Flame retardant scoping review

Chief Scientist's Group report

June 2025

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Professor Robert Bradburne
Chief Scientist

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Executive summary

Flame retardants (FRs) are extensively used around the world to prevent products from catching fire or to slow the growth of a fire once it has started. The Environment Agency (EA) published a report in 2003 to summarise existing information on FRs and prioritise them for further investigation of environmental concerns. Since then, all FR substances manufactured in, or imported to, the European Union (EU) by individual companies above 1 tonne/year have been registered under the EU Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) Regulation. This has produced an updated dataset, documenting chemical properties, hazards and use information.

Now that the UK has left the EU, there is an opportunity to reconsider chemical priorities. Some UK stakeholders have asked for a renewed focus on FRs, and this report has been produced in response. The project began in 2022 with the aim of updating the 2003 report with evidence that has become available since then, to establish priorities for further assessment and help Government develop a strategic approach for FR substances known to be on the market. The geographic focus is the Great Britain (GB) market, to align with the scope of UK REACH.

Substances on the GB market were identified through a review of academic and institutional information sources. Information on the tonnages and uses of each substance was collated via a desk-based search, including data in the EU REACH and UK REACH systems (including records of Downstream User Import Notifications (DUIN)). Important findings and assumptions on tonnages and use patterns were verified with industry stakeholders in a series of short interviews. Changes in the GB market and new developments, such as new substitution processes and replacement of banned substances, have been summarised.

73 FRs were registered under UK REACH as of August 2022. One additional substance identified in the European Chemicals Agency (ECHA)'s *Regulatory Strategy for Flame Retardants* was also highlighted as relevant to GB. Over 150 further FR substances have DUINs, suggesting that they are also on the GB market. These may be formally registered in due course (the first registration deadline is in October 2026), but there is currently no specific information on their uses within GB. As their relative importance is unknown, 51 of these DUIN substances were therefore selected based on EU supply volume for inclusion in the screening processes used in this project based on hazard data and available GB monitoring data.

FR substances are chemically diverse, and this report considers 22 brominated, 4 chlorinated, 34 organophosphorus, 4 halogenated organophosphorus, 49 inorganic, 9 nitrogen-based and 2 further uncategorised organic FRs.

Research was carried out to find up-to-date information on properties, hazard and use. Priority was given to evidence compiled and submitted for EU regulatory compliance and disseminated by ECHA and the European Commission. The research process sourced over 90% of the property data from the public EU REACH registration database. Where data gaps remained, other recognised published sources and property prediction software were used in a targeted way.

Conclusions and status of EU REACH evaluation processes were recorded, along with data relevant for Persistent, Bioaccumulative and Toxic (PBT), very Persistent and very Bioaccumulative (vPvB), Persistent, Mobile and Toxic (PMT), very Persistent and very Mobile (vPvM) and endocrine disruption (ED) concerns, human health hazards and current status of UK, EU and United Nations' risk management activity.

To provide an alternative approach to hazard-based prioritisation, generic exposure assessment was carried out where possible. This involved predicting exposure from service life and waste life cycle stages using a standard model (for UK REACH registered FRs only). Recent environmental monitoring data for FRs in GB freshwater, groundwater, marine water, sewage discharges, drinking water, foodstuffs and air were also collated from EA datasets and selected published literature sources. There is a very large amount of international scientific literature on FR occurrence and a limited review was performed.

FRs were prioritised for further action based on of 3 considerations:

(1) Quantities manufactured in, or supplied to, the GB market

It was not possible to present the ranking of substances according to their tonnages on the GB market due to the commercial sensitivity of these data. Of the 73 registered substances with GB supply information, the most frequently associated use was plastics (57 substances; 78% of the database). Organophosphorus FRs account for over 10%, while other substance groups constitute up to 4% of the total tonnage each.

(2) Hazard analysis

This used 5 indicators:

- potential PBT / vPvB properties, identified either by EU REACH registrants, by EU regulators or by the authors of this scoping review;
- potential PMT / vPvM properties, identified by the authors of this scoping review based on EU hazard criteria;
- significant ecotoxic effects based on the environmental hazard category under the Classification, Labelling and Packaging (CLP) Regulation, or reported toxicity at low concentrations in water (in the absence of a hazard classification), sediment and/or soil;
- potential ED concern, identified by regulatory organisations or by non-governmental screening programmes (Chemsec SIN and TEDX lists); and
- significant human health hazard, particularly indications of carcinogenicity, reproductive effects, mutagenicity or specific target organ effects (based on CLP classifications), or reported toxicity at low levels of exposure.

Around a third of the 124 UK REACH-registered or "higher volume" DUIN FRs have at least two of these hazards and 8% of them have three or more. The most common hazard indicator was human health hazard (38 FRs), followed by environmental hazard (30 FRs), potential ED (25 FRs), potential PMT or vPvM (22 FRs) and potential PBT or vPvB (13 FRs).

(3) Potential environmental risk (including humans exposed via the environment)

Based on generic exposure modelling, industrial use of FRs in the production of flame retarded textiles is expected to lead to the highest levels of potential risk at the local scale (i.e. near to a point source) compared to other FR applications and life-cycle stages. Many of the organic FRs scoring highest in terms of potential risk to the environment (or humans exposed via the environment) were organophosphorus FRs.

The scoping nature of the review means that chemical property data were taken at face value rather than evaluated in detail. Recommendations for further investigation include:

- refinement of information associated with quantities and use,
- refining understanding of risks to the environment (or humans via the environment), for example by performing more detailed assessments for some substances, and
- improving monitoring evidence on environmental concentrations in GB.

Longer-term engagement with relevant industry sectors is also recommended to seek further market and life cycle information from manufacturers and importers until UK REACH registration deadlines have passed (the final one is in October 2030).

Regulatory data generation and risk management processes are in progress for FRs in other jurisdictions. Collaboration with other UK and non-UK stakeholders is therefore recommended, particularly in relation to direct exposure to workers and consumers via indoor air and dust ingestion.

1 Introduction

1.1 Purpose and background

Flame retardants (FRs) are extensively used around the world to prevent products from catching fire or to slow the growth of a fire once it has started. Compliance with flammability standards is mandatory for various types of goods and in this context use of FRs is proportionally high in the UK, because of its history of relatively stringent fire safety standards for soft furnishings (Note: The Furniture and Furnishings (Fire) (Safety) Regulations 1988 are under review at the time of writing). Certain properties of concern (e.g. persistence, bioaccumulation and/or toxicity) and diffuse release patterns of various FR types has attracted widespread international interest in their risks to the environment and human health. Some have been subject to risk management measures under European Union (EU) programmes and some have also been internationally restricted under the United Nations (UN) Stockholm Convention for Persistent Organic Pollutants (POPs). FRs have also been subject to a detailed inquiry into *Toxic Chemicals in Everyday Life* by the UK Parliament's Environmental Audit Committee (2019), within the context of improving the circular economy, transparency for consumers and the objective of a non-toxic environment in the UK.

The Environment Agency published a report in 2003 to summarise existing information on FRs and prioritise them for further investigation of environmental concerns (Environment Agency, 2003). The report was supported by an unpublished database, in which substance use and physicochemical, fate and hazard property data available at that time were collected. Since then, the EA has contributed to various individual assessments of FRs, for example under the Existing Substances Regulation, national programmes and EU REACH, several of which have resulted in risk management. Eleven FRs have also been screened through the EA Prioritisation and Early Warning System (PEWS): 1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE), Dechlorane Plus™, Melamine, Tetrabromobisphenol A bis(2,3-dibromopropyl) ether (TBBPA-DBPE), Tetrabromobisphenol- A (TBBPA), Triphenyl phosphate (TPP, TPhP), Tris[2-chloro-1-(chloromethyl)ethyl] phosphate (TDCPP), Tris(2-chloro-1-methylethyl) phosphate (TCPP), Tris(2-chloroethyl) phosphate (TCEP), Trixylyl phosphate and 2,4,6-tris(2,4,6-Tribromophenoxy)-1,3,5-triazine (TTBP-TAZ).

Now that the UK has left the EU, there is an opportunity to reconsider chemical priorities, including revisiting the earlier prioritisation work for contemporary concerns such as endocrine disruption and persistence combined with mobility. Some UK stakeholders have also asked for a renewed focus on FRs. This scoping project was commissioned as part of the response, with work beginning in 2022. The aim was to update EA (2003) with the latest evidence. In particular, all FR substances manufactured in, or imported to, the European Union (EU) by individual companies above 1 tonne/year have been registered under the EU Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) Regulation. This has produced an updated dataset, documenting chemical properties, hazards and use information. This project will enable priorities for further assessment to be established, and help Government develop a strategic approach for FR substances known to be on the market. The geographic focus is the Great Britain (GB) market, to align with the scope of UK REACH.

This report summarises the approaches and findings of this scoping work, and is supported by a stand-alone set of *summary tables*, reporting important data for each substance in a convenient reference format. These summary tables are available on request.

This report reflects the information available at the time the research was conducted. It is to be expected that new data will continue to become available over time, particularly as many FRs are subject to regulatory evaluation and data generation in other parts of the world, which may result in new testing.

1.2 Project focus and scope

The principal areas of focus include:

1. Identification of FRs that are relevant to, and significant for, the GB market. Three distinct groups were identified:
    a. Substances which are known to be used as FRs, have at least one new or "grandfathered" UK REACH registration or inquiry, and for which FR use has been confirmed based on validation evidence in the UK REACH registration. ("Grandfathering" allows EU REACH registrations held by GB-based legal entities to be recognised under UK REACH following EU exit.)
    b. As for Group (a) but for which validation checks in the UK REACH registration did not positively confirm FR use in GB.
    c. Substances which are known to be used as FRs elsewhere and have at least one Downstream User Import Notification (DUIN) or have been detected in the GB environment but are not yet registered under UK REACH. DUINs are a special category of substances during the transitional period – they are imported by companies who were previously "downstream users" under EU REACH, i.e. the EU REACH registration was held by a different company who supplied them. DUIN substances do not need to be registered under UK REACH until a series of formal deadlines have passed (the first being in October 2026). Uncertainties remain about whether such substances will eventually be registered, since this depends on the costs of registration and whether companies need to obtain access to additional information. However, based on feedback from the project Advisory Group (see Section 1.3), they are considered relevant (i.e. FR use in GB is suspected but unconfirmed) if they were registered under EU REACH at ≥ 100 tonnes/year at the time this review was conducted.

    Based on the criteria above, the terms Group (a), Group (b) and Group (c) are used throughout this report to indicate the UK REACH registration status of individual FRs, and whether FR use in GB has been verified or not.

Note: This project does not consider any FRs that enter GB **only** in imported articles, because they cannot be reliably identified or supply volumes quantified based on existing data sources.

2. Searches for chemical property, environmental / health hazard and use data, especially based on evidence compiled for EU / UK REACH compliance purposes.
3. Recording the evaluation status and conclusions from an EU / UK REACH perspective. This includes screening for persistence, bioaccumulation, environmental mobility and toxic properties (including endocrine disruption (ED)). This also includes current status of global risk management activity, for example whether substances are or have been on the EU Community Rolling Action Plan (CoRAP) or UK Rolling Action Plan (RAP) for Substance Evaluation or are included in an Assessment of Regulatory Needs (ARN).
4. Identifying changes in the GB market and new developments, such as important new substitution processes and replacement of banned substances, based on public information.
5. Carrying out generic exposure assessment for the environment and humans via the environment (and risk characterisation where possible), including exposure from service life and waste (Group (a) and (b) substances only), and applying recent UK environmental monitoring data in freshwater, groundwater, marine water, and sewage discharges, drinking water supply, foodstuffs and air (Groups (a), (b) and (c)).

A review of the legal context of FR use (e.g. requirements for different types of products or articles) was not part of this project.

Polymeric FRs are also of interest but are not currently addressed by UK or EU REACH. For this reason, such FRs cannot be screened / assessed in the same way as FRs that are registered substances, owing to the lack of comparable data on properties and hazard. A literature review was conducted to find information on the presence of polymeric FRs on the GB market, and some potentially relevant substances were highlighted. Further information can be found in Section 4.3.1.

Similarly, FR transformation products do not require registration, and may not be identified in publicly available information from registration dossiers. They have therefore not been systematically considered.

Fire retardancy achieved by means other than the use of chemical FRs is outside the scope of the project. The project does not address FRs used to suppress forest, moorland, heathland and grassland fires.

1.3 The Project Advisory Group

The Environment Agency assembled and chaired an Advisory Group to provide evidence and insights as the work progressed, and help to manage relationships with the collaborating organisations.

The role of the Advisory Group included (but was not limited to):

- Discussing and providing technical advice on the draft report during a review meeting with the contractor, Technical and Project Lead and Project Manager.
- Providing written comments on the draft report by an agreed date for consideration by the contractor to inform the conclusions.
- Considering whether consultation with the Committee on Toxicity (COT) for specific human health related questions was necessary.

The Advisory Group's membership is listed below. Comments from the Advisory Group were considered when finalising the report, but approval of the final text was not sought.

Government bodies

Department for Business and Trade: https://www.gov.uk/government/organisations/office-for-product-safety-and-standards

Department for Environment Food & Rural Affairs (Defra): https://www.gov.uk/government/publications/uk-reach-rationale-for-priorities/rationale-for-prioritising-substances-in-the-uk-reach-work-programme-2023-to-2024

Department of Agriculture, Environment and Rural Affairs (DAERA) (Northern Ireland Executive): https://www.daera-ni.gov.uk/topics/pollution/pollution-prevention-and-control

Food Standards Agency (FSA): https://www.food.gov.uk/business-guidance/chemical-contaminants

Health and Safety Executive (HSE) (Chemicals Regulation Division): https://www.hse.gov.uk/reach/index.htm

Natural Resources Wales (NRW): https://naturalresources.wales/about-us/what-we-do/what-we-regulate/how-we-regulate-chemicals/?lang=en

Scottish Environment Protection Agency (SEPA): https://www.sepa.org.uk/regulations/chemicals/

UK Health Security Agency (UK HSA): https://www.gov.uk/government/organisations/uk-health-security-agency

Non-governmental organisations

Fidra: https://www.fidra.org.uk/projects/sustainablefiresafety/

The Cancer Prevention and Education Society (CPES): https://www.cancerpreventionsociety.org/

Academia

University of Birmingham (School of Geography, Earth and Environmental Sciences): https://www.birmingham.ac.uk/research/life-environmental/gees

Industry

Albemarle: https://www.albemarle.com/offerings/bromine-specialties/fire-safety-solutions

International Bromine Council (BSEF): https://www.bsef.com/uses-innovations/brominated-flame-retardants/

Phosphorus, Inorganic and Nitrogen Flame Retardants Association (Pinfa) (Cefic Sector Group): https://www.pinfa.eu/#gsc.tab=0

2 General information on flame retardants

The purpose of incorporating chemical FRs in any material or product is to reduce its flammability. This section provides an introduction to some of the most common FR types, their uses and modes of action.

Environment Agency (2003) summarised general information on FR technologies, modes of action of significant FR types, and common applications. Notable published sources included the Kirk-Othmer Encyclopaedia of Chemical Technology (1991 edition), European Commission (EC) European Integrated Pollution Prevention and Control Bureau (EIPPCB) Best Available Techniques reference documents (2002 edition), and Troitzsch (1998), in addition to data gathered by research and consultation during that project. The content from Environment Agency (2003) is largely reproduced in Sections 2.1-2.3 of this report, with the addition of insights from market research undertaken during the current project. More recent updates to relevant content of the Kirk-Othmer Encyclopaedia have also been referenced, especially relating to developing technologies.

Findings specific to the UK (or GB) are expanded upon in Section 4 and Appendix 9.

Throughout this report, the chemical names and identifying numbers (CAS and EC inventory numbers) used for the FRs are those that are (or are expected to be) used in UK REACH. Other synonyms may be used in some publications and these are highlighted where relevant.

2.1 Additive and reactive flame retardants

In the context of flame retardancy of a polymeric material, FRs can be applied in different ways. A polymer chain can, to a certain extent, be made less flammable by the careful selection of the monomers from which it is constructed. Ring-structures and ionisable side-groups, for example, are relatively resistant to burning (Wiley, ca. 1991). In general, the base polymer itself must be modified to introduce FR properties. There are three main ways of doing this:

- Use of additive FRs. FR substances are dispersed in the final polymer product, but they do not bind chemically to the polymer chain. These are usually used with thermoplastics. They may be lost during the lifetime of the treated product (when washed, for example). Flame retardancy properties can therefore diminish over time.
- Use of reactive FRs. These are FR monomers that can be co-polymerised with other monomers. They are chemically bound within the polymer structure, and so losses during the lifetime of the product are limited. Reactive FRs are usually used with thermosetting polymers.
- Use of polymeric FRs. These are made by reaction of the polymer chain, once formed, to render it flame retarded (e.g. perchlorination of a hydrocarbon polymer chain or bromination of polystyrene).

Historically, additive FRs have been more widely used than reactive FRs. To be effective, a significant level of the FR active substance may need to be present (typical concentrations in the range 10-20 per cent by weight may be required, though for some systems a far lower loading, e.g. <1 per cent by weight, is effective). The appearance and chemical, physical and mechanical properties of the polymer may be affected. Some FRs are especially compatible or effective in specific types of polymers, types of articles, or end-use settings, meaning that different FRs have different profiles of use.

The life cycle of a reactive FR differs from an additive FR in that there will only be a small amount of unreacted FR present in the polymer and thus a small fraction of the tonnage (assumed to be up to 0.3% as a worst case (BRE, 2009)) is assessed for the exposure assessment for reactive FRs. For additive FRs, the total tonnage will be assessed.

For both types of FR, long-term release is possible, in addition to losses from the industrial manufacture and processing of the FR substance itself.

2.2 Flame retardant uses and modes of action

When exposed to heat, polymers will in most cases decompose to volatile combustible products due to the properties of organic compounds. The flammable nature of polymers can restrict their use in many fields (e.g. electronics, transport, buildings). To reduce the “fire risk” nature of polymers and allow use in these areas, FRs can be added to polymers. An FR may inhibit ignition, prevent combustion by altering the nature of the polymer in the vicinity of the flame, or extinguish the flame.

Vapour-phase FRs act by interfering with free radical mechanisms, or simply reducing the availability of flammable gases and oxygen. Condensed-phase FRs are active in the molten polymer in the vicinity of the flame, interfering with the thermal degradation processes. Intumescent systems, often used in flame retarded coatings, puff up in the presence of flame and produce charrable foams, which have low thermal conductivity (Wiley, ca. 1991).

Five specific modes of action have been identified:

1. gas dilution – use of additives which decompose into non-flammable gases. This reduces both fuel and oxygen levels in the vicinity of the flame (e.g. metal hydroxides, metal salts, and some nitrogen compounds);
2. thermal quenching – FRs which undergo endothermic decomposition, reducing the rate of burning (e.g. metal hydroxides, metal salts, and some nitrogen compounds);
3. protective coating – additives which promote charring or the formation of a liquid barrier, thus shielding the flammable material from the flame (e.g. phosphorus compounds, intumescent systems based on nitrogen or phosphorus compounds);
4. physical dilution of the flammable material – introduction of an inert non-flammable component (e.g. glass or minerals); and
5. chemical interaction – an FR that decomposes into radical species, which compete effectively with the burning process (e.g. halogenated compounds).

FRs for **thermoplastic** polymers frequently make use of the plasticity and flow behaviour that occur at high temperatures. They initiate chain scission to promote decomposition of the polymer. This encourages the material to melt and drip, physically removing it from the source of ignition. The physical properties of **thermosetting** polymers prevent the use of this type of physical flame retardancy. Significantly higher levels of FR substances are therefore necessary.

Both natural (e.g. silk, flax, cotton) and synthetic **textile** fibres (e.g. polyester, polyamide) may be flame retarded. They are either treated with an FR finish (during fibre manufacture or by application of a coating compound to the surface of the finished textile), or through chemical modification of the polymer (EC EIPPCB 2023). The latter performs best if the fabric is washed or weathered. Exposure to sunlight can significantly diminish the flame retardant properties of treated materials. Performance of an FR in such circumstances can be fundamental to its acceptability for a specific application since textiles are much more likely than plastics to be laundered and weathered. Some types of FR (e.g. chlorinated paraffins) can also confer an element of rainproofing.

Even after a flame is extinguished, the 'afterglow' can still consume the fabric. It is important, therefore, that FRs used for textiles inhibit this effect. Often, combinations of FR products are used (Wiley, ca. 1991). Most FR finishes for cellulosic materials contain phosphorus, possibly in addition to brominated and/or nitrogen compounds. These are the most effective at preventing oxidation of the char that forms when flame retarded cotton burns. Thus the 'afterglow' effect is prevented.

Applications include clothing (especially protective clothing), upholstery and furnishings in homes and vehicles, tents, and glass-fibre products. An important application is the back-coating of textiles (especially upholstery fabrics and carpets) with a flame retarded backing layer. Many different substances are used for this purpose. Textiles used in upholstered furniture and mattresses also require flame retardancy, at least in some regions (such as the UK).

The EIPPCB Reference Document on Best Available Techniques (BREF) for textiles has recently undergone revision and the new edition (EC EIPPCB, 2023) provides an extensive description of the industry sector including best available techniques in respect of pollution control for the different fibre manufacturing and treatment processes used to achieve flame retardancy.

FR **coatings** can be used to protect materials from fire and prevent fires from spreading. FR coating materials include paints and varnishes. These can be particularly useful for highly combustible materials such as wood and plastics. Intumescent coatings are common. Whilst FR coatings prevent fire from spreading and prevent damage to coated objects, heat resistant coatings protect surfaces from high temperatures.

FRs applied in polymer cable coatings are covered in this project under polymers; FRs applied to textiles in the form of a back-coating are covered in this project under Textiles.

The use of FRs in **adhesives** can be used to resist burning, retain join integrity at high temperature, reduce smoke production, and to reduce the release of toxic material when heated (SpecialChem, n.d.). Sealants and adhesives may be flame retarded, especially for assembly processes in the construction, electronics or transportation sectors (Petrie, 2007). For these purposes, material joins must have equivalent flame-resistance as the parts and components being joined, to maintain compliance of the finished article with the necessary requirements and to ensure that the adhesive continues to support the integrity of the assembled article during a fire (as failure of a joint and disintegration of the article could worsen the fire).

2.3 Chemical categories of flame retardant

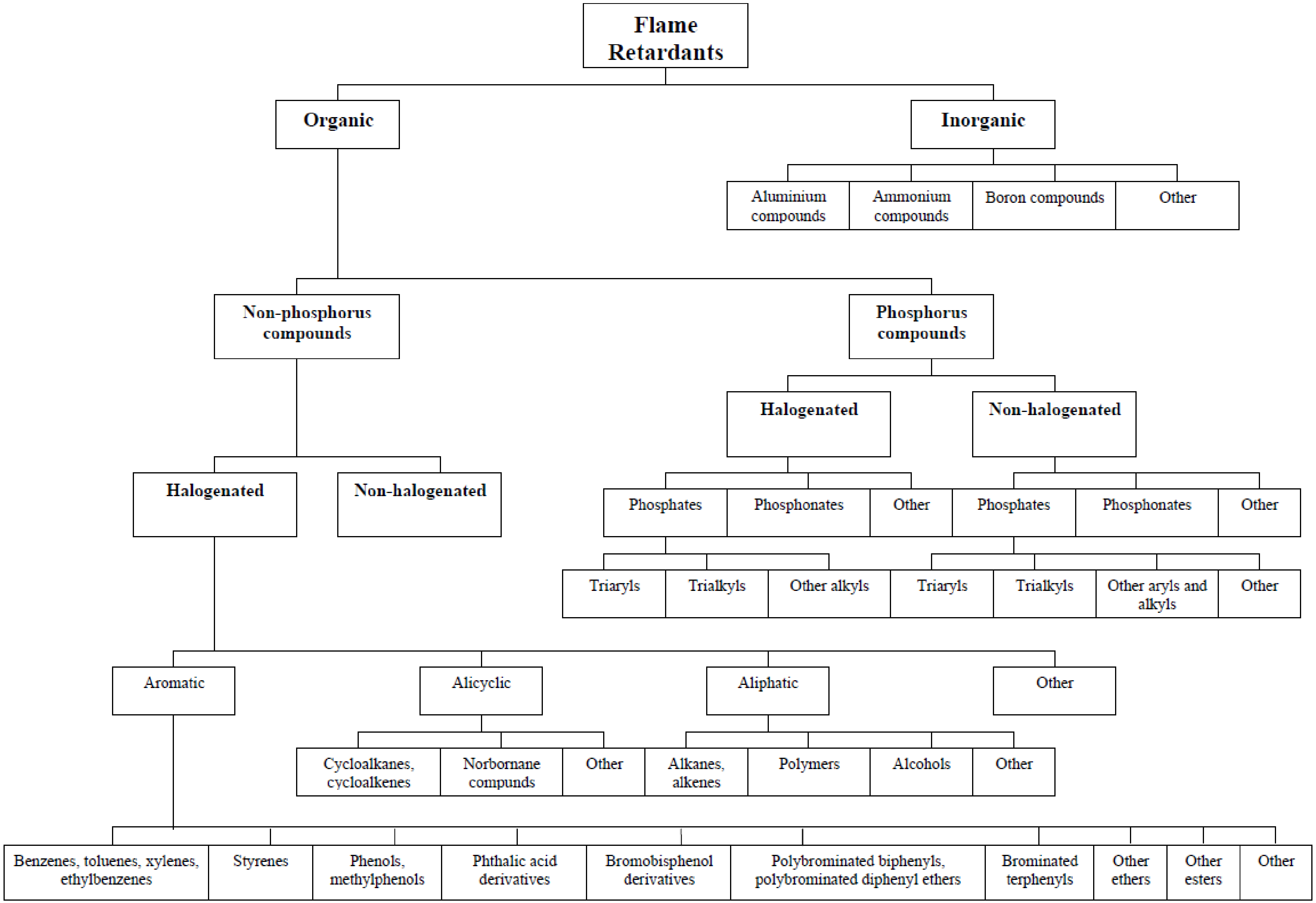
Environment Agency (2003) summarised the chemistry of different FR modes of action, and the typical uses of different chemical types of FR. Six generic chemical categories of FR were identified, and the same categories are applied in the current project:

1. Inorganic (FR type "I" indicated later in this report)
2. Brominated organic (FR type "B")
3. Chlorinated organic (FR type "C")
4. Organophosphorus (mainly phosphate esters) (FR type "P")
5. Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters) (FR type "HP")
6. Nitrogen-based (FR type "N")

In addition, one organic substance was identified which does not fall into the above categories. This substance is a polyol (see Section 3.4).

The FR chemical types (and some noted chemistries within each type) were summarised by Environment Agency (2003) (adapted from KemI, 1996) and that summary is reproduced in Figure 2.1 overleaf.

Figure 2.1 Breakdown of flame retardant chemical types (adapted from Keml, 1996)



2.3.1 Inorganic flame retardants (I)

Most inorganic FRs act in the condensed (i.e. solid and/or liquid) phase. Most decompose endothermically, releasing water of hydration and/or carbon dioxide, both of which inhibit burning. Some flame heat is absorbed in such reactions. The residue conducts heat away from the area, contributing further to the extinction of the flame. Many FRs act as smoke suppressants and additionally, promote char. All have a dilution effect.

Metal compounds

Antimony compounds and metal hydroxides have historically been used at highest volume of the inorganics in this sector.

Metal hydroxides, such as aluminium trihydroxide and magnesium hydroxide, decompose in the heat of the flame and release water of hydration. Such substances also act as smoke suppressants. These FRs may be used as secondary additives to flame retarded polymer systems in which other FRs are present (e.g. antimony trioxide, zinc borate, phosphorus-based).

Antimony oxides and sodium antimonate provide a pigment as well as flame retardancy. Antimony compounds can be used in a variety of plastics. They are particularly effective when used in cellulosic polymers. Antimony-silicon compounds are sometimes used, though these are less effective than antimony trioxide. Antimony compounds are not FR in their own right. Instead, they act as synergists with organohalogens. Antimony trioxide is usually used in conjunction with heat-labile halogenated compounds. In the heat of the flame, antimony trihalide is formed in the condensed phase which subsequently evaporates to the gas phase. This then decomposes in the flame phase to release halogen radicals, modifying the reactions in the flame such that less energy is released. The halogen radicals in the condensed phase abstract hydrogens from the polymer causing the molten polymer to char in the vicinity of the flame thereby creating a seal rather than releasing reactive and flammable gases.

Some other metal compounds, particularly zinc and zinc/tin compounds act synergistically with halogenated hydrocarbons. Synergistic action means that a smaller quantity of additives is needed to provide the same level of protection.

Molybdenum oxide is used as an FR, particularly for cellulosics. Ammonium octamolybdate is used as an FR for polyvinyl chloride (PVC), mainly for smoke suppression (Kirk-Othmer 2018). Titanium and zirconium compounds are used as FRs for textiles, particularly wool (EC EIPPCB 2023).

Boron compounds

Boric acid and sodium borate are frequently used in cellulosics (especially cotton and paper) where the presence of hydroxyl groups contributes to the effectiveness of these FRs. In the first instance, the compounds melt in the heat of the flame and form a glasslike coating. Continued exposure to the heat causes water to be released, which cools the flame. Finally, an inorganic char is produced. This dilutes and protects the flammable material (Troitzsch 1998).

Zinc borate is frequently used to flame retard PVC; hydrogen chloride released in the presence of flame reacts with the zinc borate producing non-volatile products (which promote char), and water.

Ammonium fluoroborate and zinc borate are frequently used in conjunction with antimony trioxide. Again, flame retardancy is thought to arise through release of water and formation of inorganic char in the presence of a flame.

Other inorganic FR compounds

Phosphorus-containing compounds act by promoting the dehydration of the polymer in the presence of a flame and increasing the level of charring. Ammonium phosphates are used in cellulosic textiles. Phosphoric acid itself has been used to treat cellulosics. Ammonium polyphosphates of varying chain lengths are used in many applications, particularly in coatings, paints and intumescent applications. Other FRs are frequently used in conjunction with them.

Elemental phosphorus exists in several allotropic forms. The red form is used as an FR in plastics, commonly polyamides.

Expandable graphite was identified by Environment Agency (2003) as an emerging FR technology at that time. Expandable graphite exploits a mechanical process whereby, in a fire, a cross-linked carbon char is generated on the surface of the substrate. A wide range of substrates have been investigated (Wenne, 2002). In respect of the textiles industry, the new edition of the BREF (EC EIPPC 2023) notes that grades are available with an acidic or neutral character and that expandable graphite is sometimes used in combination with other FRs like ammonium polyphosphate (APP). In the market research carried out as part of this project, graphite and a graphite/sulfuric acid compound were both identified as potentially relevant for the GB market (see Section 3.1.1-3.1.2; it is noted that graphite as such is not a FR (Advisory Group comments, January 2024).

2.3.2 Organohalogens

Three general classes of organohalogen FR may be identified: aromatic, aliphatic and cycloaliphatic. The halogen is generally either chlorine or bromine. In addition to persistence concerns, fluorinated compounds are expensive and generally not effective; iodinated compounds are effective but unstable and are therefore not used. A wide variety of organohalogens are used as additives or reactive FRs, and a few can be used as either, depending upon the application; this group also includes halogenated polymeric FRs.

Incorporation of phosphorus compounds along with halogenated FRs further inhibits ignition. This effect is also achieved if the phosphorus and halogen are present in the same molecule. The effect can sometimes be synergistic.

Brominated organic (B)

These are frequently used in electrical and electronic equipment (EEE) such as television sets, computer hardware housings and monitors, etc. Brominated aromatics tended to be the most widely used at the time of the Environment Agency (2003) study (due to their thermal stability, efficiency and low amounts needed (Advisory Group comments, 2023)). Historically, brominated substances have also been widely used in the UK in back coatings for fabrics (Stubbings *et al.*, 2016).

The effectiveness of this category of FRs may be connected with the Br· radical. This competes effectively with hydroxyl radicals HO· and hydrogen radicals H· for the substrate in the vapour phase, and extinguishes the flame. An alternative theory is that halogens dilute flames with non-combustible gases and push flames away from the polymer surface (Advisory Group comments, 2023).

In recent years, a number of countries and environmental groups have focused their attention on restricting the use of brominated flame retardant (BFRs) (e.g., ECHA, 2023), and a number of these substances have been targeted by international regulation including the Stockholm Convention on Persistent Organic Pollutants (POPs) (see Section 4.3 for further discussion on regulation and substitution of substances).

Chlorinated organics (C)

Some aliphatic chlorinated FRs are declining in use. The level of chlorination necessary for sufficient flame retardancy often has a detrimental effect on the desired properties of the polymer. Chlorinated paraffins (aliphatics) are used in plastics, textiles and coatings. Chlorinated aromatics are not used as FRs.

A number of chlorinated FR substances have been assessed by the Stockholm Convention; short-chain chlorinated paraffins (SCCPs) and Dechlorane Plus™ have been listed for elimination (Annex A), and medium-chain chlorinated paraffins (MCCPs) have been proposed for listing under the Convention.

2.3.3 Organophosphorus compounds (P)

Phosphorus-based FRs inhibit further combustion by making use of the catalytic properties of mineral acids in the pyrolysis of cellulose to water and char (as opposed to volatile and combustible organics). The low volatility of phosphoric acid and derivatives makes it the preferred choice. These FRs are most effective in polymers that char readily. Some phosphorus compounds, though, are thought also to act by increasing the rate of polymer melt.

Physical or chemical vapour-phase mechanisms can also occur, particularly in non-charring polymers and also when the FR in question is volatilised at the temperature of the flame. There is some evidence that the substances act as free radical scavengers.

Again, there are several compounds within this category, both additive and reactive. Phosphate esters are the most widely used family of organophosphorus FRs. Polyols, phosphonium derivatives, phosphonates, phosphinates and phosphine oxides are also used (Advisory Group comments, 2023). Phosphate esters are widely used in plastics. They are also used in polyvinylchloride (PVC) because as well as their FR properties, they also increase the flexibility of PVC (where this is desirable).

Halogenated organophosphorus compounds (HP)

Halogenated phosphate esters are widely used. They combine the properties of both the halogen and the phosphorus components. The presence of the halogen also increases the lifetime of the FR in the end-product by decreasing its mobility in the polymer. Examples include tris(1-chloroisopropyl) phosphate (TCIPP) used in polyurethane foams, and tris(1,3-dichloro-2-propyl)phosphate (TDCPP), used in polyurethane foams and sometimes in fabrics. TCIPP is now identified in Europe and the UK by a more complex nomenclature required under REACH (see Section 3.4).

2.3.4 Nitrogen-based flame retardants (N)

These are used mainly in polymers in which nitrogen is present (e.g. polyurethanes, polyamides), and also polyolefins. Compounds and derivatives of 1,3,5-triazine-2,4,6-triamine (melamine) or guanidine are the most commonly used, and are relatively cost-effective. Melamine derivatives are also used in intumescent coatings, where they act as blowing agents, catalysing the formation of foam. Some polymers are cross-linked by the internal generation of melamine rings.

Melamine derivatives act synergistically with phosphorus-containing FRs. This combination is often used in thermoplastics and intumescent systems (Kirk-Othmer 2015) and in foams (Advisory Group comments, 2023). Compounds incorporating both active groups in one molecule (i.e. melamine phosphates) are also used.

Ammonium sulfate and sulfamate and the ammonium halides are used as FRs in various cellulosic products (textiles, paper, and wood).

2.3.5 Other organic flame retardants (O)

In addition to the broader substance groups listed above, Figure 2.1 identifies a number of smaller categories of organic FRs, including aromatic, alicyclic and aliphatic substances.

2.3.6 Developing technologies

Environment Agency (2003) noted two new approaches to the provision of flame retardancy under development at that time, making particular mention of 'nanocomposites' (Beyer, 2002) and 'expandable graphite'. Expandable graphite has now been used for several years in FR applications, while nanocomposites remain a developing technology with limited commercial success and application thus far. The use of graphite is discussed in Section 2.3.1.

