Flame retardants and breast cancer

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Peer reviewed by two members of Breast Cancer UK's independent Science Panel

1. Summary

Flame retardants are widely used chemicals added to consumer products to reduce fire risk, but many are persistent organic pollutants that accumulate in our environments. Growing evidence suggests that some of these substances can disrupt the functions of the hormone (endocrine) system in the body, potentially linking them to a range of adverse health effects, including breast cancer. Many halogenated flame retardants that were commonly used are now being restricted, but there are emerging concerns around the suitability of their replacements, organophosphorus flame retardants (OPFRs). Overall, whilst further research is warranted, stronger policy action is needed to protect individuals and communities from unnecessary exposure to flame retardants of concern.

2. Introduction

Breast cancer is the most common cancer in the UK, with around 59,000 cases in women and 400 cases in men diagnosed each year [1]. Breast Cancer UK estimates that at least one in four cases are preventable and can be attributed to modifiable risk factors, including lifestyle and environmental factors [2,3].

Flame retardants are chemicals added to materials to prevent or delay the spread of fire. They act through a combination of chemical mechanisms (e.g., interrupting combustion) and physical mechanisms (e.g., heat absorption and formation of a protective layer) and are commonly found in furniture, electronics, textiles, and building materials [4].

They are integrated into these products either by being chemically bound (reactive) or physically mixed in (additive). Since additive flame retardants are not chemically bonded, they are more likely to become released than reactive flame retardants, leaching into dust, air, food, and water, increasing the likelihood of human exposure [5,6]. There is evidence that additive flame retardants are linked to a range of adverse health effects, including breast cancer [7–10].

Although several harmful flame retardants have been phased out in most settings, two key challenges remain. First, many of the compounds used historically, often called 'legacy flame retardants', are difficult to break down, meaning they can persist in the environment for long periods of time, resulting in ongoing unintentional exposure [11]. Second, when a specific flame retardant is restricted,

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replacement chemicals are often introduced that have not undergone comprehensive safety evaluations. This leads to 'regrettable substitution', where newer compounds may pose similar or greater risks [8,12].

This review summarises the current evidence on flame retardants and breast cancer risk, including exposure routes, regulation, and other health effects.

3. Types of flame retardants and their uses

Flame retardants are broadly classified into inorganic and organic compounds based on their chemical make-up (Figure 1). Inorganic compounds were developed first and are generally less toxic, while organic flame retardants are typically more efficient but have been associated with detrimental health effects [13].

3.1 Inorganic flame retardants

Inorganic flame retardants, such as aluminium and magnesium hydroxides, work primarily by releasing water during combustion. This cools the material, reduces oxygen availability, and forms a protective barrier that insulates against further heat and gas transfer [4].

These compounds are less effective than organic alternatives and must be used at high concentrations – up to 60% of total material weight [15]. This can affect the physical properties of materials, restricting their use to specific applications such as wires, cables,

Glossary box:

Adipose tissue: body fat tissues that store energy, insulate the body, and release some hormones

Anti-oestrogenic: see oestrogenic

Apoptosis: controlled and deliberate cell death that allows the body to remove damaged or unwanted cells without causing inflammation

Bioaccumulation: the gradual buildup of chemicals within an organism or the body over time

Brominated: chemicals that have been treated or reacted with bromine

Carcinogenic: having the capacity to cause cancer

Chlorinated: chemicals that have been treated or reacted with chlorine

Halogenated: chemicals that have been treated or reacted with halogens, including bromine or chlorine

Menarche: the first menstrual period

Oestrogenic: the ability of a substance to mimic or produce the effects of the hormone oestrogen

Thermoplastics: plastic materials that are soft at high temperatures but become harder when cooled

Transformation: a stable change in a cell's characteristics, often following genetic alteration. In cancer biology, often refers to the acquisition of characteristics associated with cancer

