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Title: BDE-209 in the Australian Environment: desktop review

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ABSTRACT

The commercial polybrominated diphenyl ether (PBDE) flame retardant mixture c-decaBDE is now being considered for listing on the Stockholm Convention on Persistent Organic Pollutants. The aim of our study was to review the literature regarding the use and detection of BDE-209, a major component of c-decaBDE, in consumer products and provide a best estimate of goods that are likely to contain BDE-209 in Australia. This review is part of a larger study, which will include quantitative testing of items to assess for BDE-209. The findings of this desktop review will be used to determine which items should be prioritized for quantitative testing. We identified that electronics, particularly televisions, computers, small household appliances and power boards, were the items that were most likely to contain BDE-209 in Australia. Further testing of these items should include items of various ages. Several other items were identified as high priority for future testing, including transport vehicles, building materials and textiles in non-domestic settings. The findings from this study will aid in the development of appropriate policies, should listing of c-decaBDE on the Stockholm Convention and Australia's ratification of that listing proceed.

Keywords: polybrominated diphenyl ethers (PBDEs), Stockholm Convention, persistent organic pollutants (POPs), flame retardants, decaBDE

1. Introduction

Since the 1970's flame retardants have been used in a diverse array of petroleum-based consumer products, including textiles, foam, electronics and electrical equipment (1). Polybrominated diphenyl ethers (PBDEs) are synthetic bromine based flame retardants that have been amongst the most abundantly used flame retardants. Including isomers, there are 209 different possible types of brominated diphenyl ethers, called congeners. Historically, three commercial mixtures of PBDEs have been or still are used, known as c-octaBDE, c-pentaBDE and c-decaBDE. The BDE-209 congener is the major component of c-decaBDE, see Figure 1 (2). Global commercial production of BDE-209 is estimated to have begun in the 1960's to early 1970's (3). By 2010, approximately 1.3 million tonnes of c-decaBDE had been produced worldwide (3).

The main application of c-decaBDE is in high impact polystyrene (HIPS) used in consumer goods, particularly electronic goods, although it also has applications in a wide range of additional commercial polymers, including acrylonitrile butadiene styrene (ABS), rubber, polyvinyl chloride, and polycarbonates (1). Another major application of c-decaBDE is to treat textiles, including upholstery materials for the aviation and automotive industries (seat covers and carpets), as well as textiles used for domestic and commercial furnishings, including carpets, furniture upholstery and curtains (1, 4). Estimates of how much c-decaBDE has been used for each of these purposes vary greatly. For example, applications in electrical appliances and equipment are estimated at anywhere from ~13-80% of total usage; whilst applications to textiles and building and construction are estimated to account for 10-26% and 26% of total usage, respectively (5-7).

PBDEs are semi-volatile additive flame retardants. PBDEs are not physically bonded to polymers or textiles and may be released from their point source by off-gassing (volatilization), directly partitioning from their point source into other materials and via abrasion (8-11). The widespread use of PBDEs in items commonly found in homes leads to contamination of the indoor environment, particularly of household dust (12, 13). Once in the environment, PBDEs can debrominate to form lower BDE congeners and can also form other products, such as bromophenols, furans and dioxins (14-19). The relevance of debromination to human exposure may be most pronounced for BDE-209, the dominant congener in dust (20, 21). Infants and toddlers have the highest intake of BDE-209,

which is likely due in large part to intake via dust, due to greater dust ingestion rates (55 – 200 mg/day) compared to adults (4 – 100 mg/day) (22).