A nanocomposite is a two-phase material comprising a polymer with a dispersed filler phase. Amine-modified silicate fillers incorporated into nanocomposites confer enhanced thermal stability and FR properties. The filler is layered within the structure of the polymer with a layer thickness in the order of nanometres. As a result, the silicates are present at levels of between 2% and 10%, most commonly in the form of montmorillonite, hectorite or saponite organoclays. Three synthesis routes are possible:

- *in-situ* polymerisation;
- solvent method;
- melt-intercalation.

Of these, the first two rely on polymerisation occurring within the layered silicate structure of the clay. The third involves the molten polymer blending with the organoclay.

FR properties are achieved by the formation of a char layer that insulates the base layer from heat. This layer also acts as a barrier to volatile gases that could maintain combustion.

The manufacturers of nanocomposites claim that these substances have a number of advantages over polymers that are flame retarded using existing methods. These include:

- significantly lower concentrations of fillers are used;
- the properties of the virgin polymer are retained (and in some cases enhanced);
- no halogens are added during production.

Nanocomposites can also be used in combination with other FR filler systems such as aluminium trihydroxide (ATH) to achieve the same, or a higher, level of performance at a lower filler concentration. The reduced filler concentration can have significant benefits in terms of improved mechanical and rheological properties of the polymer.

Information gathered for this project indicates that nanocomposites are still a novel, emerging technology in the FRs arena (Ahmed *et al*., 2018). Yang *et al*. (2021) note that due to their limited FR properties, nano carbon materials are used largely as synergists with other substances more traditionally used to provide the flame retardancy. The same study further notes that low-cost production of nanomaterials remains a challenge, and they remain to be applied on a large scale.

Dow Chemical Company has developed a line of novel brominated styrene-butadiene block copolymer FRs as an alternative for hexabromocyclododecane (HBCDD) for extruded (XPS) and expanded polystyrene (EPS) foams for construction. This technology is referenced by Kirk Othmer (2015) and in industry literature (e.g. Chemical and Engineering News, 2013). These materials are already the main HBCDD replacements on the market for uses in EPS and XPS insulation.

Kirk Othmer (2015) also notes that newer phosphorus-based FRs are generally reactive, or polymeric in structure, some notable examples being polyphosphonates and polyphosphonate-co-polycarbonates. The Nofia® product range is a specific example referenced in Kirk Othmer. According to the Nofia® manufacturers literature this range (halogen-free FR homopolymers, copolymers and oligomers) are compatible with a wide range of polymers, formats (foam, bulk plastic, fibres, wire and cable) and various typical FR polymer applications (textile, electronics, automotive, building and construction) (FRX Polymers, 2019). FRX Polymers' Nofia® copolymers are polyphosphonate-co-carbonates, available at a range of phosphonate concentrations; Nofia® Oligomers are low molecular weight, reactive FR additives. The oligomers are phosphorus-based additives with phenolic end groups. The chemical composition of Nofia® homopolymers is not specified (FRX Innovations, 2022). An Advisory Group member confirmed that polymeric FRs are already now a relevant portion of the market (Advisory Group comments, 2023).

ECHA's Regulatory Strategy for FRs (ECHA, 2023) highlights that there is a trend in the market towards use of polymeric FRs. The Strategy also points out that reactive FRs have a comparably small market share. Polymeric FRs are discussed further in Section 4.3.1.

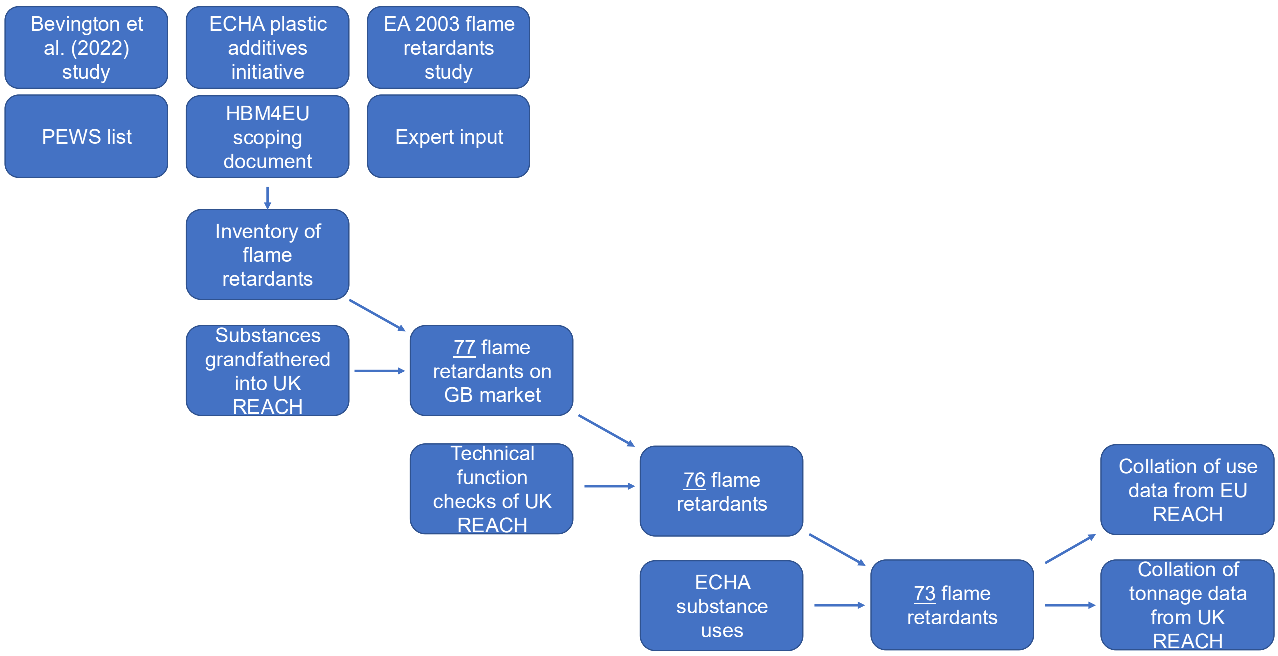
Recent developments in academia have seen the production of bio-based FRs from renewable, plant-derived feedstocks. However, these efforts have required natural materials to have their FR properties strengthened by the incorporation of traditional petrochemicals. Challenges also remain in applying these processes at industrial scale due to the costs of bioresources and associated biorefining processes (Feng *et al.* 2023)

3 Research methods for this report

3.1 Substance identification and use pattern

The initial phase of the analysis identified GB-relevant FR substances and defined their tonnages and main uses on the GB market. Figure 3.1 provides an overview of the process used for collating this information. The following sub-sections detail the approaches taken in each of the steps of the overall process.

Figure 3.1 Overview of substance identification and use pattern analysis process

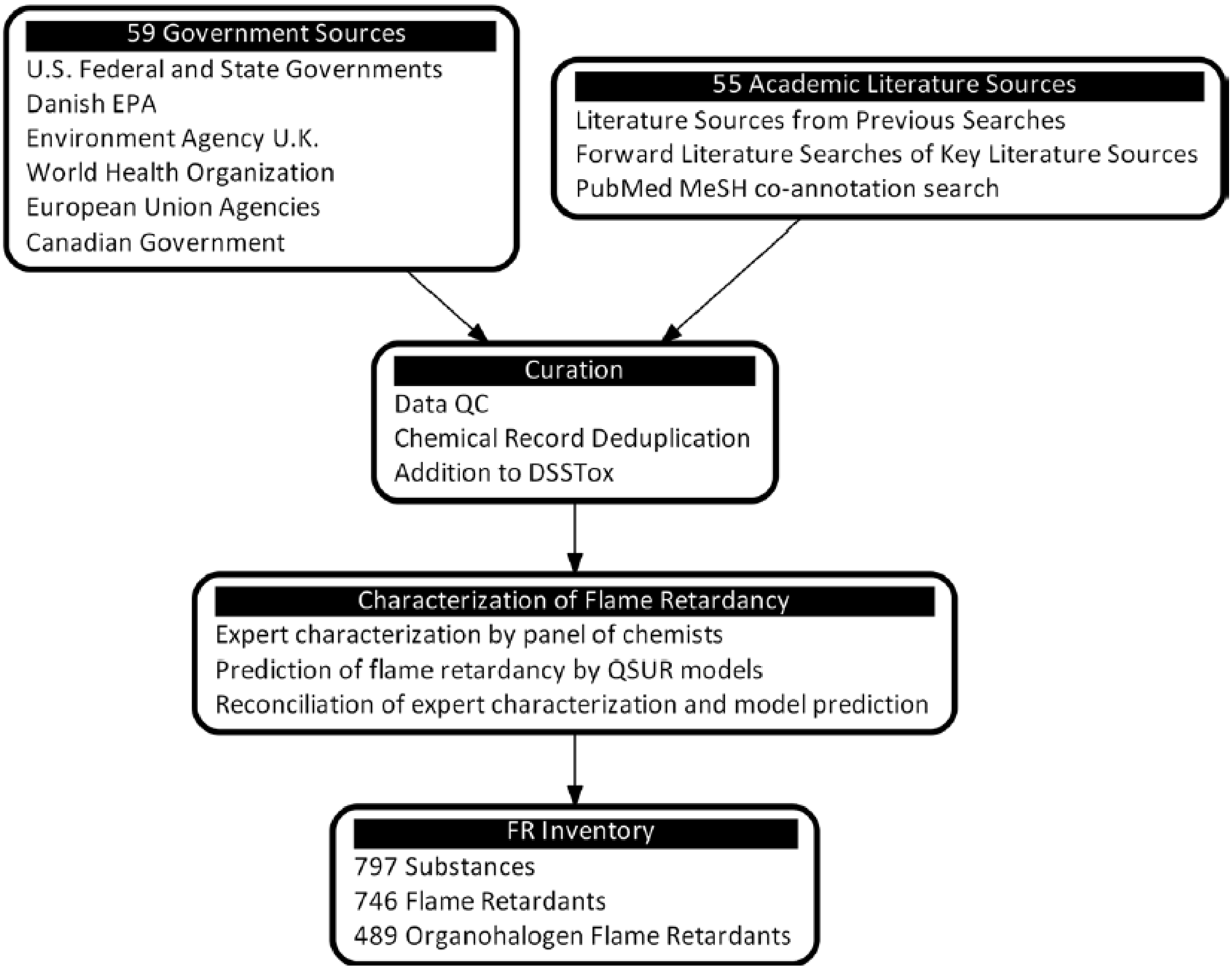


3.1.1 Identification of flame retardants

Substance identification was conducted via a review of academic and institutional sources as well as the Environment Agency (2003) study. Evidence on FR substances was collated from the sources discussed below.

Bevington *et al.* (2022) undertook a review of academic literature as well as sources produced by national governments (including Environment Agency, 2003), and produced an inventory of 746 FRs[1], classified using a number of substance categories. The process adopted in the Bevington *et al*. study to identify substances is displayed in Figure 3.2.

Figure 3.2: Process used in the Bevington study to identify flame retardants (Bevington *et al.* 2022). This image is included in the article's Creative Commons license: http://creativecommons.org/licenses/by/4.0/. No changes have been made.



Between 2016 and 2018, the European Chemicals Agency (ECHA) along with industry organisations investigated the use of additives in plastics. The plastic additives initiative (ECHA, 2022a) identified over 400 additives, including 39 FRs.

The Environment Agency provided a list of 100 FR substances nominated for prioritisation through the PEWS which is used to identify emerging substances of concern. The

[1] As highlighted in Figure 3.2, the Bevington study identified a total of 797 substances of which 746 were identified as flame retardants. The remaining 51 substances were screened out as flame retardants by the authors of the study on the grounds that they were unlikely to be used as flame retardants due to their chemical properties, or because they are chemical intermediates rather than flame retardants.

European HBM4EU biomonitoring project[2] has identified FRs as a priority substance group and produced a scoping document on FRs (Melymuk *et al*. n.d.). This includes a list of 62 identified FRs.

Additional expert input from the Advisory Group included a separate list of 106 substances. An additional substance (dipotassium 3,4,5,6-tetrabromophthalate (CAS 18824-74-3)) was highlighted by the Environment Agency for inclusion in the evidence base. ECHA's *Regulatory Strategy for Flame Retardants* (2023) highlights this substance for inclusion in a proposed restriction of aromatic BFRs.

Along with the database produced as part of Environment Agency (2003), the above sources provided an evidence base for the screening of substances on the GB market to identify GB-relevant FRs. The approach to screening is detailed in the following section.

3.1.2 Screening of GB-relevant flame retardants

Following the collation of general data on FR substances (Section 3.1.1), these were compared with substances on the GB market to produce a list of GB-relevant FRs. Defra has produced a list of registrations for substances grandfathered into the UK REACH system following the UK's exit from the European Union (Defra, 2021a). The list is from notifications submitted to HSE up to and including 1st July 2021. For this assessment, only substances which were registered in the UK REACH system were considered as substances currently on the GB market.

Under the UK REACH system, GB-based entities that were not holders of EU REACH registrations before EU Exit and were intending to import substances into GB at or above 1 tonne per year were required to submit a downstream user import notification (DUIN) by 27th October 2021. This deferred the obligation to submit a registration by a set period of time. Substances for which DUINs were submitted, but were not grandfathered into UK REACH, were not considered as currently in use for the purpose of this project (see Section 3.1.6 for how these substances were addressed). This is because the existence of a DUIN was not considered definite evidence of a substance being on the GB market, due to uncertainties about the likelihood of an eventual registration in GB. As such, the findings of this assessment regarding FRs in GB are not likely to fully reflect tonnages of substances imported into GB.

The list of grandfathered substances was compared against the sources outlined in the previous section to highlight FR substances on the GB market. In addition, these sources were made available to the Environment Agency to identify additional FR substances on

[2] The HBM4EU project (https://www.hbm4eu.eu/) is a joint effort of 30 countries, the European Environment Agency, and the European Commission aimed at improving the evidence base on citizen exposure to chemicals and the potential health effects. The evidence collected through the project is intended to support further policy-making.

the UK REACH system, but which are not captured by the published list of grandfathered substances. This was done in August 2022. These comparisons identified 77 substances classed as FRs on the GB market based on UK REACH registrations.

Many substances have multiple technical functions; for example, a substance used as an FR may also be used to achieve other properties such as plasticising. As such, it was necessary to confirm that the 77 identified substances were indeed used as FRs. The Environment Agency undertook checks of the 77 substances on the UK REACH system, specifically looking at technical functions listed under the substance service life (covering all environmental release categories (ERCs)) and industrial use entries (covering ERC5 and ERC6c. ERC5 is defined as "use at an industrial site leading to inclusion into/onto an article" and ERC6c is defined as "use of a monomer in polymerisation processes at an industrial site (including or not into/onto article)" (ECHA, 2015). The purpose of focussing on these ERC descriptors for the industrial life cycle stage was to find instances of industrial processing of a substance through which it is incorporated into an article, as would be expected for an FR being applied in a manufacturing process). Substances were then classified as follows:

- **Confirmed FRs:** substances listed in UK REACH with an FR technical function mentioned in service life and/or industrial use (these substances are termed "Group (a)" FRs in this report (see also Section 1.2);
- **Confirmed non-FRs:** substances where technical function information was available for both service life and industrial use, neither of which mentioned flame retardancy; and
- **Potential FRs:** substances which had data gaps (such as a lack of technical function information) and could not be ruled out as FRs.

For substances classed as 'potential FRs', there is evidence of their use as FRs in the sources discussed in Section 3.1.1. In addition, checks of the substance uses (detailed in Section 3.1.3) confirmed they are used in sectors and article types that are typically flame retarded. However, the direct evidence that REACH registrants are supplying them as FRs to the GB market is absent. In the absence of conclusive evidence to the contrary, these substances have not been disregarded from further assessment, but it is necessary to highlight the uncertainty regarding their status as GB-relevant FRs. These substances are termed "Group (b)" FRs in this report (see also Section 1.2).

This final screening step confirmed that one substance (hexachlorocyclopentadiene; CAS No. 77-47-4) from the original list of 77 substances had no FR technical function under either service life or industrial use, and was therefore discounted from further analysis. The remaining 76 substances proceeded to the next step of analysis.

3.1.3 Substance use patterns

Information on substance use in products and in manufacturing were obtained from the ECHA database of registered substances (ECHA, 2022b), which hosts publicly available substance "info cards" setting out use information. It is assumed that EU use patterns are similar to those in GB for the purpose of this project. Descriptor codes from the EU

REACH system for describing industry sectors, product types and technical function in use were used for this. For each substance, the relevance of four use categories (polymers, sealants, textiles and coatings, labelled ‘use class 1’) was checked for the purpose of the subsequent substance exposure assessment (see Section 3.2). The Product Categories (PC) of each substance were sub-categorised and logged as ‘use class 2’. This categorisation followed the classification scheme set out in Table 3.1.

Information on substance use in manufacturing was also obtained from the ECHA database and logged according to the same four use categories. For manufacturing, uses in the ECHA database are listed using sector of use categories (SU) which do not align completely with the four categories under use class 1. Consequently, identifying the relevant use classes for manufacturing was more reliant on judgement than a formalised categorisation scheme. However, uses identified under product use and manufacturing were largely consistent with each other for all substances. Except for one substance, all database entries were identified with product uses, most of them also having manufacturing uses. One substance (magnesium chloride; CAS No. 7786-30-3) was recorded with a manufacturing use, but no product use.

Note: Use information was obtained from the Brief Profile page for each substance in the EU REACH database as opposed to the corresponding Substance Factsheet. In collating use information, some inconsistencies were noticed between the uses reported on these profiles compared to the factsheets. In several instances the profiles were found to include uses not listed on the factsheets. This introduces some uncertainty concerning the relevant uses for each substance, although it is likely that analysis over-scoped uses rather than omitting any as a result of the additional uses listed in the Brief Profiles.

Table 3.1: Flame retardant use classes

Use class 1	Use class 2 / Product Category (PC)	PC code
Textiles	Textile dyes, and impregnating products	PC34
	Leather treatment products	PC23
Sealants	Adhesives, sealants	PC1
	Fillers, putties, plasters, modelling clay	PC9B
Coatings	Coatings and paints, thinners, paint removers	PC9A
	Metal surface treatment products	PC14
	Non-metal surface treatment products	PC15
	Ink and toners	PC18
	Lubricants, greases, release products*	PC24
	Paper and board treatment products	PC26
Polymers	Polymer preparations and compounds	PC32
Other	Other	PC0
	Heat transfer fluids	PC16
	Hydraulic fluids	PC17
	Metal working fluids	PC25
Non-FR	Adsorbents	PC2
	Air care products	PC3
	Anti-freeze and de-icing products	PC4
	Base metals and alloys	PC7
	Biocidal products	PC8
	Finger paints	PC9C
	Explosives	PC11
	Fertilisers	PC12
	Fuels	PC13
	Processing aids such as pH-regulators, flocculants, precipitants, neutralisation agents	PC20
	Laboratory chemicals	PC21
	Plant protection products	PC27
	Perfumes, fragrances	PC28
	Pharmaceuticals	PC29
	Photochemicals	PC30
	Polishes and wax blends	PC31
	Semiconductors	PC33
	Washing and cleaning products	PC35
	Water softeners	PC36
	Water treatment chemicals	PC37
	Welding and soldering products, flux products	PC38
	Cosmetics, personal care products	PC39
	Extraction agents	PC40
	Oil and gas exploration or production products	PC41
	Electrolytes for batteries	PC42

* While 'lubricants, greases, release products' does not match the use characteristics of coatings, it was judged that environmental releases of lubricants to the environmental are similar to or less than those from coatings. Classing 'lubricants, greases, release products' under coatings therefore represents a realistic worst-case scenario within the exposure assessment.

In collating use information, the following three substances were identified as not having uses fitting into the four use categories under use class 1. These substances were excluded from further assessment, with 73 substances proceeding to the next stage of market assessment.

- Dimethyl phosphonate (CAS No. 868-85-9);
- Ferrocene (CAS No. 102-54-5); and
- Tetrakis(hydroxymethyl)phosphonium chloride (CAS No. 124-64-1). Sources indicate that this substance is used in the production of FR finishes for textiles (PubChem, n.d.). Tonnage data gathered under the following step of the analysis (Section 3.1.4) also revealed no presence of the substance on the GB market.

3.1.4 Substance tonnages

For the 73 FR substances identified as being relevant for GB, annual market tonnage data were first obtained for the EU from the ECHA database of registered substances (ECHA, 2022b). Maximum and minimum EU tonnages from the tonnage band were extracted for each substance and logged. Minimum and maximum tonnages (where available) for each substance on the GB market were then obtained from the UK REACH IT system by the Environment Agency. Where only a single figure was available in UK REACH, this was assumed to be the lower threshold tonnage value. The corresponding upper value was then assumed using UK/EU REACH tonnage bands. (e.g. a minimum tonnage band of 1,000 tonnes/year was assumed to have a maximum tonnage of 10,000 tonnes/year). The total maximum tonnage for each substance was subsequently used in the exposure assessment. The consequence of this approach is discussed further in Section 3.3.

Tonnage split by sector of use

Following collation of annual GB market tonnages for each substance, tonnages had to be apportioned to the four use categories under ‘use class 1’ for the exposure modelling (polymers, textiles, sealants and coatings). There is limited information in the public domain concerning the breakdown of the overall FRs market by use. To address this, a variety of data sources were consulted to inform assumptions on the potential use class splits for the different types of FRs, which is discussed below.

As a reasonable worst-case scenario, it was assumed that all substance tonnages are used as FRs in the four use categories, and no adjustment has been made for non-FR uses. This is likely to overestimate the tonnages attributed to the use categories.

One industry trade body (Pinfa) states that 85% of FR consumption is accounted for by use in plastics (Pinfa, 2021); however this does not distinguish by substance type. This figure is corroborated by other findings which also state that plastics accounted for 85% of global FR consumption in 2013, with textiles and rubber accounting for the remainder (Uddin, 2019). Where no additional substance-specific information is available, this split has been used to apportion tonnages to the four use categories. Assumptions used in allocating tonnages for different tonnage groups are set out below.

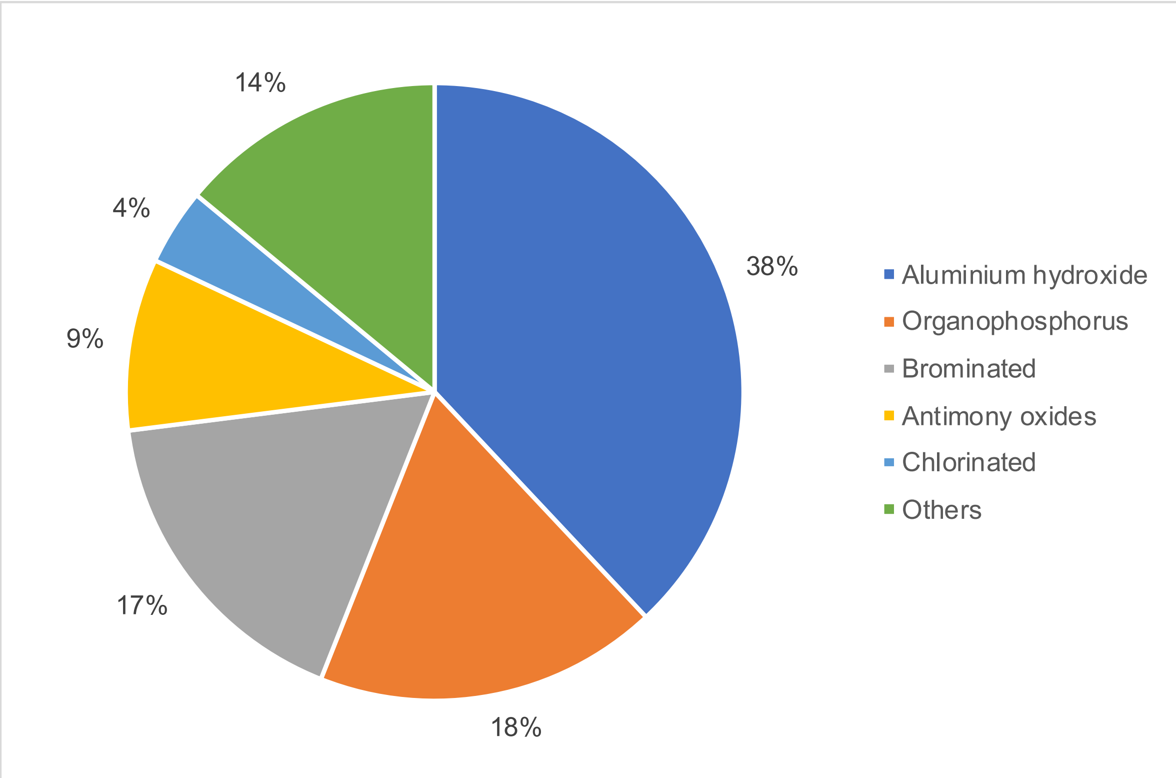
Inorganic flame retardants

Figure 3.3 shows that the inorganic compound aluminium hydroxide represented 38% of world consumption of FRs in 2019. Due to its significance on the global market, research into the split of tonnages by use for inorganic FRs focused on aluminium hydroxide.

A global market report (ReportLinker, 2019) states that aluminium hydroxide is predominantly used in plastics as an FR with almost 50-60% of produced aluminium hydroxide used in the plastics industry.

Consequently, for inorganic substances with polymers as an identified use, 60% of the total substance tonnage has been assumed to be attributable to polymers. For substances where textiles are also listed as a use, half the remaining tonnage was assigned to textiles. The remaining tonnage was then split evenly among any remaining uses (e.g. coatings; sealants).

Figure 3.3: World consumption of flame retardant types, by tonnage, 2019 (based on data from Flame Retardants Online, n.d., citing IHS Consulting, 2020)



Brominated flame retardants

Stockholm Convention Risk Management Evaluations and Risk Profiles provide some historical use information on a number of legacy BFRs, including commercial pentabromodiphenyl ether (UNEP, 2006a), decabromodiphenyl ether (decaBDE; UNEP, 2014), hexabromobiphenyl (UNEP, 2006b), and hexabromocyclododecane (HBCDD; UNEP, 2010).

While hexabromobiphenyl and decaBDE were used primarily in the production of plastic products globally (up to 90% (UNEP, 2019a)), decaBDE was sold predominantly in textiles (52%), closely followed by plastics (48%) in Europe (UNEP, 2014). Around 95% of commercial pentabromodiphenyl ether was used in the manufacture of polyurethane foam (EC, 2001; UNEP, 2006a). The report on HBCDD mentioned various uses including adhesives and coatings (UNEP, 2010), while a risk assessment of HBCDD under the

Existing Substances Regulation (ESR) identified the four principal product types it was used in at the time as expandable polystyrene, extrudable polystyrene, high impact polystyrene, and polymer dispersion for textiles (EC, 2008a). A justification document for the selection of a CoRAP substance published as part of the EU REACH substance evaluation process indicates that 90% of 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol (TBBPA; CAS No. 79-94-7) in the EU was used as a reactive FR in printed circuit boards (Danish Environmental Protection Agency, 2015). The ESR risk assessment for TBBPA (EC, 2008b) and the Norwegian Environment Agency (2022) proposal to identify TBBPA as a substance of very high concern (SVHC) under EU REACH also identify FR substrates in printed wiring boards as the primary use of the substance. While these data represent historical use patterns for substances (including some that are now restricted in Europe), they are a useful basis for assumptions about use patterns of BFRs currently in use.

Information shared by stakeholders consulted as part of this project (see Section 3.1.5), indicated that the predominant use of BFRs worldwide is electrical and electronic equipment, followed by building and construction applications. Much less is used in wires and cables, transport, textiles, and other uses, which account for less than 30% of the total tonnage.

Based on their historic use patterns (listed above), tonnages for BFRs were apportioned to uses as follows: where polymers are an identified use (which is the case for all screened substances), they are assumed to be the dominant use, accounting for 80% of the total tonnage. Where textiles are also identified as a relevant use, they are the second dominant use accounting for half the remaining tonnage (10%). Where coatings and sealants are also identified as uses, the remaining tonnage is split evenly among them (5% and 5% respectively).

Other flame retardant substance types

In the absence of any other information, other FR types (including chlorinated FRs, organophosphorus, halogenated organophosphorus, nitrogen-based FRs, and other organic FRs) have a use-tonnage split based on the Pinfa estimate of 85% of FR consumption used in polymers, as detailed above. The remaining uses are split 10% for textiles, and 2.5% each for sealants and coatings where they are also an identified use for the substance.

3.1.5 Stakeholder consultation

Following the collection of information via the desk-based evidence review detailed in the preceding sections, a small number of stakeholder interviews were undertaken. Invitations to short fact-finding interviews were sent via email to a variety of stakeholders including the trade associations listed below, covering the sectors of use that the study has focused on, as well as companies operating in the FRs sector.

- Pinfa;
- BSEF;
- British Coatings Federation (BCF);

- British Plastics Federation (BPF);
- British Interiors and Textiles Association (BITA);
- British Adhesives and Sealants Association (BASA).

Invitations generated several responses from stakeholders, and six interviews were undertaken with seven industry respondents operating in the UK and/or EU FR sectors. These interviews centred on verifying that the information gathered primarily on substance use patterns and tonnages was reflective of the industry respondents' experiences of the GB FR market.

Interviewees were also invited to share any information available on technical developments and innovations in FR technologies (see Section 4.3). The industry respondents confirmed that the assumptions made concerning the tonnages of different substance groups on the GB market, and the split of tonnages of the different substance groups by use (see Section 3.1.4) were broadly consistent with their experience of the market. Information was also provided on the trends in the FRs sector with regard to past substitutions of substances, and likely future developments (see Section 4.3).

3.1.6 Group (c) substances

As outlined in Section 1.2, an additional suite of 51 substances was identified as potentially relevant to GB based on a DUIN being submitted by January 2023, or because further review of those specific substances was recommended by the project Advisory Group. A list of the Group (c) substances is provided in Table 3.3. Additional research was conducted focusing on the collation of physicochemical and hazard property data (see Section 3.2 for details on the approach taken), but these substances were not subject to the review of tonnages and use patterns conducted for Group (a) and (b) substances (see Sections 3.1.1 to 3.1.5) as UK registration data was not available.

3.2 Substance physicochemical and hazard property data

The following publicly available data sources were consulted for each substance in a stepwise manner. A review of the reliability of each individual endpoint was not performed:

1. EU REACH registration datasets, disseminated in the form of Substance Factsheets and Brief Profiles by ECHA.
2. For substances on the Candidate List, properties and hazard information published by ECHA.

If data were not found in the above sources, further sources were checked in sequence as follows:

3. For physicochemical properties, experimental database values and predicted values were obtained from EPI Suite version 4.11 (US EPA, 2012). In particular, data were collected for the n-octanol–water partition coefficient (K_{OW}), soil organic

carbon–water partition coefficient (K_{OC}), water solubility and vapour pressure, all of which are of particular importance for exposure modelling and/or mobility assessment.

4. Background information from Environment Agency (2003), which reported data from the following sources (which has not been revisited in the current project):
    a. IUCLID database of existing substances data (confidential version)
    b. Syracuse Research Corporation PhysProp and ChemFate databases
    c. Danish brominated flame retardant report (Danish EPA, 1999)
    d. Published ESR reports and drafts dating up to 2003
    e. WHO (World Health Organization) IPCS (International Programme on Chemical Safety) Environmental Health Criteria series.

Further sources were consulted to fill remaining data gaps for substances not covered in Environment Agency (2003), or to address specific questions:

5. OECD eChemPortal data search for fate, ecotoxicity and toxicity endpoints.
6. The Hazardous Substances Data Bank (HSDB) (via PubChem).

3.2.1 Physicochemical data

The authors' judgement was used in several cases when interpreting the data presented in the EU REACH registration dossiers. For example:

- Vapour pressure estimates were based on the melting point for solid substances, for example, high melting point substances (>100°C) were given a minimum vapour pressure value as a worst-case scenario.
- To interpret the water solubility of inorganic substances, highly water-soluble substances were assumed to partition into the water phase, and poorly water-soluble substances were assumed to partition to solid phases.
- If a range was reported for K_{OW} or K_{OC}, a value was selected based on the middle of the range, or a value from calculated methods was selected if it lay within the reported range. For ionisable substances, the log K_{OW} value at pH 6-7 was selected, where available.
- For complex substances with many constituents, it was often found that either a range of values or limit values were presented for some properties. In such cases the worst-case values were used and/or estimates were derived based on the CAS number (for equilibrium constants).

3.2.2 Distribution and degradation data

While physicochemical data are useful for modelling the distribution of a substance in the environment, the following data, where available, take precedence:

• K_{OC};

• Fish bioconcentration factor (BCF).

Degradation data for biodegradability were prioritised over abiotic degradation data. Environment Agency (2003) additionally collected photodegradation (including photo-oxidation) data. Based on the sources available (see Section 3.1), it appears that few of the organic FR substances are significantly degradable (excluding acid anhydrides undergoing rapid hydrolysis). As noted by Pinfa (n.d.), “chemical stability is a prerequisite to ensure durability”. Stability of FR compounds over several years or even decades allows their FR properties to be preserved throughout the lifetime of an article, therefore a general low degradability is not unexpected. Quantitative data for environmental half-life under relevant conditions are generally scarce, with almost no photodegradation data (which is not a REACH-required endpoint), or detailed reporting of hydrolysis.

For inorganic substances, the K_{OW} is often not determined. In this situation, adsorption evidence and bioconcentration factors (BCF) for fish and earthworms are essential if exposure calculations are to be carried out:

- If a range was reported for K_{OC}, a value was selected based on the middle of the range, or a value from calculated methods was selected if it lay within the reported range.
- The highest BCF values were generally used, as a worst-case scenario.

Potential for mobility in the environment is assessed based on the K_{OC} value, and can indicate the potential for a persistent, toxic chemical to enter groundwater. The present scoping review has applied the EU criteria for Mobility as part of the classification and labelling of PMT/vPvM substances under CLP (EC, 2023): “*A substance shall be considered to fulfil the mobility criterion (M) when the log K_{OC} is less than 3. For an ionisable substance, the mobility criterion shall be considered fulfilled when the lowest log K_{OC} value for pH between 4 and 9 is less than 3. … A substance shall be considered to fulfil the ‘very mobile’ criterion (vM) when the log K_{OC} is less than 2. For an ionisable substance, the mobility criterion shall be considered fulfilled when the lowest log K_{OC} value for pH between 4 and 9 is less than 2.*” Although these criteria do not apply in UK REACH, they have been included to provide supplementary information on potential environmental hazards.

3.2.3 Ecotoxicity data

For simplicity, the data collation focused on predicted no-effect concentrations (PNECs) reported in EU REACH registrations where available, as well as environmental classification and labelling (C&L) under CLP (both mandatory under GB CLP and/or harmonised (ECHA, 2022c) and self-classified by EU REACH lead registrants applicable to joint registrations). This approach does not necessarily compare substances on an equal basis, because PNECs and hazard classification are influenced by the nature of the dataset. However, it allows a screening assessment of hazard and risk across a large number of substances to be performed. Other sources of PNEC information (e.g. the NORMAN Network database: https://www.norman-network.com/nds/ecotox/lowestPnecsIndex.php) were not consulted, because the derivation method differs from UK REACH.

Where absent, effects data were sought from other sources. In a small number of cases, it was considered appropriate to read-across PNEC conclusions from one substance to another: when two substances on the list use the same chemical identifiers (e.g. CAS No. 181028-79-5 and 5945-33-5); when ECHA reroutes a search for one substance to the dataset for another, indicating ECHA considers them to be the same substance; or when single PNECs were presented for a multi-constituent substance, they were used for each constituent.