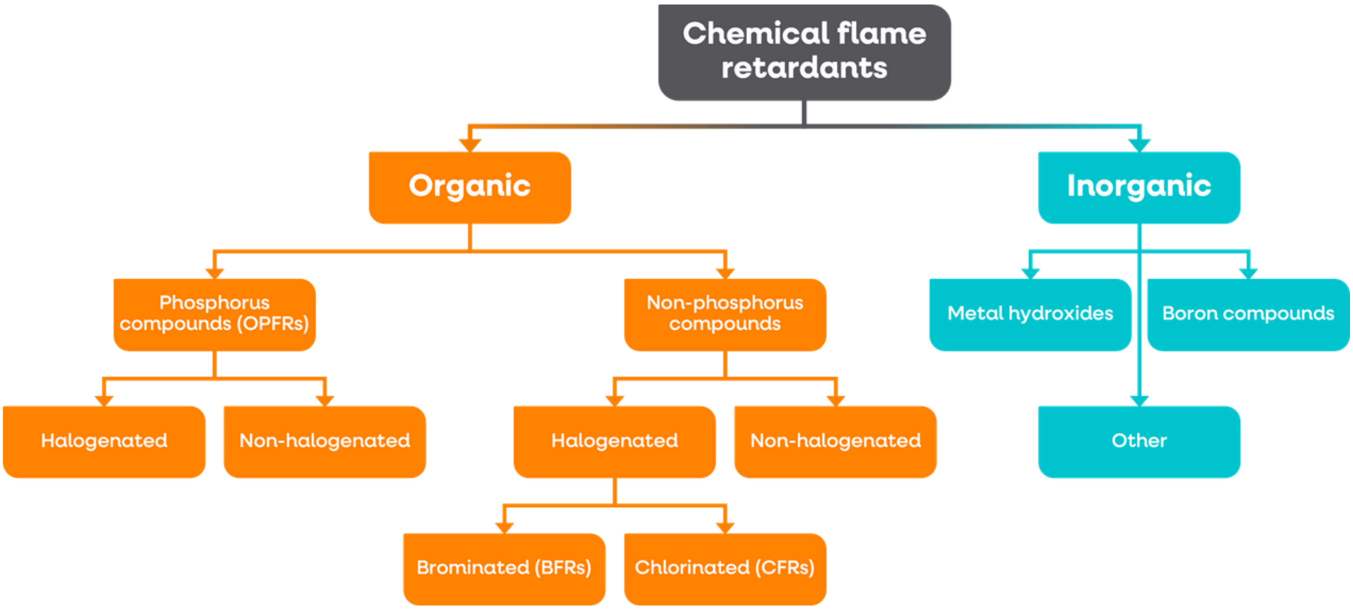

Figure 1. Simplified classification of chemical flame retardants. Adapted from a report published by the UK Environment Agency [14]. Abbreviations: BFRs: brominated flame retardants, CFRs: chlorinated flame retardants, OPFRs: organophosphorus flame retardants.

thermoplastics, and rubber products [13,16]. As they are generally regarded as safe for use, they will not be discussed further in this review [17].

3.2 Organic flame retardants

Organic flame retardants are carbon-based compounds that are often added to reduce flammability, increasing their potential to migrate into the environment [5,18]. They are commonly grouped by chemical composition based on the presence of specific chemical groups such as halogens (bromine or chlorine) or phosphorus (Figure 2, Table 1).

3.2.1 Brominated flame retardants (BFRs)

BFRs have been widely used in electronics, insulation, and textiles over many decades [19]. Tetrabromobisphenol A (TBBPA) is one of the most common examples and is used both reactively (in circuit boards) and additively (in plastics) [20,21]. However, there are growing concerns that it may have carcinogenic and endocrine-disrupting effects [14,22]. Most other BFRs have already been heavily restricted or phased out:

- Polybrominated biphenyls (PBBs) were removed from markets in the 1970s due to an accidental livestock poisoning incident that caused health problems in local families [23]. Today, they are classified as probably carcinogenic and have been largely banned globally [24].

- Hexabromocyclododecane (HBCD) was banned in the EU in 2015 and restricted in the US in 2022 [25,26].