As with other persistent chemicals capable of long-range transport that have been produced in large volumes, BDE-209 has been detected in environmental samples of soil, sediment, leachate, sewage, dust, mammals, birds and fish (13, 20, 23-34). Biomonitoring studies have found BDE-209 in human blood serum (35, 36), breast milk (37-40), cord blood (41), placenta (42, 43) and infant faeces (44). However, as with all PBDE congeners, there is limited data on human health effects associated with exposure to BDE-209. Studies suggest an association between BDE-209 and impaired cognitive development and delayed neurological development in early life (45, 46). As summarised and detailed in Costa and Giordiano (47), animal studies report BDE-209 may cause developmental neurotoxicity, affecting motor and cognitive domains, as seen for other PBDEs, including BDE-47 and BDE-99. Its acute and chronic toxicities are relatively low, with the liver and the thyroid as the primary targets, though there is some evidence of carcinogenicity (47). Limited in vivo and in vitro studies have also evidenced effects of BDE-209 on thyroid hormone homeostasis and direct effects on nervous system cells (47).

Concerns over the bioaccumulation potential, persistence, long-range transport and toxicity of the congeners found in c-octaBDE and c-pentaBDE resulted in their addition to the Annexes of Stockholm Convention in 2009. Now c-decaBDE is being considered for listing on the Stockholm Convention (48). To inform decision making on how best to manage BDE-209 in the Australian context, in particular with regards to listing on the Stockholm Convention, we reviewed the extent of use of BDE-209 in Australian consumer products. This review forms the first part in a larger study that will include quantitative testing of BDE-209 in goods. We aim to provide a best estimate of which goods are likely to contain BDE-209 in Australia and also identify areas of uncertainty. This will enable prioritisation of testing in the subsequent component of this study.

2. Methods:

To provide a best estimate of products likely to contain BDE-209 in Australia we undertook the following:

- A review of standards and codes pertaining to flammability in Australia, to identify products that may require treatment with flame retardants (we did not search for flammability standards pertaining to electronics and electrical appliances, as it has previously demonstrated that BDE-209 is likely to be found in these products (52))
- A review of grey-literature (industry, government and technical) reports regarding reported uses of BDE-209
- A review of scientific reports assessing products for their BDE-209 content, to identify any further items that may contain BDE-209, as well as to provide a best estimate for likely concentrations of BDE-209 in treated items

We initially sought to clarify some uses of BDE-209 by contacting major Australian manufacturers or organisations in the relevant areas of uncertainty. Attempts to obtain information through this approach proved extremely difficult and the information obtained (if available) was neither specific nor informative to the Australian context. We were therefore unable to pursue this aspect of the approach further.

Using the information obtained, we then provided an estimate of the likelihood of specific goods containing BDE-209 in Australia.

3. Results

Despite the dearth of primary scientific reports, we identified a variety of other sources of information regarding potential applications of BDE-209 in Australia. We identified several standards and one code, the Building Code of Australia (BCA), pertaining to flammability of items being manufactured, sold or used in construction within Australia (Figure 2), which we believe may be important drivers of the use of flame retardants in these materials.

Several informative grey literature reports were identified. The most comprehensive industry report of BDE-209 applications is provided by the Bromine Science and Environmental Forum (51). The reference text "Flame Retarded Materials", provided a technical description of BDE-209 applications (56). Several government and other institutional reports were identified that were informative regarding potential applications of BDE-209 (2, 4, 6, 7, 57-59). We failed to identify any scientific papers that discussed the use of BDE-209 in goods specific to the Australian market; although our group has previously conducted a study quantifying the presence of PBDEs in products imported into Australia in 2012 (52). We identified testing studies from elsewhere that assessed the concentration of BDE-209 in consumer goods and may be informative to the situation in Australia (see Table 2). In the following sections, we discuss pertinent findings for each of electronics and electrical appliances, textiles, construction materials, automotive/transport applications and toys.