In general, only data summaries have been accessed, and the adequacy of the underlying approach and datasets were not reviewed for reliability. Given the REACH context the hazard properties and conclusions relate generally to those datasets required for compliance with REACH. Environment Agency (2003) compiled ecotoxicity data from a range of sources because at that time relatively few substances had PNEC values or classification and labelling information in the public domain. Additional research was therefore a necessary step for the purpose of conducting simple environmental hazard and risk assessments. It was not necessary to use these data in the current project as the only substances which did not have PNEC values and CLP conclusions in REACH datasets were substances for which no ecotoxicity data were available for the 2003 report either.

3.2.4 Mammalian toxicity data and human health

Data collection focused on $PNEC_{oral}$ values for predators exposed via the food chain and derived no-effect level (DNEL) values for humans (consumers/members of the general population) exposed long-term orally or via inhalation. These were taken from the EU REACH registration dossiers, where available. Information on human health classifications under CLP was also collated (both mandatory under GB CLP and/or harmonised under EU CLP (ECHA, 2022c), and self-classified by EU REACH lead registrants applicable to joint registrations). Particular attention was given to classification for carcinogenicity, mutagenicity or reproductive toxicity, and specific target organ toxicity following repeated exposure. These human health hazard classes are one element of the toxicity evaluation in PBT assessment. Hazard conclusions for other human health endpoints such as skin and respiratory sensitisation were not collated because they are not relevant to environmental concerns.

Where absent, effects data were sought from other sources. As for the environmental PNEC conclusions, it was considered appropriate to read-across DNEL conclusions from one substance to another in a small number of cases.

Environment Agency (2003), which pre-dated EU REACH, required a wider literature search. At that time, the approach taken was to search the publicly available databases (such as HSDB, IRIS, CCRIS and IUCLID 2000) for mammalian and genetic toxicity data, in addition to literature sources provided by the Environment Agency and Industry.

The Advisory Group drew attention to the topic of developmental neurotoxicity of organophosphate ester (OPE) substances. COT published a statement about this in 2019 (COT, 2019). This has not been considered directly for this report, but both mandatory /

harmonised and self-classifications for reproductive and developmental toxicity under CLP have been recorded, which should include cases where classifiable effects were observed in the available studies. It is noted that there is an increasing body of literature, with numerous publications released within the last 3 years. Notably this includes Zhao *et al*. (2022) (reporting on epidemiological studies reporting associations between early life exposure to OPE FRs and effects) and Patisaul *et al*. (2021) (a review which has used the framework of Adverse Outcome Pathways (AOP) to organise and illustrate key events and evidence).

3.2.5 Endocrine disruption effects

Substances are defined as having endocrine disrupting (ED) properties if they meet the following criteria (WHO/IPCS, 2002; ECHA and EFSA 2018):

- "*It shows an adverse effect in [an intact organism or its progeny]/[non-target organisms], which is a change in the morphology, physiology, growth, development, reproduction or life span of an organism, system or (sub)population that results in an impairment of functional capacity, an impairment of the capacity to compensate for additional stress or an increase in susceptibility to other influences;*
- *It has an endocrine mode of action, i.e. it alters the function(s) of the endocrine system;*
- *The adverse effect is a consequence of the endocrine mode of action.*"

ED properties are recognised as a significant concern under EU and UK chemical legislation. Several "Substances of Very High Concern" (SVHCs) have been identified under UK and EU REACH based on their ED properties. Two new hazard classes for ED properties have also recently been adopted under the EU CLP Regulation (EC, 2023). Regulatory guidance currently prioritises ED in vertebrates, focusing on estrogenic, androgenic, thyroid and steroidogenic modalities (ECHA and EFSA, 2018; OECD, 2018). However, a future roadmap for identifying ED properties in invertebrates has been suggested (Crane *et al*., 2022).

A decision about the relevance of ED properties for any given substance requires a thorough review of the available (eco)toxicity data. This was beyond the scope of this project, so a simplified approach was adopted for screening purposes. This involved a comparison of the CAS numbers, EC numbers and substance names against five sources that list substances either known to have ED properties or under regulatory investigation due to suspected ED properties: the EC (2000) Endocrine Disruptors Priority list, the list of substances assessed by the ECHA Endocrine Disruption Expert Group (ECHA, 2022d), the UN Environmental Programme (2017a;b;c) Endocrine Disruption reports, Endocrine Disruption lists (Danish Environmental Protection Agency, 2022) and the Danish Endocrine Disruptors list (Danish Centre on Endocrine Disrupters, 2017). The appearance of a substance on these lists is taken to indicate that it is has been (or will be) reviewed by a panel of ED experts. However, this does not mean that the same conclusions would be drawn by UK experts.

Two additional sources – the TedX list (2018) and SIN list (2022) – use peer-reviewed scientific literature data to indicate that a substance may have endocrine disrupting properties. The TedX list is no longer kept up to date. Although these sources were searched, they do not provide definitive evidence that substances have ED properties within the context of the available regulatory guidance.

Based on these searches, eight substances are undergoing regulatory investigation of ED properties:

- 1,3,5-triazine-2,4,6-triamine,
- TBBPA,
- boric acid,
- MCCPs,
- phenol, isopropylated, phosphate (3:1),
- tetraphenyl m-phenylene bis(phosphate),
- reaction products of phosphoryl trichloride and 2-methyloxirane, and
- triphenyl phosphate.

Eight additional substances were identified as potentially having ED properties according to the TedX list, at one biological level for each substance (e.g. interaction with nuclear receptors):

- ammonium chloride,
- ammonium sulfate,
- magnesium chloride,
- tetrakis(hydroxymethyl)phosphonium sulfate (2:1),
- tributyl phosphate,
- tris(2-butoxyethyl) phosphate,
- zinc chloride, and
- zinc oxide.

A further substance, 1,1'-oxybis[2,3,4,5,6-pentabromobenzene], was included on the SIN list due to potential ED properties.

3.3 Commentary on the approach taken

The data gathering for this scoping exercise, particularly on toxic hazard, has mainly focussed on data available from EU REACH registration dossiers and other EU-based regulatory resources (covering around 90% of the data considered), which allows assessment of a relatively large number of substances.

An exhaustive literature review was outside the scope of the project. Advisory Group commentators have noted that there are hundreds of papers in the scientific literature reporting developmental, metabolic, neurotoxic, ED and other effects of FRs and that many *in vivo* studies in the scientific literature show effects at environmentally relevant concentrations (Advisory Group written comments, 2023). These could be considered as part of any follow-up work on specific substances or groups. Nevertheless, selected published reviews, including those of UK relevance which were highlighted by the Advisory Group, have been checked within this project.

Supply tonnages in both UK and EU REACH registration dossiers are expressed in broad bands to protect commercial confidentiality (e.g. 10 to 100 tonnes/year). This report has taken a precautionary approach based on the maximum potential tonnage for each substance gathered in the market research phase. This represents an evidence-based worst-case scenario, but likely overestimates the actual levels of exposure. This is compounded by the use of generic tonnage splits for different applications.

In addition, it is important to highlight that the Northern Irish market is not reflected in this assessment, although it is unlikely that substances have been missed, and supply volumes will be relatively small relative to the rest of the UK.

The impact of co-exposure with other substances (including any combined use of two or more FRs in the same product or article), or exposure via particulates or microplastics, has not been evaluated.

(Eco)toxicity data considered by REACH registrants will normally be limited to the standard information requirements at the relevant tonnage level. Evidence from human studies, non-standard test species and effects associated with very long-term chronic exposures, if available, may not be summarised for REACH compliance purposes. Although this means that the dataset may not cover all aspects of hazard, comparable evidence should be available allowing for screening level prioritisation on a relative basis, at least within tonnage bands. The type of studies required for REACH registration and used as the basis for deriving PNECs and DNELs generally focus on identifying the concentrations or doses at which no (or low) adverse effects occur in the context of the endpoints studied and the associated test guidelines. This provides a level of consistency when trying to reach an understanding of the magnitude of the hazard or risks. Nevertheless, it is accepted that some strategies for understanding (or predicting) hazard may not be covered.

Some FRs are REACH-registered under different chemical identifiers (names and CAS numbers) than those used in the past (and frequently still used in the scientific literature). One example is “reaction products of phosphoryl trichloride and 2-methyloxirane” (EC no: 807-935-0; CAS no. 1244733-77-4), which prior to REACH was commonly known as tris(2-chloroisopropyl)phosphate, CAS no. 13674-84-5 (TCIPP or TCPP). This needs to be borne in mind if more in-depth literature searching and data evaluation is performed as a follow-up to this project.

3.4 General analysis of the information collected

The substances identified as GB-relevant FRs (Groups (a), (b) and (c); see Section 1.2 and 3.1) are listed in Table 3.2 and Table 3.3, including alternative names used in the scientific literature (Environment Agency, 2003; Bergman *et al.*, 2012; Bevington *et al.*,

2022) where relevant. The following market analysis discussion focuses on Group (a) and (b) substances.

The research undertaken shows that the 73 FRs manufactured or imported for supply in GB in 2022 are diverse in type and include seven brominated and three chlorinated FRs, 19 organophosphorus and two halogenated organophosphorus, 37 inorganic FRs, four nitrogen-based FRs, and one uncategorised organic FR.

Sections 3.4.1 to 3.4.3 summarise the most important data gaps reported in Environment Agency (2003) and comments on the findings of the current project in respect of the same topics.

The following current data were collated for the 73 GB-relevant FRs, covering the different chemical substance categories detailed in Section 2.3:

- Candidate List status under EU REACH;
- Use tonnage in the EU and UK;
- Uses as described in the EU REACH database of registered substances; and whether the substance is used as an additive or reactive FR.

Inorganic substances make up half and organophosphorus FRs around a quarter of the GB inventory (in terms of number of substances, not supply volume):

- Inorganic (51%)
- Organophosphorus (26%)
- Brominated organic (10%)
- Nitrogen-based (5%)
- Chlorinated organic (4%)
- Halogenated organophosphorus (3%)
- Other organic (1%)

Table 3.2 **Substances screened as GB-relevant based on a UK REACH registration (Groups (a) and (b))**

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
Brominated flame retardants			
84852-53-9	284-366-9	1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene]	1,1'-Ethane-1,2-diylbis(pentabromobenzene); Decabromodiphenyl ethane; DBDPE; BDPE-209; 1,2-bis(pentabromophenyl) ethane, EBP
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidene-diphenol	3,3',5,5'-Tetrabromobisphenol A; Tetrabromobisphenol A; TBBPA; 2,2-Bis(3,5-dibromo-4-hydroxyphenyl)propane; 2,2-Bis(4-hydroxy-3,5-dibromophenyl)propane
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Pentaerythritol dibromide; Dibromoneopentyl glycol; 2,2-Bis(bromomethyl)-1,3-propanediol; 1,3-Dibromo-2,2-bis(hydroxymethyl)propane; DBPT; DBNPG; bBMe-PrDiOH
3234-02-4	221-779-5	2,3-Dibromo-2-butene-1,4-diol	
26040-51-7	247-426-5	Bis(2-ethylhexyl) tetrabromophthalate	Bis(2-ethylhexyl) tetrabromophthalate; TeBrDEHP; BEH-TEBP; Phthalic acid, tetrabromo-, bis(2-ethylhexyl) ester
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	
632-79-1	211-185-4	Tetrabromophthalic anhydride	4,5,6,7-Tetrabromo-1,3-Isobenzofurandione; 3,4,5,6-Tetrabromophthalic anhydride; Phthalic anhydride, tetrabromo- (6CI,7CI,8CI);

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
			4,5,6,7-Tetrabromobenzofuran-1,3-dione; TBPA; TEBP-Anh; TeBPht-Anh
Chlorinated flame retardants			
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Chlorendic anhydride
85535-85-9	287-477-0	Chloroalkanes, C14-17	Cercelor S 52; Medium chain chlorinated paraffins (C14-17); MCCP; MCCPs
63449-39-8	264-150-0	Paraffin waxes, chloro	Chlorinated paraffins; Paraffin waxes and hydrocarbon waxes, chloro; Long-chain chlorinated paraffins; LCCPs
Halogenated organophosphorus flame retardants			
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester	Phosphoric acid, 2,2-bis(chloromethyl)-1,3-propanediyl tetrakis(2-chloroethyl) ester; 2,2-Bis(chloromethyl)-1,3-propanediol bis[bis(2-chloroethyl) phosphate]; Phosphoric acid, 2,2-bis(chloromethyl)-1,3-propanediyl tetrakis(2-chloroethyl) ester (9CI); Phosphoric acid, bis(2-chloroethyl) ester, diester with 2,2-bis(chloromethyl)-1,3-propanediol (7CI); BCMP-BCEP; bCMePrDiOHbbCEtP; 2,2-bis(chloromethyl)trimethylene bis(bis(2-chloroethyl)phosphate); V6
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCPP)	Tris(2-chloroisopropyl)phosphate; Tris(2-chloroisopropyl) phosphate; 2-Propanol, 1-chloro-, phosphate (3:1); Fyrol PCF;

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
			TCPP; TCIPP; tCiPP; Tris (2-chloroisopropyl) phosphate; CAS no: 13674-84-5.
Inorganic flame retardants			
12251-53-5	235-487-0	Aluminate ($Al(OH)_4^{1-}$), sodium, (T-4)-	Aluminium sodium tetrahydroxide
21645-51-2	244-492-7	Aluminium hydroxide	Aluminium trihydroxide; ATH
1344-28-1	215-691-6	Aluminium oxide	Alumina
1302-42-7	215-100-1	Aluminium sodium dioxide	Sodium aluminate
12125-02-9	235-186-4	Ammonium chloride	
7722-76-1	231-764-5	Ammonium dihydrogenorthophosphate	Ammonium phosphate
7773-06-0	231-871-7	Ammonium sulphamidate	Ammonium sulfamate
7783-20-2	231-984-1	Ammonium sulphate	Ammonium sulfate
1309-64-4	215-175-0	Antimony oxide (Sb_2O_3)	Antimony III oxide
1318-23-6	215-284-3	Boehmite ($Al(OH)O$)	
10043-35-3	233-139-2	Boric acid	H_3BO_3
1303-86-2	215-125-8	Boron oxide (B_2O_3)	Boric oxide; Diboron trioxide
1330-43-4	215-540-4	Boron sodium oxide ($B_4Na_2O_7$)	Sodium tetraborate ($Na_2B_4O_7$)
12767-90-7	235-804-2	Boron zinc oxide ($B_6Zn_2O_{11}$)	Zinc borate (ZnO_3 $2B_2O_3$)
10043-52-4	233-140-8	Calcium chloride ($CaCl_2$)	
1305-62-0	215-137-3	Calcium dihydroxide	Calcium hydroxide
7783-28-0	231-987-8	Diammonium hydrogenorthophosphate	Diammonium hydrogen phosphate; Diammonium phosphate

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
1314-60-9	215-237-7	Diantimony pentoxide	Antimony pentoxide; Antimony V oxide
1314-56-3	215-236-1	Diphosphorus pentaoxide	Phosphorus pentoxide
7782-42-5	231-955-3	Graphite	
7786-30-3	232-094-6	Magnesium chloride ($MgCl_2$)	
1309-42-8	215-170-3	Magnesium hydroxide	
12411-64-2	235-650-6	Molybdate ($Mo_8O_{26}^{4-}$), ammonium (1:4)	Tetraammonium octamolybdate; Ammonium octamolybdate; AOM
7789-82-4	232-192-9	Molybdate (MoO_4^{2-}), calcium (1:1), (T-4)-	Calcium molybdate(VI)
1313-27-5	215-204-7	Molybdenum trioxide	
7723-14-0	231-768-7	Phosphorus	Red phosphorus
7631-86-9	231-545-4	Silicon dioxide	Silica
7727-43-7	231-784-4	Sulfuric acid, barium salt (1:1)	Barium sulfate
12777-87-6	235-819-4	Sulfuric acid, compd. with graphite (1:?)	Sulfuric acid--methane (1/1)
12027-96-2	404-410-4	Tin(4+) zinc(2+) hexahydroxide	Tin zinc hydroxide ($ZnSn(OH)_6$)
16919-27-0	240-969-9	Titanate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	Dipotassium hexafluorotitanate; Potassium fluorotitanate
7550-45-0	231-441-9	Titanium chloride ($TiCl_4$) (T-4)-	Titanium tetrachloride
1314-35-8	215-231-4	Tungsten trioxide	
7646-85-7	231-592-0	Zinc chloride ($ZnCl_2$)	
1314-13-2	215-222-5	Zinc oxide	
12036-37-2	405-290-6	Zinc stannate	Tin zinc oxide ($SnZnO_3$)

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
16923-95-8	240-985-6	Zirconate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	Dipotassium hexafluorozirconate(2-); Potassium fluorozirconate
Nitrogen-based flame retardants			
123-77-3	204-650-8	1,2-Diazenedicarboxamide	Azodicarbonamide
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Melamine
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	6-Phenyl-1,3,5-triazine-2,4-diamine
1271172-98-5	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Diphosphoric acid, zinc salt, compd. with 1,3,5-triazine-2,4,6-triamine (1:1:2)
Organophosphorus flame retardants			
5945-33-5[3]	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	
2809-21-4	220-552-8	Etidronic acid	
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Triphenyl phosphates isopropylated; Tris(isopropylphenyl) phosphate
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	
1241-94-7	214-987-2	Phosphoric acid, 2-ethylhexyl diphenyl ester	2-Ethylhexyl diphenyl phosphate; 2EHDPP

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
181028-79-5[3]	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	
101-02-0	202-908-4	Phosphorous acid, triphenyl ester	Triphenyl phosphite; TPP
	945-730-9	Reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate	Cresyl diphenyl phosphate[4]
68937-40-6	700-990-0	Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate	Triphenyl phosphates tert-butylated
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Phosphoric acid, P,P'-1,3-phenylene P,P,P',P'-tetrakis(2,6-dimethylphenyl) ester; Resorcinol bis[di(2,6-dimethylphenyl) phosphate]; Phosphoric acid, 1,3-phenylene tetrakis(2,6-dimethylphenyl) ester (9CI); 1,3-

[3] The flame retardants inventory collated by Bevington *et al.* (2022) lists the substances with CAS nos. 181028-79-5 and 5945-33-5 as separate substances, and during the early phases of this project they were listed separately in the UK REACH grandfathered substances list. By the end of this project, they are listed as one entry with the same EC number in both the UK and EU REACH databases. For the purpose of this analysis, they have been kept as separate items.

[4] The CAS number 26444-49-5 and EC number 247-693-8 have previously been associated with this substance name (Environment Agency, 2003; 2009).

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
			Phenylenebis(2,6-dimethylphenyl phosphate); PBDMPP; RebDiDiMePhP
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Tetrakis(hydroxymethyl)phosphonium sulfate; THPS
27104-30-9	500-057-6	Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	Tetrakis(hydroxymethyl)phosphanium carbamimidate--hydrogen chloride (1/1/1); Tetrakis-hydroxymethyl phosphonium chloride based prepolymer
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Tetraphenyl m-phenylene bis(phosphate); Resorcinol bis(diphenyl phosphate); Phosphoric acid, 1,3-phenylene tetraphenyl ester (9CI); 1,3-Phenylene bis(diphenyl phosphate); PBDPP; RebDiPhP; Resorcinol bis-diphenylphosphate
126-73-8	204-800-2	Tributyl phosphate	Tris(butyl) phosphate; Tri-n-butyl phosphate; MCS2495; TnBP; TNBP; tBuP; TBP
78-40-0	201-114-5	Triethyl phosphate	Tris(ethyl) phosphate; Ethyl phosphate; TEP; tEtP
115-86-6	204-112-2	Triphenyl phosphate	Tris(phenyl) phosphate; Phosphoric acid, triphenyl ester; TPP; TPHP; TPhP; tPhP

CAS number	EC number	Substance name used in UK REACH	Other names and common abbreviations
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate [5]	Ethanol,2-butoxy-, phosphate (3:1); Phosphoric acid, tris(2-butoxyethyl)ester; TBEP; TBOEP; tBuOEtP
25155-23-1	246-677-8	Trixylyl phosphate[6]	Trixylenyl phosphate; TXP
Other organic flame retardants			
115-77-5	204-104-9	Pentaerythritol	2,2-Bis(hydroxymethyl)-1,3-propanediol

Table 3.3 Substances screened as GB-relevant based on a DUIN and/or advice from project Advisory Group (Group (c))

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
Brominated organic flame retardants			
59447-55-1	261-767-7	(Pentabromophenyl)methyl acrylate	2,3,4,5,6-Pentabromobenzyl acrylate; 2-Propenoic acid, (2,3,4,5,6-pentabromophenyl)methyl ester; (2,3,4,5,6-Pentabromophenyl)methyl prop-2-enoate; Halogenated benzyl ester acrylate; PBMA

[5] Information provided by stakeholders through consultation activities indicated that this substance is not currently used as an FR (Advisory Group comments, 2024).

[6] Information shared by stakeholders through consultation activities indicated that this substance is used in the EU primarily as a hydraulic fluid in power plants and aircraft, and it is no longer used as an FR.

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
97416-84-7	306-832-3	1,1’-(Isopropylidene)bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)-benzene)	1,1’-(1-Methylethylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)]-benzene; Benzene, 1,1’-(1-methylethylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)-; Pyroguard SR-130, SR-130; AP 1300 S; Ecoflame B-972; FR130; 2,2-Bis[3,5-dibromo-4-(2,3-dibromo-2- methylpropoxy)propane]
1163-19-5	214-604-9	1,1’-Oxybis[2,3,4,5,6-pentabromobenzene][7]	Bis(pentabromophenyl) ether; decabromodiphenyl ether; DecaBDE; 1,1’-Oxybis(pentabromobenzene); 1,2,3,4,5-Pentabromo-6-(2,3,4,5,6-pentabromophenoxy)benzene; 2,3,4,5,6-Pentabromo-1-(2,3,4,5,6-pentabromophenoxy)-benzene; Decabromodiphenyl oxide; FR-1210, BDE-209
32588-76-4	251-118-6	1,2-Bis(tetrabromophthalimido)ethane	1H-Isoindole-1,3(2H)-dione, 2,2 -(1,2-ethanediyl)bis[4,5,6,7-tetrabromo-; 2,2'-(1,2-Ethanediyl)bis[4,5,6,7-tetrabromo-1H-isoindole-1,3(2H)-dione]; N,N'-Ethylenebis(3,4,5,6-tetrabromophthalimide); 2,2'-Ethane-1,2-diylbis(4,5,6,7-tetrabromo-1H-isoindole-1,3(2H)-dione); Ethylene bis(tetrabromophthalimide); N,N'-Ethylene-bis-(tetrabromo-phthalimide); N,N'-Ethylenebis (3,4,5,6-tetrabromophthalimide); N,N'-Ethylenebis(tetrabromophthalimide); Tetradec-1-ene; 4,5,6,7-Tetrabromo-2-[2-(4,5,6,7-tetrabromo-1,3-dioxo-2,3-dihydro-1H-isoindol-2-yl)ethyl]-2,3-dihydro-1H-isoindole-1,3-dione; SAYTEX BT93 Flame Retardant

[7] This substance is a restricted POP and may be imported for specific exempted uses (UNEP, 2019a).

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
52434-90-9	257-913-4	1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione	1,3,5-Triazine-2,4,6(1H,3H,5H)-trione, 1,3,5-Tris(2,3-dibromopropyl)-; 1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazinane-2,4,6-trione; Tris(2,3-dibromopropyl) Isocyanurate; tris(2,3-dibromopropyl)-1,3,5-triazinane-2,4,6-trione, AP 729
3072-84-2	221-346-0	2,2’-[(1-Methylethylidene)bis[(2,6-dibromo-4,1-phenylene)-oxymethylene]]bis[oxirane]	2,2',6,6'-Tetrabromobisphenol A diglycidyl ether; Oxirane, 2,2'-[(1-methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxymethylene]]bis-; 2-[[2,6-dibromo-4-[2-[3,5-dibromo-4-(oxiran-2-ylmethoxy)phenyl]propan-2-yl]phenoxy]methyl]oxirane; F-2200 HM
118-79-6	204-278-6	2,4,6-Tribromophenol	Phenol, 2,4,6-tribromo-; FR-613; TBP; Tribromophenol
25713-60-4	426-040-2	2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine	1,3,5-Triazine, 2,4,6-tris(2,4,6-tribromophenoxy)-; 2,4,6-Tris(2,4,6-tribromophenoxy)-1,3,5-triazine; Tristriazine
68441-62-3	614-503-3	2-Butyne-1,4-diol, polymer with 2-(chloromethyl)oxirane, brominated, dehydrochlorinated, methoxylated[a]	Halogenated polyetherpolyol B 350; IXOL B350
40039-93-8	500-107-7	3,5,3',5'-Tetrabromobisphenol A, epichlorohydrin polymer[a]	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol, oligomeric reaction products with 1-chloro-2,3-epoxypropane; 4,4'-(1-Methylethylidene) bis[2,6-dibromophenol polymer with (chloromethyl) oxirane; Octene; Phenol, 4,4'-(1-methylethylidene)bis[2,6-dibromo-, polymer with 2-(chloromethyl)-oxirane; Polymer, phenol, 4,4'-(1-methylethylidene)bis-[2,6-dibromo with (chloromethyl) oxirane; TBBA-epichlorhydrin oligomer; Tetrabromobisphenol-A glycidyl ether; Bisphenol A diglycidyl ether, brominated; Diglycidylether of Tetrabromobisphenol A, oligomeric mixture; Reaction mass

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
			of 2,2'-[(1-methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxymethylene]]bisoxirane and ‘2,2',6,6’-tetrabromo-4,4'-isopropylidenediphenol, oligomeric reaction products with 1-chloro-2,3-epoxypropane; Tetrabromo-bisphenol-A-epoxy resin; D.E.R.* 560 Epoxy Resin; YDB-400
158725-44-1	500-399-6	4,4'-(1-Methylethylidene)bis[2,6-dibromophenol] polymer with (chl oro-methyl)oxirane and 2,4,6-tribromophenol[a]	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol, oligomeric reaction products with 1-chloro-2,3-epoxypropane and 2,4,6-tribromophenol; F-3014; Phenol, 4,4'-(1-methylethylidene)bis[2,6-dibromo-, polymer with (chloromethyl)oxirane and 2,4,6-tribromophenol
-	944-461-4	Reaction mass of 1,1’-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)-benzene] and 1,3-dibromo-2-(2,3-dibromo-2-methylpropoxy)-5-{2-[3,5-dibromo-4-(2,3,3-tribromo-2-methylpropoxy)phenyl]propan-2-yl}benzene	Pyroguard SR-130
21850-44-2	244-617-5	Tetrabromobisphenol A-bis(2,3-dibromopropyl ether)	1,1'-(Isopropylidene)bis[3,5-dibromo-4-(2,3-dibromopropoxy)benzene]; 1,1'-(1-Methylethylidene)bis[3,5-dibromo-4-(2,3-dibromopropoxy); 2,2-Bis[3,5-dibromo-4-(2,3-dibromopropoxy)phenyl] propane; Benzene, 1,1'-(1-methylethylidene)bis[3,5-dibromo-4-(2,3-dibromopropoxy)-; Bis(2,3-dibromopropyl ether); Dibromopropylether; TBBA-(2,3-dibromo-propyl-ether); Tetrabromobisphenol A bis(2,3-dibromopropyl ether); FR-720; TBBA; AP 1968; AP 1968G; AP 1968P; BDDP

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
77098-07-8	616-436-5	Tetrabromophthalic acid mixed esters with diethylene glycol and propylene glycol	1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-, mixed esters with diethylene glycol and propylene glycol; 3,4,5,6-Tetrabromo-1,2-benzenedicarboxylic acid, mixed esters with diethylene glycol and propylene glycol; 3,4,5,6-Tetrabromophthalic anhydride, diethylene glycol, propylene oxide reaction products
36483-57-5	253-057-0	Tribromoneopentyl alcohol	TBNPA; 2,2-Dimethylpropan-1-ol, tribromo derivative; 3-Bromo-2,2-bis(bromomethyl)propan-1-ol
Chlorinated organic flame retardants			
117-08-8	204-171-4	Tetrachlorophthalic anhydride	1,3-Dioxy-4,5,6,7-tetrachloroisobenzofuran; 1,3-Isobenzofurandione, 4,5,6,7-tetrachloro-; 4,5,6,7-Tetrachloro-1,3-isobenzofurandione; Niagathal; Phthalic anhydride, tetrachloro-; Tetrathal; NU 460T
Halogenated organophosphorus flame retardants			
1047637-37-5	809-920-4	2,2-Bis(chloromethyl)-1,3-propanediyl tetrakis(1-chloro-2-propanyl) bis(phosphate)	2.2-(Bis(chloromethyl)trimethylene bis(bis(2-chloro-1-methylethyl)phosphate)
13674-87-8	237-159-2	Tris(1,3-dichloro-2-propyl) phosphate	TDCPP; 1,3-Dichloro-2-propanol phosphate (3:1); 2-Propanol, 1,3-dichloro-, 2,2',2''-phosphate; 2-Propanol, 1,3-dichloro-, phosphate (3:1); CRP; Emulsion 212; Fosforan troj-(1,3-dwuchloroizopropylowy); Fyrol FR-2; PF 38; PF 38/3; Phosphoric acid, tris(1,3-dichloro-2-propyl) ester; TDCP; TDCIPP; Tri(beta,beta'-dichloroisopropyl)phosphate; Tris(1,3-dichloro-2-propyl)phosphate; Tris(1,3-dichloroisopropyl)phosphate; Tris(1-chloromethyl-2-chloroethyl)phosphate; Tris(2-chloro-1-(chloromethyl)ethyl)phosphate; Amgard TDCP; Antiblaze

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
			195; Antiblaze TDCP; FR2; Fyrol FR-2; PhireGuard EL-22; Phosphoric acid, Tolgard TDCP; Tolgard TDCP MK1
Inorganic flame retardants			
7784-22-7	479-150-8	Aluminum hypophosphite	Aluminium(3+) triphosphinate; Phoslite IP-A; Phosphinic acid, aluminum salt (3:1); Aluminum;phosphenous acid; Phosphinic acid, aluminum salt (3:1)
13530-50-2	236-875-2	Aluminum phosphate ($Al(H_2PO_4)_3$)	Aluminium tris(dihydrogen phosphate); Phosphoric acid, aluminum salt (3:1); Aluminium tris(dihydrogen phosphate) 35% becopal ADP; Aluminiumphosphat; Monoaluminium phosphate; Monobasic aluminium phosphate; Fosbind; Resbond adhesive, Duralco Coating; Solupray A 1350 P
12124-97-9	235-183-8	Ammonium bromide	Ammonii bromidum; Hydrobromic acid monoammoniate; Nervine
68333-79-9	269-789-9	Ammonium polyphosphates	Polyphosphoric acids, ammonium salts; Ammonium polyphosphate; IP65; Polifosforan amonu; Trihydroxidooxidophosphorus, phosphoric acid; Undecaammonium bis(phosphonooxy)phosphinate dihydrogen phosphate hydrogen (phosphonooxy)phosphonate hydrogen phosphate
13701-59-2	237-222-4	Barium metaborate	Barium borate; Barium boron oxide; Barium diboron tetraoxide; BBO (optical crystal); Boric acid (HBO2), barium salt; Boric acid (HBO2), barium salt (2:1); Busan 11M1; Barium diborate monohydrate; Barium diboron tetraborate; Barium(2+);oxido(oxo)borane
13308-51-5	236-337-7	Boron phosphate ($B(PO_4)$)	Boron orthophosphate; 2,4,5-Trioxa-1λ{5}-phospha-3-borabicyclo[1.1.1]pentan-1-one; 2,4,5-Trioxa-1λ^5-phospha-3-borabicyclo[1.1.1]pentane 1-oxide; Boron phosphate hydrate; Boron(+3) cation phosphate; Boron(3+) phosphate

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
58398-71-3	261-235-4	Calcium magnesium dihydroxide oxide	Calce idrata dolomitica; Calcium dimagnesium(2+) ion tetrahydroxide oxidandiide; Calcium dimagnesium(2+) Tetrahydroxide oxidandiide; Calcium magnesium dihydroxide; Calcium magnesium hydroxide oxide; Calcium;magnesium;oxygen(2-);dihydroxide; Batidol; Calce dolomitica semiidrata; Calce idrata adesiva; Calce idrata agricola; Calce spenta magnesiaca; Chaux magnésienne éteinte; Depurcal MG; DL 90 S1; Dolomag; Dolomitkalkhydrat; Equidol-S; Hydrat; Hydrated dolomit; Idrato di calce; Idrato dolomitico; Magnesio 32; Neutralac; Ostréidol; Purodol H; Sorbacal; Tradical; Vapno vzdusne dolomiticke hasene
7789-79-9	232-190-8	Calcium phosphinate	Calcium dihydrogen hypophosphite; Calcium hypophosphite; Phosphinic acid, calcium salt; Phosphinic acid, calcium salt (2:1); Calcium bis(phosphinate); Calcium diphosphinate; IPC
15432-85-6	239-444-7	Sodium antimonate	Antimonic acid, sodium salt; Trisodium antimonate; Trisodium stiborate
33908-66-6	251-735-0	Sodium hexahydroxyantimonate(1-)	Antimonate (Sb(OH)61-), sodium, (OC-6-11)-; Sodium hexahydroxoantimonate; Sodium antimonate; Sodium stibanylidyne hexahydroxide
13472-45-2	236-743-4	Sodium tungsten oxide (Na_2WO_4)	Disodium wolframate; Disodium dioxido(dioxo)tungsten; Disodium dioxotungstenbis(olate); Disodium wolframate dihydrate; Sodium dioxido(dioxo)tungsten hydrate (2:1:2); Sodium tungstate; Sodium tungstate dihydrate;
1314-98-3	215-251-3	Zinc sulfide	CVD zinc sulphide; Sulfanylidenezinc; Thioxozinc; Zinc(2+) ion sulfanediide; Zinc(2+) sulfanediide; Zink sulphide; Lithopone; Litopon; Sachtolith

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
Nitrogen-based flame retardants			
37640-57-6	253-575-7	1,3,5-Triazine-2,4,6(1h,3h,5h)-trione, compd. with 1,3,5-triazine-2,4,6-triamine (1:1)	Melamine cyanurate
191680-81-6	425-020-0	1,3-Propanediamine, n1,n1'-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized n-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	Reaction products of N,N'-ethane-1,2-diylbis(1,3-propanediamine), cyclohexane, peroxidized 4-butylamino-2,2,6,6-tetramethylpiperidine and 2,4,6-trichloro-1,3,5-triazine; 1,3-Propanediamine, N1,N1'-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized N-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products; N2-(2-{[4,6-bis({butyl[1-(cyclohexyloxy)-2,2,6,6-tetramethylpiperidin-4-yl]amino})-1,3,5-triazin-2-yl](3-{[4,6-bis({butyl[1-(cyclohexyloxy)-2,2,6,6-tetramethylpiperidin-4-yl]amino})-1,3,5-triazin-2-yl]amino}propyl)amino}ethyl)-N2-(3-{[4,6-bis({butyl[1-(cyclohexyloxy)-2,2,6,6-tetramethylpiperidin-4-yl]amino})-1,3,5-triazin-2-yl]amino}propyl)-N4,N6-dibutyl-N4,N6-bis[1-(cyclohexyloxy)-2,2,6,6-tetramethylpiperidin-4-yl]-1,3,5-triazine-2,4,6-triamine, CGL 116
108-80-5	203-618-0	Cyanuric acid	1,3,5-Triazine-2,4,6-trione (1,3,5-Triazine-2,4,6-triol; Cyanuric acid), inhalable fraction; 1,3,5-Triazin-2,4,6-triol; 1,3,5-Triazin-2,4,6-trion; 1,3,5-triazinane-2,4,6-triol; 1,3,5-Triazinane-2,4,6-trione; 1,3,5-Triazine-2,4,6(1H,3H,5H)-trione; 1,3,5-Triazine-2,4,6-triol; 2,4,6-Trichloro-1,3,5-triazin; 4-Amino-1,2,5-oxadiazole-3-carboxylic acid; CYA; Cyanursäure; Isocyanuric acid / ICA; Tricarbimide; Tricyanic acid; Trihydroxycyanidine
15541-60-3	239-590-1	Diphosphoric acid, compd. with 1, 3,5-triazine-2,4,6-triamine (1:?) [Expected to be: Diphosphoric	Diphosphoric acid - 1,3,5-triazine-2,4,6-triamine (1:1); Diphosphoric acid, compound with 1,3,5-triazine-2,4,6-

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
		acid, compd. with 1,3,5-triazine-2,4,6-triamine (1:1)]	triamine; Melamine prophosphate; Melamine pyrophosphate
839-90-7	212-660-9	Tris(2-hydroxyethyl) isocyanurate[8]	Tris(2-hydroxyethyl)-1,3,5-triazinetrione; 1,3,5-Triazine-2,4,6(1H,3H,5H)-trione, 1,3,5-tris(2-hydroxyethyl)-; 1,3,5-Tris(2-hydroxyethyl) -1,3,5-triazinane-2,4,6-trione; THEIC; THIEC; Tris hydroxyethyl isocyanurate
Organophosphorus flame retardants			
14852-17-6	238-914-9	1,2-Ethanediamine, phosphate	Ethylenediamine, salt with phosphoric acid; Ethane-1,2-diamine; phosphoric acid; Ethylenediamine phosphate
4090-51-1	223-829-1	1,3,2-Dioxaphosphorinane, 2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	2,2'-Oxybis[5,5-dimethyl-1,3,2-dioxaphosphorinane] 2,2'-disulphide; Flame-Retardant-5060; 2-[(5,5-Dimethyl-2-sulfanylidene-1,3,2λ⁵-dioxaphosphinan-2-yl)oxy]-5,5-dimethyl-1,3,2λ⁵-dioxaphosphinane-2-thione; 2-[(5,5-Dimethyl-2-sulfanylidene-1,3,2λ⁵-dioxaphosphinan-2-yl)oxy]-5,5-dimethyl-2-sulfanylidene-1,3,2λ⁵-dioxaphosphinane
41583-09-9	255-449-7	1,3,5-Triazine-2,4,6-triamine, phosphate	1,3,5-Triazine-2,4,6-triamine; phosphoric acid; Melamine phosphate; Phosphoric acid; 1,3,5-triazine-2,4,6-triamine; Reaction product of 1,3,5-triazine-2,4,6-triamine and orthophosphoric acid; Melapur MP1.3; MPT 11
14657-64-8	411-200-6	3-[Hydroxy(phenyl)phosphoryl] propanoic acid	3-(Hydroxyphenylphosphinyl)propanoic acid; Propanoic acid, 3-(hydroxyphenylphosphinyl)-; (2-Carboxyethyl)phenylphosphinic Acid; 3-HPP; HIRETAR-205; IDB 3-HPP; Phoretar 101, IDB 3-HPP

[8] Information provided by stakeholders through consultation activities indicated that this substance may not be used as an FR (Advisory Group comments, 2024).

