the shortest times to flashover. Source: Graph created from data in Rose (1975), Lee (1985) and Castino *et al.* (1975).

more accurate. For example, ISO 9705 is considered to be a reliable test for assessing the performance of wall/ceiling surfaces, including bare foams (International Organization for Standardization (ISO), 1993).

Foam plastic insulations treated with flame retardants as typically used in buildings are not able to achieve the desired flame spread ratings in an accurate test such as ISO 9705 (Babrauskas, 1996). As reviewed above, typical foam plastic insulation will exhibit severe fire spread behaviour if present in the walls or ceiling of a room and not covered by a thermal barrier. Thus, an accurate test would indicate this behaviour and only tests that misrepresent the actual performance can provide what appear to be acceptable results. Conversely, there is no known study which would show that foams of types economically viable for use as normal building insulation could perform acceptably in a test such as ISO 9705. Therefore, a method that accurately measured the FSI of typical foam plastic insulations would be likely to preclude the use of these materials in buildings under the current code requirement for a flame spread test.

US fire statistics support the idea that, due to use of thermal barriers, foam insulations very rarely present a fire safety problem. Insulation within a structural area was the primary item contributing to flame spread in 2% of US home structure fires, resulting in zero civilian deaths and 40 injuries (1% of the total for the whole United States). In contrast, a structural member or framing was the primary item contributing to flame spread in 26% of home fires, resulting in 360 civilian deaths and 950 injuries (Ahrens, 2011).

Though building codes often provide safety factors, and sometimes require redundant systems, there is no general rule about redundant requirements in codes. However, the research presented shows that for plastic foam insulations protected by a thermal barrier there is no added fire safety benefit from flame retardants. Without a demonstrated, significant fire safety benefit in both elements there can be no redundancy.

In summary, the studies discussed above establish that the Steiner Tunnel test is invalid for plastic foams. In the unusual case of a cavity constructed in violation of codes without proper firestopping, the Steiner Tunnel test rating for insulation materials does not influence fire propagation. If buildings are constructed in violation of code with exposed insulation, meeting the Steiner Tunnel test requirements still does not provide for acceptable behaviour 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. This conclusion is supported by fire statistics, which show no fire deaths and very few injuries attributable to fire spread by insulation (Ahrens, 2011).

Indeed, this approach is already being used in some countries in Europe (Blomqvist *et al.*, 2011; Lassen *et al.*, 2011; Persistent Organic Pollutants Review Committee (POPRC), 2011):

Using thermal barriers it is possible to fulfill fire safety requirements in most of the uses in constructions and buildings with EPS and XPS without a flame retardant.

(Posner *et al.*, 2010, p. 40)

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

(Posner *et al.*, 2010, p. 46)

Flame retardant chemicals

Given the expanded intent statement of the ICC codes to consider hazards to public safety, health and general welfare (including fire fighters), the impacts of flame retardants should be considered when evaluating code provisions.

Exposure and toxicology

The two major flame retardants currently used in plastic insulation materials are known either to be harmful or to lack adequate health data: hexabromocyclododecane (HBCD or HBCDD) and *tris*(1-chloro-2-propyl) phosphate (TCPP). The chemicals are released during the product life cycle and move into the environment, humans and animals. Such halogenated flame retardants act by releasing active halogen atoms (called free radicals) which can quench the chemical reactions occurring in the flame. HBCD and TCPP are used additively, which means they are not chemically bonded to foam and have the potential to migrate out. They can enter the environment as releases during chemical and product manufacturing, as well as leaching from products during use and disposal. The general public can be exposed by dermal contact with, inhalation or ingestion of

contaminated air, water, soil, food and/or indoor dust (Figure 4).

Both HBCD and TCPP are found in indoor dust to which the general public may be exposed. However, the source of the chemicals in the dust has not been established, nor what the contribution of migration from building insulation compared with other sources may be. Both air and moisture move through a building fabric, regardless of how tightly they are constructed. Substances within building cavities have the potential to migrate out of those cavities via movement driven by air, liquid and/or water vapour that occurs due to temperature, air and vapour pressure differentials (Liu and Nazaroff, 2001). Chemicals may be present in dust from abraded materials or could volatilize and then settle in indoor dust to which building occupants could be exposed.

Organohalogen flame retardants are semi-volatile organic chemicals (SVOCs), and for additive uses in furniture foam it is known that they do continuously migrate out, moving from areas of high to low fugacity, and settle in indoor dust (Jones-Otazo *et al.*, 2005; Weschler and Nazaroff, 2008; Zota *et al.*, 2008). The main route of human exposure for the SVOC flame retardant pentabromodiphenyl ether (pentaBDE) has been established as via hand-to-mouth contact with dust (Lorber, 2008; Watkins *et al.*, 2011). The authors are not aware of any research that has been done into the potential for HBCD or TCPP to migrate from plastic foam insulation into occupied spaces in buildings. Given the concerns about HBCD and TCPP discussed below, this should be a high-priority area for research. Exposure to these chemicals and their by-products also occurs via other pathways. Below, the health and ecological effects of these commonly used building insulation flame retardants are considered.