- Polybrominated diphenyl ethers (PBDEs) come in several forms, some of which were banned in the EU and phased out in the US in the early 2000s [20]. Since 2019, no PBDEs

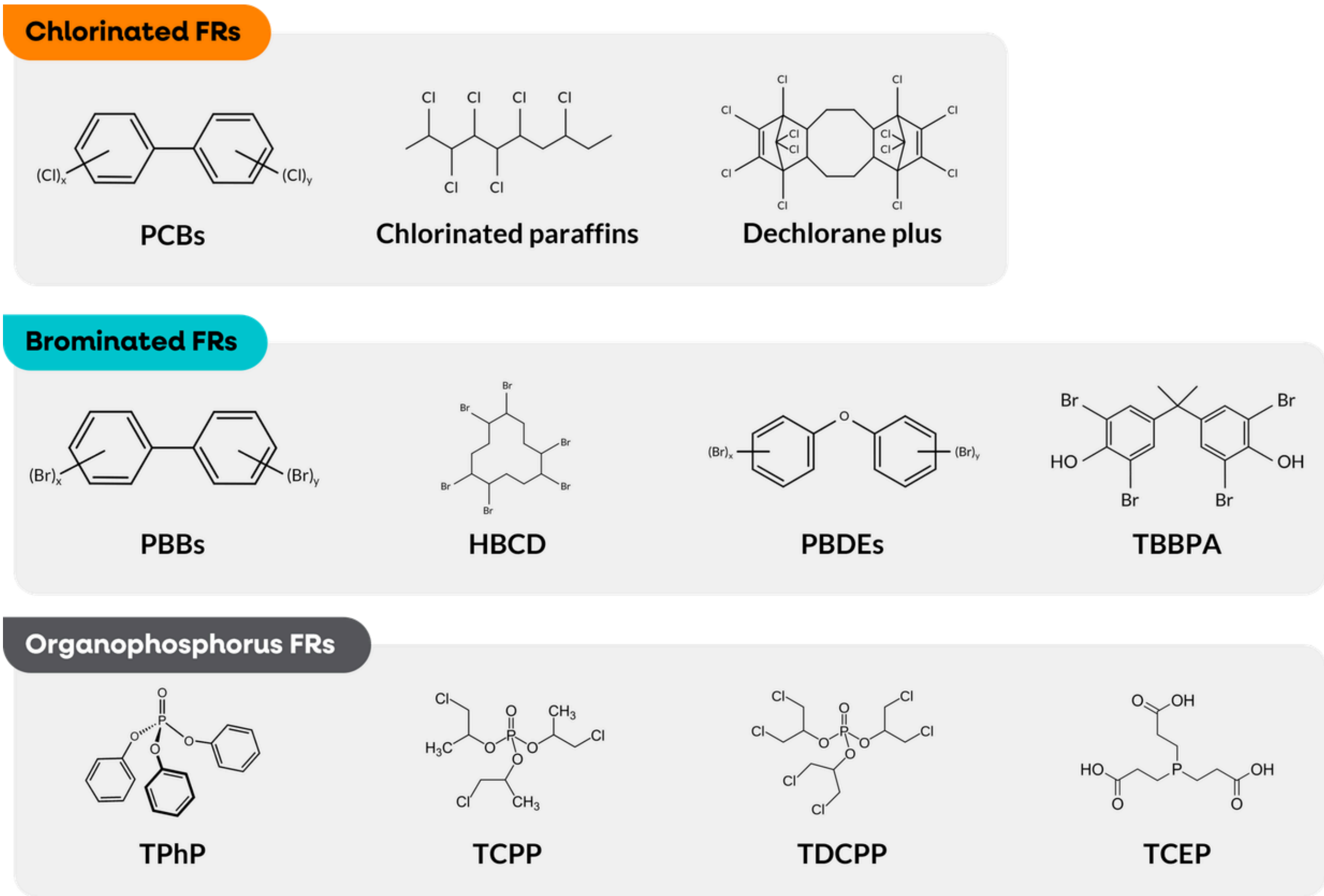

Figure 2. Chemical structures of organic flame retardants that are discussed in this review. Created with MolDraw.com. Abbreviation: FR: flame retardant.

have been allowed to be placed on the EU market [27]. While similar restrictions also apply in the UK, exceptions still exist for certain products, such as electrical equipment [28].