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
35948-25-5	252-813-7	6h-Dibenzo[c,e][1,2]oxaphosphinine 6-oxide	8-Oxa-9λ^5-phosphatricyclo[8.4.0.0^2,^{7}]tetradeca-1(10),2(7),3,5,11, 13-hexaen-9-one; 9,10-Dihydro-9-oxa-10-phosphaphenanthrene 10-oxide; Benzo[c][2,1]benzoxaphosphinin-6-ium 6-oxide; Dibenz[[1,2]oxaphosphorin 6-oxide; DOPO
225789-38-8	428-310-5	Aluminum diethylphosphinate	Aluminium tridiethylphosphinate; Phosphinic acid, P,P-diethyl-, aluminum salt (3:1); Exolit OP 930; DAPP; Exolit OP 1230 (TP)
298-07-7	206-056-4	Bis(2-ethylhexyl) phosphate	Bis(2-ethylhexyl) hydrogen phosphate; Reaction mass of 2-ethylhexyl dihydrogen phosphate and bis(2-ethylhexyl) hydrogen phosphat; Bis[(2-ethylhexyl)oxy]phosphinic acid
2781-11-5	220-482-8	Diethyl (n,n-bis(2-hydroxyethyl)-amino)methanephosphonate	Diethyl bis(2-hydroxyethyl)aminomethylphosphonate; 2-[Diethoxyphosphorylmethyl(2-hydroxyethyl)amino]ethanol; Fyrol 6; Phosphonic acid, [[bis(2-hydroxyethyl)amino]methyl]-, diethyl ester; Desmophen 4090 N; Levagard 4090 N
78-38-6	201-111-9	Diethyl ethylphosphonate	1-[Ethoxy(ethyl)phosphoryl]oxyethane; Phosphonic acid, ethyl-, diethyl ester
7526-26-3	231-388-1	Diphenyl methylphosphonate	[Methyl(phenoxy)phosphoryl]oxybenzene; DPMP
66034-17-1	457-330-7	Diphosphoric acid, compound wit h piperazine (1:1)	Phosphono dihydrogen phosphate;piperazine; Piperazine pyrophosphate; T-1063FM
	915-680-2	Reaction mass of phosphonic acid, methyl-, bis[(5-ethyl-2-methyl2,2-dioxido-1,3,2-dioxaphosphorinan-5-yl)methyl] ester with (5-ethyl-2-methyl-2-oxido1,3,2-dioxaphosphorinan-5-	Reaction mass of (5-ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl dimethyl phosphonate P-oxide and bis[(5-ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl] methyl phosphonate P,P'-dioxide; Reaction product of trimethylolpropane, trimethyl phosphite and dimethyl methylphosphonate; Amgard CU

CAS number	EC number	Substance name (expected to be) used in UK REACH	Other names and common abbreviations
		yl)methyl methyl methylphosphonate	
126-71-6	204-798-3	Triisobutyl phosphate	Phosphoric acid, tris(2-methylpropyl) ester; TiBP; Tris(2-methylpropyl) phosphate; Tri-iso-butylphosphat; Tri-isobutyl phosphate
78-42-2	201-116-6	Tris(2-ethylhexyl) phosphate	Disflamoll TOF; Phosphoric acid, tris(2-ethylhexyl) ester; TEHP; Tris(2-ethylexyl)phosphate; Trioctylphosphat
1330-78-5	809-930-9	Tris(methylphenyl) phosphate	Lindol XP, Lindol, tricresyl phosphate, Syn-O-Ad 8484; Reaction mass of 3-methylphenyl bis(4-methylphenyl) phosphate and bis(3-methylphenyl) 4-methylphenyl phosphate and tris(3-methylphenyl) phosphate; Trikresylphosphat (TKP); Disflamoll TKP; Disflamoll TKP-P; Durad 125; From CO Reofos 908; From CO TCP/TXP; Kronitex TCP; Kronitex TCP-S; Phosphoric acid tricresyl ester; Phosphoric acid, tris(methylphenyl) ester; PX 3843; TCP; Tricresyl phosphate; Tritolyl phosphate
Other organic flame retardants			
80-43-3	201-279-3	Dicumyl peroxide	Bis(α,α-dimethylbenzyl) peroxide; (Peroxybis(propane-2,2-diyl))dibenzene; 1,1'-(Dioxydipropane-2,2-diyl)dibenzene; 2-(2-Phenylpropan-2-ylperoxy)propan-2-ylbenzene; 8,8'-Dicumenylperoxid; DCP; Dicumyl peroxide{2-[(2-phenylpropan-2-yl)peroxy]propan-2-yl}benzene; PEROXAN DC

Note: a – currently, polymers need not be registered under UK REACH.

3.4.1 Data gaps in use pattern for high tonnage FRs

Environment Agency (2003) identified that 29 substances were on the EU market at or above 1,000 tonnes/year with no indication of the materials or end products in which they are used. The industry consultation as part of that project indicated that "*many of these substances appear not to be flame retardants, but substances that are fire-fighting agents, chemical intermediates or used for other purposes (Great Lakes, 2003)*".

In the current project, tonnage band information was readily available from the UK REACH system. Information on how substance tonnage is split according to different use classes (as FRs) was not available via the UK REACH system, and the market analysis (plus review of publicly available literature) yielded limited quantifiable information on this aspect. This study therefore relies on a series of generic assumptions regarding the tonnage use split for different FR groups/categories (see Section 3.1.4), resulting in a reasonable worst-case scenario estimate. These assumptions were informed by multiple lines of evidence, including data published by a trade association, high level global market data for a major inorganic FR, qualitative information on substance uses presented in regulatory risk assessments, and interviews with industrial stakeholders. While the assumptions adopted are considered broadly representative, there are significant uncertainties in the overall assessment. The data currently available on FR use patterns are limited, and further detailed market analysis would provide greater robustness and certainty for any future risk assessment work.

3.4.2 Data gaps in supply volume for highly toxic FRs

Environment Agency (2003) identified 182 substances with no EU tonnage information. Of these, 35 substances were categorised as toxic based on measured or predicted acute, or measured chronic, ecotoxicity data. Three of the 35 were acutely toxic with $L(E)C_{50}$ values below 1 mg/L based on measured data.

In the current project, UK REACH information meant that supply tonnage was known for all 73 FRs. However, in most cases the tonnage used as a functional FR in specific sectors and product types could not be readily quantified.

3.4.3 Data gaps in core property values for FRs

Environment Agency (2003) reported that 34 substances thought to be on the EU market at 1,000 tonnes/year or more lacked measured vapour pressure, water solubility and/or K_{OW} data.

In the current project, relatively few of the organic FRs (including representative structures and/or constituents, across the full range of supply volumes) required values to be estimated for one or more of these core physicochemical properties. Some properties were predicted for other reasons, for example if there were issues with the available data (e.g. REACH data available but only in the form of a limit value; data needed for a hydrolysis product or representative structure of interest). Where prediction was needed, the endpoint and reason are noted in Table 3.4 below.

Table 3.4 Substances requiring prediction of core physicochemical properties

Substance name	CAS	EC	FR Type	Endpoints	Reason
1,3,5-Triazine-2,4-diamine, 6-phenyl-	91-76-9	202-095-6	N	Vapour pressure	Only limit data at elevated temperature found
4,7-Methano-isobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	204-077-3	C	Vapour pressure	To assess the hydrolysis product of this substance
Pentaerythritol	115-77-5	204-104-9	O	Vapour pressure, K_{OC}	No experimental data found
1,2-Diazenedicarboxamide	123-77-3	204-650-8	N	K_{OW}, K_{OC}	Only limit data found
Tetrabromophthalic anhydride	632-79-1	211-185-4	B	Vapour pressure, water solubility, K_{OW}, K_{OC}	To assess the hydrolysis product of this substance
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	1241-94-7	214-987-2	P	K_{OC}	No experimental data found
2,3-Dibromo-2-butene-1,4-diol	3234-02-4	221-779-5	B	K_{OC}	No experimental data found
2,2-Bis(bromomethyl)-propane-1,3-diol	3296-90-0	221-967-7	B	K_{OC}	Only limit data found
Isodecyl diphenyl phosphate	29761-21-5	249-828-6	P	K_{OC}	No experimental data found
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	P	K_{OC}	No experimental data found
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	432-770-2	P	Water solubility, K_{OC}	Only limit data found
Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	27104-30-9	500-057-6	P	Vapour pressure, water solubility, K_{OW}, Koc	To assess a specific representative structure
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-	68937-40-6	700-990-0	P	K_{OC}	No experimental data found

Substance name	CAS	EC	FR Type	Endpoints	Reason
butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated)					

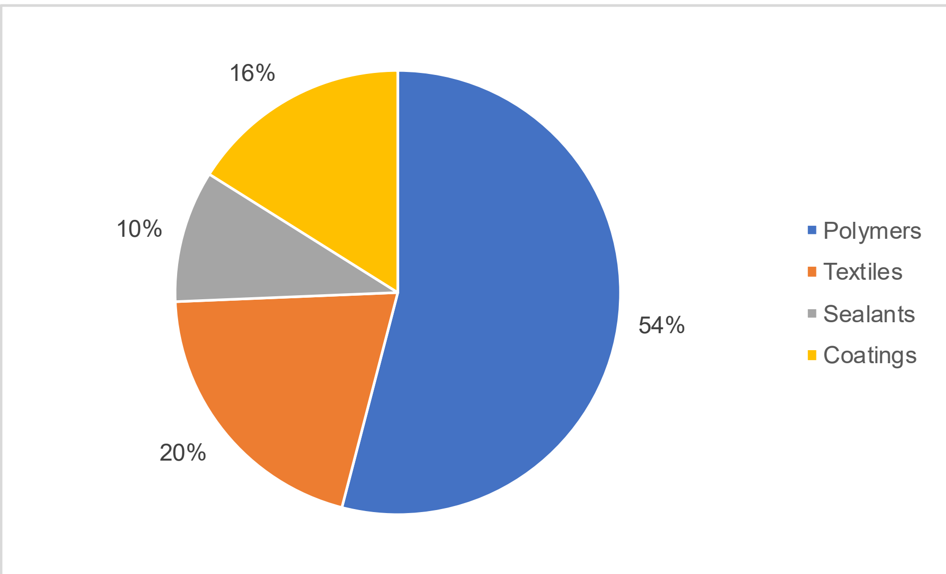
4 Findings relating to GB use patterns of flame retardants

4.1 Applications of flame retardants

Of the 73 GB-relevant FRs identified, almost 80% have applications in polymers, and over 70% are used in coatings. Around 55% are used in sealants. Most (59%) of the substances are used across three or four use categories, with less than a quarter of the database comprising single sector-use substances. This is based on the number of substances identified as having uses in a particular use class.

The split of the total maximum tonnage of FRs by use is illustrated in Figure 4.1. Over half (54%) of the GB FR inventory tonnage is used in polymers, a fifth in textiles, with sealants and coatings accounting for approximately a quarter. This differs from reports that plastics account for approximately 85% of global FR consumption (Pinfa, 2021; see Section 3.1.4). Possible reasons for this discrepancy include the fact that several high-tonnage substances are inorganic, which were assumed to have a lower percentage tonnage used in polymers (see Section 3.1.4), or were recorded with no polymer use based on information in the EU REACH database. In addition, the global figure from Pinfa accounts for use of certain BFRs, which are typically used in polymers outside of the UK, whereas these substances may no longer be in use in GB. Another reason could be the uncertainties from using the maximum potential UK REACH tonnage for each substance (see Section 3.3). Crucially however, the analysis does not account for FRs in imported articles as these are not subject to REACH registration, and therefore market supply volumes are not readily available.

Figure 4.1 Proportion of total FR tonnage split by use category



The following section discusses the four main use categories in greater detail, as well as other life cycle stages, and the substance types used in different applications. Further detailed information on substance tonnages and their splits by different uses is provided in Appendix 9. This information should be interpreted keeping in mind the caveats set out in Section 3.3 and 3.4.1 concerning the broad tonnage bands reported under REACH, and the uncertainty over the portions of tonnages attributable to non-FR uses.

4.2 Important industrial sectors for the flame retardants life cycle in GB

4.2.1 Manufacturing

While it has not been confirmed whether individual grandfathered UK REACH registrations relate to GB-based manufacturers or to importers, FRs have been manufactured in GB in the past and a manufacturing step has been included for the purposes of screening environmental exposure (see Section 5.3).

4.2.2 Main uses

As outlined in Section 3.1.3, the identified substances were categorised according to whether they are used in four key use classes: plastics, textiles, coatings, and sealants and adhesives. Of the 73 substances identified as GB-relevant FRs:

- 57 (78%) are used in plastics;
- 44 (60%) are used in textiles;
- 52 (71%) are used in coatings; and
- 40 (55%) are used in sealants and adhesives.

4.2.3 Service life of articles

When used in the applications described above, the primary function of the FR is to suppress combustion for the duration of the service life of the treated article. The releases over the service life were estimated using the combined tonnage of the FR from all the industrial and wide-dispersive uses (assuming that all of the FR ends up in an article). The standard approaches for local assessment were applied and the release factors used were taken from ECHA Guidance for these scenarios. The same release factors were applied to all FR classes.

Further information on the how service life was assessed is detailed in Appendix 3.

Emissions of FRs (and their by-products) resulting from fires are outside the scope of the project.

4.2.4 Waste disposal

In 2016, approximately 1.53 million tonnes of plastic waste were produced in the UK, an increase of 24% since 2010 (Smith, 2022). Eurostat (2022) records indicate that approximately 1-1.6 million tonnes of end-of-life vehicle waste were generated annually in the UK between 2010 and 2019, and around 460,000-960,000 tonnes of waste electrical and electronic equipment (WEEE) were collected from households over the same period. Domestic furniture waste data in 2011 (WRAP, 2011, cited by Environment Agency, 2021) suggests around 216,000 tonnes of sofas reached the end of their useful life each year, of which approximately 70% were landfilled. More recent (unpublished) research on behalf of UK government indicates approximately 250,000 tonnes of upholstered domestic seating waste is produced every year (Defra, 2023). A higher proportion is expected to be incinerated as a result of work on POPs in waste domestic seating (e.g. Environment Agency, 2021).

Disposal of waste arising from packaging, end-of-life vehicles, and electrical and electronic equipment are subject to specific regulations. These may well have direct impacts on the use of certain FRs in future, especially if the FRs are not easy to retrieve or recycle. The following is a summary of the alternative routes of disposal of flame retarded products at the end of their service lives.

Recycling

This broad term covers a range of activities, including re-processing into new articles, re-use of items and incineration for energy recovery. The nature of different types of re-processing varies depending on the form of substrate (e.g. thermoplastic or thermosetting plastic; foamed or solid; polymer type, etc.). Methods of recycling polymeric material plus any additives include mechanical recycling, chemical recycling, and energy recycling (Plastics for Change, 2021).

The feasibility of recovering and recycling bromine from plastics containing BFRs has been investigated in various studies. For example, pilot trials conducted at a municipal solid waste combustion plant have demonstrated that recycling of bromine from additives in WEEE is technically feasible in modern installations equipped with suitable wet scrubbing systems (Vehlow *et al.*, 2002). Changes in polymer performance over several recycling cycles has also been assessed. For example, Dawson and Landry (2002) found that high-impact polystyrene (HIPS) and polybutylene terephthalate flame retarded with ethylene bis(tetrabromophthalimide) (EBTBP) perform well through several cycles of recycling. In the same study, flame retarded acrylonitrile-butadiene-styrene (ABS) polymers containing brominated epoxy oligomer maintained the original material's performance best.

An important factor in successful recycling is the separation of different plastics into polymer types and sorting the plastic components of composite products (e.g. electronic equipment, white goods, and cars). Haarman *et al.* (2020) studied the impacts of BFRs on the recycling of WEEE plastics across Europe. They identified six methods for sorting plastics containing these substances:

- Manual waste segregation based on International Standards Organisation (ISO) markings. This method is very inconsistent, as many waste items have missing, incomplete, or incorrect ISO labels. Additionally, many WEEE streams are shredded so identifying ISO labels is not possible.
- Manual waste source segregation. This requires detailed knowledge about the WEEE source, including equipment models, types and components that contain BFRs. The study notes that no exhaustive database exists at present that could inform this process.
- Sink/float method. This is the most commonly used method for separating BFR-containing fractions, based on the density of plastic particles. Plastic particles containing BFRs have a higher density, and it is estimated that 95% of BFRs are captured in the high-density fraction separated by this process, along with other additives and high-density plastics (Chaine *et al.,* 2022).
- Sensor-based sorting methods:
  - X-ray transmission (XRT)
  - Laser-induced Breakdown Spectroscopy (LIBS)
  - X-ray fluorescence (XRF)

Fraunhofer (2019) concluded that most of the plastic / halogen-free FR formulations they studied retained their FR properties after multiple recycling cycles. Nevertheless, there does not appear to be consensus yet on the impacts of phosphorus, inorganic and nitrogen-based FRs on recycling of plastics, suggesting that further investigation is required (PNO, 2022).

In the UK, 37% of post-consumer plastic waste was recycled in 2020 (Plastics Europe, 2022). In 2018, 93% of end-of-life vehicles were reused or recovered and 85% were reused or recycled (Eurostat, 2021). These high rates are likely to be a consequence of the implementation of the End-of-Life Vehicles Directive (UK Government, 2021).

Separation of plastic waste streams is already established in the UK through the WEEE Regulations 2013, which specifies that different categories of articles must be collected in separate waste streams. However, this places no specific requirement on the separation of plastic wastes with FRs from those without. Information shared by Defra indicates that there are eight plastic waste separation facilities operating in the UK and, although they do not sort wastes with FRs from those without, they do concentrate BFRs (along with some other heavy additives and materials) into a high-density fraction for subsequent processing. This high-density fraction typically includes PC/ABS, PVC, and PMMA. Research overseen by the Environment Agency concluded that for WEEE plastic streams analysed in the UK, between 80-95% of bromodiphenyl ethers were found in the heavy waste fraction, indicating a relatively high level of separation (Environment Agency (draft), 2022a).

Landfill

In 2020, 19% of post-consumer plastic waste in the UK was sent to landfill (Plastics Europe, 2022). As mentioned above, a WRAP study (2011) focusing on domestic furniture identified that some 70% of the sofas reaching end of life in the UK in one year pass to landfill. Issues that require consideration are the leaching of the additive out of the substrate into landfill leachate from which it could volatilise, enter groundwater, degrade or adsorb onto solids.

Incineration (with or without energy recovery)

In 2020, 44% of post-consumer plastic waste in the UK was subject to energy recovery (Plastics Europe, 2022). Insufficient incineration temperatures can result in only partial destruction of FRs (for example, polybromodiphenyl ethers can form polybrominated dibenzofurans and dibenzo-p-dioxins). According to BSEF, plastics with halogenated additives in municipal solid waste can, however, safely be incinerated (BSEF, n.d.)). Technical guidelines adopted through the UN Basel Convention identify technologies for the destruction and irreversible transformation of some POPs in wastes (including HBCDD, PeCB, and SCCPs); applicable technologies include advanced solid waste incineration, cement kiln co-incineration, and hazardous waste incineration (UNEP, 2019b).

Further consideration of incineration breakdown products is beyond the scope of this project.

Flytipping and litter

These are potential sources of uncontrolled environmental exposure to FRs but have not been considered further for this project.

4.3 Overall trends in the industry

As a result of international regulation, certain FR substances are being phased out, and alternatives sought. Overall, there is clear emphasis on reducing the use of chemical FRs in general, with special attention given to halogenated FRs, and increasingly organophosphate FRs too (e.g. Blum *et al.*, 2019).

For example, several substances used as FRs are listed under Annex A of the UN Stockholm Convention on POPs, and thereby identified for international elimination. These restrictions are implemented in the UK by the Persistent Organic Pollutants (Amendment) (EU Exit) Regulations 2020. Both brominated and chlorinated substances are listed, such as polybromodiphenyl ethers, HBCDD, hexabromobiphenyl, pentachlorobenzene (PeCB), SCCPs and Dechlorane Plus™. MCCPs is expected to be formally listed soon (Defra, 2021b).

Risk management evaluations conducted for these substances under the Stockholm Convention identified several alternatives to their use; these are listed for plastics, textiles, and other uses in Table 4.1. Other sources (e.g. Crain *et al.*, 2013; EC, 2016) indicate that some BFRs, including HBCDD, have been partially replaced by brominated polymeric FRs such as benzene, ethenyl-, polymer with 1,3-butadiene, brominated (brominated butadiene-styrene co-polymer) in extruded and expanded polystyrene applications.

Table 4.1 Alternatives to brominated flame retardants restricted through the Stockholm Convention (UNEP, 2007; UNEP, 2008; UNEP, 2011; UNEP, 2015)

	Polymers	Textiles	Other uses
Aluminium trihydroxide (ATH)	✓	✓	✓
Magnesium hydroxide (MDH)	✓	✓	✓
Ethylene bis(tetrabromophthalimide) (EBTBP)	✓	✓	✓
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	✓	✓	✓
Red phosphorus	✓	✓	✓
Bisphenol A bis(diphenyl phosphate) (BDP/BAPP)	✓		
Resorcinol bis(diphenylphosphate) (RDP)	✓		
Triphenyl phosphate (TPHP)	✓		
Ammonium polyphosphates		✓	
Dimethylphosphono (N-methylol) propionamide		✓	
Phosphonic acids such as (3-{[hydroxymethyl]-amino}-3-oxopropyl)-dimethyl ester		✓	
Tetrakis (hydroxymethyl) phosphonium urea ammonium salt		✓	
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)		✓	
2,2'-Oxybis[5,5-dimethyl-1,3,2-dioxaphosphorinane] 2,2'-disulphide		✓	
Substituted amine phosphate mixture (P/N intumescent systems)			✓
Zinc borate			✓

None of the brominated substances restricted under the Stockholm Convention appear in the list of 73 GB-relevant substances. However, there are derogations and 1,1'-oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE) is included in the DUINs list. Several of the 'alternative' substances listed in Table 4.1 are featured in the list of 73 GB-relevant substances, possibly indicating that they have been adopted in place of substances that have been phased out as a result of regulatory action. A detailed mapping of alternative substances to those no longer in use is outside the scope of the current project. Some form of flame retardancy technology, whether use of chemicals or inherently less flammable materials, will continue to be necessary to ensure materials comply with current UK and international fire safety regulations. For substitution to be successful, alternatives of acceptable performance and hazard profile with sufficient commercial availability and acceptable price differentials must be identified. Alternatives may be found from substances already on the market or through novel or emerging technologies (see also Section 2.3.6). Regulatory bodies must remain alert to market changes that may represent "regrettable substitution", whereby removal of one toxic substance leads to its replacement by a different substance type with similar (or other) hazards.

Information gained through consultation with industry stakeholders indicated that there are no significant ongoing technical developments and innovations which are likely to change the landscape of FR use in the UK in the coming years. The dominant trend at present is a gradual shift away from additive to reactive and polymeric FRs, and stakeholder input indicated that this is likely to continue in the future due to increased consumer and regulatory concerns over release of additive FRs from articles. One stakeholder noted that in the fabric and textiles sector, trials are currently under way using nanotechnology and gene-editing to alter the shape and form of natural fibres such that their FR properties are augmented without the use of FRs. This technology is, however, in its early stages and unlikely to reach markets soon. A recent review of sustainable FR technologies (Feng *et al.*, 2023) highlighted a number of initiatives under development. These include application of machine learning to guide molecular design, production of nature-derived FRs, and investigation of green synthesis routes of existing FRs. The review highlighted that further development of biorefining technologies is required to make production of nature-derived FRs cost-effective.

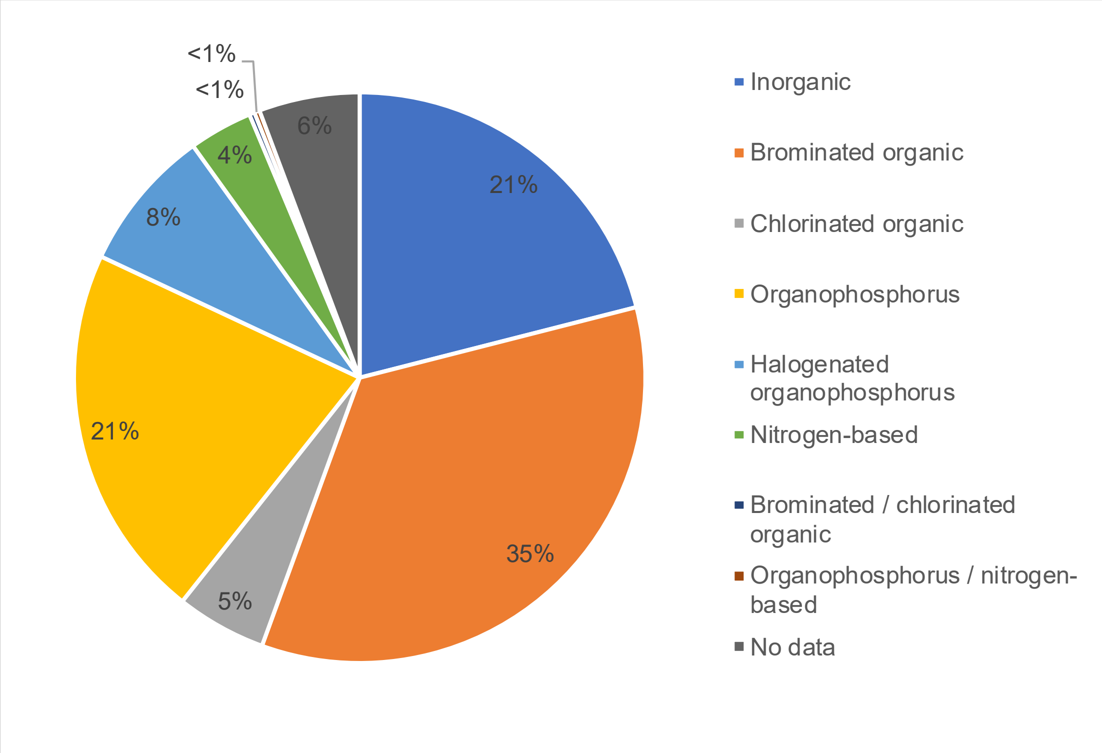
Substitution has been investigated through the EU LIFE-FLAREX project (https://www.life-flarex.eu/), undertaken between 2017 and 2020. This analysed environmental impacts of conventional and alternative FRs for the textiles sector (focusing on conventional halogenated, antimony-containing and formaldehyde-releasing FRs) and makes recommendations on the best alternatives (lower hazard and with lower environmental impact). This study’s recommendations, as communicated via the textiles sector BREF (EC EIPPCB, 2023), are that ammonium sulfamate, ammonium polyphosphate and expandable graphite FRs are the best environmental solutions (taking into account impacts on climate change, human toxicity (cancer and non-cancer effects), ionising radiation, acidification, freshwater and terrestrial eutrophication, water and mineral resources depletion, particulate matter generation and photochemical ozone formation, in addition to ecotoxicity).

Substitution in some polymer and coating applications have been investigated through the EC-funded ENFIRO project (www.enfiro.eu/). This investigated halogen-free substitution options for specific BFRs in printed circuit boards (PCBs), electronic components, injection moulded products, textile coatings and intumescent paint through evaluation of hazard and risk, life cycle analysis and socioeconomic impact. The project concluded that seven of the halogen-free alternatives appear to be of lower hazard, but important data gaps in respect of their PBT properties were noted and follow-up work on a substance-by-substance level was recommended in a resulting publication (Waaijers *et al.*, 2013).

The FLAREX and ENFIRO projects also took account of some elements of socio-economic analysis and technical feasibility considerations, which are important aspects of substitution.

Figure 4.2 presents the split of the project database compiled for Environment Agency (2003) by substance type (based on number of substances). Compared with the split determined in the present report (Section 3.4), the FRs in use in 2003 were more varied, with no single substance group dominating the inventory. Whereas brominated substances made up the largest fraction of the inventory in 2003 (35%), they account for only 8% of the inventory compiled in 2022. Simultaneously, the proportion of inorganic substances has increased from 21% in 2003 to over 50% in 2022. This is consistent with the regulation described above, with restrictions targeting certain halogenated FRs having led to their substitution with a broad suite of substances, including organophosphorus and inorganic compounds.

Figure 4.2 Breakdown of previous 2003 project database by substance type (number of substances)



Note: The 'no data' category represents entries in the 2003 database for which no substance type was specified, or the data were labelled 'confidential'.

4.3.1 Polymeric flame retardants

ECHA's *Regulatory Strategy for Flame Retardants* (2023), along with industrial literature (see LANXESS 2018), identifies several polymeric FRs:

- Brominated butadiene-styrene co-polymer (CAS no. 1195978-93-8; also identified by LANXESS, 2018);
- Brominated polystyrene – BPS (CAS no. 88497-56-7; also identified by LANXESS, 2018);
- Polyphosphonate (CAS no. 68664-06-2); and
- Oligomeric ethyl ethylene phosphate (CAS no. 184538-58-7).

As polymers do not currently need to be registered under UK or EU REACH, no tonnage and use information is available for these substances, nor do they appear on the list of substances grandfathered into the UK REACH system (and, therefore, do not feature in the list of 73 substances). It is therefore not possible to conclude on the relevance of these substances specifically to the UK. Information published by the International Bromine Council (BSEF, 2018) indicates that brominated butadiene-styrene copolymer is commonly used as an alternative to HBCDD in building and construction; it is therefore likely that it is also commonly used in these applications in the UK. Registration of polymers under EU REACH is currently under consideration, and should this be adopted, further information on the use and tonnages of polymeric FRs should become available via registration dossiers in future. This may include information on manufacturing residuals, which might warrant attention from an environmental hazard perspective, particularly if they are heavily halogenated.

4.3.2 Reactive flame retardants

ECHA's *Regulatory Strategy for Flame Retardants (2023)* also highlights the following reactive FRs:

- Brominated FRs:
    - TBBPA (EC no. 201-236-9);
    - 2,2-dimethylpropan-1-ol, tribromo derivative (EC no. 253-057-0);
    - 2,2-bis(bromomethyl) propane1,3-diol (EC no. 221-967-7);
    - PHT4 (tetrabromophthalic anhydride) (EC no. 211-185-4);
    - PHT4-diol (reaction product of 3,4,5,6-tetrabromobenzene-1,2-dicarboxylate with 2,2'-oxydiethanol and 2-epoxypropane (EC no. 616-436-5);
    - Reaction products of tetrabromophthalic anhydride with 2,2'-oxydiethanol and methyloxirane (EC no. 616-436-5).
- Phosphorous-based FRs:
    - dibenzo oxaphosphorine oxide derivatives (DOPO) (EC no. 252-813-7);
    - 3-(hydroxyphenylphosphinyl) propanoic acid (EC no. 411-200-6);
    - aluminium tridiethylphosphinate (EC no. 428-310-5);
    - diphenyl phosphonate (EC no. 225-202-8);
    - methylphosphonic acid (EC no. 213-607-2);
    - phosphorus rich reactive intermediate

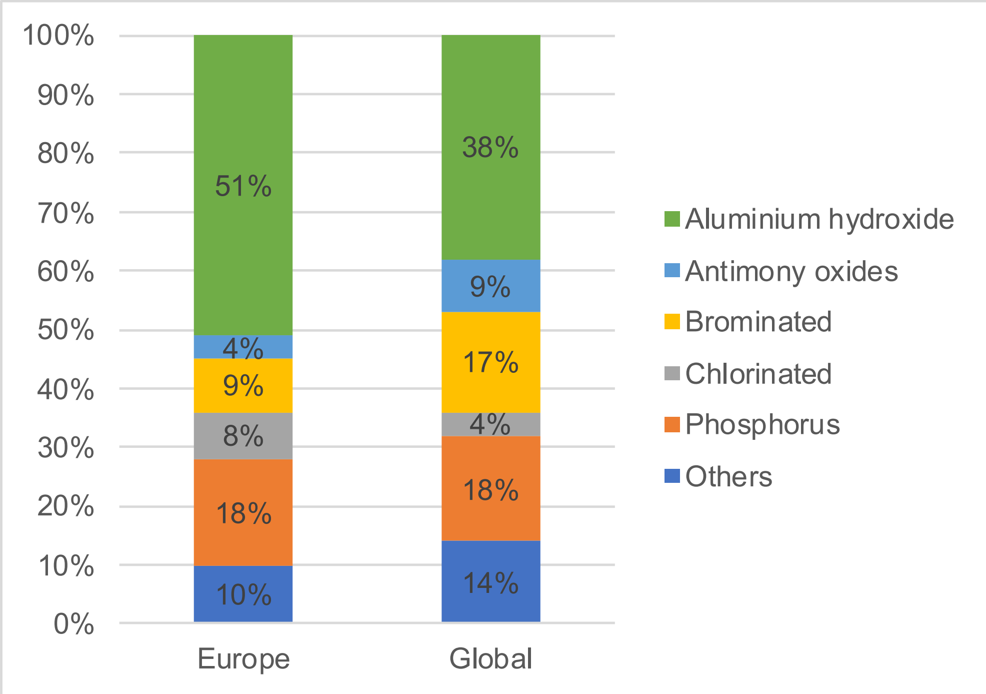
The Strategy also points out that, compared to traditional additive FRs, reactive FRs continue to occupy a small part of the overall FRs market.