Hexabromocyclododecane (HBCD)

Polystyrene foam insulation for use in buildings in the United States is treated with HBCD, an additive brominated flame retardant. The levels of HBCD commonly used are 0.7% in EPS and 2.5% in XPS. Other uses of HBCD are in upholstery textiles and electrical equipment housing (Bromine Science and Environmental Forum (BSEF), 2009). Current worldwide annual production is estimated at 31 000 tons (POPRC, 2012). The use of HBCD has been increasing in the European Union and in the United States. It is the second highest volume-use brominated flame retardant in Europe and a high-production-volume chemical in the United States (Covaci *et al.*, 2006; Marvin *et al.*, 2011; US Environmental Protection Agency (USEPA), 2006). Polystyrene insulation is the main use, accounting for 90% of consumption (Figure 5) (European Commission, 2008a).

HBCD is a chemical of concern due to its potential for long-range transport, bioaccumulation, toxicity and human exposure. The source of HBCD found in indoor air and dust is unknown. Outdoors, HBCD is found in landfill leachate, sediment, soil, sewage sludge and animals. Mussels, fish, marine mammals and birds contain HBCD. This chemical tends to associate with fat and bioaccumulate, so animals towards the top of the food chain such as falcons and dolphins have higher levels (Figure 5) (Covaci *et al.*, 2006; Marvin *et al.*, 2011). HBCD is found in fish, poultry, meat and other foods worldwide (Kakimoto *et al.*, 2012; Schecter *et al.*, 2010). In a recent study of 36 foods in a supermarket in Dallas, Texas, 42% had detectable levels of HBCD (Schecter *et al.*, 2012).

Several studies of sources of HBCD emissions have concluded that uses for textiles are the primary source of HBCD emissions and releases to the outdoor environment. However, these studies did not consider the impact of the disposal of insulation containing HBCD (European Chemicals Agency (ECHA), 2009; National Industrial Chemicals Notification and Assessment Scheme (NICNAS), 2012). In a European Union study, uses for building insulation were estimated to account for 87% of all HBCD releases to the outdoor environment when releases from insulation disposal were included in the calculation (see Table A1) (ECHA, 2009). This indicates that disposal of insulation should also be evaluated as a primary source of emissions.

While disposal estimates contain considerable uncertainty, these figures suggest that HBCD uses for building insulation contribute to the global pollution. Disposal releases will continue to grow as an increasing number of buildings containing XPS/EPS with HBCD are refurbished or demolished (POPRC, 2011).

Concerns about HBCD include aquatic toxicity and possible human health effects, as it causes thyroid hormone disruption and adversely affects the developing nervous system in animal studies (Marvin *et al.*, 2011; USEPA, 2008). Human exposure may be through dermal contact with, or inhalation/ingestion of, air, soil, food and dust containing HBCD (Figure 4). It is unknown what the relative contributions of each of these pathways is to total human exposure, and thus how much building insulation contributes compared with other sources.

HBCD crosses the placenta and is found globally in human blood, adipose tissue and breast milk (Covaci *et al.*, 2006; Marvin *et al.*, 2011). Babies and young children are a population of concern because of their sensitive developmental stage and higher exposures to the chemical via dust ingestion and breast milk (Harrad *et al.*, 2010). No limits on HBCD exposure for workers or the general public have yet been set.