3.1 Electronics and Electrical Equipment

A major use of BDE-209, including in Australia, is in high impact polystyrene (HIPS) for computer and TV housings and rear covers (7). As of the late 2000's, BDE-209 was the most commonly used flame retardant in HIPS (60). To reach US flammability standards for TV sets (a likely major driver of BDE-209 content in TVs also destined for the Australian market), at least 10% total weight BDE-209 is required in HIPS (60). Flammability standards pertaining to specific states, territories or countries affect the flame retardant content of goods outside that jurisdiction, because of globalisation of markets (61). The reported use of BDE-209 in TV sets is confirmed in testing studies (see Table 2), which consistently find the highest BDE-209 concentrations in the rear covers of TVs. In composite samples from waste TVs in Europe, the maximum permitted concentrations (MPC) of BDE-209 specified in the European Union's (EU's) Restriction of Hazardous Substances (RoHS) Directive (0.1% total weight) are regularly exceeded (58). The inclusion of substantial concentrations of BDE-209 into TV rear covers is not exclusive to older, cathode ray TVs. In Australia, testing of nine new LCD and LED TVs found five contained BDE-209 concentrations in the rear cover between 4.9% - 9.1% total weight (all five televisions were manufactured in China) (52).

The concentration of BDE-209 in HIPS in the housing of computers and TVs, excluding rear covers, is consistently lower than that found in rear TV covers. Average concentrations are almost always less than <1% total weight of the polymer, but frequently greater than 0.1% (see Table 2). The highest concentration for a computer housing composite sample was reported at 0.48% by Morf et al., in Switzerland in 2003 (62). In Australia, one computer housing unit that was tested contained BDE-209 at 0.14% (52).

BDE-209 may also be incorporated into most other commercial polymers, including ABS, polypropylene (PP), polyethylene (PE), polybutylene terephthalate (PBT), polyamides/nylon (PA), polycarbonates, polyvinyl chloride (PVC) or polyphenyl ether (PPE), for applications where heat is a concern; including light fittings, electrical plugs and connectors, and other components within electrical goods (2, 49, 60). Electronic and electrical items in Australia that have previously been found to contain BDE-209 include plugs of electrical appliances and power boards (~1% total product weight), an A4 laminator (0.52%), a tower fan (0.08%), deep fryer (0.08%), and a microwave (0.01%) (52). Results from swipe testing in Australia also indicated that BDE-209 can be found in various small household appliances, including bread makers, ice cream makers, milk frothers, hair dryers, high pressure cleaners, slow cookers, toasters, vacuum cleaners, hair straighteners, and various audio visual systems. This finding is supported by the international literature (see Table 2). In particular,

the broad survey of waste electronics and electrical appliances (WEEE) in Europe by Wager et al. (2012) reported that BDE-209 concentrations in waste from small household items with high-temperature applications approached 0.1% (58).

BDE-209 is also incorporated into ABS, which is the major source of the flame retardant in larger household appliances, including cooling devices such as refrigerators, dishwashers, and washing machines (58). However, in the previous testing by our group, BDE-209 was infrequently detected in these items and at concentrations generally lower than in other electronic items (52). It is not known if older models of refrigerators in Australia contain BDE-209, as the focus of the earlier study was on newly imported products (52). Internationally, concentrations of close to 0.1% BDE-209 have been reported from WEEE composite samples from large household appliances without cooling, while composite samples from cooling devices are around 0.01-0.03% (58).

BDE-209 has also been reported by the Bromine Science Environmental Forum to have been used in electrical wires/cables and connectors/plugs (51). Data on the content of BDE-209 in plugs and particularly wires/cables in Australia are limited. In the earlier research our group undertook, BDE-209 was found in plugs of small electrical appliances, but wiring and cables were not examined using quantitative assessment (52). Only very low or non-detectable levels of bromine were found in cabling products using xray fluorescence analysis (52). Elsewhere, the concentration of BDE-209 has been reported to be low (0.017%) in telecommunications cabling waste samples (62).

3.2 Soft Furnishings

The main application of BDE-209 for textiles is for the transport industry, including in motor vehicles, planes, and trains, with additional textile applications including upholstered furniture and curtains/drapes (63). The use of flame retardant treated textiles are likely to be more common in public locations (hospitals, schools etc.) or regions where flammability standards are stricter. Figure 2 summarises the main standards that apply to textiles and soft materials in Australia.