4.3.3 Comparison of global and EU trends

Worldwide consumption of FRs was 2.17 million tonnes in 2019 (Flame Retardants Online, n.d.) or around 3.18 million tonnes in 2020 (Pinfa, 2021). European consumption amounted to 452,000 tonnes in 2015 (Pinfa, 2017). The global FR market size is estimated to increase to USD 14.90 billion by 2030 (Grand View Research, n.d.).

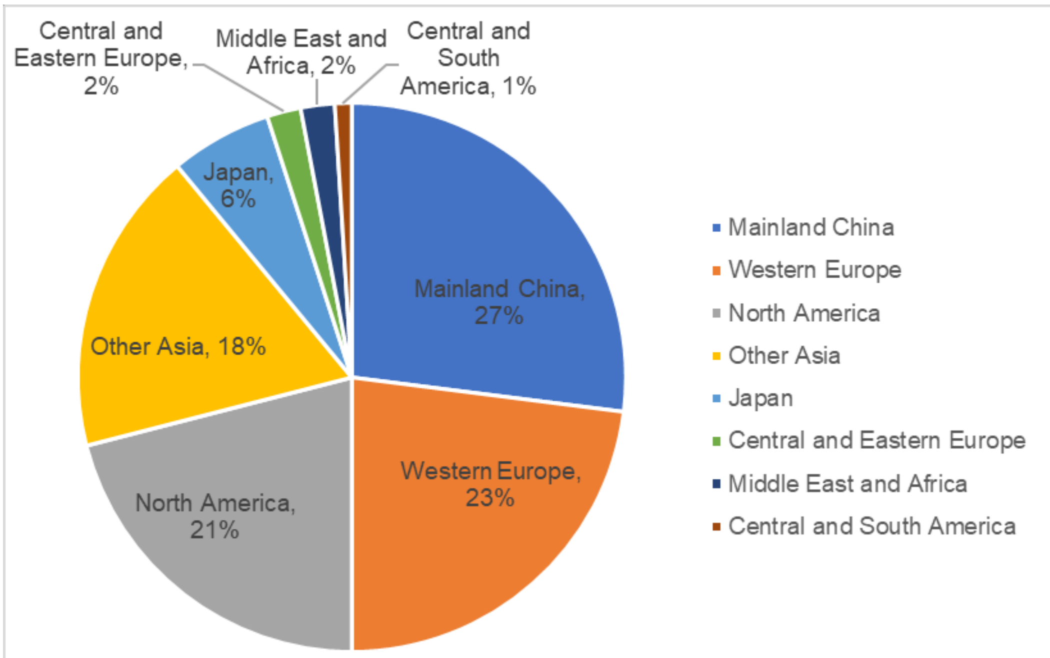
Figure 4.3 indicates that the largest share of this consumption is attributable to aluminium hydroxide, with organophosphorus and brominated FRs accounting for the next highest share globally. Consumption in Europe is skewed more towards inorganic substances and away from BFRs (see Section 4.3).

Figure 4.3 Global and European consumption of flame retardants by type (global data 2019 (Flame Retardants Online, n.d., citing IHS Consulting, 2020), EU data 2015 (Pinfa, 2017))



A break-down of global consumption by region is provided in Figure 4.4.

Figure 4.4 Flame retardants consumption share by region, 2019 (data from Flame Retardants Online, n.d., citing IHS Consulting, 2020)



This shows that mainland China accounts for the greatest share (27%), with Asian regions together accounting for over half of global consumption (51%). Western Europe and North America both account for over 20%, while other regions represent smaller shares.

A comparison of important aspects of the FRs markets globally and in Europe is provided in Table 4.2.

Table 4.2 Comparison of global, EU, and UK trends in FRs use

Parameter	Global market	European market
Annual FR consumption	2.17 million tonnes (2019) – 3.18 million tonnes (2020) (Flame Retardants Online, n.d., Pinfa, 2021)	452,000 tonnes (2015) (Pinfa, 2017)
Market value	USD 8.63 billion (2022; Grand View Research, n.d.)	USD 1.98 billion (2023; Mordor Intelligence, n.d.)
Key FR uses	85% in plastics. Textiles, rubber products, wood and timber account for most of the rest (Pinfa, 2021)	No data
Key FR types	Inorganics (aluminium hydroxide 38%; antimony oxides 9%), organophosphorus (18%) (see Figure 3.3). Regional variation based on regulatory requirements (e.g. brominated FRs use more prevalent in Asia than North America) (Ceresana, 2022)	Aluminium hydroxide accounts for over half of consumption (51%), phosphorus FRs account for a further 18% (Pinfa, 2017).

Note: Tonnage figures reported in imperial tons in the referenced sources for the global and European markets have been converted to metric tonnes to ensure consistency with other values cited in this report.

5 Environmental Prioritisation

Three approaches to prioritise substances of concern were used:

a) The first method considered the substances that are on the market at the highest tonnage (a crude indication of potential for environmental exposure, at least for additive FRs). The approach taken in this project to quantifying tonnage is explained in Section 3.1. As summarised in Section 3.4, a total of 73 substances were listed as confirmed or potentially GB-relevant FRs. Under UK and EU REACH, the substance data required in terms of properties and hazards depends on the supply tonnage. In this project, substances were categorised as “high” and “low” tonnage, and this information is presented in Table 5.8 at the end of this chapter. A high-level analysis of tonnages and splits by use is provided in Appendix 9. This is however complicated by uncertainties associated with the underlying REACH data, particularly total tonnage and the split of tonnage per use (discussed in more detail in Section 3.3 and Appendix 9).

b) The second method deals with hazard potential in multiple ways:
   i) substances already prioritised for regulatory action in the UK or Europe;
   ii) substances which carry hazard classifications under CLP;
   iii) substances identified as known or suspected endocrine disruptors;
   iv) persistent, bioaccumulative and toxic (PBT) substances; and
   v) substances with significant mobility combined with persistence and toxicity.

c) The third method is a simple environmental risk assessment approach using generic exposure scenarios, UK REACH tonnage information apportioned to different use categories (as described in Section 3.1.4) and measured (or predicted) physicochemical, fate and PNEC data. Generic exposure scenarios were developed to estimate the release of the FRs from manufacturing, industrial and wide-dispersive uses (sealants, coatings, polymers and textiles), service life and waste (landfill). Full details are provided in Appendix 3.

These approaches are consistent with the original Environment Agency (2003) report. They are also consistent with the criteria used to justify the selection of substances for the RAP for Substance Evaluation under UK REACH. Further detail on the second and third approaches used and findings for the GB-relevant FRs are provided in the sections below.

Note: FRs identified as potentially relevant but with no UK REACH registrations (“Group (c)” substances - see Section 1.2) were prioritised using hazard data and available UK monitoring data only, due to the lack of reliable UK tonnage information.

5.1 Prioritisation based on hazard potential

The data collected for regulatory activity status, prior PBT/vPvB conclusions, classification and labelling and endocrine disruption were applied directly as indicators of the hazard status of the GB-relevant FRs covered by the project. In cases where the substance was already identified as persistent and toxic (P and T), or very persistent (vP), the potential for mobility (represented quantitatively by the K_{OC} value collected as part of the property data gathering) was reviewed to give an insight into potential for added concerns in this area in future.

The findings are summarised in Table 5.1, which gives an overview and allows a ranking approach to be applied. A positive indication is denoted by “1”, otherwise a ”0” is assigned. The figure in the overall hazard ranking column is the sum of the identifiers in the first 5 columns, with a maximum value of 5. A higher position in Table 5.1 indicates that multiple issues may have already been identified for the substance. It should be noted that no weighting has been applied. Only those FRs for which at least one of these indicators was positive appears in this table. The findings for all substances in the project are presented in Appendix 2.

As noted in Section 1.1, the prioritisation reflects the information available at the time of compilation, and they have not been reviewed for quality or relevance. The emergence of new data following completion of this report could affect the relative ranking of specific substances in future. In addition, this list is not intended to pre-empt any UK regulatory conclusions on specific substances (for example, if a substance is on the EU REACH registry of intention for SVHC identification).

Table 5.1: Combined hazard ranking for FRs

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low PNEC[b]	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Chloroalkanes, C14-17	85535-85-9	287-477-0	Chlorinated organic	1	1	1	1	0	**4**	1	1
2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	79-94-7	201-236-9	Brominated organic	1	1	1	1	0	**4**	1	1
Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	359406-89-6	436-230-7	Organo-phosphorus	0	1	1	0	1	**3**	0	1
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	Organo-phosphorus	0	1	1	1	0	**3**	0	1
Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	55566-30-8	259-709-0	Organo-phosphorus	0	1	1	1	0	**3**	0	1
1,3,5-Triazine-2,4,6-triamine	108-78-1	203-615-4	Nitrogen-based	0	0	1	1	1	**3**	1	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL [c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	Organo-phosphorus	1	1	0	1	0	**3**	0	1
Tris(methylphenyl) phosphate	1330-78-5	809-930-9	Organophosphorus	0	1	1	1	0	**3**	0	1
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	237-159-2	Halogenated organophosphorus	0	1	1	1	0	**3**	0	1
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE)	1163-19-5	214-604-9	Brominated organic	1	0	1	1	0	**3**	1	1
2,2-Bis(bromomethyl)propane-1,3-diol	3296-90-0	221-967-7	Brominated organic	0	0	1	0	1	**2**	1	1
Trixylyl phosphate	25155-23-1	246-677-8	Organo-phosphorus	0	1	1	0	0	**2**	1	1
Dicumyl peroxide	80-43-3	201-279-3	Other organic	0	1	1	0	0	**2**	1	1
2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine (TTBP-TAZ)	25713-60-4	426-040-2	Brominated organic	1	1	0	0	0	**2**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low PNEC[b]	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Barium metaborate	13701-59-2	237-222-4	Inorganic	0	1	1	0	0	**2**	1	1
Tribromoneopentyl alcohol	36483-57-5	253-057-0	Brominated organic	0	0	1	0	1	**2**	1	1
Boron sodium oxide ($B_4Na_2O_7$)	1330-43-4	215-540-4	Inorganic	0	0	1	1	0	**2**	1	1
Boron zinc oxide ($B_6Zn_2O_{11}$)	12767-90-7	235-804-2	Inorganic	0	1	1	0	0	**2**	0	1
Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	27104-30-9	500-057-6	Organo-phosphorus	0	1	1	0	0	**2**	0	1
Boric acid	10043-35-3	233-139-2	Inorganic	0	0	1	1	0	**2**	1	1
Zinc chloride ($ZnCl_2$)	7646-85-7	231-592-0	Inorganic	0	1	0	1	0	**2**	0	0
Zinc oxide	1314-13-2	215-222-5	Inorganic	0	1	0	1	0	**2**	0	1
Tributyl phosphate	126-73-8	204-800-2	Organo-phosphorus	0	0	1	1	0	**2**	0	1
Triphenyl phosphate	115-86-6	204-112-2	Organo-phosphorus	0	1	0	1	0	**2**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Isodecyl diphenyl phosphate	29761-21-5	249-828-6	Organo-phosphorus	0	1	1	0	0	**2**	0	1
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated)	68937-40-6	700-990-0	Organo-phosphorus	1	1	0	0	0	**2**	0	1
1,3,5-Triazine-2,4-diamine, 6-phenyl-	91-76-9	202-095-6	Nitrogen-based	0	0	1	0	1	**2**	0	1
Paraffin waxes, chloro	63449-39-8	264-150-0	Chlorinated organic	0	1	0	1	0	**2**	0	1
Sodium hexahydroxy-antimonate(1-)	33908-66-6	251-735-0	Inorganic	0	1	1	0	0	**2**	0	1
1,3,5-Triazine-2,4,6-triamine, phosphate	41583-09-9	255-449-7	Organophosphorus	0	0	1	0	1	**2**	0	1
2,4,6-Tribromophenol	118-79-6	204-278-6	Brominated organic	0	1	0	1	0	**2**	0	1
1,3,5-Triazine-2,4,6(1h,3h,5h)-trione, compd. with 1,3,5-	37640-57-6	253-575-7	Nitrogen-based	0	0	1	0	1	**2**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL [c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
triazine-2,4,6-triamine (1:1)											
4,4'-(1-Methylethylidene)bis[2,6-dibromophenol] polymer with (chloro-methyl)oxirane and 2,4,6-tribromophenol	158725-44-1	500-399-6	Brominated organic	1	1	0	0	0	**2**	0	1
1,3-Propanediamine, n1,n1'-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized n-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	191680-81-6	425-020-0	Nitrogen-based	1	0	0	0	1	**2**	0	1
2,2-Bis(chloromethyl)-1,3-propanediyl tetrakis(1-chloro-2-propanyl) bis(phosphate)	1047637-37-5	809-920-4	Halogenated organo-phosphorus	0	0	1	0	1	**2**	0	1
Diphenyl methylphosphonate	7526-26-3	231-388-1	Organophosphorus	0	1	0	0	1	**2**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low PNEC[b]	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Diethyl ethylphosphonate	78-38-6	201-111-9	Organo-phosphorus	0	1	0	0	1	**2**	0	1
Tetrachlorophthalic anhydride	117-08-8	204-171-4	Chlorinated organic	0	1	0	0	1	**2**	0	1
Diphosphoric acid, compd. with 1,3,5-triazine-2,4,6-triamine (1:?)	15541-60-3	239-590-1	Nitrogen-based	0	0	1	0	1	**2**	0	1
Phosphorous acid, triphenyl ester (TPP)	101-02-0	202-908-4	Organo-phosphorus	0	1	1	0	0	**2**	0	1
4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	204-077-3	Chlorinated organic	0	0	1	0	0	**1**	0	1
Antimony oxide (Sb_2O_3)	1309-64-4	215-175-0	Inorganic	0	0	1	0	0	**1**	0	1
Boron oxide (B_2O_3)	1303-86-2	215-125-8	Inorganic	0	0	1	0	0	**1**	1	1
Bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP)	26040-51-7	247-426-5	Brominated organic	1	0	0	0	0	**1**	1	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low PNEC[b]	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
1,1'-(Ethane-1,2-diyl)bis[penta-bromobenzene] (DBDPE)	84852-53-9	284-366-9	Brominated organic	1[+]	0	0	0	0	**1**	0	1
Molybdenum trioxide	1313-27-5	215-204-7	Inorganic	0	0	1	0	0	**1**	0	1
Magnesium chloride ($MgCl_2$)	7786-30-3	232-094-6	Inorganic	0	0	0	1	0	**1**	0	0
Ammonium chloride	12125-02-9	235-186-4	Inorganic	0	0	0	1	0	**1**	0	1
Ammonium sulphate	7783-20-2	231-984-1	Inorganic	0	0	0	1	0	**1**	0	0
Calcium dihydroxide	1305-62-0	215-137-3	Inorganic	0	0	1	0	0	**1**	0	1
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	1241-94-7	214-987-2	Organo-phosphorus	0	0	1	0	0	**1**	0	1
Phosphoric trichloride, reaction products with bisphenol A and phenol	181028-79-5	425-220-8	Organo-phosphorus	1	0	0	0	0	**1**	0	1
(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	5945-33-5	425-220-8	Organo-phosphorus	1	0	0	0	0	**1**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	38051-10-4	253-760-2	Halogenated Organo-phosphorus	0	0	1	0	0	**1**	0	1
Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	1271172-98-5	690-512-6	Nitrogen-based	0	1	0	0	#	**1**	0	0
Tris(2-butoxyethyl) phosphate (TBOEP)	78-51-3	201-122-9	Organo-phosphorus	0	0	0	1	0	**1**	0	1
Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	1244733-77-4	807-935-0	Halogenated Organo-phosphorus	0	0	0	1	0	**1**	0	1
Reaction mass of 1,1'-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene] and 1,3-dibromo-2-(2,3-dibromo-2-		944-461-4	Brominated organic	1	0	0	0	0	**1**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
methylpropoxy)-5-{2-[3,5-dibromo-4-(2,3,3-tribromo-2-methylpropoxy)phenyl] propan-2-yl}benzene											
Dipotassium 3,4,5,6-tetrabromophthalate	18824-74-3	242-604-9	Brominated organic	0	0	0	0	1	**1**	0	1
Calcium magnesium dihydroxide oxide	58398-71-3	261-235-4	Inorganic	0	0	1	0	0	**1**	0	0
Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6	Organo-phosphorus	0	0	0	1	0	**1**	0	1
1,3,2-Dioxaphosphorinane, 2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	4090-51-1	223-829-1	Organo-phosphorus	0	0	0	0	1	**1**	0	1
Ammonium bromide	12124-97-9	235-183-8	Inorganic	0	0	1	0	0	**1**	0	1
1,2-Ethanediamine, phosphate	14852-17-6	238-914-9	Organo-phosphorus	0	1	0	0	0	**1**	0	1
Tetrabromobisphenol a-bis(2,3-dibromopropyl ether)	21850-44-2	244-617-5	Brominated organic	0	0	0	1	0	**1**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low PNEC[b]	Health concern based on C&L HH OR low DNEL [c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
6h-Dibenzo[c,e][1,2]-oxaphosphinine 6-oxide	35948-25-5	252-813-7	Organo-phosphorus	0	0	0	0	1	**1**	0	1
(Pentabromophenyl)methyl acrylate	59447-55-1	261-767-7	Brominated organic	0	0	1	0	0	**1**	0	0
Diphosphoric acid, compd. with piperazine (1:1)	66034-17-1	457-330-7	Organo-phosphorus	0	0	0	0	1	**1**	0	1
Tetrabromophthalic acid mixed esters with diethylene glycol and propylene glycol	77098-07-8	616-436-5	Brominated organic	0	0	0	0	1	**1**	0	1
2-Butyne-1,4-diol, polymer with 2-(chloromethyl)oxirane, brominated, dehydrochlorinated, methoxylated	68441-62-3	614-503-3	Brominated organic	0	0	0	0	1	**1**	0	1
1,1'-(Isopropylidene)bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene)	97416-84-7	306-832-3	Brominated organic	0	0	0	1	0	**1**	0	1

Substance name	CAS number	EC number	FR type	PBT or vPvB[a]	Environmental concern based on C&L Env OR low	Health concern based on C&L HH OR low DNEL[c]	Potential ED or ED screen[d]	Potentially PMT or vPvM (screening)[e]	Overall hazards ranking	SVHC[f]	Already prioritised for regulatory investigation[g]
Aluminum diethylphosphinate	225789-38-8	428-310-5	Organo-phosphorus	0	0	0	0	1	**1**	0	1
Boron phosphate ($B(PO_4)$)	13308-51-5	236-337-7	Inorganic	0	0	1	0	0	**1**	0	1
3-[Hydroxy(phenyl)-phosphoryl]propanoic acid	14657-64-8	411-200-6	Organo-phosphorus	0	0	0	0	1	**1**	0	1
Sodium antimonate	15432-85-6	239-444-7	Inorganic	0	1	0	0	0	**1**	0	1
Diethyl (n,n-bis(2-hydroxy-ethyl)amino)methane-phosphonate	2781-11-5	220-482-8	Organo-phosphorus	0	0	0	0	1	**1**	0	1

Notes:

a – PBT or vPvB refers to the conclusions of REACH registrants or of regulatory authorities, or conclusions of the authors based on the data collected.

b - C&L for the environment indicates classification as a Chronic category 1 or 2 hazard under CLP, whether as a mandatory, harmonised or self-classification by REACH registrants. Where none of these classifications apply, a PNEC value below 0.01 mg/L in fresh water or below 0.01 mg/kg dry weight (dw) in soil or freshwater sediment are used as indicators of a significant hazard (these selection criteria are indicative and not based on a specific regulatory threshold).

c – C&L for human health indicates classification for carcinogenic, mutagenic, reproductive or specific target organ hazard under CLP, whether as a mandatory, harmonised or self-classification by REACH registrants. Where none of these classifications apply, a DNEL value below 0.1 mg/m^3 for inhalation or below 0.1 mg/kg bw/d by the oral route, or a qualitative conclusion of “high hazard” are used as indicators of a significant hazard (these values applied as selection criteria are indicative and not based on a specific regulatory threshold).

d – Potential ED or ED screen is based on appearance of the substances on any of the five major lists (potential ED) or CHEMSEC or TEDX lists (ED screen) based on research carried out. The CHEMSEC SIN list and TEDX list use peer-reviewed literature data to indicate that a substance may have endocrine disrupting properties and provide screening level information often based on *in vitro* data. Table A2.1. provides a differentiation of potential ED and ED screen for all of the substances. Further assessment of ED properties of organophosphate esters (OPEs), including some FRs, were reviewed under a separate study by the Environment Agency ((draft) 2022b). That project notes tricresyl phosphate (CAS no. 1330-78-5), tris(2-butoxyethyl) phosphate (CAS no. 78-51-3), tris(2-ethylhexyl) phosphate (CAS no. 78-42-2), phenol, isopropylated, phosphate (3:1) (CAS no. 68937-41-7), tris(1,3-dichloro-2-propyl) phosphate (TDCPP, CAS no. 13674-87-8), and triphenyl phosphate (CAS no. 115-86-6) as substances showing positive ED activity within *in vitro* studies. This is consistent with the findings in the table above.

e – Mobility is based on assessment made in the present project based on Koc values collected, by applying the criteria presented in Section 3.2.2; for the purpose of ranking mobility conclusions are only taken into account here if combined with persistence/toxicity (so mobile/very mobile in combination with persistent and also toxic; or very mobile in combination with very persistent).

f – SVHC is based on identification of a substance on the ECHA Registry of SVHC Intentions, Candidate List (ECHA, 2022e;f), or UK SVHC list (HSE, 2022a).

g – Prioritisation for further regulatory investigation is based upon the listing of a substance on CoRAP (ECHA, 2022g) or RAP (HSE, 2022b), ECHA (2022h) “assessment of regulatory needs” group assessment process, PBT assessment under development, or another type of follow up activity under ECHA’s Integrated Regulatory Strategy (searched via ECHA’s Public Activities Coordination Tool, PACT (ECHA, 2022i)). This reflects the situation at the time the information was collected for this project. All of these areas are under continuous development, and new ECHA assessments of regulatory needs, including documents relating to FRs, continue to be published under the Restrictions Roadmap.

Insufficient data for assessment of mobility.

+ Pending completion of the CoRAP process (this concern is based on the impurities).

5.2 Prioritisation using exposure assessment and risk characterisation

The data collected on properties and hazard described in Section 3 were applied as inputs in a simple generic exposure model. The nature of the use was considered when definite evidence of applications as an FR in GB was confirmed. With reference to relevant published evidence and drawing on industry sector group standard exposure scenarios and ECHA's default exposure scenarios, 13 generic release scenarios were created for:

- manufacturing,
- use in sealants (formulation, industrial use and wide-dispersive use),
- use in coatings (formulation, industrial use and wide-dispersive use),
- use in polymers (formulation and industrial use),
- use in textiles (formulation and industrial use),
- service life of articles and
- waste disposal of articles.

It was assumed for simplicity that all substances are manufactured in GB. Although this might over-estimate the risk for any substances that are not manufactured in GB, this is a conservative approach and is not expected to have a significant impact on the ranking.

"Releases" in this context relate releases to the environment (and indirect exposure of humans via the environment) to the substances as such. Based on the environmental releases from the 13 exposure scenarios, predicted environmental concentrations (PECs) were calculated using the EUSES 2.1.2 model (ECHA, 2022j) for surface water (freshwater and marine water), sediment (freshwater sediment and marine sediment) and soil at the local and regional scales of the model. Human exposure via the environment (drinking water and consumption of fish, meat, dairy and crops) at the local and regional scale and predator exposure via the food chain at the local scale were also estimated. At the 'local' scale, concentrations are estimated immediately downstream of a point of discharge or release. The point source can be an industrial discharge or a sewage treatment plant. The 'regional' scale represents the background concentration arising from multiple inputs in a heavily industrialised and populated area. Appendix 3 contains further explanation.

The PECs were divided by the available PNECs for water, sediment, soil and predators (secondary poisoning) (see Section 3.2.3), or DNELs for the general population (see Section 3.2.4), to produce risk characterisation ratios (RCRs). An RCR above 1 suggests a potential concern for the relevant compartment or population, because the predicted level of exposure exceeds a concentration that is considered 'acceptable'. This approach allowed a large number of substances to be screened on a broadly similar basis, to give an indication of <u>relative</u> concern. However, given the limited nature of the information available, lack of detailed consideration of the underlying property and hazard data, and worst-case generic assumptions made, a substance-specific assessment would be required to provide more in-depth understanding of the potential risks, which was beyond the scope of this project. It is highlighted in particular that UK REACH registrants' exposure assessments were not reviewed. It should also be noted that the modelling approach does not take any account of abiotic factors (such as pH or hardness) on the bioavailability or (eco)toxicity of metals such as aluminium.

Where available, environmental monitoring data from the Environment Agency and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), and foodstuff monitoring data from the FSA, were used in place of PECs to assess relative risk potential. A selection of environmental monitoring data reported in the peer-reviewed scientific literature was also used in the same way, based on collations made under PEWS and selected published studies recommended by members of the Advisory Group. Whilst monitoring provides real world verification of exposure levels to provide a further line of evidence, it should be noted that the sampling approach might not always be appropriate for some applications or substances, and some FRs are challenging to analyse. This approach therefore provides a starting point for further investigations, and is discussed further in Section 5.2.3.

5.2.1 Prioritising FRs based on local scale risk characterisation

Table 5.2 gives an overview of all FRs for which a risk assessment was performed. The exposure scenario resulting in the highest exposure and level of concern is identified for each FR along with the environmental compartment which had the highest RCR. Ranking on this basis is relative within the substance list only. Given the conservative worst-case nature of the assessment and confidentiality of some data, individual RCRs are not presented.

For most of the FRs, industrial use of textiles (Exposure Scenario 11) had the highest releases into the environment resulting in the highest RCRs. In many cases this led to RCRs above1 in freshwater, marine water and/or Sewage Treatment Plant (STP). Manufacturing (ES1), formulation of coatings (ES5) and formulation of polymers (ES8) are also lifecycle stages leading to high releases of several FRs, and leading to RCRs above 1 in freshwater, marine water and/or STP.

Based on this ranking approach, the top 5 FRs listed in Table 5.2 were organophosphate FRs, with phenol, isopropylated, phosphate (3:1) (CAS no. 68937-41-7) being ranked highest. The other FRs in the top 5 are trixylyl phosphate (CAS no. 25155-23-1), tetrakis[hydroxymethyl] phosphonium chloride (CAS no. 27104-30-9), and two aryl phosphate reaction masses: EC no. 945-730-9 and CAS no. 68937-40-6. A full list of all FRs ranked based on their RCR value for each of the compartments are provided in Appendix 4.

Table 5.2: Ranking of FRs based on local scale risk characterisation

Substance name	CAS Number	EC Number	FR type	Exposure Scenario with highest exposure	Compartment with highest RCR	Priority ranking [a]
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	P	11 textiles - industrial use	Secondary poisoning (terrestrial)	Very high
Trixylyl phosphate	25155-23-1	246-677-8	P	05 coatings – formulation	Soil	Very high
Tetrakis[hydroxy-methyl] phosphonium chloride	27104-30-9	500-057-6	P	11 textiles - industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	High
Reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate (Cresyl diphenyl phosphate)		945-730-9	P	11 textiles - industrial use	Soil	High
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate	68937-40-6	700-990-0	P	05 coatings – formulation	Secondary poisoning (terrestrial)	High

Substance name	CAS Number	EC Number	FR type	Exposure Scenario with highest exposure	Compartment with highest RCR	Priority ranking [a]
(Triphenyl phosphates tert-butylated)						
Aluminate (Al(OH)41-), sodium, (T-4)-	12251-53-5	235-487-0	I	11 textiles - industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	High
Aluminium sodium dioxide	1302-42-7	215-100-1	I	11 textiles - industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	High
Chloroalkanes, C14-17	85535-85-9	287-477-0	C	11 textiles - industrial use	Soil	High
2,2',6,6'-Tetrabromo-4,4'-isopropylidene-diphenol (TBBPA)	79-94-7	201-236-9	B	08 polymers – formulation	Marine sediment	High
Isodecyl diphenyl phosphate	29761-21-5	249-828-6	P	11 textiles - industrial use	Soil	High
Ammonium sulphate	7783-20-2	231-984-1	I	11 textiles - industrial use	Marine water, Marine sediment	Medium-high
Phosphonium, tetrakis(hydroxy-methyl-, chloride (1:1), reaction products with 1-tetradecanamine and urea	359406-89-6	436-230-7	P	08 polymers - formulation	STP	Medium-high
Tetrakis(hydroxy-methyl)-phosphonium sulphate (2:1)	55566-30-8	259-709-0	P	05 coatings - formulation	Soil	Medium-high

Substance name	CAS Number	EC Number	FR type	Exposure Scenario with highest exposure	Compartment with highest RCR	Priority ranking [a]
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	1241-94-7	214-987-2	P	11 textiles - industrial use	Secondary poisoning (terrestrial)	Medium-low
Paraffin waxes, chloro	63449-39-8	264-150-0	C	11 textiles - industrial use	Secondary poisoning (terrestrial)	Medium-low
Ammonium dihydrogenortho-phosphate	7722-76-1	231-764-5	I	11 textiles - industrial use	STP	Medium-low
Diammonium hydrogenortho-phosphate	7783-28-0	231-987-8	I	11 textiles - industrial use	STP	Medium-low
1,3,5-Triazine-2,4,6-triamine	108-78-1	203-615-4	N	11 textiles - industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	Medium-low
Triphenyl phosphate	115-86-6	204-112-2	P	11 textiles - industrial use	Freshwater, Freshwater sediment	Medium-low
4,7-Methanoisobenzo-furan-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	204-077-3	C	01 Manufacturing of FR	Humans via the environment - oral	Medium-low
Tetrabromophthalic anhydride	632-79-1	211-185-4	B	01 Manufacturing of FR	Secondary poisoning (terrestrial)	Medium-low
Dipotassium 3,4,5,6-tetrabromophthalate	18824-74-3	242-604-9	B	11 textiles - industrial use	Soil	Low
Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl]	38051-10-4	253-760-2	HP	11 textiles - industrial use	Secondary poisoning (terrestrial)	Low

Substance name	CAS Number	EC Number	FR type	Exposure Scenario with highest exposure	Compartment with highest RCR	Priority ranking [a]
P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)						
Tributyl phosphate	126-73-8	204-800-2	P	05 coatings - formulation	Soil	Low
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	P	11 textiles - industrial use	Soil	Low
Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	1244733-77-4	807-935-0	HP	11 textiles – industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	Low
2,2-Bis(bromomethyl)-propane-1,3-diol	3296-90-0	221-967-7	B	01 Manufacturing of FR	Freshwater, Freshwater sediment	Low
(1-Methylethylidene)di-4,1-phenylenetetra-phenyl diphosphate	5945-33-5	425-220-8	P	08 polymers – formulation	Secondary poisoning (terrestrial)	Low
Phosphoric trichloride, reaction products with bisphenol A and phenol	181028-79-5	425-220-8	P	02 sealants – Formulation	Secondary poisoning (terrestrial)	Low
Pentaerythritol	115-77-5	204-104-9	O	03 sealants – industrial use	Humans via Environment – oral	Low
Triethyl phosphate	78-40-0	201-114-5	P	11 textiles – industrial use	Freshwater, Marine water, Freshwater sediment, Marine sediment	Low

Substance name	CAS Number	EC Number	FR type	Exposure Scenario with highest exposure	Compartment with highest RCR	Priority ranking [a]
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	432-770-2	P	13 Waste – landfill	STP	Very low
Phosphorous acid, triphenyl ester (TPP)	101-02-0	202-908-4	P	11 textiles – industrial use	Freshwater, Freshwater sediment, Humans via the environment – oral	Very low
1,3,5-Triazine-2,4-diamine, 6-phenyl-	91-76-9	202-095-6	N	11 textiles – industrial use	Freshwater, Freshwater sediment	Very low
Tris(2-butoxyethyl) phosphate (TBOEP)	78-51-3	201-122-9	P	11 textiles - industrial use	Soil	Very low
Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	1271172-98-5	690-512-6	N	01 Manufacturing of FR	Freshwater, Freshwater sediment	Very low
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	84852-53-9	284-366-9	B	10 textiles - formulation	STP	Very low

Note: a) Very high (highlighted in red): RCR in the range 1,000 – 10,000
High (highlighted in red): RCR in the range 100 – 1,000
Medium-high: RCR in the range 10 – 100
Medium-low: RCR in the range 1 – 10
Low: RCR in the range 0.1 – 1
Very low: RCR in the range 0.01 – 0.1 or less

5.2.2 Prioritising FRs based on regional scale risk characterisation

Assessment of the regional scale in EUSES gives insight into the overall magnitude of potential risks. This is because the higher the regional PEC, the lower the local contribution can be before a risk is identified. A relative ranking of the FRs was made based on the RCR value for each of the compartments at the regional level.

Several FRs had a high ranking in multiple environmental compartments, including the five highest-ranked FRs. Trixylyl phosphate (CAS no. 25155-23-1) ranked highest in the water, sediment and soil compartments, while it ranked second for humans exposed via the environment (oral route). Other FRs that ranked high among all six compartments were phenol, isopropylated, phosphate (3:1) (CAS no. 68937-41-7), aluminate ($Al(OH)_4^{1-}$), sodium, (T-4)- (CAS no. 12251-53-5), TBBPA (CAS no. 79-94-7) and MCCPs (CAS no. 85535-85-9).

Organophosphate FRs were the predominant class in the top ten ranking for each compartment, containing between four and six substances. The second commonest class was inorganic, with one to three entries in the top ten. Brominated, chlorinated or nitrogen-based FRs had up to two entries in the top ten.

5.2.3 Risk characterisation of FRs based on measured data

A variety of chemical identifiers are used in regulatory and academic reports of measured environmental concentrations of FRs. The UK REACH chemical names are used for consistency but there is no confirmation that the substance analysed and reported in these sources is identical to the equivalent substances as registered (or notified by downstream users). The monitoring data have been taken at face value, but it should be noted that interpretation is complicated by the proportion of non-detects, shape of the distribution, frequency of sampling and extent to which sampling reflects local sources or historical pollution events.

5.2.3.1 Environment Agency monitoring data

The Environment Agency uses semi-quantitative analytical screening methods to analyse water samples for a wide range of substances at once (Environment Agency, 2023). The dataset concerns freshwater, groundwater, marine water, drinking water supply and sewage discharge samples collected between 2018 and 2022. The analytical method involved gas or liquid chromatography with mass spectrometry (GCMS or LCMS), and both techniques were used for some FRs. The reported concentrations should only be considered approximate values as a result, although in most cases the data are reasonably consistent across several years' sampling. In addition, the sampling strategy does not necessarily provide comprehensive coverage across England or focus on areas where higher levels of FRs might be expected (e.g. downstream from STP serving textile coating facilities).

Table 5.3 lists the ten FRs included in this assessment, for which Environment Agency monitoring data were available.

Table 5.3: FRs for which Environment Agency monitoring data were available

Name	CAS number
Phosphoric acid, 2-ethylhexyl diphenyl ester	1241-94-7
Dimethyl phosphonate	868-85-9
Isodecyl diphenyl phosphate	29761-21-5
Tributyl phosphate	126-73-8
Triphenyl phosphate	115-86-6
Trixylyl phosphate	25155-23-1
1,3,5-Triazine-2,4,6-triamine	108-78-1
Hexachlorocyclopentadiene	77-47-4
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8
2,4,6-Tribromophenol	118-79-6

Detectable concentrations were reported for phosphoric acid, 2-ethylhexyl diphenyl ester, tributyl phosphate, triphenyl phosphate, trixylyl phosphate, 1,3,5-triazine-2,4,6-triamine, hexachlorocyclopentadiene, TDCPP and 2,4,6-tribromophenol in freshwater, groundwater, marine water and/or sewage discharge (see Appendix 5 which also includes sample sizes). Isodecyl diphenyl phosphate was below the detection limit of 0.01 µg/L. Dimethyl phosphonate was not detected although the detection limit for this substance was not evaluated.