3.2.2 Chlorinated flame retardants (CFRs)

By convention, organic flame retardants that contain both chlorine and phosphorus are often categorised as organophosphorus compounds (see section 3.2.3). Purely chlorinated compounds were previously found in plastics and cables, but few are still in use today due to health and environmental concerns:

- Polychlorinated biphenyls (PCBs) are classified as carcinogenic and have been banned globally [24].
- Dechlorane plus and chlorinated paraffins are persistent organic pollutants (POPs) and have been subject to international restrictions due to concerns about environmental toxicity and endocrine disruption [29,30].

3.2.3 Organophosphorus flame retardants (OPFRs)

OPFRs were introduced as replacements for brominated and chlorinated compounds and are now commonly found in furniture, insulation, and childcare products [8,19,31].

Common examples include TPhP (triphenyl phosphate), TCPP (tris(chloropropyl) phosphate), TCEP (tris(2-carboxyethyl) phosphate), and TDCPP (tris(1,3-dichloroisopropyl) phosphate).

Although initially considered safer alternatives, evidence from the last decade indicates that OPFRs may also exhibit endocrine-disrupting properties and other toxic effects, raising concerns about their long-term safety [8].

4. Flame retardant levels worldwide

Flame retardant levels are normally monitored in the environment (measured in indoor air and dust) or in people (measured in bodily fluids). The results of these studies cannot always be directly compared, as some flame retardants are broken down when they enter the body, requiring the measurements of their metabolites

Table 1. List of organic flame retardants referred to in this review [24,27–30,32–45]. This list is not exhaustive. Abbreviations: OPFR: organophosphorus flame retardant. *Note that some PBDEs are banned (i.e., there are no exemptions for use/production).

	Class or compound	Chemical name	Uses	Restrictions (UK/EU)
Chlorinated flame retardants	PCBs	Polychlorinated biphenyls	Building materials, electrical equipment, plastics	Banned in the UK and EU
	Chlorinated paraffins (SCCPs, MCCPs, LCCPs)	Short-, medium- or long-chain chlorinated paraffins	Rubbers, plastics, paints	SCCPs restricted in the UK; SCCPs and MCCPs restricted in the EU
	Dechlorane plus	-	Cables, furniture, plastics	Restricted in the EU
Brominated flame retardants	PBBs	Polybrominated biphenyls	Electronics, plastics, textiles	Restricted in the UK; banned in the EU
	HBCD	Hexabromocyclododecane	Thermoplastics, textiles, cables	Restricted in the UK; banned in the EU
	PBDEs (tetra-, penta-, hexa-, hepta-, octa-, decaBDE)	Polybrominated diphenyl ethers	Electrical equipment, textiles, plastics	Restricted in both the UK and the EU*
	TBBPA	Tetrabromobisphenol A	Circuit boards (reactive), polystyrene (additive)	Restricted in both the UK and the EU
OPFRs	TPhP	Triphenyl phosphate	Electronic equipment, resins, thermoplastics	Restricted in the EU (classed as EDC)
	TCPP	Tris(chloropropyl) phosphate	Furniture, textiles, polyurethane foam	Restricted in the EU
	TDCPP	Tris(1,3-dichloroisopropyl) phosphate		Restricted in the EU
	TCEP	Tris(2-carboxyethyl) phosphine		Restricted in both the UK and the EU