The main application of BDE-209 to textiles is in the form of a back-coating. A brominated flame retardant with antimony III oxide was first patented for back-coating application to textiles in 1982 (64). Since then, BDE-209 and hexabromocyclododecane (HBCDD), in combination with antimony III oxide, have been the two most commonly used brominated flame retardants for back-coating of textiles. Textiles commonly back-coated with these chemicals include cottons, cotton-polyester blends, acrylics, nylon, polypropylene and polyester (63, 65). These flame retardants are applied to the textile with a resin binder, for example an acrylic copolymer or ethylene-vinyl acetate copolymer (66). Although the actual application amount may vary depending on the weight of the textile, a typical application amount is approximately 50 grams of BDE-209 per square metre of textile, or 10-25% of the total weight of the textile (60, 66). The use of BDE-209 back-coatings on textiles is dependent on the inherent flammability of the textile, and the standards/codes affecting its end use.

The BCA excludes curtains from mandatory flammability testing; however this exclusion is subject to some uncertainty with regards to interpretation. Although the BCA sets minimum codes for construction in Australia, it is not uncommon for additional performance criteria to be specified by individual entities such as hospitals, institutions or commercial buildings. Therefore, major manufacturers of curtains in Australia may subject their textiles to flammability testing methods described in AS 1530 parts 2 and 3. However, besides hospitals and institutions, there are actually no standards pertaining to the flammability of curtains in Australia. The majority of curtains available for non-domestic purposes in Australia are manufactured from inherently flame retarded polyester (i.e. Trevira CS®), which means that the use of BDE-209 on these materials would be unlikely. In hospitals, disposable polypropylene curtains are commonly used, and these may be treated with organophosphorus flame retardants. Curtains that are not inherently flame retardant may be treated with BDE-209 back-coatings or with hexabromocyclodecane (HBCDD) (67), another bromine containing flame retardant that is listed in the Stockholm Convention.

Upholstery fabrics represent another major use of BDE-209 back-coatings in the textile industry, particularly for transport applications. The use of back-coating of upholstery textiles is relatively common, particularly if the fabric is not otherwise inherently flame retardant or is otherwise unable to meet flammability standards (63).

Application of BDE-209 to tents and tarpaulins has also been reported by industry (51), and a recent study in North Carolina found BDE-209 in the majority of tents tested (68). No data are available on tents in Australia.

Although flammability standards apply to protective clothing in Australia, the use of BDE-209 back-coating is not appropriate for protective clothing applications. Protective clothing items are generally manufactured from inherently flame resistant textiles, including polyaramides and polybenzimidazole.

3.3 Building and Construction

Despite the wide variety of building materials that are reported to be treated with BDE-209, data are limited regarding actual concentrations of flame retardants in these materials, particularly in Australia (51). A wide variety of building materials are subject to the BCA. The major application of BDE-209 (by sheer volume) in building materials is likely to be to extruded polystyrene insulation, although HBCDD is also used for this purpose (69). Low levels of BDE-209 have been detected in polyurethane foam insulation (0.002% by weight), however extruded polystyrene insulation was not specifically tested (52). Other applications of BDE-209 include hot melt adhesives (these are used in lamination processes, including laminated wood), air-handling ductwork, and lift cars, although more research is needed to assess the proportion of these products containing BDE-209 in Australia (69).

Most carpets available in Australia are either wool, nylon, polyester or polypropylene. Of these carpet types, for technical reasons, nylon is probably the most likely to be back-coated with BDE-209 (55). Wool is commonly treated with ammonium based or other flame retardants, while polyester and polypropylene may be manufactured with organophosphate flame retardants (63). It is likely that some carpets that are back-coated with BDE-209 are being used in Australia for flooring in buildings. However, carpets used for both domestic and commercial uses in Australia have previously been tested, using both XRF and swipe testing, and the use of brominated flame retardants does not appear to be widespread (52).