The earlier review of OPEs by the Environment Agency ((draft) 2022b) noted that tris(2-chloroethyl) phosphate (CAS no. 115-96-8), tris(1,3-dichloro-2-propyl) phosphate (TDCPP, CAS no. 13674-87-8) and triphenyl phosphate (CAS no. 115-86-6) were the most frequently detected in both surface water and groundwater in England, with relatively high concentrations reported from some localities.

RCRs were derived by dividing the measured environmental concentrations (MECs) in freshwater, marine water and STP effluent to the corresponding PNEC values (the groundwater MECs were compared to the PNEC for freshwater). All RCRs were less than 0.1 for tributyl phosphate and 1,3,5-triazine-2,4,6-triamine. Table 5.4 provides an overview of other RCRs generated based on minimum, maximum, mean and median environmental concentrations. All RCRs were less than 1 for trixylyl phosphate. Though phosphoric acid, 2-ethylhexyl diphenyl ester was reported at concentrations above the limits of detection, PNECs for freshwater, marine water and STP effluent were not available for this substance because no adverse effects were observed up to the water solubility limit in acute and chronic ecotoxicity tests and it is readily biodegradable.

For triphenyl phosphate, RCRs generally exceeded 1 in all samples regardless of which summary statistic for the concentrations was used (i.e. minimum, maximum, mean or median) in freshwater, groundwater and marine water based on GCMS data. In freshwater, the highest RCR (180) was based on a MEC reported in 2018; in groundwater the highest RCR was 15 in 2018 while in marine water the highest RCR was 12,000 in 2021 (the latter is an extremely high value, and may be an outlier). Based on mean concentrations, the RCRs ranged from 1.5 to 2.5 in fresh water, between 1.3 and 2 in groundwater, and from 9.8 to 193 in marine water. For marine water, the lowest concentrations reported for each year also exceeded the PNEC value resulting in RCRs ranging from 1.2 to 9. It should be noted that the apparently higher concern for marine water could be an artefact, because the marine PNEC is typically based on ecotoxicity data for freshwater organisms with a high assessment factor to account for the higher biodiversity in marine ecosystems, and can be refined with ecotoxicity data for marine species. This has not been checked for the purposes of this project.

For TDCPP, the RCRs for the freshwater compartment based on the maximum concentrations were above 1 for all sampling years. In groundwater the maximum concentration exceeded the freshwater PNEC for one of the sampling years resulting in RCRs above 1. For the marine compartment, RCRs based on the mean and maximum concentrations resulted in RCRs above 1 for three sampling years.

For 2,4,6-tribromophenol, RCRs above 1 were only observed for the maximum concentration detected in freshwater in 2019 and in marine water collected in 2020 (in the only sample with a concentration above the level of quantitation (LOQ)).

Table 5.4: Risk characterisation ratios for FRs based on Environment Agency monitoring data

Name (CAS number)	Environmental compartment	PNEC (µg/L)	Year	Concentration RCR[a] is based on			
				Minimum	Maximum	Arithmetic mean	Median
Triphenyl phosphate (115-86-6[c])	Freshwater	0.48	2018	0.11	180	2.5	1.7
	Freshwater	0.48	2019	0.58	7.3	1.6	1.1
	Freshwater	0.48	2020	0.63	5.4	1.5	1.3
	Freshwater	0.48	2021	0.63	20	1.5	1.2
	Groundwater	0.48	2018	0.63	15	2	1.6
	Groundwater	0.48	2019	0.63	10	1.4	1
	Groundwater	0.48	2020	0.67	8.3	2	0.9
	Groundwater	0.48	2021	0.63	2.7	1.3	1.2
	Marine water	0.048	2018	6.3	42	18	17
	Marine water	0.048	2019	6.5	19	9.8	8.4
	Marine water	0.048	2020	9	9	[b]	[b]
	Marine water	0.048	2021	1.2	12000	190	17
	Sewage discharge	5000	2018	<0.1	<0.1	<0.1	<0.1
Trixylyl phosphate (25155-23-1)	Freshwater	0.66	2018	<0.1	<0.1	[b]	[b]
	Freshwater	0.66	2019	0.11	0.11	[b]	
	Marine water	0.066	2018	0.15	0.15		
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP) (13674-87-8)	Freshwater	0.2	2019	<0.1	4.2	0.21	0.15
	Freshwater	0.2	2020	<0.1	1.5	0.18	0.15
	Freshwater	0.2	2021	<0.1	4.4	0.21	0.13
	Freshwater	0.2	2022	<0.1	3.6	0.22	0.13
	Groundwater	0.2	2019	<0.1	2.3	0.3	0.17
	Groundwater	0.2	2020	<0.1	0.29	0.14	0.1
	Groundwater	0.2	2021	0.31	0.43	[b]	[b]
	Groundwater	0.2	2022	<0.1	<0.1	[b]	[b]
	Marine water	0.02	2019	0.5	2	1.1	1
	Marine water	0.02	2021	0.4	8.3	1.8	1.5
	Marine water	0.02	2022	0.3	4.5	1.2	1
2,4,6-Tribromo-phenol	Freshwater	0.5	2019	<0.1	1.5	<0.1	<0.1
	Freshwater	0.5	2020	<0.1	0.16	<0.1	<0.1
	Freshwater	0.5	2021	<0.1	0.13	<0.1	<0.1

Name (CAS number)	Environmental compartment	PNEC (µg/L)	Year	Concentration RCR[a] is based on			
				Minimum	Maximum	Arithmetic mean	Median
(118-79-6)	Freshwater	0.5	2022	<0.1	0.36	<0.1	<0.1
	Groundwater	0.5	2019	<0.1	0.13	<0.1	<0.1
	Groundwater	0.5	2020	<0.1	<0.1	[b]	[b]
	Groundwater	0.5	2022	<0.1	<0.1	[b]	[b]
	Marine water	0.05	2019	<0.1	0.24	0.16	0.2
	Marine water	0.05	2020	[d]	3.9	[b]	[b]
	Marine water	0.05	2021	<0.1	0.52	0.18	0.14
	Marine water	0.05	2022	<0.1	0.6	0.22	0.18

Note: a) RCRs above 1 are highlighted in red.

b) Insufficient data above the LOQ to allow the mean and median to be defined.

c) RCRs are based on GCMS data, which were generally higher compared to LCMS data. The reason for this is unknown.

d) There was only 1 detect in this year given as the maximum concentration.

5.2.3.2 Monitoring data compiled from Environment Agency PEWS reports

PEWS reports were available for 11 FRs, listed in Table 5.5. Substances can be nominated for PEWS by internal Environment Agency staff or external stakeholders due to particular concerns, such as findings reported in the scientific literature. Nominated substances are then sifted based on initial indications of widespread dispersed use and hazardous properties. Nominated substances with a sifting result for high priority are subsequently subjected to a rapid high level screening review to determine prioritisation scores based on hazard data in combination with environmental monitoring data. This is not a formal detailed risk assessment.

Table 5.5: FRs for which EA PEWS screening has been performed

Name	CAS number
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene (DBDPE)	84852-53-9
Dechlorane Plus™	13560-89-9
Tetrabromobisphenol a-bis(2,3-dibromopropyl ether) (TBBPA-DBPE)	21850-44-2
2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	79-94-7
Triphenyl phosphate (TPHP)*	115-86-6
1,3,5-Triazine-2,4,6-triamine	108-78-1
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8
Reaction products of phosphoryl trichloride and 2-methyloxirane (Tris(2-chloro-1-methylethyl) phosphate, TCIPP, TCPP)	13674-84-5
Tris(2-chloroethyl) phosphate (TCEP)*	115-96-8
Trixylyl phosphate	25155-23-1
2,4,6-Tris(2,4,6-tribromophenoxy)-1,3,5-triazine (TTBP-TAZ)	25713-60-4

*These two substances were prioritised for screening because they featured in the top 50 most frequently detected emerging substances in the Environment Agency's GCMS and LCMS surface water target screen data.

PEWS reports include GB-relevant monitoring data published in the peer-reviewed scientific literature, and so these were extracted for consideration in this report.

The PEWS reports for Dechlorane Plus™, TBBPA-DBPE, TBBPA, TCPP and TTBP-TAZ did not include any GB-relevant monitoring data. Some of these have a very low solubility in water, so may not be detectable in surface water samples without very sensitive substance-specific analytical methods. Triphenyl phosphate, 1,3,5-triazine-2,4,6-triamine and trixylyl phosphate are already covered in Section 5.2.3.1.

The PEWS report for TCEP included semi-quantitative data from the monitoring programme run by the Environment Agency. TCEP is not registered under UK REACH and manufacture has ceased under EU REACH, and so has not been reviewed in this report. However, it was considered 'high risk' with high certainty for both groundwater and surface water under PEWS because it is an SVHC (based on reproductive toxicity) and EA monitoring data from 2017-2019 showed detections in UK surface water and groundwater. Biota and sediment were flagged for concern based on peer-reviewed literature showing positive detections in these compartments. No authorisation applications were made for TCEP under EU REACH (the sunset date was 21 August 2015, when the UK was still a member of the EU). The positive detections may therefore relate to legacy issues (e.g. releases from products that were put on the market before 2015), a continued low level of supply below 1 tonne/year by individual companies, and/or releases from treated articles that are still being imported.

1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE) is not included in the EA monitoring programme at the time of writing. The PEWS report for the substance included monitoring data from the peer-reviewed literature showing that this FR was detected in UK soils sampled at intervals along a rural/urban transect in the West Midlands, with concentrations ranging between 0.2 and 1 µg/kg organic matter (Drage *et al.*, 2016), which would result in an RCR below 0.01.

5.2.3.3 CEFAS and FSA monitoring data

Unpublished CEFAS water and sediment monitoring data for samples from river and coastal locations (North Sea, Irish Sea, Celtic Sea and English Channel) were shared by the Environment Agency for use in this project. Where possible, MECs are compared with PNECs (µg/L for water and mg/kg dry weight (dw) for sediment) as described in Section 5.2.3.1, and the data are summarised in Table 5.6.

Marine sediment samples collected in triplicate in 2005-2006 from five locations contained five FRs that are covered in this report (total sample size of 15 for each FR) (CEFAS, 2011). Four of these FRs had RCRs below 1 based on the maximum sediment concentration reported. For triphenyl phosphate, the highest reported sediment concentration exceeded the PNEC value at three of the sampling sites with the highest RCR being 2.6.

Two FRs were detected in marine water samples from the same period analysed in triplicate (total sample size of three for each FR) (CEFAS, 2011), with RCRs below 1 for the highest concentrations.

Freshwater sediment was collected in 2014 at five sampling locations (total sample size of five for each FR) (CEFAS, 2014). Ten FRs were detected and are covered in this report with available PNECs. RCRs were all below 1. Phosphoric acid, 2-ethylhexyl diphenyl ester (CAS no. 1241-94-7) was also reported in these sediment samples, although no hazard has been identified for the sediment compartment and the substance is readily biodegradable.

Freshwater samples collected in 2013 from three locations contained four FRs (total sample size of three for each FR) (CEFAS, 2014). RCRs were below 1 for three of these FRs. No hazard has been identified for the freshwater compartment for tris(2-ethylhexyl) phosphate (CAS no. 78-42-2) because no adverse effects were observed up to the water solubility limit in acute and chronic ecotoxicity tests.

Table 5.6: Risk characterisation ratios for FRs based on measured environmental concentrations from CEFAS monitoring

Name	CAS no.	Environmental compartment	PNEC	Year	RCR
Tributyl phosphate	126-73-8	Marine sediment*	1.44 mg/kg dw	2005-2006	<0.1**
		Freshwater sediment#	14.4 mg/kg dw	2014	<0.1##
		Freshwater#	82 µg/L	2013	<0.1##
Triphenyl phosphate	115-86-6	Marine sediment*	0.014 mg/kg dw	2005-2006	Liverpool Bay 0.61
		Marine sediment*	0.014 mg/kg dw	2005-2006	Tees Bay 0.86
		Marine sediment*	0.014 mg/kg dw	2005-2006	Off Tyne/Tees 1.4E+00
		Marine sediment*	0.014 mg/kg dw	2005-2006	Thames 1.1E+00
		Marine sediment*	0.014 mg/kg dw	2005-2006	River Mersey 2.6E+00
		Marine water*	0.048 µg/L	2005-2006	0.52**
		Freshwater sediment#	0.143 mg/kg dw	2014	0.22##
		Freshwater#	0.48 µg/L	2013	<0.1##
Tris(methylphenyl) phosphate	1330-78-5	Marine sediment*	0.205 mg/kg dw	2005-2006	0.3**
		Freshwater sediment#	2.05 mg/kg dw	2014	<0.1##
Tris(2-butoxyethyl) phosphate (TBOEP)	78-51-3	Marine sediment*	0.08 mg/kg dw	2005-2006	0.18**

Name	CAS no.	Environmental compartment	PNEC	Year	RCR
		Marine water*	2.4 µg/L	2005-2006	<0.1**
		Freshwater sediment#	0.804 mg/kg dw	2014	<0.1##
		Freshwater#	24 µg/L	2013	<0.1##
Tris(2-ethylhexyl) phosphate	78-42-2	Marine sediment*	83.1 mg/kg dw	2005-2006	<0.1**
		Freshwater sediment#	0.831 mg/kg dw	2014	0.13##
Triethyl phosphate	78-40-0	Freshwater sediment#	5 mg/kg dw	2014	<0.1##
Triisobutyl phosphate	126-71-6	Freshwater sediment#	2.05 mg/kg dw	2014	<0.1##
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	Freshwater sediment#	0.83 mg/kg dw	2014	<0.1##
Trixylyl phosphate	25155-23-1	Freshwater sediment#	7.92 mg/kg dw	2014	<0.1##

Note: RCRs>1 are highlighted in red

* Data taken from CEFAS, 2011

** RCR based on the highest sediment or water concentrations reported among the sampling locations.

Data taken from CEFAS, 2014

RCR based on the highest sediment or water concentrations reported among the sampling locations

Of the Goup (a), (b) and (c) substances, positive detections in some foodstuffs were found for TBBPA and 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE) in two FSA studies (FSA, 2012 and FSA, 2015). However, it is not possible to determine the total daily intake for members of the general population via diet or carry out risk characterisation from the limited information available:

- FSA (2012) found that DBDPE was detectable only in the fish group (with concentrations of 0.23 and 2.47 µg/kg whole weight) and not in any of the other 19 food

groups analysed. TBBPA was detectable only in the “fats and oils” group (with concentrations of 0.02 and 0.03 µg/kg whole weight) and had a possible (indicative) detection in potatoes (at concentrations of 0.01 and 0.19 µg/kg whole weight). Composite samples were analysed for each food group in this study. The number of sub-samples was 140 in the fish group, 84 in the fats and oils group and 23 in the potatoes group.
- TBBPA was rarely detectable in the human foodstuffs analysed in 207 samples in FSA (2015), with only a few positive detections in shellfish and fish at concentrations ranging from <0.01 to <0.05 ng/g (median: 0.01 ng/g). No detects were reported for DBDPE in the subset of 30 samples across different food types screened by GCMS.

5.2.3.4 Monitoring data from the peer-reviewed scientific literature

A large number of monitoring and analytical method development studies are published for FRs each year, by both public bodies and academia around the world. Reviewing them all was not possible with the resources available for this project. Exposure will differ between countries depending on their approach to risk management of chemicals and waste disposal, so relevance for GB will vary widely. In addition, a significant proportion of the studies concern FRs that are no longer commercially supplied and/or already subject to regulatory controls in the UK, or which have not been registered under UK REACH. As this report is about the prioritisation of FRs for further regulatory control under UK REACH, a review of legacy FRs that already have extensive controls in place is outside scope.

To provide a more targeted approach, 27 GB studies highlighted by the Advisory Group have been summarised in Appendix 8. These cover a wide range of sample types. For those FRs that have been assessed in this project and considered GB-relevant (Group (a), (b) or (c)), RCRs were determined (where PNECs or DNELs are available) and are generally all below 0.1, with the following exceptions:

- Ganci *et al.* (2019) collected surface sediment samples along a 110 km transect of the River Thames (starting from Teddington Lock and out to the southern North Sea) in October 2011. An RCR of 17.5 was estimated for 2,4,6-tribromophenol (TBP) based on the maximum concentrations measured towards the North Sea.

- Onoja *et al.* (2023) reported the presence of FRs in sediment collected from four locations in England (Worcester-Birmingham Canal, River Severn, River Sowe and River Tame) during 2019-2021. Using the highest concentrations among all sampling locations, an RCR of 0.21 was obtained for tris(2-butoxyethyl) phosphate (TBOEP) and 0.18 for triphenyl phosphate.

Additional studies highlighted before completion of this project were briefly reviewed:

- TCIPP/TCPP was reported in two studies in UK freshwater with the highest concentration being 26 µg/L (Cristale *et al.*, 2013; Wang *et al.*, 2020). This results in an RCR of 0.08.

- Triethyl phosphate (CAS no. 78-40-0) was reported in UK freshwater with a highest concentration of 0.16 µg/L (Wang *et al*., 2020). This results in an RCR below 0.01.
- TBBPA was detected in UK marine sediment at a concentration of 2.7 µg/kg dry weight (dw) (Sühring *et al*., 2015). This results in an RCR below 0.01.

It should be noted that potential risks to people exposed to FRs in indoor air or dust have not been considered in this report.

5.2.3.5 Monitoring summary

Relatively few GB-relevant FRs have been subject to monitoring programmes by regulators and academic researchers in GB, although 17 have been detected in a range of environmental media, human tissues and foodstuffs. It is not possible to compare the reported concentrations with the worst-case exposure modelling due to sampling limitations and uncertainties about which geographical scale (local or regional) the monitoring represents and the influence of historical pollution events. These would need to be considered in substance-specific assessments.

Where relevant PNECs and DNELs are available, the level of risk suggested by the monitoring is generally very low (RCRs less than 0.01). A small number of FRs have environmental RCRs in the “low” to “medium-high” range, and one (triphenyl phosphate) has RCRs in the “very high” range. These are generally based on maximum reported values, although triphenyl phosphate and TDCPP have RCRs above 1 when considering mean or median concentrations. It is beyond the scope of this report to comment further on data distributions, but typically a 90th percentile of the distribution would be used for formal risk assessment purposes.

The substances that have been detected in different media and those for which RCRs above 1 have been identified are summarised in Table 5.7.

Table 5.7: Potential risks based on monitoring data

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
Triphenyl phosphate	115-86-6	RCRs 1 – 1,000 (EA monitoring) and <1 (literature)	RCRs <1 (CEFAS and literature)	RCRs <1 – 100 (EA monitoring)	RCRs 1 - >10,000 (EA monitoring) and <1 (CEFAS and literature)	RCRs <1 - 10 (CEFAS and literature)	RCRs <1 (literature)	RCRs <1 (literature)	Air: RCRs <1 (literature)
Tris(1,3-dichloro-isopropyl) phosphate (TDCPP)	13674-87-8	RCRs <1 – 10 (EA monitoring)	RCRs <1 (CEFAS and literature)	RCRs <1 – 10 (EA monitoring, one instance only)	RCRs 1 – 10 (EA monitoring)	-	RCRs <1 (literature)	RCRs <1 (literature)	Air: RCRs <1 (literature)
2,4,6-Tribromo-phenol	118-79-6	RCRs <1 – 10 (EA monitoring, one instance only)	-	-	RCRs <1 – 10 (EA monitoring, one instance only)	RCRs 10 – 100 (literature)	-	-	-

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
Tributyl phosphate	126-73-8	RCRs <1 (EA monitoring and literature)	RCRs <1 (CEFAS and literature)	RCRs <1 (EA monitoring)	RCRs <1 (EA monitoring)	RCRs <1 (CEFAS and literature)	RCRs <1 (literature)	RCRs <1 (literature)	Sewage discharge: RCRs <1 (EA monitoring); Air: RCRs <1 (literature)
Trixylyl phosphate	25155-23-1	RCRs <1 (EA monitoring)	RCRs <1 (CEFAS and literature)	-	RCRs <1 (EA monitoring)	-	-	-	-
1,3,5-Triazine-2,4,6-triamine	108-78-1	RCRs <1 (EA monitoring)	-	RCRs <1 (EA monitoring)	RCRs <1 (EA monitoring)	-	-	-	-
Tris(methylphenyl) phosphate	1330-78-5	-	RCRs <1 (CEFAS and literature)	-	-	RCRs <1 (CEFAS and literature)	-	-	-

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
Tris(2-butoxy-ethyl) phosphate (TBOEP)	78-51-3	RCRs <1 (literature)	RCRs <1 (CEFAS and literature)	-	RCRs <1 (CEFAS and literature)	RCRs <1 (CEFAS and literature)	RCRs <1 (literature)	RCRs <1 (literature)	
Tris(2-ethylhexyl) phosphate	78-42-2	# (literature)	RCRs <1 (CEFAS and literature)	-	-	RCRs <1 (CEFAS and literature)	-	-	-
Triethyl phosphate	78-40-0	-	RCRs <1 (CEFAS and literature)	-	-	-	-	-	-
Triisobutyl phosphate	126-71-6	-	RCRs <1 (CEFAS and literature)	-	-	-	-	-	-

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
Tributyl phosphate	126-73-8	-	RCRs <1 (CEFAS and literature)	-	-	-	-	-	-
Phosphoric acid, 2-ethylhexyl diphenyl ester	1241-94-7	-	# (literature)	-	-	-	RCRs <1 (literature)	RCRs <1 (literature)	Air: RCRs <1 (literature)
2,2',6,6'-Tetrabromo-4,4'-iso-propylidenediphenol (TBBPA)	79-94-7	RCRs <1 (literature)	RCRs <1 (literature)	-	-	RCRs <1 (literature)	-	Freshwater fish: # (FSA and literature)	Human milk: # (literature)

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	84852-53-9	-	-	-	-	RCRs <1 (literature)	-	# (FSA and literature)	Human milk: # (literature)
Bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP)	26040-51-7	-	# (literature)	-	-	# (literature)	-	# (literature)	Human milk: # (literature)

Substance name	CAS no.	Freshwater	Freshwater sediment	Groundwater	Marine water	Marine sediment	Drinking water	Foodstuffs	Other
Reaction products of phosphoryl trichloride and 2-methyl-oxirane (tris(2-chloro-isopropyl) phosphate; TCIPP/ TCPP)	13674-84-5 / 1244733-77-4	RCRs <1 (literature)	-	-	-	-	RCRs <1 (literature)	RCRs <1 (literature)	-

Note: RCRs>1 are highlighted in red

Substance detected but risk characterisation is not possible due to the lack of a suitable PNEC/DNEL.

5.3 Prioritisation summary tables

The previous sections summarise a variety of ways of ranking FRs. This section brings these all together. Substances from Group (a), (b) and (c) are included in Table 5.8 or Table 5.9 if they have a high supply volume combined with at least one hazard or RCR above 1 based on measured or modelled exposure data. Substances that are listed as POPs, or are on UK REACH Authorisation, Restriction, or SVHC Candidate lists, are excluded as these are already subject to active regulatory control or consideration in the UK.

Both tables follow the same format. The supply volume is indicated as either “high” or “low”, based on a generic threshold value using the upper range limit for each substance. The hazards are those identified through this project – see Section 5.1 (especially the footnotes to Table 5.1) for clarification of the approach to determining these hazard categories based on the data collected. The risk ranking is based on measured or modelled exposure data as described in Section 5.2.

Table 5.8: UK REACH registered or grandfathered substances

In this table, substances for which FR use in GB is suspected but not confirmed are presented in italic font.

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Brominated organic							
2,2’,6,6’-Tetrabromo-4,4’-isopropylidene-diphenol (TBBPA)	79-94-7	201-236-9	ECHA SVHC candidate list: Carcinogenic. CoRAP: Suspected reprotoxic, potential ED, suspected PBT/vPvB.	High	Potential PBT or vPvB, Potential ED, Environmental concern, Health concern	Yes	
1,1’-(Ethane-1,2-diyl)bis[pentabromo-benzene] (DBDPE)	84852-53-9	284-366-9	CoRAP: Suspected PBT/vPvB.	High	Potential PBT or vPvB		
Bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP)	26040-51-7	247-426-5	ECHA SVHC candidate list: vPvB. CoRAP: Potential ED, suspected PBT/vPvB, other hazard based concern.	High	Potential PBT or vPvB		

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
2,2-Bis(bromo-methyl)propane-1,3-diol	3296-90-0	221-967-7	ECHA SVHC candidate list: Carcinogenic.	High	Health concern, Potential PMT or vPvM	Potential	
Dipotassium 3,4,5,6-tetrabromophthalate	*18824-74-3*	*242-604-9*	*ARN: Suspected vPvB*	*Low*	*Potential PMT or vPvM*	*Potential*	*Uses as FR in UK not validated*
Tetrabromophthalic anhydride	*632-79-1*	*211-185-4*	*ARN: CMR inconclusive*	*High*		*Yes*	*Uses as FR in UK not validated*
Chlorinated organic							
Chloroalkanes, C14-17	85535-85-9	287-477-0	ECHA SVHC candidate list: PBT/vPvB. UK POP proposal.	High	Potential PBT or vPvB, Potential ED, Health concern, Environmental concern	Yes	
4,7-Methanoiso-benzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	*115-27-5*	*204-077-3*	*CoRAP: CMR, suspected PBT/vPvB, suspected sensitiser.*	*High*	*Health concern*	*Yes*	*Uses as FR in UK not validated*
Paraffin waxes, chloro	63449-39-8	264-150-0	UK RAP: Suspected PBT/vPvB.	High	Present on CHEMSEC and/or TEDX ED lists,	Yes	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
					Environmental concern		
Halogenated organophosphorus							
(1-Methyl-ethylidene)di-4,1-phenylene-tetraphenyl diphosphate	*5945-33-5*	*425-220-8*	*ARN: Hazards inconclusive*	*High*	*Potential PBT or vPvB*	*Potential*	*Uses as FR in UK not validated* *See also CAS no.181028-79-5*
Phosphoric trichloride, reaction products with bisphenol A and phenol	*181028-79-5*	*425-220-8*	*ARN: Hazards inconclusive*	*High*	*Potential PBT or vPvB*	*Potential*	*Uses as FR in UK not validated* *See also CAS no. 5945-33-5*
Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	1244733-77-4	807-935-0	CoRAP: Suspected carcinogenic, suspected reprotoxic, potential ED.	High	Potential ED	Potential	Pending assessment of new carcinogenicity data by EC.
Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	38051-10-4	253-760-2	ARN: Potential CMR; indications of ED	High	Health concern	Potential	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Inorganic							
Antimony oxide (Sb_2O_3)	1309-64-4	215-175-0	CoRAP: Carcinogenic, risk based concern.	High	Health concern		
Zinc oxide	1314-13-2	215-222-5	CoRAP: Other hazard based concern (health and environmental; hazard of nanoform) and risk based concern.	High	Present on CHEMSEC and/or TEDX ED lists, Environmental concern		
Zinc chloride ($ZnCl_2$)	*7646-85-7*	*231-592-0*		*High*	*Present on CHEMSEC and/or TEDX ED lists, Environmental concern*		
Ammonium sulphate	7783-20-2	231-984-1		High	Present on CHEMSEC and/or TEDX ED lists	Yes	
Ammonium chloride	*12125-02-9*	*235-186-4*		*High*	*Present on CHEMSEC*		

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
					and/or TEDX ED lists		
Magnesium chloride ($MgCl_2$)	*7786-30-3*	*232-094-6*		*High*	*Present on CHEMSEC and/or TEDX ED lists*		
Boron zinc oxide ($B_6Zn_2O_{11}$)	12767-90-7	235-804-2		High	Health concern, Environmental concern		
Calcium dihydroxide	1305-62-0	215-137-3	Approved BPR*, Approved PPPR**	High	Health concern		
Molybdenum trioxide	*1313-27-5*	*215-204-7*	*ARN: CMR, persistence*	*High*	*Health concern*		
Ammonium dihydrogenortho-phosphate	7722-76-1	231-764-5		High		Yes	
Diammonium hydrogenortho-phosphate	7783-28-0	231-987-8		High		Yes	
Aluminate ($Al(OH)_4^{1-}$), sodium, (T-4)-	12251-53-5	235-487-0		High		Yes	
Aluminium sodium dioxide	1302-42-7	215-100-1		High		Yes	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Nitrogen-based							
1,3,5-Triazine-2,4,6-triamine (Melamine)	108-78-1	203-615-4	ECHA SVHC candidate list: Equivalent level of concern having probable serious effects to human health and the environment.	High	Potential ED, Health concern, Potential PMT or vPvM	Yes	
Organophosphorus							
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	ARN: ED	High	Potential PBT or vPvB, Potential ED, Environmental concern	Potential	
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated)	68937-40-6	700-990-0	ARN: Known or potential hazard for repro and ED; inconclusive neurotoxicity hazard	High	Potential PBT or vPvB, Environmental concern	Yes	
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	CoRAP: Potential ED and suspected PBT/vPvB.	High	Potential ED, Health concern, Environmental concern	Yes	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Tetrakis(hydroxy-methyl)phosphonium sulphate (2:1)	*55566-30-8*	*259-709-0*	*Approved BPR* *ARN: known or potential CMR, STOT RE and sensitisation, aquatic toxicity, P and M.*	*High*	*Present on CHEMSEC and/or TEDX ED lists, Health concern, Environmental concern*	*Yes*	*Uses as FR in UK not validated*
Tributyl phosphate	*126-73-8*	*204-800-2*		*High*	*Present on CHEMSEC and/or TEDX ED lists, Health concern*	*Potential*	*Uses as FR in UK not validated*
Triphenyl phosphate	115-86-6	204-112-2	CoRAP: Potential ED	Low	Potential ED, Environmental concern	Yes	
Tris(2-butoxyethyl) phosphate (TBOEP)	*78-51-3*	*201-122-9*		*Low*	*Present on CHEMSEC and/or TEDX ED lists*	*Potential*	
Phosphonium, tetrakis(hydroxy-methyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	359406-89-6	436-230-7	ARN: Known/potential CMR, STOT RE, skin sensitisation, aquatic toxicity, P and M.	High	Health concern, Potential PMT or vPvM, Environmental concern	Yes	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Isodecyl diphenyl phosphate	*29761-21-5*	*249-828-6*		*High*	*Health concern, Environmental concern*	*Yes*	*Uses as FR in UK not validated*
Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	27104-30-9	500-057-6	ARN: Known/potential CMR, STOT RE, skin sensitisation, aquatic toxicity, P and M.	High	Health concern, Environmental concern	Yes	
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	*1241-94-7*	*214-987-2*		*High*	*Health concern*	*Yes*	*Uses as FR in UK not validated*
Triethyl phosphate	78-40-0	201-114-5	ARN: Known or potential ED, CMR.	High		Potential	
Reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate (cresyl diphenyl phosphate)		945-730-9	ARN: Known or potential CMR, ED, inconclusive neurotoxicity.	High		Yes	

Name	CAS no.	EC no.	Current regulatory investigation	Assumed supply volume (GB)	Hazard(s) identified	Risk issues identified	Comment
Other							
Pentaerythritol	*115-77-5*	*204-104-9*		*High*		*Potential*	*Uses as FR in UK not validated*

Notes:

*Approved under the Biocidal Products Regulation (BPR) (ECHA, 2022k)

**Approved under the Plant Protection Products Regulation (PPPR)

Table 5.9: Substances screened as GB-relevant based on a DUIN and/or advice from project Advisory Group

Name	CAS no.	EC no.	Current regulatory investigation	Supply volume (EU)	Hazard(s) identified	Risk issues identified	Comment
Brominated organic							
2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine	25713-60-4	426-040-2	ARN: Suspected PBT, potential CMR and potential ED.	High	Potential PBT or vPvB, Environmental concern		
Reaction mass of 1,1'-(isopropylidene)-bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene] and 1,3-dibromo-2-(2,3-dibromo-2-methylpropoxy)-5-{2-[3,5-dibromo-4-(2,3,3-tribromo-2-methylpropoxy)phenyl]propan-2-yl}benzene		944-461-4	ARN: Potential carcinogenicity, ED and/or PBT/vPvB.	High	Potential PBT or vPvB		
2,4,6-Tribromophenol	118-79-6	204-278-6	CoRAP: CMR, suspected PBT/ vPvB, high RCR.	Low	Present on CHEMSEC and/or TEDX ED lists, Environmental concern	Yes	
Tetrabromobisphenol A-bis(2,3-dibromopropyl ether)	21850-44-2	244-617-5	CoRAP: Potential ED, suspected PBT/ vPvB.	High	Potential ED		
1,1'-(Isopropylidene)-bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)-benzene)	97416-84-7	306-	CoRAP: Potential ED,	High	Potential ED		

Name	CAS no.	EC no.	Current regulatory investigation	Supply volume (EU)	Hazard(s) identified	Risk issues identified	Comment
		832-3	suspected PBT/ vPvB.				
2-Butyne-1,4-diol, polymer with 2-(chloromethyl)-oxirane, brominated, dehydrochlorinated, methoxylated	68441-62-3	614-503-3		High	Potential PMT or vPvM		
Halogenated organophosphorus							
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	237-159-2	CoRAP: Potential ED. ARN: Carcinogenic, mutagenic / toxic for reproduction concerns.	High	Potential ED, Health concern, Environmental concern	Yes	
Inorganic							
Sodium hexahydroxyantimonate(1-)	33908-66-6	251-735-0		High	Health concern, Environmental concern		
Calcium magnesium dihydroxide oxide	58398-71-3	261-235-4		High	Health concern		

Name	CAS no.	EC no.	Current regulatory investigation	Supply volume (EU)	Hazard(s) identified	Risk issues identified	Comment
Ammonium bromide	12124-97-9	235-183-8	ARN: Toxic for reproduction.	High	Health concern		
Organophosphorus							
Tris(methylphenyl) phosphate	1330-78-5	809-930-9	CoRAP: Suspected PBT/vPvB, potential ED and other hazard-based concern.	High	Potential ED, Health concern, Environmental concern	Potential	
Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6	ARN: Potential ED and potential CMR.	High	Present on CHEMSEC and/or TEDX ED lists		Detected (freshwater) but risk characterisation not possible (literature).
1,3,5-Triazine-2,4,6-triamine, phosphate	41583-09-9	255-449-7		High	Health concern, Potential PMT or vPvM		

Name	CAS no.	EC no.	Current regulatory investigation	Supply volume (EU)	Hazard(s) identified	Risk issues identified	Comment
Diphenyl methylphosphonate	7526-26-3	231-388-1	ARN: Potential vPvM.	High	Potential PMT or vPvM, Environmental concern		
1,3,2-Dioxaphosphorinane,2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	4090-51-1	223-829-1		High	Potential PMT or vPvM		
6h-Dibenzo[c,e][1,2]-oxaphosphinine 6-oxide	35948-25-5	252-813-7	ARN: Skin sensitisation.	High	Potential PMT or vPvM		
Aluminum diethyl-phosphinate	225789-38-8	428-310-5	ARN: Potential vPvM.	High	Potential PMT or vPvM		
1,2-Ethanediamine, phosphate	14852-17-6	238-914-9	ARN: Suspected respiratory sensitiser.	High	Environmental concern		
Other organic							
Dicumyl peroxide	80-43-3	201-279-3	ECHA SVHC intentions: Toxic for	High	Health concern, Environmental concern		

Name	CAS no.	EC no.	Current regulatory investigation	Supply volume (EU)	Hazard(s) identified	Risk issues identified	Comment
			reproduction (Article 57c). CoRAP: Suspected PBT/vPvB, high RCR.				