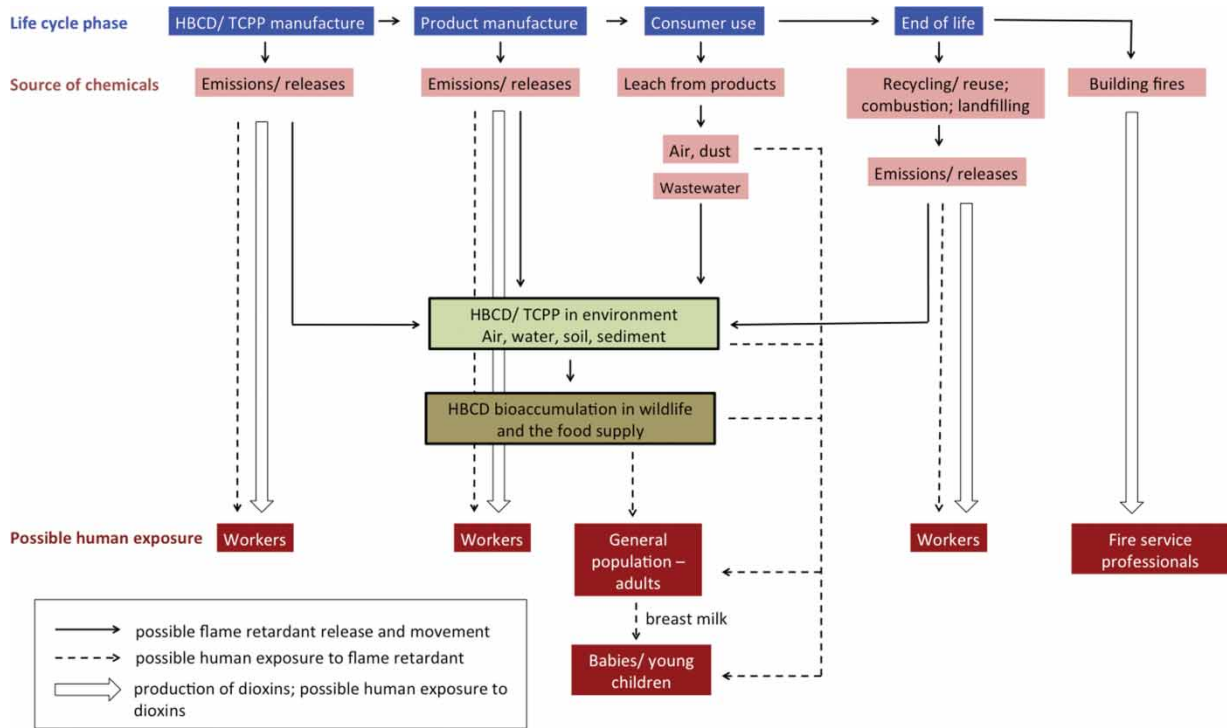


Figure 4 Sources of hexabromocyclododecane (HBCD)/tris(1-chloro-2-propyl) phosphate (TCPP) and their by-products in the environment and human exposure. Flame retardants whose primary use is in building insulation can enter the environment in a number of ways. Solid arrows indicate releases of HBCD/TCPP and movement in the environment. Dashed arrows indicate possible human exposure to HBCD and TCPP. Block arrows indicate the production of and possible human exposure to the HBCD by-products brominated dioxins. Proposed routes of exposure for humans are through dermal contact with, inhalation and ingestion of contaminated dust, food or water. Quantitative information is not available on the relative contribution of HBCD and TCPP used in building insulation to human exposure. Weights of arrows do not represent release amounts – for quantitative information on releases of HBCD and TCPP in the European Union, see Tables A1 and A2. For HBCD, the dominant source of release is from disposal of insulation. For TCPP, uses for building insulation account for a majority of releases, but it is unclear what phase of the life cycle is the dominant source.

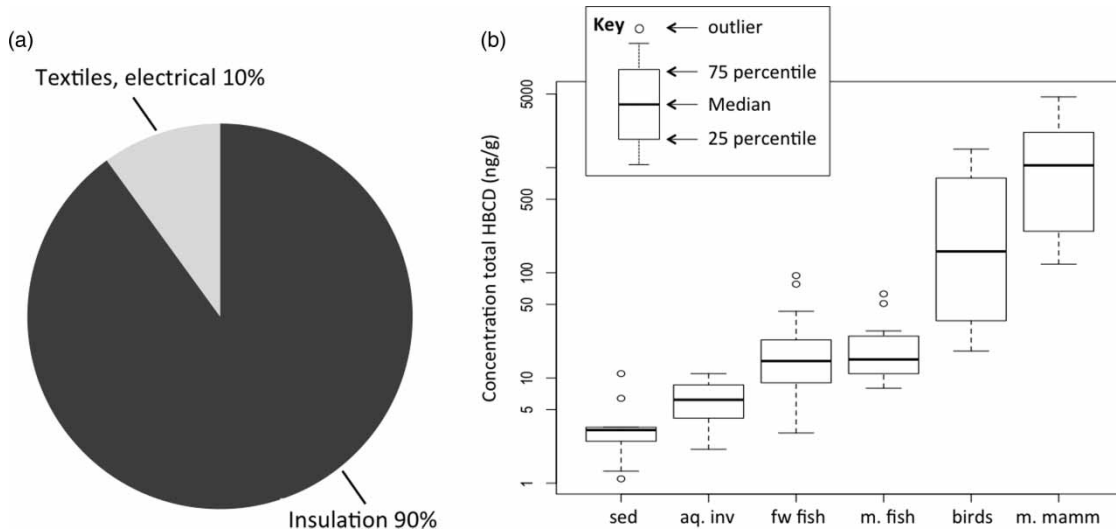


Figure 5 Hexabromocyclododecane (HBCD) usage and bioaccumulation. (A) The primary use of HBCD is in polystyrene building insulation. (B) HBCD in the food chain. Species at the top of the food chain have the highest levels of HBCD. The graph shows the concentration of HBCD in sediments (sed, ng/g dry weight) and biological samples (ng/g lipid weight). aq. inv. = aquatic invertebrates; fw fish = freshwater fish; m. fish = marine fish; and m. mamm = dolphins, porpoises. *Source:* Graphs created from data in Covaci *et al.* (2006)

The lowest observed adverse effect level dose in animal studies showed developmental neurotoxicity in mice at 0.9 milligrams per kilogram of body weight per day (mg/kg bw/day) (Eriksson *et al.*, 2006). A recent assessment estimates a worst-case scenario as two-year-old toddlers having an exposure of 0.3 mg/kg bw/day from all sources. When comparing the amount of HBCD in dust, breast milk, and food within and between studies, HBCD levels ranged over several orders of magnitude (NICNAS, 2012). There are uncertainties in comparing effects in mice with humans, but these values suggest a cause for concern and further study would be warranted.

Due to the above concerns, HBCD is one of the first 'Substances of Very High Concern' scheduled to be phased out by 2015 in the European Union (European Commission, 2011). Canada

is proposing to implement regulations to prohibit the manufacture, use, sale, offer for sale, import and export of HBCD and products containing HBCD [by the end of 2016].

(Environment Canada, 2012)

HBCD is also under consideration for listing as a persistent organic pollutant by the 178 member countries belonging to the Stockholm Convention on Persistent Organic Pollutants in 2013 (POPRC, n.d.). In October 2012, an expert review committee recommended listing HBCD under Annex A (Elimination) with limited exemptions (United Nations Environment Programme (UNEP), 2012).