3.4 Automotive/Transportation

Carpets and other interior upholstery from cars, but not other forms of transport, have been tested using both XRF and destructive testing in Australia (52). Only 2 of 47 automotive carpets tested through XRF were positive for bromine (maximum concentration 2.7%), 8 of 12 car seats tested were positive for bromine (maximum concentration 2.7%), while only one sample (back-seat lining) was found to contain BDE-209, and at a concentration of less than 0.0001%.

Much higher concentrations of BDE-209 are likely to be found in planes, commercial vehicles and public transport vehicles, for which the flammability standards are very stringent (70). Almost all items within planes are subject to flammability standards, including floor and floor coverings, panelling, light covers, storage bins, passenger seats, stowage bins, insulation, windows, hoses, and air ducting (70). Scientific studies have reported elevated dust and air concentrations of BDE-209 in planes and elevated BDE-209 body burden in aircraft maintenance workers (71).

3.5 Toys

We have included toys in this review because hard plastic toys may be a significant source of exposure to BDE-209, particularly to young children who may suck on these items. In the study by Chen et al. (2009), hard plastic toys were found to contain BDE-209 up to concentrations of 0.4% total weight (72). Although BDE-209 was also detected in other toy types, the highest concentrations were two orders of magnitude lower. In Australia, of two plastic toys that were tested (a remote control train and slot car race track), BDE-209 was not detected in either, however TBBPA was found to contribute 14.4% of the total weight of plastic used in the slot car race track (52). Testing using XRF of 109 toys

in the same study, found that bromine was detected in typically very low levels (<0.1% bromine by weight)(52).

4.0 Discussion: Estimate of Goods Likely to Contain BDE-209 in Australia

Given the scarcity of data specific to Australia, our analysis is based on a subjective assessment of the multiple sources of evidence presented throughout this review. We assessed industry reported uses, technical resources, building codes, flammability standards and the scientific literature. Below, we provide our synthesis of these findings: a best estimate of goods likely to contain BDE-209 in Australia. These findings identify products that require further testing, to confirm the likelihood of BDE-209 being found in these products at what concentrations.

Items that were estimated to have the highest likelihood of containing BDE-209 were electronics and electrical appliances and items used in transport modes including planes and public transport. Electronic goods that were most likely to contain very high concentrations of BDE-209 (>10% total weight) included TVs and power boards. Although the concentration of BDE-209 varies between individual TVs, there were no specific trends, in terms of age or specific type of TV, that were associated with higher or lower concentrations of BDE-209. The implications of this for waste management are profound.

In Europe the concentration of BDE-209 in mixed plastics derived from TV housing regularly exceeds 0.1%, the RoHS directive for the limit of concentration of BDE-209 in new products (58). If similar concentrations occur in Australia, then composite plastics from TV housing may be unsuitable for recycling, unless processes are established to ensure that the final composite mixture contains an acceptable limit of BDE-209. Similarly, plastics derived from small household appliances are also likely to contain BDE-209, although the concentrations are generally lower than those found in TVs. Concentrations are greatest for components associated with heat production, indicating that it may be possible to recycle some plastics from small household appliances, if BDE-209 containing components could be identified and removed. In general, composite plastics from large devices, excluding refrigerators, are also likely to contain BDE-209 at levels close to the RoHS, potentially rendering them unsuitable for recycling. Newer refrigerators are unlikely to contain levels of BDE-209 in exceedance of the RoHS, but data were not available for older refrigerators.

One of the main provisions of the Stockholm convention, in addition to eliminating or restricting the production of POPs, is to ensure that "stockpiles and wastes consisting of, containing or contaminated with POPS are managed safely and in an environmentally sound manner (Article 6)" (73). Recycling of materials containing BDE-209 could prolong the lifespan of BDE-209 in the environment, unless technologies to effectively remove BDE-209 from composite polymer materials are employed. The alternative to recycling is secure land-fill or incineration, both of which have substantial costs.