6 Recommendations

This project has identified FRs of concern at a scoping level that were in the UK REACH system by January 2023. This provides a starting point for government discussion on further investigations.

Based on the findings, various activities could be carried out by government and other stakeholders to improve information on emissions, hazards and/or risks. The suggested tasks outlined in the following sections are organised by approach and context.

6.1 Further investigation options

Activities to clarify and refine information associated with market and use:

There is significant uncertainty in the tonnages of substances placed on the GB market, along with the specific uses associated with each substance. The uncertainty is compounded by a lack of information on the breakdown of substance tonnages by different uses. This report has relied on assumptions on the tonnage breakdown based on substance groupings. This report also did not include the import of finished articles which could contain FRs as additives as they cannot be readily quantified (as there is no UK REACH registration requirement for FRs that enter GB already incorporated within articles). Further investigation could involve broad industry surveys and consultations with the FRs sector to fill some of the gaps in market data.

Specific objectives include a better understanding of the import of FRs as substances; import of FRs in articles; and clarification of FR use volumes in comparison with other uses. This particularly applies to the numerous substances concluded to be “potential” FRs in the absence of corroborating evidence.

Furthermore, there is scope to investigate tonnage and use information declared in UK REACH registrations (including submitted Chemical Safety Reports (CSRs), where available), which may provide more detail on the volumes of specific FRs used in specific applications.

These issues can realistically only be clarified by working with industry, academic and other expert consultation (see Section 6.2).

Activities to refine the understanding of risks to the environment or risks to humans exposed via the environment:

Due to a prior interest, the assessment of etidronic acid was limited to collection of easily-verifiable information, and excluded exposure assessment, data interpretation and prioritisation, to ensure no conflict of interests could arise.

In general, the approach taken to risk assessment in this project is conservative, particularly with regard to tonnages. In addition, there has been no review of the reliability of the property data or derivation of PNECs or DNELs. The risk-based ranking should therefore not be considered to indicate actual risks in need of management. Instead, further substance-specific risk assessments could be pursued where properties and exposure can be considered in more detail.

Ideally, the confidential information in the UK REACH registration database could be reviewed for all substances for which a concern for environmental compartments has been highlighted by the generic exposure and risk work described in Section 5.2. This would allow a more accurate, substance-specific tonnage to be used for FR uses. It must be recognised that this information will not be available for most substances until at least October 2027 (the final registration deadline is October 2030). Academic and regulatory risk assessments may also be available.

Adaptations to standard exposure scenario parameters to reflect FR use in GB might be appropriate, should further market research and industry consultation support it (e.g. in relation to import of articles and service life). UK REACH compliance guidance to registrants could make clear any specific expectations or adaptations relating to the life cycle of a substance in use as an FR.

The potential for mixture effects could also be considered, particularly if an FR undergoing further review is found to be commonly used with another FR from the same chemical group in the same product type.

Similar to Environment Agency (2003), inorganic FRs were less straightforward to assess because inorganic ions can have numerous sources (including natural occurrence) and their environmental fate and toxicity is strongly influenced by environmental conditions and bio-essentiality. Their hazard potential may therefore be a more reliable guide for prioritisation than risk.

Activities to improve monitoring evidence on environmental concentrations in GB:

Substances deemed to be of concern and not already subject to monitoring by the Environment Agency could be added to its monitoring programme to collect further data, noting that this is currently restricted to water samples. Any expansion of the existing monitoring suite will need to take account of available resources. Industry and academic stakeholders could also consider how they can provide additional monitoring information.

Two of the six organophosphorus FRs within the top ranked FRs based on the local and regional scale risk characterisation are already part of the annual monitoring programme (isodecyl diphenyl phosphate, CAS no. 29761-21-5; and trixylyl phosphate, CAS no. 25155-23-1). The other four could therefore be considered for addition to the monitoring programme, noting that some are multi-constituent substances:

- phenol, isopropylated, phosphate (3:1), CAS no. 68937-41-7
- tetrakis[hydroxymethyl] phosphonium chloride, CAS no. 27104-30-9

- reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate (cresyl diphenyl phosphate), EC no. 945-730-9;
- reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated), CAS no. 68937-40-6

Although triphenyl phosphate (CAS no. 115-86-6) had a low ranking in the local and regional scale risk assessment (with RCRs below 1), it had RCRs exceeding 1 based on the risk assessment using GB monitoring data. It could be that the generic exposure approach to estimate releases did not capture all (local) sources for this substance. In particular, it might be a constituent in other organophosphate FRs (e.g. as an impurity).

An Advisory Group member recommended that the Environment Agency monitor all FRs with high supply volumes in the EU, and specifically recommended monitoring for the chlorinated organophosphates TCIPP / TCPP and TDCPP in water, and 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE) in sediment (Advisory Group comments, 2023-24).

Further monitoring data are likely to be published in the academic literature in the future, and this can be taken into account for substance-specific assessments.

Activities to improve understanding of specific properties or hazards:

The project findings indicate that the substances prioritised based on their hazards are spread across different group chemistries.

Specific aspects of hazard could be explored further, building upon the scoping approach of this project. Examples include:

- More in-depth assessment of ecotoxicity data needs for soil or sediment, for example as part of formal (or informal) UK REACH evaluation processes.

- A systematic review of the hazards of the transformation products for each substance. For instance, 1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE) is a POP because it transforms to other substances of higher concern.

- A case-by-case review of the data gaps for PNECs and DNELs highlighted in Appendix 1.

- Closer scrutiny of environmental fate and long-term ecotoxicity for poorly-soluble substances (for which the key studies could be deficient). For example, some older BCF studies are known to have used aqueous concentrations above the limit of water solubility of the test substance. It is therefore recommended to review bioaccumulation data for FRs with experimental fish BCF results that appear to indicate a low level of bioaccumulation, but for which the log K_{ow} value would suggest otherwise.

- The approach to assessing (eco)toxicological effects that are sometimes considered to have no safe threshold (such as endocrine disrupters).

- Review the status of chemicals currently undergoing EU Substance Evaluation, as new data investigating specific hazards such as PBT or ED will be available in the future to refine the concern.

- Review the significance of additional hazards that have been highlighted for substances undergoing current/completed regulatory investigation for a different concern.

Several FRs have multiple chemical synonyms and some literature sources refer to abbreviations; in the regulatory context, there are cases of substances which have multiple congeners with different properties (for example, HBCDD) or which have changed substance identifiers to comply with UK or EU REACH, introducing new nomenclature and CAS numbers. An example is tris(2-chloroisopropyl) phosphate (TCPP or TCIPP, CAS no. 13674-84-5), which has been registered under EU REACH as “Reaction products of phosphoryl trichloride and 2-methyloxirane” (CAS no. 1244733-77-4). Research for this project also identified two separate CAS numbers associated with EC no. 425-220-8 (CAS nos. 5945-33-5 and 181028-79-5). So, there may be cases where it is not immediately apparent if a REACH-registered substance is the same as the one which has been studied and discussed under a different name. Therefore, extra care is needed in search strategies to ensure data are not overlooked.

Common properties and mechanisms of action of substances prioritised based on hazard in this scoping review could be considered along with the potential for group-level hazard evaluation. An Advisory Group member recommended further review of OPEs, citing the human health findings of Patisaul (2021) (Advisory Group comments, 2024).

Further evaluation of candidate ED FRs could be considered. This could include prioritising further assessment based on a review of the strength of current screening data. New requirements for the classification and labelling of ED chemicals recently entered into force in the EU. This may trigger further testing, so additional information is likely to become available in due course.

A new $PNEC_{water}$, accounted for in this project, has recently become available for triphenyl phosphate (CAS no. 115-86-6), based on an LC_{10} from a study carried out to OECD Test Guideline 234 which was published in 2021. This was requested under EU REACH Substance Evaluation due to ED concerns. The reliability of this result could be reviewed, and if so, the Environment Agency PEWS screening results may need to be updated for this substance.

Activities to improve understanding of specific substances or types of substances:

The assessment of polymeric FRs has been limited as they are not subject to REACH registration and so relevant property and use pattern data are generally unavailable. Nevertheless, as noted earlier in the report (Section 2.3.6), use of polymeric FRs is increasing according to ECHA. With REACH registration for polymers also under consideration in the EU, further evidence on this type of FR may become available in future. Until then, further industry consultation is likely to be the best way to obtain further information (see Section 6.2).

As noted above, there are examples of substances which have changed nomenclature to comply with REACH. In case UK REACH registrations or inquiries are received under the old chemical name and CAS or EC inventory numbers, the UK REACH regulator (HSE) should be aware of these cases as a substance 'sameness' check may be appropriate.

6.2 Work with industry

UK REACH registrants are responsible for assessing their substances to demonstrate how they can be used safely. Following EU exit, a transitional period was set up to provide GB companies time to adjust to the new situation since many did not previously have duties under EU REACH. The registration deadlines applicable for GB-based manufacturers and importers are in October 2026, 2028 and 2030 (depending on tonnage band and hazard classification). The registration information will support further regulatory prioritisation.

Prior to the deadlines, a consultation approach (including surveys and direct dialogue) may be the most appropriate and effective way to obtain further information from manufacturers, importers and/or downstream users. This could follow a similar approach to that adopted under the former UK Co-ordinated Chemicals Risk Management Programme, which provided a bridge between the close of activities under the Existing Substances Regulation and the first registration deadlines under EU REACH. The UK assessed 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE) (Environment Agency, 2007) and a series of organophosphate FRs (Environment Agency, 2009b) under this programme.

Longer-term engagement and consultation with relevant industry sectors could be considered to discuss companies' current approaches to managing risks in the supply chain of these substances. This could also address questions raised above (such as market data for substances identified as 'potential' FRs, those listed in Appendices 6 and 7, quantities of FRs in imported articles, polymeric FRs, and refinement of hazard data and potential risks).

6.3 Collaboration with other government stakeholders

Regulators whose remit involves human health protection (HSE, FSA and UK HSA) were included on the Advisory Group for this project. Where the only hazard identified falls under a human health category, the Environment Agency could also share the findings with the Buildings Safety Regulator (part of HSE). These organisations could consider how to address other aspects that are outside the Environment Agency's regulatory remit, such as assessing exposure and risk to the general public and workers arising from direct exposure, for example from indoor air or dust ingestion.

Active regulation, risk management and regulatory data-generation processes are in progress for FRs in other regions, covering a range of objectives (ED, human bio-monitoring (HBM4EU, https://www.hbm4eu.eu/), EU CoRAP, authorisation/restriction or ARNs). Co-operation with other regulators outside the UK would lead to a shared understanding of the need for, and a consistent approach to, risk management of specific substances. Examples recommended by the Advisory Group include to:

- participate in or monitor research activities by other regulators, for example, EU-led activity relating to consulting the supply chain about polymeric FRs and reactive FRs;
- take account of information from the Republic of Ireland, which has very similar furniture fire safety regulations to the UK. For example, data have been published on 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE) levels in Irish groundwater, outdoor air, soil, indoor air, dust, and human milk, and on concentrations of current use BFRs, TCEP, TDCPP, and TCIPP in WEEE, construction and demolition waste, childcare articles, and soft furnishings; and
- monitor regulatory activities in other jurisdictions, such as restriction proposals under EU REACH.

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8 List of abbreviations

Abbreviation	Explanation
BCF	The Bioconcentration Factor is the ratio between the concentration in an organism (usually fish) and the concentration in water.
CAS number (no.)	Chemical Abstracts Service (Registry Number), international unique number allocated to a chemical substance listed in the CAS Registry. CAS is a division of the American Chemical Society.
CMR	Carcinogenicity, mutagenicity, reproductive toxicity
DNEL	Derived No-Effect Level (a threshold concentration used in quantitative human health risk characterisation as part of REACH chemical safety assessment)
DUIN	Downstream User Import Notification: a notification process under which GB-based companies that were downstream users and distributors prior to the end of the transition period under EU REACH notify HSE about the substances that they wish to continue importing into Great Britain from the EU at or above one tonne per year.
EC_x	The concentration that causes adverse effects (but not necessarily mortality) in *x*% of the exposed population in an ecotoxicity test (50% or 10% are commonly reported, see below).
EC_{10}	EC_{10} is the usual endpoint measured in long-term ecotoxicity studies (see also NOEC)
EC_{50}	EC_{50} is the toxicity measure normally used to express the results of short-term *Daphnia* and algal tests.
ECHA	European Chemicals Agency
ES	Exposure Scenario

ESR	Existing Substances Regulation, EC 793/93. Under this regulation, data have been collected and published in IUCLID, and some substances have been selected to be subject to risk assessment on a priority basis.
EU	European Union
EUSES	European Union System for the Evaluation of Substances. A computer program that carries out many of the calculations required under the REACH Regulation automatically.
FR	Flame retardant
HSDB	Hazardous Substances Databank (see reference above)
IUCLID	International Uniform ChemicaL Information Database; a database compiled by the Joint Research Centre of the European Chemicals Bureau based on data submitted by industry (see reference above).
$L(E)C_{50}$	A shorthand term to describe both LC_{50} and EC_{50} together.
$L(E)L_{50}$	A shorthand term to describe both LL_{50} and EL_{50} together
LC_{50}	The concentration that is lethal to 50% of the exposed population. This is the toxicity measure normally used to express the results of short-term fish toxicity tests.
LD_{50}	The dose that is lethal to 50% of the exposed population. This is the endpoint measured in some mammalian toxicity studies.
NOEC	No Observed Effect Concentration. This is defined as the highest concentration tested that caused no adverse effects on the test organisms compared to controls. NOEC is usually reported for all ecotoxicity studies and may be the main endpoint measured in long-term ecotoxicity studies.
OECD	Organisation for Economic Co-operation and Development. The OECD co-ordinates international

	chemical assessment activity under its HPV programme. It also publishes Guidelines for the Testing of Chemicals, which are the approved methods for carrying out tests on substances. OECD has also published guidance on testing difficult
PBT	Persistence, bioaccumulation potential and toxicity
Pinfa	Phosphorus, Inorganic and Nitrogen Flame Retardants Association
PNEC	Predicted No-Effect Concentration (a threshold concentration used in quantitative environmental risk characterisation as part of REACH chemical safety assessment)
QSAR	Quantitative Structure-Activity Relationship, a mathematical relationship between properties of a chemical compound.
RCR	Risk Characterisation Ratio
vPvB	Very persistent and very bioaccumulative. See also PBT

9 Glossary

Term	Full name and description
Acute toxicity	A toxic effect resulting from a short-term exposure. The effect is often mortality but may also include immobilisation.
Adsorption	The uptake of a substance from the water phase onto the solid phase. Such adsorption can typically occur from water onto sediments, suspended sediments and soil. Usually expressed as Koc, the adsorption coefficient normalised for the organic carbon content of the soil or sediment.
Bioaccumulation	A term to describe transfer of a substance from the environment into an organism. Thus, bioaccumulation can occur typically from sediment, soil, water or via the food chain, or any combination of them. The transfer of a substance from water alone into an organism is called bioconcentration.
Bioavailability	The extent to which a substance is available for uptake into an organism.
Bioconcentration	The uptake of a substance into an organism from water. One component of the total process called bioaccumulation. Bioconcentration factors are usually determined as the ratio between the concentration in the organism and the exposure concentration.
Biodegradation	The actions of biological processes to break down a substance; usually implied to mean bacterial action (in soil, water or WWTP (Waste Water Treatment Plant)) whereby the organisms utilise the substance as food. Biodegradation can be complete, resulting in complete breakdown to minerals, or partial, producing particular end products, or may not occur at all. There are many standard tests of biodegradability, the ready and inherent studies leading to substances being described as ‘readily biodegradable’, ‘inherently biodegradable’, ‘nonbiodegradable’, etc.
Chronic toxicity	A toxic effect resulting from a longer-term exposure. The effect is often a reduction in growth or reproduction.
Daphnia	A type of invertebrate commonly used in aquatic toxicity tests. Also sometimes referred to as a “water flea”.

Endocrine disruptors	Substances that cause effects on the endocrine (or hormonal) system – these can be inhibition or stimulation.
Half-life	The time taken for 50% of the substance to be degraded or removed.
Humans via the environment	Refers to indirect human exposure to chemicals, via foodstuffs, drinking water and outdoor air, aligned with standard approaches to chemicals exposure assessment in UK and Europe.
Hydrolysis	The action of water to break down a substance. It is almost always partial, giving rise to definite end products. It usually depends strongly on pH.
Life cycle	The uses and applications of a substance from manufacture through to disposal or destruction.
Log K_{OW}	The log10 value of the octanol-water partition coefficient. Also sometimes known as log P.
Long-term toxicity study	Long term toxicity studies are usually considered those where more than one life cycle stage of an organism is tested. The duration of the exposure period in a long-term study is normally >2 weeks. The end point derived from a long-term study is often a NOEC or EC_{10}. The commonest examples of long-term studies are the fish early life stage (FELS) test and the *Daphnia* reproduction test. An algal growth inhibition test conducted over only 3 to 4 days is also considered a long-term study since it assesses effects over multiple generations.
Partition coefficient	The ratio between the concentrations of a substance in more than one phase. Examples include suspended sediment-water, sediment-water, soil-water, air-water (also known as Henry's constant), fish-water (better known as BCF), and octanol-water (better known as K_{OW})
Photodegradation	The action of light on a substance to break it down. It may be direct, or via a mediator (photosensitiser) which traps light energy and then transfers it to the substance.
Photo-oxidation	Action of light to generate oxidising agents in the air, such as the hydroxyl radical, which then can oxidise substances.

Product Category (PC)	A descriptor from EU REACH, which defines the types of product in which a chemical substance is used (ECHA Guidance defines over 40 different PCs)
Short-term toxicity study	Short-term studies normally only assess effects on one sensitive life-stage of an organism. The duration of the exposure period typically ranges between <1day to 4 days. The end point derived from a short-term study is often an LC_{50} or EC_{50}. The common short-term toxicity studies are the 96-hour fish toxicity test and the 48-hour Daphnia toxicity test. An EC_{50} obtained from a 72-96 hour growth inhibition test with a unicellular alga is also considered to be a short-term result.

Appendix 1 - Heat map of environmental and human health hazard based on PNEC and DNEL values

Table A1.1 presented over the following pages brings together the PNEC and DNEL values for selected protection targets that were gathered for this project. Colour shading is used to highlight the degree of toxicity and make clearer when toxicity in multiple compartments is indicated for the same substance.

Group (a) and (b) substances are combined. Group (c) substances are presented separately but using the same formatting. Refer to Sections 1.2 and 3.1 for further explanation of these terms.

Shading is used as follows, based on the value of the PNEC and DNEL in units of milligrams (either as mg/L / mg/kg or mg/m^3):

- Dark red – values <0.01
- Bright red – values <0.1
- Orange – values <1
- Yellow – values <10

These are intended to draw attention 'at a glance' to the potential for hazard across multiple protection targets, and do not imply direct equivalence of impact in (or risk to) those targets.

Instances of data gaps (for example, where data were not available, or the registrant has asserted that testing is not technically feasible), or where PNEC or DNEL values have not been derived (for example, secondary poisoning PNEC values where the registrant has considered that the substance has no bioaccumulation potential) are shaded grey.

Table A1.1: Summary of hazard based on PNEC (environmental) and DNEL (human health, general population) values

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	27104-30-9	500-057-6	1 µg/L	2.03 µg/kg sediment dw	0.13 µg/kg soil dw	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	no hazard identified	no hazard identified	Group (a)
1,3,5-Triazine-2,4-diamine, 6-phenyl-	91-76-9	202-095-6	0.038 mg/L	0.233 mg/kg sediment dw	0.036 mg/kg soil dw	no potential for bioaccumulation	1.65 mg/m³	0.095 mg/kg bw/day	Group (b)
Triphenyl phosphate	115-86-6	204-112-2	0.48 µg/L	0.143 mg/kg sediment dw	0.028 mg/kg soil dw	16.667 mg/kg food	0.91 mg/m³	0.525 mg/kg bw/day	Group (a)
Diphosphorus pentaoxide	1314-56-3	215-236-1	66.5 µg/L	249 µg/kg sediment dw	10.7 µg/kg soil dw	no potential for bioaccumulation	1 mg/m³	68.7 mg/kg bw/day	Group (b)
2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	79-94-7	201-236-9	0.016 mg/L	9 mg/kg sediment dw	0.031 mg/kg soil dw	222.22 mg/kg food	4.3 mg/m³	2.5 mg/kg bw/day	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Phosphorous acid, triphenyl ester (TPP) (Hydrolysis product)	101-02-0	202-908-4	0.008 mg/L	0.091 mg/kg sediment dw	0.136 mg/kg soil dw	no potential for bioaccumulation	0.452 mg/m³	0.5 mg/kg bw/day	Group (b)
4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	204-077-3	0.097 mg/L	0.097 mg/kg sediment dw	0.106 mg/kg soil dw	2.51 mg/kg food	0.29 µg/m³	0.167 µg/kg bw/day	Group (b)
2,2-Bis(bromomethyl)propane-1,3-diol	3296-90-0	221-967-7	0.037 mg/L	0.037 mg/kg sediment dw	0.54 mg/kg soil dw	no potential for bioaccumulation	0.2 mg/m³	0.058 mg/kg bw/day	Group (a)
Tetrakis(hydroxymethyl)phosphonium sulphate (2:1)	55566-30-8	259-709-0	2.42 µg/L	46 µg/kg sediment dw	102 µg/kg soil dw	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (b)
Isodecyl diphenyl phosphate	29761-21-5	249-828-6	0.38 µg/L	0.85 mg/kg sediment dw	0.251 mg/kg soil dw	0.74 mg/kg food	0.088 mg/m³	0.017 mg/kg bw/day	Group (b)
Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	38051-10-4	253-760-2	0.074 mg/L	0.45 mg/kg sediment dw	0.37 mg/kg soil dw	1 mg/kg food	0.065 mg/m³	0.075 mg/kg bw/day	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Tris(2-butoxyethyl) phosphate (TBOEP)	78-51-3	201-122-9	24 µg/L	0.804 mg/kg sediment dw	165.75 µg/kg soil dw	4.44 mg/kg food	1 mg/m³	0.25 mg/kg bw/day	Group (b)
Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	359406-89-6	436-230-7	0.042 mg/L	0.79 mg/kg sediment dw	0.134 mg/kg soil dw	0.167 mg/kg food	no hazard identified	no hazard identified	Group (a)
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	2.1 µg/L	1.55 mg/kg sediment dw	0.308 mg/kg soil dw	220 mg/kg food	high hazard (no threshold derived)	0.995 mg/kg bw/day	Group (a)
Reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate (cresyl diphenyl phosphate)		945-730-9	0.0022 mg/L	3.43 mg/kg sediment dw	0.68 mg/kg soil dw	267 mg/kg food	0.875 mg/m³	0.25 mg/kg bw/day	Group (a)
1,3,5-Triazine-2,4,6-triamine	108-78-1	203-615-4	0.51 mg/L	2.524 mg/kg sediment dw	0.206 mg/kg soil dw	no potential for bioaccumulation	1.5 mg/m³	0.42 mg/kg bw/day	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	1271172-98-5	690-512-6	0.51 mg/L	2.524 mg/kg sediment dw	0.206 mg/kg soil dw	no potential for bioaccumulation	1.5 mg/m³	0.42 mg/kg bw/day	Group (a)
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated)	68937-40-6	700-990-0	3.99 µg/L	3.12 mg/kg sediment dw	0.246 mg/kg soil dw	23.89 mg/kg food	1.87 mg/m³	5.375 mg/kg bw/day	Group (a)
Triethyl phosphate	78-40-0	201-114-5	0.632 mg/L	5 mg/kg sediment dw	0.64 mg/kg soil dw	no potential for bioaccumulation	1.74 mg/m3	1 mg/kg bw/day	Group (a)
Magnesium hydroxide	1309-42-8	215-170-3	0.17 mg/L	1.37 mg/kg sediment dw	0.17 mg/kg soil dw	66.67 mg/kg food	3.86 mg/m³	2.21 mg/kg bw/day	Group (a)
Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	1244733-77-4	807-935-0	0.32 mg/L	11.5 mg/kg sediment dw	0.34 mg/kg soil dw	11.6 mg/kg food	1.45 mg/m³	0.52 mg/kg bw/day	Group (a)
Ammonium chloride	12125-02-9	235-186-4	0.25 mg/L	no hazard identified	0.163 mg/kg soil dw	no potential for bioaccumulation	9.4 mg/m³	11.4 mg/kg bw/day	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	0.31 µg/L	0.185 mg/kg sediment dw	2.5 mg/kg soil dw	1.85 mg/kg food	14.5 µg/m³	0.04 mg/kg bw/day	Group (a)
Boron oxide (B_2O_3)	1303-86-2	215-125-8	1.16 mg/L	7.11 mg/kg sediment dw	2.58 mg/kg soil dw	no hazard identified			Group (b)
Tributyl phosphate	126-73-8	204-800-2	0.082 mg/L	14.4 mg/kg sediment dw	2.83 mg/kg soil dw	no potential for bioaccumulation	0.77 mg/m³	0.22 mg/kg bw/day	Group (b)
Boric acid	10043-35-3	233-139-2	2.9 mg/L	no exposure of sediment expected	5.7 mg/kg soil dw	no potential for bioaccumulation	4.15 mg/m³	0.98 mg/kg bw/day	Group (a)
Boron zinc oxide ($B_6Zn_2O_{11}$)	12767-90-7	235-804-2	2.9 mg/L	no exposure of sediment expected	5.7 mg/kg soil dw	no potential for bioaccumulation	0.88 mg/m³	0.507 mg/kg bw/day	Group (a)
Tungsten trioxide	1314-35-8	215-231-4	0.338 mg/L	960 mg/kg sediment dw	2.17 mg/kg soil dw	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Tetrabromophthalic anhydride (hydrolysis product)	632-79-1	211-185-4	1 mg/L	11.9 mg/kg sediment dw	1.79 mg/kg soil dw	no potential for bioaccumulation	exposure based waiving	exposure based waiving	Group (b)
Boron sodium oxide ($B_4Na_2O_7$)	1330-43-4	215-540-4	3.38 mg/L	20.76 mg/kg sediment dw	7.52 mg/kg soil dw	no hazard identified			Group (b)
Ammonium sulphate	7783-20-2	231-984-1	0.312 mg/L	0.063 mg/kg sediment dw	62.6 mg/kg soil dw	no potential for bioaccumulation	1.667 mg/m³	6.4 mg/kg bw/day	Group (a)
Trixylyl phosphate	25155-23-1	246-677-8	0.66 µg/L	7.92 mg/kg sediment dw	11.7 mg/kg soil dw	no potential for bioaccumulation	0.522 mg/m³	0.15 mg/kg bw/day	Group (a)
Aluminium sodium dioxide	1302-42-7	215-100-1	14 µg/L	no data available: testing technically not feasible	no data available: testing technically not feasible	no potential for bioaccumulation	high hazard (no threshold derived)	high hazard (no threshold derived)	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Aluminate (Al(OH)41-), sodium, (T-4)-	12251-53-5	235-487-0	14 µg/L	no data available: testing technically not feasible	no data available: testing technically not feasible	no potential for bioaccumulation	high hazard (no threshold derived)	high hazard (no threshold derived)	Group (a)
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	1241-94-7	214-987-2	no data: aquatic toxicity unlikely	no hazard identified	no hazard identified	1.62 mg/kg food	0.19 mg/m^3	0.036 mg/kg bw/day	Group (b)
Chloroalkanes, C14-17	85535-85-9	287-477-0	1 µg/L	13 mg/kg sediment dw	11.9 mg/kg soil dw	10 mg/kg food	2 mg/m^3	0.58 mg/kg bw/day	Group (a)
Zinc oxide	1314-13-2	215-222-5	20.6 µg/L	117.8 mg/kg sediment dw	35.6 mg/kg soil dw	no potential for bioaccumulation	2.5 mg/m^3	0.83 mg/kg bw/day	Group (a)
Zinc chloride ($ZnCl_2$)	7646-85-7	231-592-0	20.6 µg/L	117.8 mg/kg sediment dw	35.6 mg/kg soil dw	no potential for bioaccumulation	1.25 mg/m^3	0.83 mg/kg bw/day	Group (b)
Ammonium dihydrogenorthophosphate	7722-76-1	231-764-5	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	1.45 mg/m^3	0.42 mg/kg bw/day	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Diammonium hydrogenorthophosphate	7783-28-0	231-987-8	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	1.45 mg/m³	0.42 mg/kg bw/day	Group (a)
Paraffin waxes, chloro	63449-39-8	264-150-0	0.003 mg/L	5710 mg/kg sediment dw	4640 mg/kg soil dw	10 mg/kg food	hazard unknown but no further hazard information necessary as no exposure expected	4.5 mg/kg bw/day	Group (a)
Boehmite (Al(OH)O)	1318-23-6	215-284-3	74.9 µg/L	insufficient hazard data available (further information necessary)	insufficient hazard data available (further information necessary)	insufficient hazard data available (further information necessary)	no DNEL derived	2.37 mg/kg bw/day	Group (b)
Phosphoric trichloride, reaction products with bisphenol A and phenol	181028-79-5	425-220-8	0.04 mg/L	29.6 mg/kg sediment dw	10 mg/kg soil dw	66.67 mg/kg food	4.8 mg/m³	1.6 mg/kg bw/day	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	5945-33-5	425-220-8	0.04 mg/L	29.6 mg/kg sediment dw	10 mg/kg soil dw	66.67 mg/kg food	4.8 mg/m³	1.6 mg/kg bw/day	Group (a)
Pentaerythritol	115-77-5	204-104-9	2 mg/L	no exposure of sediment expected	no exposure of soil expected	no potential for bioaccumulation	8.7 mg/m³	5 mg/kg bw/day	Group (b)
Magnesium chloride ($MgCl_2$)	7786-30-3	232-094-6	1.6 mg/L	1050 mg/kg sediment dw	1045 mg/kg soil dw	no potential for bioaccumulation	no hazard identified	7 mg/kg bw/day	Group (b)
Molybdenum trioxide	1313-27-5	215-204-7	17.9 mg/L	31800 mg/kg sediment dw	14.9 mg/kg soil dw	no potential for bioaccumulation	2 mg/m³	5.1 mg/kg bw/day	Group (b)
Aluminium oxide	1344-28-1	215-691-6	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	0.75 mg/m³	1.32 mg/kg bw/day	Group (b)
Molybdate (MoO_4^{2-}), calcium (1:1), (T-4)-	7789-82-4	232-192-9	24.8 mg/L	44200 mg/kg sediment dw	20.6 mg/kg soil dw	no potential for bioaccumulation	6.94 mg/m³	7.09 mg/kg bw/day	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalatio n)	DNEL (oral)	GB-relevant
Molybdate ($Mo_8O_{26}^{4-}$), ammonium (1:4)	12411-64-2	235-650-6	19.5 mg/L	347000 mg/kg sediment dw	16.2 mg/kg soil dw	no potential for bioaccum ulation	5.45 mg/m^3	5.56 mg/kg bw/day	Group (a)
Aluminium hydroxide	21645-51-2	244-492-7	no hazard identifie d	insufficient hazard data available (further information necessary)	insufficien t hazard data available (further informatio n necessary)	insufficien t hazard data available (further informatio n necessary)	no hazard identified	4.74 mg/kg bw/day	Group (a)
Titanate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	16919-27-0	240-969-9	0.02 mg/L	24.45 mg/kg sediment dw	19.1 mg/kg soil dw	no potential to cause toxic effects if accumulat ed (in higher organisms) via the food chain	hazard unknown but no further hazard information necessary as no exposure expected	hazard unknown but no further hazard informati on necessar y as no exposure expected	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Calcium dihydroxide	1305-62-0	215-137-3	0.49 mg/L	insufficient hazard data available (further information necessary)	1080 mg/kg soil dw	no potential for bioaccumulation	1 mg/m³	no hazard identified	Group (a)
Antimony oxide (Sb_2O_3)	1309-64-4	215-175-0	0.135 mg/L	13.4 mg/kg sediment dw	44.3 mg/kg soil dw	no potential for bioaccumulation	0.095 mg/m³	33.5 mg/kg bw/day	Group (a)
Diantimony pentoxide	1314-60-9	215-237-7	0.15 mg/L	14.88 mg/kg sediment dw	49.2 mg/kg soil dw	no potential for bioaccumulation	0.137 mg/m³	22.1 mg/kg bw/day	Group (a)
Sulfuric acid, barium salt (1:1)	7727-43-7	231-784-4	115 µg/L	600.4 mg/kg sediment dw	207.7 mg/kg soil dw	no potential for bioaccumulation	10 mg/m³	13000 mg/kg bw/day	Group (b)
Zirconate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	16923-95-8	240-985-6	0.163 mg/L	28.86 mg/kg sediment dw	22.5 mg/kg soil dw	no potential for bioaccumulation	no DNEL derived	no hazard identified	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Phosphorus	7723-14-0	231-768-7	2500 µg/L	insufficient hazard data available (further information necessary)	no hazard identified	no potential for bioaccumulation	28.99 mg/m^3	33.33 mg/kg bw/day	Group (b)
1,2-Diazenedicarboxamide	123-77-3	204-650-8	no hazard identified	no exposure of sediment expected	no exposure of soil expected	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (b)
2,3-Dibromo-2-butene-1,4-diol	3234-02-4	221-779-5	no PNEC(s) derived	no PNEC(s) derived	no PNEC(s) derived	no PNEC(s) derived	no DNEL derived	no DNEL derived	Group (b)
Titanium chloride (TiCl4) (T-4)-	7550-45-0	231-441-9	no data available: testing technically not feasible	no data available: testing technically not feasible	no data available: testing technically not feasible	no potential for bioaccumulation	exposure based waiving	exposure based waiving	Group (b)
Silicon dioxide	7631-86-9	231-545-4	no data: aquatic toxicity unlikely	no hazard identified	no hazard identified	no potential for bioaccumulation	low hazard (no threshold derived)	low hazard (no threshold derived)	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Ammonium sulphamidate	7773-06-0	231-871-7	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (a)
Graphite	7782-42-5	231-955-3	no data: aquatic toxicity unlikely	no hazard identified	no hazard identified	no potential to cause effects if accumulated (in higher organisms) via the food chain	0.3 mg/m^3	813 mg/kg bw/day	Group (b)
Calcium chloride ($CaCl_2$)	10043-52-4	233-140-8	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	2.5 mg/m^3	no hazard identified	Group (b)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Sulfuric acid, compd. with graphite (1:?)	12777-87-6	235-819-4	no hazard identified	no hazard identified	no hazard identified	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	no data available: testing technically not feasible	exposure based waiving	Group (b)
Bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP)	26040-51-7	247-426-5	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (a)
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	84852-53-9	284-366-9	no hazard identified	100 mg/kg sediment dw	156 mg/kg soil dw	no potential for bioaccumulation	low hazard (no threshold derived)	low hazard (no threshold derived)	Group (a)
Tin(4+) zinc(2+) hexahydroxide	12027-96-2	404-410-4	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (a)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Zinc stannate	12036-37-2	405-290-6	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (a)
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	432-770-2	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (b)
2,4,6-Tribromophenol	118-79-6	204-278-6	0.5-1 µg/l	0.229-22.9 µg/kg sediment dw	0.000178-201 µg/kg soil dw	10 mg/kg food	400 µg/m³	167 µg/kg bw/day	Group (c)
1,2-Ethanediamine, phosphate	14852-17-6	238-914-9	5 µg/L	32.1 µg/kg sediment dw	3.48 µg/kg soil dw	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	179 µg/m³	750 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Barium metaborate	13701-59-2	237-222-4	7.8 µg/L	55.1 µg/kg sediment dw	6.45 µg/kg soil dw	no potential for bioaccumulation	600 µg/m³	400 µg/kg bw/day	Group (c)
Diethyl ethylphosphonate	78-38-6	201-111-9	3.07 µg/L	19.22 µg/kg sediment dw	34.4 µg/kg soil dw	no data available: testing technically not feasible	434.8 µg/m³	250 µg/kg bw/day	Group (c)
Diphenyl methylphosphonate	7526-26-3	231-388-1	1.3 µg/L	39 µg/kg sediment dw	7 µg/kg soil dw	0.128 mg/kg food	hazard unknown but no further hazard information necessary as no exposure expected	hazard unknown but no further hazard information necessary as no exposure expected	Group (c)
Tribromoneopentyl alcohol	36483-57-5	253-057-0	44 - 220 µg/L	84.8-424 µg/kg sediment dw	46.1 - 230 µg/kg soil dw	1 mg/kg food	400 µg/m³	250 µg/kg bw/day	Group (c)
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	237-159-2	0.2 µg/L	830 µg/kg sediment dw	330 µg/kg soil dw	3.3 mg/kg food	58 µg/m³	17 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
2,2-Bis(chloromethyl)-1,3-propanediyl tetrakis(1-chloro-2-propanyl) bis(phosphate)	1047637-37-5	809-920-4	74 µg/L	450 µg/kg sediment dw	370 µg/kg soil dw	1 mg/kg food	65 µg/m³	75 µg/kg bw/day	Group (c)
Diphosphoric acid, compd. with 1,3,5-triazine-2,4,6-triamine (1:?)	15541-60-3	239-590-1	98 µg/L	130 µg/kg sediment dw	40 µg/kg soil dw	no potential for bioaccumulation	130.4 µg/m³	75 µg/kg bw/day	Group (c)
Tetrachlorophthalic anhydride	117-08-8	204-171-4	84-98.9 µg/L	303-663 µg/kg sediment dw	11-176 µg/kg soil dw	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	hazard unknown but no further hazard information necessary as no exposure expected	hazard unknown but no further hazard information necessary as no exposure expected	Group (c)
3-[Hydroxy(phenyl)phosphoryl]propanoic acid	14657-64-8	411-200-6	100 µg/L	540 µg/kg sediment dw	49 µg/kg soil dw	no potential for bioaccumulation	exposure based waiving	330 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Aluminum hypophosphite	7784-22-7	479-150-8	418 µg/L	818 µg/kg sediment dw	100 µg/kg soil dw	no potential for bioaccumulation	205 µg/m³	587 µg/kg bw/day	Group (c)
6h-Dibenzo[c,e][1,2]oxaphosphinine 6-oxide	35948-25-5	252-813-7	100 µg/L	720 µg/kg sediment dw	85.3 µg/kg soil dw	no potential for bioaccumulation	no DNEL derived	no DNEL derived	Group (c)
Calcium phosphinate	7789-79-9	232-190-8	418 µg/L	757 µg/kg sediment dw	100 µg/kg soil dw	no potential for bioaccumulation	0.205 mg/m³	0.508 mg/kg bw/day	Group (c)
Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6	no hazard identified	831 µg/kg sediment dw	3.7 mg/kg soil dw	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)
Tris(methylphenyl) phosphate	1330-78-5	809-930-9	1 µg/L	2.05 mg/kg sediment dw	1.01 mg/kg soil dw	0.65 mg/kg food	30 µg/m³	20 µg/kg bw/day	Group (c)
Dicumyl peroxide	80-43-3	201-279-3	2.34 µg/L	2.24 mg/kg sediment dw	447 µg/kg soil dw	no potential for bioaccumulation	1.4 mg/m³	400 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
4,4'-(1-Methylethylidene)bis[2,6-dibromophenol] polymer with (chloro-methyl)oxirane and 2,4,6-tribromophenol	158725-44-1	500-399-6	1.02 µg/L	1.01 mg/kg sediment dw	823 µg/kg soil dw	33.3 mg/kg food	no hazard identified	no hazard identified	Group (c)
Triisobutyl phosphate	126-71-6	204-798-3	14.3 µg/L	2.05 mg/kg sediment dw	426 µg/kg soil dw	no potential for bioaccumulation	8.89 mg/m³	2.13 mg/kg bw/day	Group (c)
Diphosphoric acid, compd. with piperazine (1:1)	66034-17-1	457-330-7	42 µg/L	5.43 mg/kg sediment dw	630 µg/kg soil dw	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)
2-Butyne-1,4-diol, polymer with 2-(chloromethyl)oxirane, brominated, dehydrochlorinated, methoxylated	68441-62-3	614-503-3	520 µg/L	2.6 mg/kg sediment dw	215 µg/kg soil dw	no potential for bioaccumulation	1.07 mg/m³	750 µg/kg bw/day	Group (c)
Cyanuric acid	108-80-5	203-618-0	12.1 mg/L	7.56 mg/kg sediment dw	756 µg/kg soil dw	no potential for bioaccumulation	5.36 mg/m³	1.54 mg/kg bw/day	Group (c)
2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine	25713-60-4	426-040-2	0.01 µg/L	10 mg/kg sediment dw	246 µg/kg soil dw	111 mg/kg food	12 mg/m³	1.7 mg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Ammonium bromide	12124-97-9	235-183-8	56 µg/L	no hazard identified	10 mg/kg soil dw	33.33 mg/kg food	870 µg/m³	500 µg/kg bw/day	Group (c)
Zinc sulfide	1314-98-3	215-251-3	20.6 µg/L	117.8 mg/kg sediment dw	35.6 mg/kg soil dw	no potential for bioaccumulation	2.5 mg/m³	830 µg/kg bw/day	Group (c)
Aluminum phosphate ($Al(H_2PO_4)_3$)	13530-50-2	236-875-2	30 µg/L	no hazard identified	no hazard identified	no potential for bioaccumulation	2.78 mg/m³	1.86 mg/kg bw/day	Group (c)
Tetrabromophthalic acid mixed esters with diethylene glycol and propylene glycol	77098-07-8	616-436-5	11 µg/L	no exposure of sediment expected	no hazard identified	no potential for bioaccumulation	hazard unknown but no further hazard information necessary as no exposure expected	hazard unknown but no further hazard information necessary as no exposure expected	Group (c)
Bis(2-ethylhexyl) phosphate	298-07-7	206-056-4	412 µg/L	11.82 mg/kg sediment dw	2.12 mg/kg soil dw	no potential for bioaccumulation	870 µg/m³	250 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Sodium tungsten oxide (Na_2WO_4)	13472-45-2	236-743-4	338 µg/L	960 mg/kg sediment dw	2.17 mg/kg soil dw	11 mg/kg food	900 µg/m³	500 µg/kg bw/day	Group (c)
Dipotassium 3,4,5,6-tetrabromophthalate	18824-74-3	242-604-9	100 µg/L	insufficient hazard data available (further information necessary)	insufficient hazard data available (further information necessary)	no potential for bioaccumulation	4.35 mg/m³	1.25 mg/kg bw/day	Group (b)
Calcium magnesium dihydroxide oxide	58398-71-3	261-235-4	380 µg/L	insufficient hazard data available (further information necessary)	833.7 mg/kg soil dw	no potential for bioaccumulation	1 mg/m³	no hazard identified	Group (c)
Sodium antimonate	15432-85-6	239-444-7	179 µg/L	17.7 mg/kg sediment dw	58.5 mg/kg sediment dw	no potential for bioaccumulation	10 mg/m³	26.3 mg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Sodium hexahydroxy-antimonate(1-)	33908-66-6	251-735-0	229 µg/L	22.7 mg/kg sediment dw	75 mg/kg soil dw	no potential for bioaccumulation	10 mg/m³	33.8 mg/kg bw/day	Group (c)
Aluminum diethylphosphinate	225789-38-8	428-310-5	1 mg/L	no exposure of sediment expected	no exposure of soil expected	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)
(Pentabromophenyl)methyl acrylate	59447-55-1	261-767-7	no hazard identified	no hazard identified	6.66 mg/kg soil dw	no potential for bioaccumulation	12.5 µg/m³	250 µg/kg bw/day	Group (c)
1,1'-(Isopropylidene)bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene)	97416-84-7	306-832-3	no hazard identified	381 mg/kg sediment dw	76.1 µg/kg soil dw	no potential for bioaccumulation	1.74 mg/m³	500 µg/kg bw/day	Group (c)
1,3,5-Triazine-2,4,6-triamine, phosphate	41583-09-9	255-449-7	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	420 µg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
2,2'-[(1-Methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxymethylene]]bis[oxirane]	3072-84-2	221-346-0	no hazard identified	no hazard identified	3.33 mg/kg sediment dw	no potential for bioaccumulation	1.75 mg/m^3	500 µg/kg bw/day	Group (c)
3,5,3',5'Tetrabromobisphenol a, epichlorohydrin polymer	40039-93-8	500-107-7	no hazard identified	no hazard identified	3.33 mg/kg soil dw	no potential for bioaccumulation	3.5 mg/m^3	500 µg/kg bw/day	Group (c)
Boron phosphate ($B(PO_4)$)	13308-51-5	236-337-7	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	1.64 mg/m^3	940 µg/kg bw/day	Group (c)
1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine2,4,6(1H,3H,5H)-trione	52434-90-9	257-913-4	no hazard identified	insufficient hazard data available (further information necessary)	insufficient hazard data available (further information necessary)	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	2.9 mg/m^3	1.67 mg/kg bw/day	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Reaction mass of 1,1'-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene] and 1,3-dibromo-2-(2,3-dibromo-2-methylpropoxy)-5-{2-[3,5-dibromo-4-(2,3,3-tribromo-2-methylpropoxy)phenyl]propan-2-yl}benzene		944-461-4	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	17.4 mg/m³	5 mg/kg bw/day	Group (c)
Ammonium polyphosphates	68333-79-9	269-789-9	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	4.45 mg/m³	1.28 mg/kg bw/day	Group (c)
Tetrabromobisphenol a-bis(2,3-dibromopropyl ether)	21850-44-2	244-617-5	no hazard identified	927 mg/kg sediment dw	no hazard identified	55.3 mg/kg food	5.8 mg/m³	1.6 mg/kg bw/day	Group (c)
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE)	1163-19-5	214-604-9	no data: aquatic toxicity unlikely	384 mg/kg sediment dw	98 mg/kg soil dw	222 mg/kg food	70 mg/m³	20 mg/kg bw/day	Group (c)
1,2-Bis(tetrabromophthalimido)ethane	32588-76-4	251-118-6	no data: aquatic toxicity unlikely	no data available: testing technically not feasible	no data available: testing technically not feasible	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
1,3,2-Dioxaphosphorinane, 2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	4090-51-1	223-829-1	no hazard identified	no hazard identified	no hazard identified	no potential to cause toxic effects if accumulated (in higher organisms) via the food chain	no hazard identified	no hazard identified	Group (c)
1,3,5-Triazine-2,4,6(1h,3h,5h)-trione, compd. with 1,3,5-triazine-2,4,6-triamine (1:1)	37640-57-6	253-575-7							Group (c)
1,3-Propanediamine, n1,n1'-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized n-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	191680-81-6	425-020-0	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)