Tris(1-chloro-2-propyl) phosphate (TCPP)

Most polyurethane insulations including flexible-faced laminate, panels, block and injected foams contain TCPP, an additive chlorinated flame retardant. In addition, TCPP is often used in polyisocyanurate (isocyanurate-modified polyurethane) board. It is used at 2–25% in boards and 5% levels in foam (European Commission, 2008b). TCPP is also used in flexible foam for furniture and bedding (European Commission, 2008b; van der Veen and de Boer, 2012).

In 1997, worldwide use was 40 000 tons (Van der Veen & de Boer, 2012). In 2000 this same amount was consumed in the European Union (European Commission, 2008b). In 2006, the quantity of TCPP manufactured and imported in the United States qualified it as a high-production-volume chemical (4500–22,600 tons) (USEPA, 2006). A total of 80% of TCPP use is in polyurethane insulations (Figure 6) and 32 000 tons of TCPP were used in this type of insulation in the European Union in 2000 (European Commission, 2008b).

There is a lack of general agreement regarding the safety of TCPP. A 2008 European Union risk

assessment concluded that no further restrictions on its use were required, after a comprehensive review of available data on environmental and health effects (European Commission, 2008b). A 2012 study found TCPP to be a chemical of concern due to its potential for long-range transport, persistence, toxicity and human exposure (van der Veen and de Boer, 2012).

The source of this chemical in indoor air and dust (Figure 6) is unknown (Brommer *et al.*, 2012; Covaci *et al.*, 2012; van der Veen and de Boer, 2012). TCPP is found outdoors globally in wastewater, coastal and marine waters, surface water, drinking water, groundwater, sediment, sewage, soil, landfill leachate, mussels, fish, and birds (Eggen *et al.*, 2010; Fries and Mihajlović, 2011; Möller *et al.*, 2012; van der Veen and de Boer, 2012). It does not readily break down into non-biologically available chemicals, which means that it is persistent. For the European Union, uses for building insulation account for 76% of all TCPP releases to the environment (see Table A2) (European Commission, 2008b). These figures suggest that TCPP uses for building insulation are contributing significantly to global pollution.

Human exposure may be through inhalation, ingestion or dermal contact with air, water and dust containing TCPP (Figure 4) (van den Eede *et al.*, 2011). It is unknown what the relative contributions of each of these pathways is to total human exposure, and thus how much the uses for building insulation are contributing compared with other sources. No limits on TCPP exposure for workers or the general public have yet been set. Little is known about the levels of this chemical in people, though it has been found in breast milk and its breakdown product has been

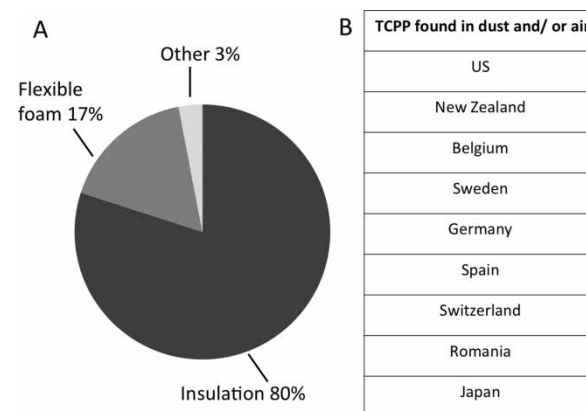


Figure 6 *Tris*(1-chloro-2-propyl) phosphate (TCPP) uses and presence in dust and air around the world. (A) The primary use of TCPP is in polyurethane and polyisocyanurate insulations. Source: European Commission (2008b). (B) TCPP is found in air and dust from homes, offices and cars around the world. Source: Graph created from data in Covaci *et al.* (2012)

detected in urine, confirming that exposure occurs (Covaci *et al.*, 2012).

This is of concern because TCPP is a potential carcinogen, accumulates in the liver and kidneys, and may affect the developing nervous system based on cellular and animal studies (Crump *et al.*, 2012; Dishaw *et al.*, 2011; van der Veen and de Boer, 2012). TCPP is structurally similar to three chemical compounds that have been identified as causing cancer: TCEP (*tris* (2-chloroethyl) phosphate), TDCPP/chlorinated *tris* (*tris*(1,3-dichloro-2-propyl) phosphate), and TDBPP/brominated *tris* (*tris*(2,3-dibromopropyl)phosphate) (European Commission, 2008b; Office of Environmental Health Hazard Assessment (OEHHA), 2009, 2011). Due to the lack of studies on both human exposure and TCPP carcinogenicity, it is difficult to assess whether the current levels of exposure to TCPP pose a risk to adults and/or young children. Further study is needed to learn more about the ecotoxicity, routes of exposure, levels in humans and possible adverse health effects of TCPP.

End of life

Building fires and increased fire toxicity

Most fire deaths and injuries result from the inhalation of carbon monoxide (CO), smoke, soot and other irritant gases, such as hydrogen cyanide (HCN) (Department for Communities and Local Government (DCLG), 2006, 2011; Hall, 2011). The addition of halogenated flame retardants such as those used in plastic building insulations can increase fire toxicity following ignition (Purser, 2000; Wichman, 2003), unless such a large loading of flame-retardant chemical is used that combustion does not occur. Such high levels of flame retardants are not commonly used in commercial foam plastic insulation.