Previous waste management practices, particularly disposal of electronic waste into older municipal landfills, has led to leaching of PBDEs, including BDE-209, into the Australian environment (74). This poses a complex management issue. The extent of this issue is difficult to characterise without a more accurate understanding of the distribution of BDE-209 in older electronic and other items in Australia.

Although much consumer concern has focused on the presence of PBDEs in soft furnishings and textiles, including couches, carpets, curtains and clothing (particularly for children), the findings of our review indicate that it is unlikely that BDE-209 is widespread in these applications in Australia, particularly in the domestic environment. However, further research is required to

quantify the distribution of BDE-209 in these applications in the non-domestic setting in Australia, including in offices and institutions.

The use of BDE-209 in textiles intended for the transport industry has been documented overseas and in Australia. While the application of BDE-209 in carpets in private vehicles in Australia appears to be relatively uncommon, its application to textiles covering transport seats may be more common. However, no data were available regarding the use of BDE-209 in public or commercial transport vehicles and planes in Australia. It is likely that the use of BDE-209 in these applications is widespread, given the strict flammability standards and findings from studies elsewhere (71). Testing of transport vehicles for BDE-209 should be a priority for future research.

One of the greatest areas of uncertainty that may have important implications for waste management and human exposure, given the bulky nature of these items and their long life-span in the built environment, is the use of BDE-209 in building materials. The use of BDE-209 in insulation materials, including polystyrene insulation and other building materials (ducting, piping, hot melt adhesives), is likely, but data specific to Australia were not available. As such, quantitative testing of building materials for BDE-209 presence is a priority for future studies.

This work highlights the fundamental difficulties in analysing where and in what quantities BDE-209, has been used in Australia. The lack of information in Australia highlights the difficulty of monitoring toxic substances in consumer goods and in the environment. In particular, no specific information on the use of BDE-209, particularly in building materials, could be obtained from manufacturers or distributors and material safety data sheets were not commonly available online.

5. Conclusion

The estimates provided in this review provide an initial platform for identifying future research priorities with regards to BDE-209 in the Australian environment. These should include testing of a greater range of goods in Australia for their BDE-209 content. The main priority areas we identified were: building materials and transport vehicles, including public transport and planes, textiles in non-domestic settings, including commercial settings and offices. Although our research group has previously identified BDE-209 in new electronics and electrical appliances, more extensive testing is required to determine the distribution of BDE-209 in older items. This review also provides a starting point for the design and implementation of a national response to a future listing of c-decaBDE on the Stockholm Convention.

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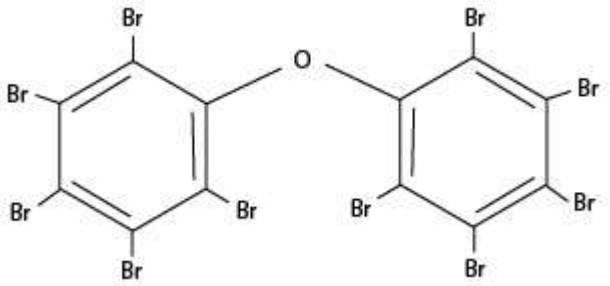

Figure 1 Chemical Structure of BDE-209

Australian Flammability Codes, Standards and Legislation

- Section C of the Building Code Australia (BCA) sets performance criteria for the fire resistance requirements of buildings types 2-9 (i.e. generally buildings other than single-dwelling homes). Under specification C1.10 of the BCA the following components of buildings must meet minimum fire hazard standards: floor linings and floor coverings, wall linings and ceiling linings, air-handling ductwork, lift cars, sarking (reflective foil), attachments to floors, ceilings, internal walls and the internal linings of external walls (curtains, drapes and blinds are generally exempt from this specification), and other insulation materials other than sarking materials.