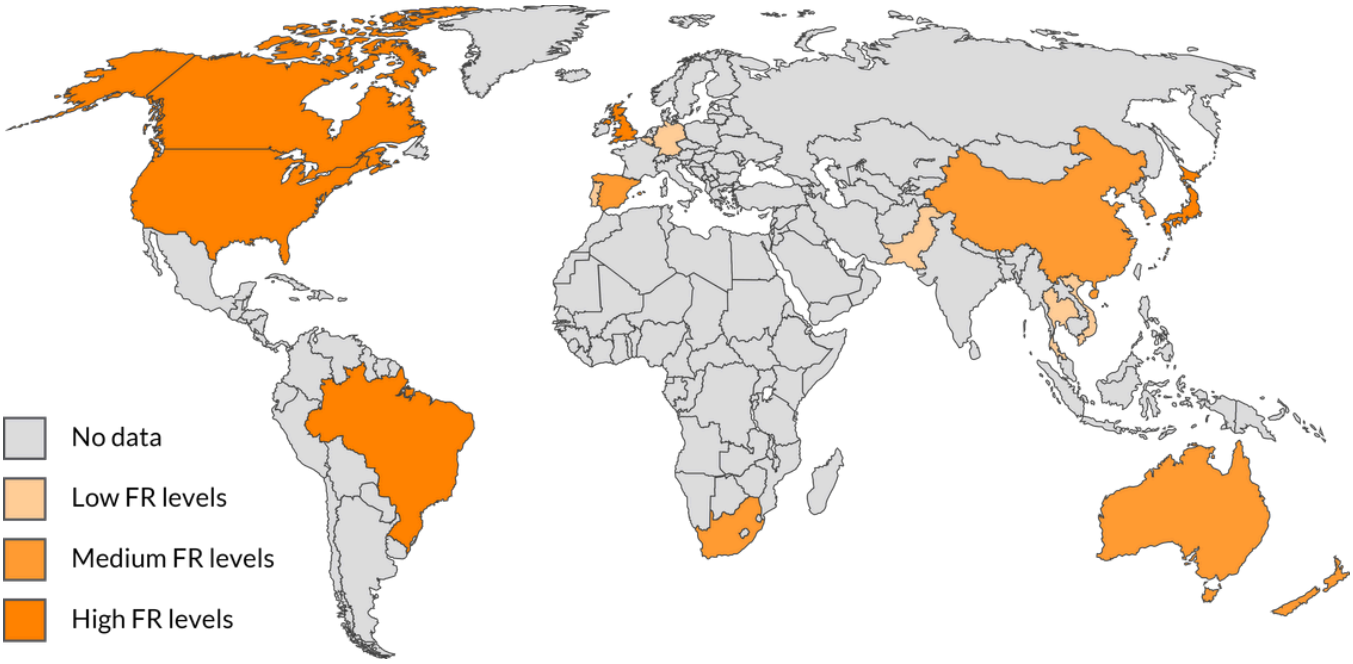

Figure 3. Indoor levels of flame retardants across the world. Using published data [46], OPFR or BFR levels in indoor dust for each country were expressed as a ratio to global OPFR or BFR levels and summed to a composite score. Scores were ranked and divided into thirds.
Abbreviations: FR: flame retardant.

(breakdown products) instead.

However, as a general trend across these different measurement types, exposure is greater in countries with a higher GDP (gross domestic product) per capita [6,46]. This may be because wealthier nations tend to have stricter fire safety regulations or that people in these countries buy more consumer goods treated with flame retardants, such as electronics and furniture [47].

4.1 Environmental measurements

A comparison of the results of several studies found that the highest levels of BFRs in indoor dust are found in North America, the UK, and Ireland, while Brazil, Japan, and the UK rank highest for OPFRs [46]. Figure 3 shows a combined score for indoor dust levels of both BFRs and OPFRs for each country where data is available [46].

Across countries, however, exposure can also vary with the type of indoor environment. Public environments (such as offices, buses, and trains) often show higher levels of flame retardants than residential settings [46,48], but one study suggests that the highest levels of certain flame retardants are found in cars [49]. This may be because automotive manufacturers design vehicles for markets with the strictest flammability standards, even when sold in other areas [49].

In addition to polluting human environments, flame retardants have also been found to contaminate natural environments and wildlife. These chemicals have been detected in more than 150 different wildlife species across all continents and may be contributing to population declines in some species [50].

4.2 Biological measurements

For biological measurements, BFRs are typically measured in serum while OPFR metabolites are measured in urine. The highest levels of both BFRs and OPFRs are found in North American and Australian populations. In European populations, BFR levels are declining, which is presumed to be because of the earlier introduction of regulations that restrict BFR usage [6,46].

Measurements also indicate that serum BFR levels and urinary OPFR levels are higher in children than in adults [5,46]. This difference may be because children exhibit hand-to-mouth activity and spend more time on the floor, increasing their exposure to chemically treated fabrics and rugs [5,46].

5. Exposure routes and mode of action

Additive flame retardants are continuously released from the products to which they are added, contaminating our environments. This release occurs throughout a product's life cycle and can continue when materials are recycled into new products [6,51].