Fire effluents from the combustion of materials containing halogenated flame retardants may be more toxic for three reasons (Schnipper *et al.*, 1995; Stec and Hull, 2011). The effluents may contain:

- more CO
- irritant acid gases (hydrogen chloride or hydrogen bromide)
- a mixture of respiratory irritants comprising unburned and partially burned hydrocarbons whose toxicity depends on the combustion conditions

However, this is a complex issue depending on the fire scenario and products involved, and the overall toxic hazard for fires involving flame-retardant-treated materials may be lower or higher than for non-flame-retardant materials. Under some combustion

conditions (as shown in Figure 7), the incorporation of halogenated flame retardants into materials increases the yield of toxic gases and particulate matter during combustion. Increased CO, irritants, soot and smoke hinder escape from a fire.

In summary, when flame retardants are present, comprehensive evaluation is needed to determine if they provide a fire safety benefit to overcome possible increased hazards from CO, irritant gases, smoke and soot particles. The potential increased toxicity of the combustion products is particularly an issue for first responders who can be exposed to high levels of the harmful combustion products.

Formation of dioxins

Dioxins are a group of toxic halogenated compounds that are persistent environmental pollutants and can be unintentionally formed and released during the production and life cycle of halogenated flame retardants. This can lead to environmental, food and human contamination (Figure 4) (Hanari *et al.*, 2006; Shaw *et al.*, 2010). After flame retardant incorporation, processing of plastic may occur at sufficiently elevated temperatures to cause formation of dioxins. This is seen when HBCD is incorporated into polystyrene and formation of the by-products can be increased if the material is subjected to repeated extrusion cycles. The by-products can be found in the commercial product and in workplace air (Ebert and Bahadir, 2003). Finally, when halogenated flame retardants burn either in accidental fires or during intentional incineration for disposal, they can produce dioxins (Ebert and Bahadir, 2003; Weber and Kuch, 2003).

Chlorinated dioxins are regulated in many countries, which has led to their decrease in the environment and in humans (Hites, 2011). Human exposure to chlorinated dioxins is associated with adverse health effects such as skin and liver problems, impairment of immune, endocrine or reproductive function, effects on the developing nervous system, and certain types of cancer (World Health Organization (WHO), 1998). The general population is mostly exposed to chlorinated dioxins through diet; dairy, meat and seafood are monitored for dioxin content by the US Food and Drug Administration (USFDA) in the United States and the European Food Safety Authority (EFSA) in the European Union.

Less is known about the brominated dioxins that are formed during the life cycle of brominated flame retardants such as HBCD. Human exposure guidelines pertain to chlorinated dioxins and no guidelines yet exist for brominated dioxins, though development of these has been identified as high priority by the WHO (van den Berg *et al.*, 2006).

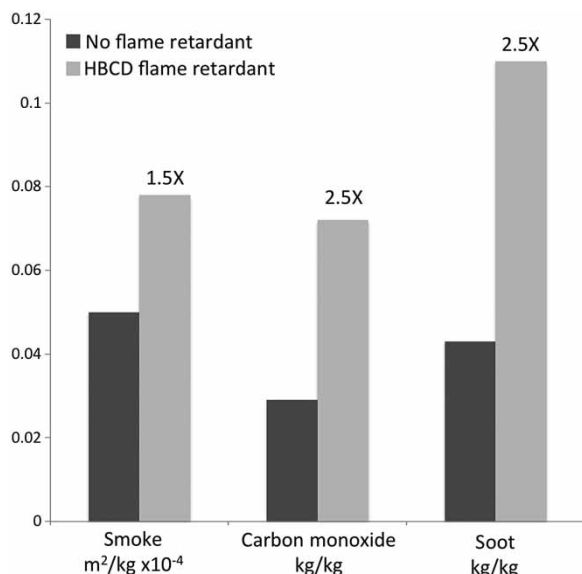


Figure 7 Hexabromocyclododecane (HBCD) increases fire toxicity. Polypropylene containing 5% HBCD releases 50% more smoke and 150% more carbon monoxide (CO) and soot than material with no flame retardant. *Source:* Graph created from data in Babrauskas (1992)

Scientists have found brominated dioxins in the environment, food supply, indoor dust, human milk and tissue (Suzuki *et al.*, 2010; van den Berg *et al.*, 2006). Brominated dioxins can have similar effects as the related chlorinated compounds and could be contributing to the total dioxin toxicity experienced by humans (Birnbaum *et al.*, 2003).

Emissions regulations pertain only to the chlorinated dioxins, and are set for processes such as municipal waste incineration at 0.1 nanograms per cubed metre (ng/m³) (USEPA, 2003). Polystyrene containing HBCD produces from 400 to 5000 ng brominated dioxin per kg of polystyrene when burned, depending on the conditions (Desmet *et al.*, 2005; Ebert and Bahadir, 2003). This is of concern to fire service professionals who are exposed to these substances during and after fires (Ebert and Bahadir, 2003; Weber and Kuch, 2003). Studies show higher rates of cancers associated with exposure to dioxins in this population, including multiple myeloma, non-Hodgkin's lymphoma, prostate and testicular cancers (Bates, 2007; Hsu *et al.*, 2011; International Agency for Research on Cancer (IARC), 2010; LeMasters *et al.*, 2006).