- Fire standards related to consumer goods include: children's nightclothes AS/NZS 1249:2014, protective clothing AS/NZS ISO 2801:2008 , floor coverings AS/NZS 2111.18:1997 (R2013), curtains – health care facilities and institutions AS 3789.9-1998 , upholstery materials AS/NZS 4088.1:1996 (R2013), tarpaulin fabric AS 2930-1987, child-restraint systems used in motor vehicles AS/NZS 1754:2013

- Australian standards also cover a wide range of additional items, such as plastics and electrical equipment, as summarised in the Handbook of Australian Flammability Standards.

- Legislation in other regions that certainly affects products in Australia include stringent flammability standards for commercial aircrafts that fly in European or US air space, as well as automotive standards for vehicles produced for the European and US market, which may also enter the Australian market, as well as other imported goods that are manufactured to meet flammability standards in other markets.

Figure 2 Flammability Codes, Standards and Legislation in Australia (53-55)

Table 1 Industry Reported Uses of BDE-209 by Product Type (1, 49-51)

Electronic and Electrical Equipment	Soft Furnishings	Construction materials	Automotive / Transportation
Housing of TVs and computers	Upholstery backing in some domestic settings (dependent on flammability standards)	Pipes	Fabric coatings (i.e. textiles in cars, planes, public transportation)
Mobile phones	Upholstery backing in public places (theatres, schools, hotels etc.)	Pillars for telephone and communications cables	Electrical wiring and cables
Fax machines, Scanners, Printers and Photocopiers	Carpets and curtains/drapes in domestic settings (dependent on flammability standards)	Air ducts	Interior components (predominantly housing of electrical components)
Audio and video equipment	Carpets and curtains/drapes in public places	Switches and connectors	Housing of entertainment units, audiovisual equipment
Remote controls	Camping equipment	Reinforced plastics	
Wire and cables	Military applications (clothing, equipment etc.)	Insulation	
Capacitor films		Solar panels	
Printed circuit boards			
Connectors in electrical and electronic equipment			
Circuit breakers			
Transformers			
Small household appliances (i.e. hair dryers, vacuum cleaners)			
Large household appliances (i.e. washing machines)			

Table 2 Studies Assessing BDE-209 content of consumer goods through destructive testing

Toys

Reference	Country of product origin	Source	Product details (if applicable)	Study location	Study year	Year of manufacture	Total number of samples	Proportion Positive	Concentration Range	Average Concentration
Chen, Ma (72)	China	New Items	Hard plastic	China	2009	Not Specified (NS)	30	93.3	0 - 0.42%	0.02%
			Soft plastic				15	26.7	0 - 0.003%	0.0003%
			Foam				18	100	0 - 0.006%	0.0003%
			Stuffed				6	100	0 - 0.0001%	0.00003%
van Bergen and Stone (57)	NS	New items	Baby activity gym, tablets, stuffed toys	Washington State, US	2012-2013	NS	11	0	NA	NA

Car interiors and accessories

Reference	Country of product origin	Source	Product details (if applicable)	Study location	Study year	Year of manufacture	Total number of samples	Proportion Positive	Concentration Range	Average Concentration
Bentley (52)	NS	NS		Australia	2012	NS	11	27	<0.001	<0.0001
Keet, Giera (59)	NS	NS		New Zealand	2010	NS	4	50	<0.001	<0.001
Chen, Ma (75)	NS	NS		China	2009	NS	5	60%	0 - 0.003%	0 - 0.0007%
van Bergen and Stone (57)	NS	NS		Washington State, US	2012-2013	NS	4	0	NA	NA