Human exposure therefore occurs through several routes, primarily ingestion of contaminated dust, inhalation of indoor air, and dermal (skin) contact [46]. Some additional exposure may also occur through food and diet. Flame retardants have been detected in black plastic utensils (from where they can migrate into food during cooking) [52] and fatty food products (e.g., fish, meat, dairy) for consumption [9,20].

Occupational exposure is also significant in industries such as manufacturing, e-waste recycling, and firefighting [53]. Legacy flame retardants, though phased out of production, can still be present in older buildings and become airborne during fires, exposing firefighters to high levels of restricted compounds [54]. In one study, female firefighters were found to have levels of BDCPP (an OPFR metabolite) that were five times higher than office workers, with evidence of measurable disruption to endocrine function [55].

Once absorbed, many of these compounds can distribute throughout the body and accumulate in lipid-rich compartments [21]. Studies have detected flame retardants and their metabolites in blood, urine, adipose tissue, and breast milk [46,56,57]. The accumulation of flame retardants in adipose tissue is particularly relevant to breast cancer, as it makes up a large part of the breast and plays an important role in hormone metabolism. Persistent storage of these chemicals within the breast is likely to create an opportunity for prolonged exposure of breast cells to biologically active compounds.

A major concern is the ability of some flame retardants to act as Endocrine Disrupting Chemicals (EDCs) in the body. These compounds can interfere with the normal function of the endocrine system by, for example, mimicking natural hormones, altering hormone levels, and disrupting the expression of hormone receptors, interfering with hormone sensitivity [58,59]. High oestrogen levels are a breast cancer risk factor, so flame retardants that increase oestrogen may also increase breast cancer risk. Additionally, exposure to some flame retardants may be associated with neurotoxic effects, thyroid disruption, and other endocrine cancers [8,60,61].

6. Flame retardants and breast cancer

Most evidence linking flame retardants to breast cancer comes from in vitro and animal studies, with relatively limited data in humans. However, their persistence and ability to bioaccumulate raise concerns about long-term exposure and cancer risk [9].

6.1 In vitro studies

Laboratory studies show that several flame retardants can act as EDCs and exhibit oestrogenic activity, meaning they can mimic or interfere with oestrogen signalling.

- PBDEs can activate oestrogen receptors and stimulate proliferation in breast cancer cells [62,63]. They have also been shown to increase proliferation and inhibit apoptosis in both normal and cancerous breast cells [64,65].
- HBCD has been shown to have oestrogenic activity and can induce cellular transformation [60,66].
- TBBPA may inhibit oestrogen metabolism [60] or increase its production [67,68], potentially increasing circulating oestrogen levels.
- OPFRs can be active at the oestrogen receptor, with some displaying oestrogenic effects and others anti-oestrogenic effects [69]; TPhP specifically has been shown to increase oestrogen production [67,68].

These experiments provide potential mechanisms for how flame retardants could disrupt the endocrine system, but it is difficult to know how closely they reflect real-world conditions. Many studies use concentrations much higher than typical human exposure and rely on cell lines (cells grown continuously outside the body) that may not behave the same way as cells inside a living body. Metabolic activity may also modify some compounds, so the forms tested in vitro may not match the forms encountered in the body [62].

6.2 Animal studies

Animal studies, primarily in rodents, suggest that exposure to flame retardants during critical developmental windows can affect mammary gland development and influence cancer risk.

Some PCBs, or their breakdown products, have been identified as capable of causing mammary tumours in rodents [67]. Exposure to mixtures of PBDEs and HBCD during pregnancy has been shown to alter mammary gland signalling, with the lowest doses having the greatest effects [70]. Research indicates that such exposures can disrupt normal mammary gland development, which may increase the risk of mammary cancer later in life [71]. BFR exposure may also affect tumour biology by potentially changing the subtypes of tumours that develop [72]. In addition, the OPFR TDCPP has been associated with an increased rate of tumour progression in a mouse model of breast cancer [73].

These findings suggest that certain flame retardants can disrupt hormonal regulation and cellular processes in mammary tissues. However, as with in vitro experiments, the concentrations of flame retardants and duration of exposure used in animal studies may be an issue. While some studies used doses similar to what humans would be exposed to in household dust [70–72], more research is needed in this area to understand how these results relate to real-world human exposures.