More research is needed to determine levels of human exposure to brominated dioxins and whether halogenated flame retardants used in building insulation are contributing significantly to human dioxin toxicity throughout their life cycle, especially for fire service professionals. The potential for dioxin toxicity should be considered in life cycle assessments and

when evaluating the benefits and hazards of including halogenated flame retardants in plastic insulations.

Managed disposal strategies

The end-of-life management for products treated with HBCD, TCPP and other halogenated flame retardants requires consideration as it can result in human exposure and environmental contamination (Figure 4). The three main options all have significant disadvantages: recycling and reuse, incineration and combustion, and landfilling.

Recycling and reuse. The preferred method for end-of-life treatment of flame-retarded materials from both energy-efficiency and life cycle toxicity perspectives is mechanical recycling. However, recycling flame-retardant-containing materials can lead to the formation of brominated dioxins, exposing workers (Sjödin *et al.*, 2001). Materials containing halogenated flame retardants are often exported to developing and transition countries, resulting in environmental and human contamination (Puckett *et al.*, 2002).

Incineration and combustion. A large proportion of flame-retarded materials are eventually burned either on purpose or during accidental fires. Depending on the temperature and quality of combustion, high levels of dioxins and other toxic combustion products can be formed and released. Dioxins are also emitted from open burning of municipal waste (Gullett *et al.*, 2010).

Halogenated flame retardants can be destroyed with high efficiency in high-temperature incinerators. But even in this type of incinerator, elevated brominated dioxin levels are found in the bottom ashes, most probably due to particle matter falling through the grate and not subjected to a complete combustion (Wang *et al.*, 2010). Further research is needed into the possible destruction of halogenated flame-retardant materials at very high temperatures in cement kilns.

Landfilling. A large portion of products treated with halogenated flame retardants end up in landfills. Flame retardants such as the HBCD and TCPP used in building insulation can leach from landfills and contaminate the environment (Danon-Schaffer, 2010; Eggen *et al.*, 2010; Morris *et al.*, 2004). As already noted, halogenated flame retardants are persistent substances. They will remain in landfills and leach into the environment for decades. Over extended time frames, landfill engineering systems typically inevitably degrade and lose their ability to contain the contaminants (Allen, 2001; Buss *et al.*, 1995). Therefore, landfilling does not appear to be a sustainable solution for long-term containment of halogenated flame retardants.

All three above options for end-of-life treatments for halogenated flame-retardant-containing materials are potentially harmful to human and ecological health and already appear to have contributed to the global environmental contamination by HBCD and TCPP. The waste management of plastic insulation containing flame retardants should be improved.

Potential replacements for HBCD

Even though HBCD will likely be phased out in some countries, flame retardants are still needed in XPS and EPS to meet the Steiner Tunnel requirements in the United States and other countries with similar codes. Three replacements for HBCD in polystyrene insulation are:

- Emerald 3000 (Chemtura, Middlebury, CT, USA)
- GreenCrest (Albemarle, Baton Rouge, Louisiana, USA)
- Pyroguard SR-130 (Dai-Ichi Kogyo Seiyaku Co., Ltd, Kyoto, Japan)

These replacements are brominated organic molecules with the potential to form brominated dioxins during their manufacture, use and end-of-life disposal. Furthermore, they rely on the same chemical mechanism as HBCD to achieve flame-retardant properties during combustion, so they are likely to increase fire toxicity. Therefore, many of the same issues with use and end-of-life management described above will still be present.

Little information is available regarding the toxicology of the proposed HBCD replacements. Emerald 3000 and GreenCrest are synthesized as large polymers to reduce exposure and bioavailability. Pyroguard SR-130 is more similar in size and chemical composition to flame retardants with a tendency to bioaccumulate and cause adverse health effects. While the polymeric nature of the first two flame retardants has the potential to reduce human exposure, it complicates the toxicological analysis. Polymers are by nature a heterogeneous mixture in which different sized particles can exhibit different properties. When evaluating the pre-manufacture notice for Emerald 3000, the USEPA (2011) predicted potential toxicity from inhalation of some particle sizes, as well as the potential for smaller polymers to be persistent, bioaccumulative and toxic.

Discussion

Shortcomings were identified for an inappropriate test method within building regulations, against which material performance is to be assessed. Consequently, chemicals known to be toxic or lacking adequate

health information are being used as building insulation flame retardants without a proven fire safety benefit. Regarding the provisions addressing the flammability of building insulation in the current IRC and IBC building codes, three questions are addressed below.

What could have been done differently in the past?

In the 1960s when requirements for Steiner Tunnel testing of foam plastic insulations were originally introduced into the model building codes, a systematic evaluation into the assumed fire safety benefit of the test for foam plastics could have been carried out. The value of the Steiner Tunnel test for other materials such as wood is not in question here, only its applicability to a new material at the time – foam plastic insulation. A regulatory impact analysis or statement was not required, but might have revealed that it was inappropriate to require that foam plastics be tested using the Steiner Tunnel test.

In 1975, a report published by UL (whose authors included Tom Castino, a future President of UL) documented that the Steiner Tunnel test did not provide reliable results for plastic insulations (Castino *et al.*, 1975). Surprisingly, in developing the original and subsequent codes, the lack of efficacy and appropriateness of the Steiner Tunnel test for use with foam plastic insulation was apparently not considered by the codes' organizations. In addition, the health and ecological impacts of the chemical flame retardants added to foams in order to comply with the Steiner Tunnel test were not considered.