Computers

Reference	Country of product origin	Source	Product details (if applicable)	Study location	Study year	Year of manufacture	Total number of samples	Proportion Positive	Concentration Range	Average Concentration
Bentley (52)	Malaysia	New items	General computer housing	Australia	2012	Various	1	100		0.13%
Abbasi, Buser (5)	NS	NA	General computer housing	USA and Canada	NA	NS	NA	NA	Not specified	0.01%
Aldrian, Ledersteger (76)	NS	E-waste facility	General computer housing	Austria	2014	NS	6	100	0.07-0.63%	0.28%
Chen, Ma (75)	NS	Homes	General computer housing	China	2009	NS	<32	25	0 - 0.0006%	0.0002%
Keet, Giera (59)	NS	New items	Computer components/circuit board	New Zealand	2010	NS	1	100	NA	0.00001%
Kumari, Sharma (77)	NS	NS	Computer components/circuit board	India	2013	NS	1	100	NA	1.15%
Morf, Tremp (62)	NS	E-waste facility	General computer housing	Switzerland	2003	NA	NA	NA	NA (composite samples)	0.48%
	NS	E-waste facility	Computer components/circuit board		2003	NA	NA	NA	NA (composite samples)	0.003%
Kajiwara, Noma (78)	NS	New items	Computer components/circuit board	NS	2008	2011	6* different components of one laptop	100	0.000- 0.004	0.0007

van Bergen and Stone (57)	NS	New items		Washington State, US	2012-2013	2009+	1	0	NA	0%
Kajiwara, Noma (78)	NS	New items		Japan	2011	~2008	2	100	0.0000-0.0014	0.0007

TV housing (not rear)

Reference	Country of product origin	Source	Product details (if applicable)	Study location	Study year	Year of manufacture	Total number of samples	Proportion Positive	Concentration Range	Average Concentration
Abbasi, Buser (5)	NS	NA		USA and Canada	NA	NS	NA	NA	0.7-4%	4%
Aldrian, Ledersteger (76)	NS	E-waste facility		Austria	2014	NS	6	100	0.06-0.75%	0.41%
Chen, Ma (75)	NS	Homes		China	2009	NS	<32	83.3	0-4.56%	0.79%
Morf, Tremp (62)	NS	E-waste facility		Switzerland	2004	NA	NA	NA	NA (composite samples)	0.48%
Park, Kang (79)	NS	E-waste facility		Korea	2014	1987-1989	2	100	0.05-0.221	0.13%
	NS	E-waste facility		Korea	2014	1990-1993	1	100		0.02%
	NS	E-waste facility		Korea	2014	1995-1998	1	100		0.03%
	NS	E-waste facility		Korea	2014	2000-2005	1	100		0.03%
Sindiku, Babayemi (80)	Asia (58), Europe (100)	E-waste facility and other waste sources		Nigeria	2011	1981-2004	160	38.125	0.086 – 23.7%	0.86%
Kajiwara, Noma (78)	NS	New items		Japan	2011	~2008	2	100	0.0000-0.0013	0.0007

Soft items

Reference	Country of product origin	Source	Product details (if applicable)	Study location	Study year	Year of manufacture	Total number of samples	Proportion Positive	Concentration Range	Average Concentration
Bentley (52)	Various	New items	Packing foam, automotive foam and textiles, baby car seats, furniture foam, children's clothing	Australia	2012	Various	19	73	26.0273973	0.01%
Chen, Ma (75)	NS	Homes	Furniture, mattresses, pillows	China	2009	NS	0	5	NA	0.0000%
DiGangi and Strakova (81)	US, Canada, Asia, Europe	Canada, Hungary, Nepal, Kyrgyzstan, Thailand, and USA	Recycled carpet padding	NA	2011	NS	23	26	88.4615385	0.0028%
van Bergen and Stone (57)	NS	New items	Children's clothes and toys, furniture foam, carpet padding, mattresses, pillow, baby care	Washington State, US	2012-2013	NS	2	80	2.5	<0.001%

			items (change-pads etc.), baby car seats							
Shin and Baek (82)	NS	New items	Curtains	Korea	2012	2012	3	100	0.0001-0.0002	0.0002
Kajiwara, Sueoka (67)	Japan	New Items	Curtain material	Japan	2008	2007	6	17		2ª%
Keller, Raju (68)	Bangladesh, China, Indonesia, Korea, Taiwan	Used items	Tents	US	2014	NA	11	4	0 – 1.78%	0.4%