6.3 Epidemiological studies

Human studies are limited and have mixed conclusions. Currently, no flame retardants are restricted because of a classification as a breast carcinogen. Instead, restrictions are based on evidence for other cancers, mainly skin cancer, or endocrine disruption in laboratory experiments.

PCBs and PBBs are both considered legacy flame retardants. Their classification by the International Agency for Research on Cancer as carcinogenic and probably carcinogenic, respectively, is primarily based on evidence from melanoma rather than breast cancer [24]. Some studies have reported an increase in breast cancer risk associated with specific PCBs [74,75], as well as higher mortality among exposed individuals [76]. Although there is limited data for PBBs, a small study in the US found that women exposed to PBB-contaminated food had an increased risk of breast cancer [77].

For BFRs, evidence is less consistent. A large study in California found no association between PBDE levels and breast cancer risk, although it did not account for exposure levels before diagnosis [78]. Smaller studies, on the other hand, have reported higher PBDE levels in breast adipose tissue among cancer cases [56,79] and potential epigenetic effects linked to increased risk [80]. A meta-analysis of 15 studies found a significant association between BFRs in adipose tissue and breast cancer [81]. There may also be indirect effects between flame retardant exposure and breast cancer risk, for example, by affecting other breast cancer risk factors. One study found that PBDE exposure was significantly linked with menarche before the age of 12 [82]. Early menarche is an established risk factor for breast cancer [83].

As OPFRs came into wider use as replacements for halogenated flame retardants, there is limited data on their health effects in humans and currently no studies on breast cancer risk. However, small studies have demonstrated a link between OPFR exposure and adverse effects on endocrine function, sperm quality, and fertility [5].

The timing of exposure can also be important and, as discussed in section

4.1, children may be exposed to higher levels of flame retardants than adults. Childhood is a critical developmental stage where exposure to some EDCs may impact the risk of breast cancer later in life. For more information, click here to read our Science Review on critical windows of susceptibility to EDC exposure.

7. Links to other health problems

Flame retardants have been associated with a wide range of negative health effects. BFRs have been linked to thyroid disruption, cardiovascular disease, neurological issues, reproductive effects, and cancers [7,9–11]. One mechanism by which BFRs may exert their effects is through structural similarity. PBDEs resemble thyroid hormones, and studies indicate that they can bind to thyroid transport proteins, potentially affecting hormone levels [84,85]. Activation of thyroid hormone signalling may also play a role in breast cancer development, possibly because these receptors are also expressed by breast cancer cells [86].

It is not clear whether PBDE exposure affects the risk of thyroid cancer, as research is inconsistent [81,87]. However, a cohort study from the US demonstrated that individuals with higher serum PBDE levels were at higher risk of death from cancer than the general population [88].

Although there is less data on OPFRs, research suggests that some are associated with reproductive effects, neurological issues, endocrine disruption, and respiratory health [8,89,90]. For health effects where data for both BFRs and OPFRs are available, their effects are comparable, suggesting that OPFRs are 'regrettable replacements' [8]. For both classes, prenatal exposure has been linked to cognitive impairment and developmental problems.

8. Regulations

Regulatory approaches to flame retardants vary globally, with most regulations focusing on banning or restricting BFRs, while OPFRs have only recently come under increased scrutiny (Table 1).

In the UK, chemical use is mainly regulated under the UK REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) framework. Many flame retardants are classed as POPs, restricting their use in the UK – including PBDEs, HBCD, short-chain chlorinated paraffins, and dechlorane plus [14].

However, the UK still has very high usage of flame retardants compared to other countries (Figure 3). This is mainly because chemical flame retardants are a cost-effective way to meet the strict fire safety standards set out in the UK Furniture and Furnishings (Fire) (Safety) Regulations 1988 [91]. Due to mounting concerns about health effects, these regulations have been under review to evaluate whether they are fit for purpose since at least 2014, with no revisions proposed to date [92]. In 2026, a government consultation was launched proposing reforms to reduce the reliance on chemical flame retardants [93].