What are the impacts of the current codes and requirements?

Flame-retardant chemicals, primarily HBCD and TCPP, are currently added to foam plastic insulation to meet the Steiner Tunnel test requirement. These chemicals make the insulations more expensive and potentially harmful to human health and the natural environment. Analysis of releases of HBCD and TCPP during their life cycle indicates that uses in building insulation contribute to environmental pollution.

The growing concern amongst designers, builders, building owners and the public about the toxicity of these flame-retardant additives could possibly lessen the use of these insulations, which are valuable for energy efficiency and reducing climate change. Although HBCD is about to be phased out in some countries due to its persistence, bioaccumulation and toxicity, the three proposed replacements are also brominated, share some similar chemical properties and lack adequate health information.

The ICC now directs that codes should consider:

minimum requirements to safeguard public safety, health and general welfare ... from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

(ICC, 2003a, 2009a:
2012 IRC Section R101.3;
2012 IBC Section 101.3)

An overall benefit of adding flame-retardant chemicals to the foam has not been established. As discussed above, in the presence of a code-mandated thermal barrier, these chemicals do not provide additional benefit in reducing fire hazard. During fires, halogenated flame retardants can add to the acute toxicity of the fire effluents and produce other toxic by-products. Dioxins may be contributing to increased levels of cancers in fire service professionals. The provisions that lead to the use of HBCD and TCPP should be reconsidered, especially in light of the intent statement.

What alternatives exist to mitigate these problems and provide safe solutions?

A change in building codes is suggested. This would provide an exemption from the Steiner Tunnel test for foam plastic insulations which are protected by a code-compliant thermal barrier. This exemption would eliminate the need to use flame-retardant chemicals in these plastic foam insulations, without reducing the current level of fire safety provided by the remaining code requirements. Some foams are used in situations where there is not a fire hazard, such as between layers of concrete or 'below grade' between soil and concrete. In these cases the concrete and soil act as thermal barriers. Building codes should also be revised to eliminate flame spread test requirements in these applications.

US fire statistics show that the use of a thermal barrier means fire spread due to insulation is a very rare occurrence. Code regulations in Sweden and Norway allow non-flame retarded EPS/XPS when protected by a thermal barrier such as gypsum drywall. A similar strategy to ensure the fire safety of buildings can be considered in other countries (Blomqvist *et al.*, 2011; Lassen *et al.*, 2011; POPRC, 2011). Alternatively, less flammable alternative insulation materials such as rockwool and fiberglass can also be used.

Currently, all polystyrene building insulation in the United States is treated with HBCD. To provide for situations where flame retardants afford a benefit, having two well-labelled foam varieties, one that is flame retarded and another that is not, would reduce the use of HBCD and its replacements. Foams without flame retardants should cost less, but

would require labelling, so that the two sorts of polystyrene would not be confused or used inappropriately.

In cases where chemical flame retardants are useful, safer flame retardants should be developed for plastic insulations. The current flame retardants and proposed substitutes are organohalogens, a chemical class that is often toxic, lipophilic (fat-loving) and/or resistant to degradation, leading to their persistence and bioaccumulation in people and the wider natural environment. All 21 chemicals globally banned as persistent organic pollutants under the Stockholm Convention are organohalogens. 'Green' chemistry – the design and use of safer materials and processes with minimal adverse impact on human health and the environment – should be employed to develop a new generation of safer flame retardants based on alternative chemistries.

The process of designing fire standards and building codes would benefit from comprehensive review and revision. For new standards or codes, a regulatory impact analysis or statement that considers both efficacy and larger impacts should be required. In the future, fire scientists, building code officials and other regulators making decisions about fire and building codes should consider the efficacy, life cycle, health and ecological impacts of materials that will be used. A more interdisciplinary approach could help, *e.g.* collaboration with toxicologists and biologists as well as other scientists who can provide information on the implications for human and ecological health, before regulations are promulgated.

Conclusions

Building codes should have reliable scientific and technical bases for their provisions. As knowledge increases, codes should change to reflect the new information. This is the basis for the three-year cycle of code development. The issues surrounding flame-retardant chemicals in foam plastic insulation are an example of the need to assess code provisions continually against the results of current research and testing, actual performance, and other relevant health and safety findings. Rigorous review of fire safety benefits of flame-retardant chemicals in plastic foam insulation, and their impacts on building occupants as well as fire fighters, is needed.

A range of chemicals such as halons, asbestos, polychlorinated biphenyls (PCBs), and Tris flame retardants in children's pyjamas were introduced to increase fire safety but subsequently were discontinued from use due to their adverse impacts. For building codes that lead to the use of added flame-retardant chemicals in plastic foam insulation, a similar question was examined, and evidence was presented that these

provisions do not appear to provide fire safety and a potential exists for serious health and ecological harm.

Code changes to exempt thermal barrier protected plastic foam insulations from the Steiner Tunnel test would prevent the use of thousands of tons of flame retardants that are either known to be persistent organic pollutants or in the same chemical family and lack adequate information. Such a change would align with the expanded intents of the codes to consider hazards to public health and to fire fighters. It could also decrease the cost of foam plastic insulations and encourage the use of insulation materials for increasing building energy efficiency and mitigating climate change. The potential for health and ecological harm from the use of flame-retardant chemicals would be reduced and the fire safety of buildings would be maintained.