Before Brexit, chemical regulation in the UK was subject to EU requirements. In the EU, flame retardants are regulated under a combination of EU REACH, POPs legislation, and the Restriction of Hazardous Substances (RoHS) directive [12]. PBDEs and HBCD are banned for use in new materials, and limits in recycled products were tightened in 2025 [27,94]. Several OPFRs have been restricted, including TCEP, TDCPP and TCPP, and further group-level assessments are underway, with a major evaluation expected in 2026 [31,95]. Currently, only one flame retardant, TPhP, is specifically restricted due to its status as an EDC [39].

Flame retardants restricted under the United Nations Environment Programme Stockholm Convention are intended to be regulated globally, but few countries outside the EU and the US have implemented bans [12]. Another problem with global restriction enforcement is that treated items are not normally required to list exactly which flame retardants they have been treated with. This makes it challenging to effectively identify and remove these sources of exposure [92].

9. Reducing exposure

9.1 Individual measures

There is little research on how best to reduce flame retardant exposure levels in individuals. However, the most effective measures are likely to involve reducing and limiting contact with major sources, especially indoor dust [96]. This is partly because legacy flame retardants can persist in dust for a long time – some estimates suggest that indoor levels only begin to decline almost two decades after a chemical is banned [6]. Regular vacuuming and good ventilation may help reduce exposure to indoor flame retardants [97,98]. The widespread use of chemical flame retardants in furniture and certain textiles makes exposure difficult to avoid; however, naturally fire-resistant materials like wool and biopolymers offer sustainable alternatives without the same health concerns [99,100].

9.2 Policy measures

There is increasing support for regulating flame retardants as chemical groups rather than individual substances to avoid 'regrettable substitution' [12]. This is similar to the comprehensive ban on per- and polyfluoroalkyl substances (PFAS) currently being considered by the EU [101]. Restricting groups of chemicals could also incentivise manufacturers to make products more fire-safe and sustainable by design [12]. In limited situations with very high fire safety requirements, using reactive rather than additive flame retardants could reduce exposure because of their inability to migrate into the environment.

Improving product lifecycle management is also important. Flame retardant-treated materials can be difficult to recycle, and their reuse in products such as childcare items may lead to unintentionally high levels of exposure [12]. Studies have found that many products made from recycled materials may still contain flame retardants above

EU regulatory limits [102]. Improved waste management and recycling practices are also needed, particularly in regions where intensive processing may expose communities and workers to high levels of chemical waste through environmental contamination [12,103].

The purpose of chemical flame retardants is to improve fire safety by reducing the number of deaths and injuries caused by fire. However, some evidence suggests that these chemicals may not be as effective at achieving this goal as once believed. The UK and New Zealand, for instance, experienced similar declines in fire deaths from the 1980s to the 2010s, even though New Zealand has no furniture flammability standards [99]. A comparable pattern is also seen in fire fatality data across Europe, despite countries having different levels of flammability requirements, suggesting that these regulations are not contributing significantly to fire safety [99]. In the US, California once had one of the strictest fire safety regulations in the country, yet its fire death and injury rates are only slightly below the national average, suggesting a similar lack of effectiveness [6].

10. Conclusion

Flame retardants are a highly diverse group of chemicals found in everyday products and our environments. Leaching of flame retardants from these products is common and can lead to unintentional human exposure via ingestion, inhalation, and dermal contact. Several organic flame retardants have been identified in human tissue and bodily fluids, including fat tissue and breast milk, with some demonstrating possible thyroid disruption, fertility issues, and endocrine-disrupting potential in humans. However, further research is needed to establish causal links to health issues, including breast cancer risk.

Although regulations in the EU and UK largely restrict the manufacturing of the previous generation of BFRs and CFRs, which are most strongly associated with adverse health effects, they can still be found in older consumer products and pose an ongoing exposure risk. In addition, research is starting to show that some of the OPFRs developed as their replacements may have similar harmful effects. Although there are measures that may reduce the exposure of individuals, regulatory bodies could offer better protection through stricter, class-wide restrictions and more support for alternative fire safety measures.

Many flame retardants are EDCs, and as new research continues to grow our understanding of the effects of EDC exposure, adopting the precautionary principle is an important strategy for reducing potential harm where credible risks have been identified. In line with this principle, Breast Cancer UK supports the ban on non-essential uses of EDCs.

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