Acknowledgements

The authors thank Roland Weber, Laura Bartels, Mark Levine and Katie McKinstry for their important contributions. This work was supported in part by funding from Art Rosenfeld, Dan Emmett, Stephen Silberstein, the Wallace Genetics Foundation, the New York Community Trust and the Fred Gellert Family Foundation. Donald Lucas was supported by Award Number P42ES004705 from the National Institute of Environmental Health Sciences (NIEHS). The content of this paper is solely the responsibility of the authors and does not necessarily represent the official views of the NIEHS or National Institutes of Health (NIH).

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Endnote

¹'Finish' in this context refers to a wall cladding layer.

APPENDIX A

Table A1 Releases of HBCD to the environment from the two major uses in building insulation and textiles in the EU

2006 Figures For Building Insulation: Use	1.3 Production of HBCD	2.7 Formulation of EPS beads/HIPS	2.8 XPS compound formulation	2.11 Use of EPS compound in manufacture of EPS	2.13 Installation of insulation	2.14 From building insulation	pg27 Release during disposal-EPS&XPS-recycled	pg27 Release during disposal-EPS&XPS-landfilled	2.18 Use of XPS compound in manufacture of XPS	2.19 Use of HBCD powder for XPS	Totals (kg/ year) insulation
Air	2.0	30.4	13.5	159.0	236.0	54.0	143.0	8512.0	118.0	28.0	9295.9
Wastewater	0.7	75.0	84.0	128.0	0.0	0.0	0.0	0.0	32.0	31.0	350.7
Surface water	0.0	330.0	10.0	31.0	236.0	0.0	0.0	0.0	8.3	7.8	623.1
these figures do not consider landfill leachate to be a significant source											10269.7
2007 Figures For Textiles: Use	1.5 Micronising	2.24 Formulation of polymer dispersion	2.25 Textile back-coating	2.28 Wearing textiles	2.29 Washing textiles	Totals (kg/ year) textiles	Total releases from insulation and textiles (kg/yr)				
Air	0.3	1.4	0.1	0.0	0.0	1.8	9297.7				
Wastewater	0.0	44.0	1130.0	21.4	2.1	1197.5	1548.2				
Surface water	0.0	11.0	283.0	5.4	0.0	299.4	922.5				
1498.7							11768.4				

Note: Numbers for high-impact polystyrene (HIPS) are not included, except where the releases could not be separated (2.7 Formulation of EPS beads/HIPS). There is only one facility that manufactures HBCD in Europe. Numbers in column titles refer to the table or page number in reference from which data was obtained. When disposal is taken into account, used for building insulation account for 87% of HBCD releases to the environment. Numbers for releases are in kilograms per year (kg/yr). *Source:* European Chemicals Agency (ECHA) (2009)

Table A2. Releases of TCPP to the environment from the two major uses in building insulation and furniture foam in the European Union

	from (a) below		from (b) below			
	Releases from all uses (tons/ yr)	Releases from other uses (2.5%) (tons/ yr)	Releases from furniture (tons/ yr)	Releases from insulation (tons/ yr)		
Air – sum of regional and continental	81.9	2.0	8.1	71.7		
Wastewater – sum of regional and continental	15.6	0.4	7.5	7.8		
Surface water – sum of regional and continental	3.9	0.1				
Soil – sum of regional and continental	3.2	0.1				
	104.6	2.6	15.6	79.5		
	Total releases from all uses	Total releases from other uses	Total releases from furniture	Total releases from insulation		
(a) Total releases from all uses						
Endpoint	Releases in kg/d	Releases in tons / year				
Total regional emission to air	134.9	49.2				
Total regional emission to wastewater	18.7	6.8				
Total regional emission to surface water	4.7	1.7				
Total regional emission to industrial soil	0.9	0.3				
Total continental emission to air	89.6	32.7				
Total continental emission to wastewater	24.1	8.8				
Total continental emission to surface water	6.0	2.2				
Total continental emission to industrial soil	7.8	2.8				
(b) Releases from uses for furniture						
		loss (fraction)	mass TCPP (mt)	loss air (mt)	loss wastewater (mt)	loss solid waste (mt)
3.1.2.2 Release from formulation: Use A						
3.1.2.3 Release from flexible foams: Use B	Production	0.0001	6482.3	0.6	wastewater	
	Volatility	0.00025	6482.3	1.6	1.6	
6482.3 mt of TCPP put into furniture foam	Casting	0.002	6482.3			13.0
Once in foam, only 40% of total TCPP (2592.9 mt) is subject to indoor service or weathering processes	Curing/storage	0.0000012	6482.3	0.0	0.0	
	Cutting/manufacture	0.000002	6482.3	0.0	0.0	
	Indoor service	0.0025	2592.9	0.6	0.6	
	Weathering	0.02	2592.9	5.2	5.2	
			Total	8.1	7.5	

Note: Numbers in titles refer to section or page in source from which numbers were obtained. Uses for building insulation account for 76% of TCPP releases to the environment. Numbers for releases are in kilograms per day (kg/d) or tons per year (tons/yr). mt = metric ton (a) Calculations for total releases from all uses (b) Calculations for releases from uses for furniture. Source: European Commission, (2008b)