Substance name	CAS no.	EC no.	PNEC (water)	PNEC (sediment)	PNEC (soil)	PNEC (oral, predators via food chain)	DNEL (inhalation)	DNEL (oral)	GB-relevant
Reaction mass of phosphonic acid, methyl-, bis[(5-ethyl-2-methyl2,2-dioxido-1,3,2-dioxaphosphorinan-5-yl)methyl] ester with (5-ethyl-2-methyl-2-oxido1,3,2-dioxaphosphorinan-5-yl)methyl methyl methylphosphonate		915-680-2	no hazard identified	no hazard identified	no hazard identified		no hazard identified	no hazard identified	Group (c)
Diethyl (n,n-bis(2-hydroxyethyl)amino)methanephosphonate	2781-11-5	220-482-8	no hazard identified	no hazard identified	no hazard identified	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)
Tris(2-hydroxyethyl) isocyanurate	839-90-7	212-660-9	no hazard identified	no hazard identified	no exposure of soil expected	no potential for bioaccumulation	no hazard identified	no hazard identified	Group (c)

Appendix 2 - Heat map of hazards based on regulatory processes

The status of substances under various regulatory processes is illustrated in the form of a heat map in Table A2.1.

Some of the issues may be interrelated. Grey shading is used to draw attention ‘at a glance’ to the potential for hazard in multiple contexts. This does not imply direct equivalence of those contexts. The substances are grouped by FR chemical type to facilitate identification of common issues.

Table A2.1: Summary of status in various hazard contexts, CHEMSEC or TEDX listings status, and CoRAP or RAP listing

The numerals 1 and 0 in the columns for the various hazard or status contexts denote that an indicator in that context was found / was not found respectively, in the research for this project.

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	79-94-7	201-236-9	Group (a)	Brominated organic	1	1	1	1	0	1	1	0	0
Tetrabromophthalic anhydride	632-79-1	211-185-4	Group (b)	Brominated organic	0	0	0	0	1	0	0	0	0
2,3-Dibromo-2-butene-1,4-diol	3234-02-4	221-779-5	Group (b)	Brominated organic	0	0	0	0	1	0	0	0	0
2,2-Bis(bromomethyl)propane-1,3-diol	3296-90-0	221-967-7	Group (a)	Brominated organic	0	1	0	0	1	0	0	0	0
Bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP)	26040-51-7	247-426-5	Group (a)	Brominated organic	1	0	0	0	0	0	1	0	0
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	84852-53-9	284-366-9	Group (a)	Brominated organic	1 +	0	0	0	0	0	1	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Dipotassium 3,4,5,6-tetrabromophthalate	18824-74-3	242-604-9	Group (b)	Brominated organic	0[9]	0	0	0	#	0	0	0	0
Tetrabromobisphenol a-bis(2,3-dibromopropyl ether)	21850-44-2	244-617-5	Group (c)	Brominated organic	0	0	0	1	0	1	1	0	0
2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine	25713-60-4	426-040-2	Group (c)	Brominated organic	1	0[10]	0	0	0	0	0	0	0
3,5,3',5'Tetrabromobisphenol a, epichlorohydrin polymer	40039-93-8	500-107-7	Group (c)	Brominated organic	0	0	0	0	0	0	0	0	0
2,4,6-Tribromophenol	118-79-6	204-278-6	Group (c)	Brominated organic	0	0	1	0	0	1	1	0	0
Tribromoneopentyl alcohol	36483-57-5	253-057-0	Group (c)	Brominated organic	0	1	0	0	1	0	0	0	0
(Pentabromophenyl)methyl acrylate	59447-55-1	261-767-7	Group (c)	Brominated organic	0	0	0	0	0	0	0	0	0

[9] Currently screened as not PBT/vPvB, but note this substance is suspected vPvB (based on grouping and pending data generation)

[10] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Tetrabromophthalic acid mixed esters with diethylene glycol and propylene glycol	77098-07-8	616-436-5	Group (c)	Brominated organic	0 [11]	0	0	0	#	0	0	0	0
4,4'-(1-Methylethylidene)bis[2,6-dibromophenol] polymer with (chloro-methyl)oxirane and 2,4,6-tribromophenol	158725-44-1	500-399-6	Group (c)	Brominated organic	1	0	0	0	0	0	0	0	0
1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine2,4,6(1H,3H,5H)-trione	52434-90-9	257-913-4	Group (c)	Brominated organic	0	0 [12]	0	0	0	0	0	0	0
2-Butyne-1,4-diol, polymer with 2-(chloromethyl)oxirane, brominated, dehydrochlorinated, methoxylated	68441-62-3	614-503-3	Group (c)	Brominated organic	0	0	0	0	1	0	0	0	0
1,1'-(Isopropylidene)bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene)	97416-84-7	306-832-3	Group (c)	Brominated organic	0	0	0	1	0	0	1	0	0
Reaction mass of 1,1'-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene] and 1,3-dibromo-2-(2,3-dibromo-2-methylpropoxy)-5-{2-[3,5-		944-461-4	Group (c)	Brominated organic	1	0	0	0	0	0	0	0	0

[11] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

[12] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
dibromo-4-(2,3,3-tribromo-2-methylpropoxy)phenyl]propan-2-yl}benzene													
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE)	1163-19-5	214-604-9	Group (c)	Brominated organic	1	1	0	0	0	1	0	1	0[13]
2,2'-[(1-Methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxymethylene]]bis[oxirane]	3072-84-2	221-346-0	Group (c)	Brominated organic	0	0	0	0	0	0	0	0	0
1,2-Bis(tetrabromophthalimido)ethane	32588-76-4	251-118-6	Group (c)	Brominated organic	0[14]	0	0	0	0	0	1	0	0
4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	115-27-5	204-077-3	Group (b)	Chlorinated organic	0	1	0	0	1	0	1	0	0

[13] In addition to the mentioned listings, this substance is also POP

[14] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Paraffin waxes, chloro	63449-39-8	264-150-0	Group (a)	Chlorinated organic	0	0	0	0	0	1	0	0	0
Chloroalkanes, C14-17	85535-85-9	287-477-0	Group (a)	Chlorinated organic	1	1	1	1	0	1	1	0	0
Tetrachlorophthalic anhydride	117-08-8	204-171-4	Group (c)	Chlorinated organic	0	0	1	0	1	0	0	0	0
Phosphoric trichloride, reaction products with bisphenol A and phenol	181028-79-5	425-220-8	Group (b)	Organo-phosphorus	1	0	0	0	0	0	0	0	0
(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	5945-33-5	425-220-8	Group (b)	Organo-phosphorus	1	0	0	0	0	0	0	0	0
Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	38051-10-4	253-760-2	Group (a)	Halogenated organo-phosphorus	0	0	0	0	0	0	0	0	0
Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	1244733-77-4	807-935-0	Group (a)	Halogenated organo-phosphorus	0	0	0	1	1	0	1	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	237-159-2	Group (c)	Halogenated organo-phosphorus	0	1	1	1	0	1	1	0	0
2,2-Bis(chloromethyl)-1,3-propanediyl tetrakis(1-chloro-2-propanyl) bis(phosphate)	1047637-37-5	809-920-4	Group (c)	Halogenated organo-phosphorus	0	0	0	0	1	0	0	0	0
Aluminium sodium dioxide	1302-42-7	215-100-1	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Boron oxide (B_2O_3)	1303-86-2	215-125-8	Group (b)	Inorganic	0	1	0	0	0	0	0	0	0
Calcium dihydroxide	1305-62-0	215-137-3	Group (a)	Inorganic	0	1	0	0	0	0	0	0	0
Magnesium hydroxide	1309-42-8	215-170-3	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Antimony oxide (Sb_2O_3)	1309-64-4	215-175-0	Group (a)	Inorganic	0	1	0	0	0	0	1	0	0
Molybdenum trioxide	1313-27-5	215-204-7	Group (b)	Inorganic	0	1	0	0	0	0	0	0	0
Zinc oxide	1314-13-2	215-222-5	Group (a)	Inorganic	0	0	1	0	0	1	1	0	0
Tungsten trioxide	1314-35-8	215-231-4	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Diphosphorus pentaoxide	1314-56-3	215-236-1	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Diantimony pentoxide	1314-60-9	215-237-7	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Boehmite (Al(OH)O)	1318-23-6	215-284-3	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Boron sodium oxide ($B_4Na_2O_7$)	1330-43-4	215-540-4	Group (b)	Inorganic	0	1	0	0	0	1	0	0	0
Aluminium oxide	1344-28-1	215-691-6	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Titanium chloride ($TiCl_4$) (T-4)-	7550-45-0	231-441-9	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Silicon dioxide	7631-86-9	231-545-4	Group (a)	Inorganic	0	0	0	0	0	0	1	0	0
Zinc chloride ($ZnCl_2$)	7646-85-7	231-592-0	Group (b)	Inorganic	0	0	1	0	0	1	0	0	0
Ammonium dihydrogenorthophosphate	7722-76-1	231-764-5	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Phosphorus	7723-14-0	231-768-7	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Sulfuric acid, barium salt (1:1)	7727-43-7	231-784-4	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Ammonium sulphamidate	7773-06-0	231-871-7	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Graphite	7782-42-5	231-955-3	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Ammonium sulphate	7783-20-2	231-984-1	Group (a)	Inorganic	0	0	0	0	0	1	0	0	0
Diammonium hydrogenorthophosphate	7783-28-0	231-987-8	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Magnesium chloride ($MgCl_2$)	7786-30-3	232-094-6	Group (b)	Inorganic	0	0	0	0	0	1	0	0	0
Molybdate (MoO_4^{2-}), calcium (1:1), (T-4)-	7789-82-4	232-192-9	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Boric acid	10043-35-3	233-139-2	Group (a)	Inorganic	0	1	0	1	0	1	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Calcium chloride ($CaCl_2$)	10043-52-4	233-140-8	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Ammonium chloride	12125-02-9	235-186-4	Group (b)	Inorganic	0	0	0	0	0	1	0	0	0
Aluminate ($Al(OH)_4^{1-}$), sodium, (T-4)-	12251-53-5	235-487-0	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Molybdate ($Mo_8O_{26}^{4-}$), ammonium (1:4)	12411-64-2	235-650-6	Group (a)	Inorganic	0	0	0	0	0	0	0	0	1
Boron zinc oxide ($B_6Zn_2O_{11}$)	12767-90-7	235-804-2	Group (a)	Inorganic	0	1	1	0	0	0	0	0	0
Sulfuric acid, compd. with graphite (1:?)	12777-87-6	235-819-4	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Titanate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	16919-27-0	240-969-9	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Zirconate(2-), hexafluoro-, potassium (1:2), (OC-6-11)-	16923-95-8	240-985-6	Group (b)	Inorganic	0	0	0	0	0	0	0	0	0
Aluminium hydroxide	21645-51-2	244-492-7	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Tin(4+) zinc(2+) hexahydroxide	12027-96-2	404-410-4	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
Zinc stannate	12036-37-2	405-290-6	Group (a)	Inorganic	0	0	0	0	0	0	0	0	0
zinc sulfide	1314-98-3	215-251-3	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Calcium magnesium dihydroxide oxide	58398-71-3	261-235-4	Group (c)	Inorganic	0	1	0	0	0	0	0	0	0
Ammonium polyphosphates	68333-79-9	269-789-9	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0
Ammonium bromide	12124-97-9	235-183-8	Group (c)	Inorganic	0	1	0	0	0	0	0	0	0
Sodium tungsten oxide (Na_2WO_4)	13472-45-2	236-743-4	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0
Aluminum phosphate ($Al(H_2PO_4)_3$)	13530-50-2	236-875-2	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0
Sodium hexahydroxyantimonate(1-)	33908-66-6	251-735-0	Group (c)	Inorganic	0	1	1	0	0	0	0	0	0
Aluminum hypophosphite	7784-22-7	479-150-8	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0
Calcium phosphinate	7789-79-9	232-190-8	Group (c)	Inorganic	0	0	0	0	0	0	0	0	0
Boron phosphate ($B(PO_4)$)	13308-51-5	236-337-7	Group (c)	Inorganic	0	1	0	0	0	0	0	0	0
Barium metaborate	13701-59-2	237-222-4	Group (c)	Inorganic	0	1	0	0	0	0	0	0	0
Sodium antimonate	15432-85-6	239-444-7	Group (c)	Inorganic	0	0	1	0	0	0	0	0	0
1,3,5-Triazine-2,4-diamine, 6-phenyl-	91-76-9	202-095-6	Group (b)	Nitrogen-based	0	0	0	0	1	0	0	0	0
1,3,5-Triazine-2,4,6-triamine	108-78-1	203-615-4	Group (a)	Nitrogen-based	0	1	0	1	1	1	0	0	0
1,2-Diazenedicarboxamide	123-77-3	204-650-8	Group (b)	Nitrogen-based	0	0	0	0	1	0	0	0	0
Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	1271172-98-5	690-512-6	Group (a)	Nitrogen-based	0	0	1	0	#	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Cyanuric acid	108-80-5	203-618-0	Group (c)	Nitrogen-based	0	0	0	0	1	0	0	0	0
Tris(2-hydroxyethyl) isocyanurate	839-90-7	212-660-9	Group (c)	Nitrogen-based	0	0	0	0	1	0	0	0	0
1,3,5-Triazine-2,4,6(1h,3h,5h)-trione, compd. with 1,3,5-triazine-2,4,6-triamine (1:1)	37640-57-6	253-575-7	Group (c)	Nitrogen-based	0	1	0	0	#	0	0	0	0
1,3-Propanediamine, n1,n1'-1,2-ethanediylbis-, reaction products with cyclohexane and peroxidized n-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	191680-81-6	425-020-0	Group (c)	Nitrogen-based	1	0	0	0	#	0	0	0	0
Diphosphoric acid, compd. with 1,3,5-triazine-2,4,6-triamine (1:?)	15541-60-3	239-590-1	Group (c)	Nitrogen-based	0	1	0	0	1	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Triethyl phosphate	78-40-0	201-114-5	Group (a)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
Tris(2-butoxyethyl) phosphate (TBOEP)	78-51-3	201-122-9	Group (b)	Organo-phosphorus	0	0	0	0	1	1	0	0	0
Phosphorous acid, triphenyl ester (TPP)	101-02-0	202-908-4	Group (b)	Organo-phosphorus	0	1	1	0	0	0	1	0	0
Triphenyl phosphate	115-86-6	204-112-2	Group (a)	Organo-phosphorus	0	0	1	1	0	1	1	0	0
Tributyl phosphate	126-73-8	204-800-2	Group (b)	Organo-phosphorus	0	1	0	0	0	1	0	0	0
Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	1241-94-7	214-987-2	Group (b)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Etidronic acid	2809-21-4	220-552-8	Group (b)	Organo-phosphorus	0	0	0	0	*	0	0	0	0
Trixylyl phosphate	25155-23-1	246-677-8	Group (a)	Organo-phosphorus	0	1	1	0	0	0	1	1	1
Isodecyl diphenyl phosphate	29761-21-5	249-828-6	Group (b)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	55566-30-8	259-709-0	Group (b)	Organo-phosphorus	0	1	1	0	1	1	0	0	0
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	260-830-6	Group (a)	Organo-phosphorus	1	0	0	1	0	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	Group (a)	Organo-phosphorus	0	1	1	1	0	0	1	0	0
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	432-770-2	Group (b)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	359406-89-6	436-230-7	Group (a)	Organo-phosphorus	0	1	1	0	1	0	0	0	0
Tetrakis[hydroxymethyl] phosphonium chloride, oligomeric reaction products with urea	27104-30-9	500-057-6	Group (a)	Organo-phosphorus	0	1	1	0	1	0	0	0	0
Reaction mass of p-t-butylphenyldiphenyl phosphate and bis(p-t-butylphenyl)phenyl phosphate and triphenyl phosphate (Triphenyl phosphates tert-butylated)	68937-40-6	700-990-0	Group (a)	Organo-phosphorus	1	0	0	0	0	0	0	0	0

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Reaction mass of 3-methylphenyl diphenyl phosphate, 4-methylphenyl diphenyl phosphate, bis(3-methylphenyl) phenyl phosphate, 3-methylphenyl 4-methylphenyl phenyl phosphate and triphenyl phosphate (cresyl diphenyl phosphate)		945-730-9	Group (a)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6	Group (c)	Organo-phosphorus	0	0 [15]	0	0	0	1	0	0	0
Triisobutyl phosphate	126-71-6	204-798-3	Group (c)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Tris(methylphenyl) phosphate	1330-78-5	809-930-9	Group (c)	Organo-phosphorus	0	1	1	1	0	0	1	0	0
1,3,2-Dioxaphosphorinane, 2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	4090-51-1	223-829-1	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
1,2-Ethanediamine, phosphate	14852-17-6	238-914-9	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
6h-Dibenzo[c,e][1,2]oxaphosphinine 6-oxide	35948-25-5	252-813-7	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0

[15] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
1,3,5-Triazine-2,4,6-triamine, phosphate	41583-09-9	255-449-7	Group (c)	Organo-phosphorus	0	1	0	0	1	0	0	0	0
Diphosphoric acid, compd. with piperazine (1:1)	66034-17-1	457-330-7	Group (c)	Organo-phosphorus	0	0 [16]	0	0	#	0	0	0	0
Reaction mass of phosphonic acid, methyl-, bis[(5-ethyl-2-methyl2,2-dioxido-1,3,2-dioxaphosphorinan-5-yl)methyl] ester with (5-ethyl-2-methyl-2-oxido1,3,2-dioxaphosphorinan-5-yl)methyl methyl methylphosphonate		915-680-2	Group (c)	Organo-phosphorus	0	0	0	0	0	0	0	0	0
Aluminum diethylphosphinate	225789-38-8	428-310-5	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
Diphenyl methylphosphonate	7526-26-3	231-388-1	Group (c)	Organo-phosphorus	0	0	1	0	1	0	0	0	0
Diethyl ethylphosphonate	78-38-6	201-111-9	Group (c)	Organo-phosphorus	0	0	1	0	1	0	0	0	0
Bis(2-ethylhexyl) phosphate	298-07-7	206-056-4	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
3-[Hydroxy(phenyl)phosphoryl]propanoic acid	14657-64-8	411-200-6	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0
Diethyl (n,n-bis(2-hydroxyethyl)amino)methanephosphonate	2781-11-5	220-482-8	Group (c)	Organo-phosphorus	0	0	0	0	1	0	0	0	0

[16] Ongoing evaluation in EU may lead to new data/conclusions in future (ECHA ARN)

Substance name	CAS number	EC number	UK-relevant FR?	FR type	PBT or vPvB[a]	C&L HH[b]	C&L Env[c]	Potential ED[d]	Mobility (M or vM)[e]	Chemsec or TEDx listings[f] (ED screen)	CoRAP and/or RAP	Annex XIV (UK)	Annex XIV or XVII (EU)
Pentaerythritol	115-77-5	204-104-9	Group (b)	Other organic	0	0	0	0	1	0	0	0	0
Dicumyl peroxide	80-43-3	201-279-3	Group (c)	Other organic	0	1	1	0	0	0	1	0	0

Notes:

a – PBT or vPvB refers to the conclusions of REACH registrants or of regulatory authorities based on research carried out, or conclusions of authors of the present report based on the data collected.

b – C&L for human health indicates the presence of classifications for carcinogenicity, reproductive effects, mutagenicity or specific target organ effects under CLP, whether as a harmonised or self-classification by REACH registrants.

c – C&L for the environment indicates the presence of classification as a chronic category 1 or 2 hazard under CLP, whether as a harmonised or self-classification by REACH registrants.

d – endocrine disruption based on appearance of the substances on any of the five major lists only, based on research carried out.

e – mobility is based on assessment made in the present project based on Koc values collected, by applying the criteria presented in Section 3.2.2.

f – The CHEMSEC SIN list and TEDX list use peer-reviewed literature data to indicate that a substance may have endocrine disrupting properties.

*not assessed by agreement between the Environment Agency and the contractor due to a prior interest.

insufficient data for assessment of mobility.

+ pending completion of the CoRAP process (this concern is based on the impurities).

Appendix 3 - Lifecycle Assessment and Generic Exposure Scenarios

Generic exposure scenarios (ES) were developed to quantify exposure to the environment and humans via the environment for selected FRs. The methods applied follow the ECHA (2022l) guidance as far as possible, and use the EUSES 2.1.2 model (ECHA, 2022j). Emission estimates are broken down by environmental compartment (i.e. air, terrestrial (soil), aquatic (surface water and groundwater)) and, where possible, the estimation of uptake by humans via the consumption of food and drinking water has been undertaken.

Generic ES were developed in order to assess releases from the different FR types (e.g., brominated FR, inorganic FRs, organophosphate FRs) during the lifecycle of an article containing FRs. The following generic ES were developed to cover all lifecycle stages of FRs used in sealants, coatings, polymers, and textiles:

- ES01 - Manufacturing
- ES02 - Formulation of sealants
- ES03 - Industrial use of sealants
- ES04 - Wide-dispersive use of sealants
- ES05 - Formulation of coatings
- ES06 - Industrial use of coatings
- ES07 - Wide-dispersive use of coatings
- ES08 - Formulation of polymers
- ES09 - Industrial use of polymers
- ES10 - Formulation of textiles
- ES11 - Industrial use of textiles
- ES12 - Service life of articles
- ES13 - Waste – landfill

An outline of the approach to the development of generic ES for each of these lifecycle stages is given below. These are based on typical methods used under the REACH Regulation including the approaches outlined in ECHA (2016) Guidance R.16, relevant OECD (2022) Emission Scenario Documents, Industry sector-group Specific Environmental Release Categories (SPERCs) (ECHA, 2022m) or information from the peer-reviewed or grey literature.

In all cases, the starting point is to estimate the initial releases to water, air and soil from each lifecycle stage. These releases are then used as inputs into the EUSES 2.1.2 model (ECHA, 2022j), which takes into account the removal/distribution in wastewater treatment if relevant and partitioning into sediment and soil. The generic ES outlined below give details on how these initial releases have been estimated and the assumptions used to carry out such estimates.

In the EUSES model, the regional scale represents an industrial and densely populated area and the continental scale representing the EU. For the current exposure modelling, the regional scale parameters (area etc) were kept and used to represent an industrial and densely populated area in the UK. As a worst-case scenario, all the tonnages are set to be released in the regional scale.

Manufacturing

For manufacture of the substance, the initial releases to water, air and soil are dependent upon the daily amount produced and the release factor to air and water. The releases are based on the methodology outlined in the ECHA Guidance R16 for Environmental Release Category 1 (ERC 1; Manufacture of the substance).

The generic assessment assumes that 100% of the manufacture occurs at one site at the regional scale and daily amount produced at a site are estimated as follows:

- Daily amount produced (kg/day) = Annual production (tonnes/year) × 1,000/number of production days.

The default number of production days are dependent on the total production tonnage and is 20 days/year for a total production of <1,000 tonnes/year or 100 days/year for a production tonnage of 1,000 to <10,000 tonnes/year.

Releases into the environment are estimated as follows:

- Initial emission to air (Eair; kg/day) = daily amount produced (kg/day) × release fraction to air.
- Initial emission to water (Ewater; kg/day) = daily amount produced (kg/day) × release fraction to water.
- Initial emission to soil (Esoil; kg/day) = daily amount produced (kg/day) × release fraction to soil.

Jonkers *et al*. (2016) reported on release factors of additive and reactive BFRs and inorganic FRs during manufacturing process. The highest release factor among the various FRs were chosen for air (0.0011%), water (0.0018%) and soil (0.0031%) (See Table A3.1). These release factors were used as read across for other FR classes.

Table A3.1: Overview of release factors during the lifecycle stages

Exposure Scenario	Emission days	RF_{air}	RF_{water}	RF_{soil}	Source
ES01 Manufacturing	20/100	0.08%	0.02 %	0%	Jonker *et al.* (2016)
ES02 Sealants - Formulation	300	0.08%	0.02 %	0%	FEICA / EFCC SPERC 2.1a.v3
ES03 Sealants - Industrial use	300	1.7%	0%	0%	FEICA SPERC 5.1a.v3
ES04 Sealants - wide-dispersive use	365	0%	1.5%	0%	FEICA SPERC 8c.3.v3
ES05 Coatings - Formulation	225	0.0097 %	0.25 %	0%	CEPE SPERC 2.2c.v2
ES06 Coatings - Industrial use	225	1.5%	0.2%	0%	CEPE SPERC 5.1a.v2/5.3.v2
ES07 Coatings - wide-dispersive use	365	0%	2%	2%	CEPE SPERC 8f.3a.v2
ES08 Polymers - Formulation	225	0.15%	0.15 %	0%	OECD ESD Plastic Additives
ES09 Polymers - Industrial use	225	0.01%	0.02 %	0%	OECD ESD Plastic Additives
ES10 Textiles - Formulation	300	0.0097 %	0.1%	0.01%	See text
ES11 Textiles - Industrial use	300	0.01%	1.8%	1%	See text
ES12 Service life of articles	365	0.05%	3.2%	3.2%	ECHA Guidance R16
ES13 Waste - Landfill	365	0.05%	3.2%	0.16%	ECHA Guidance R18

Use in sealants – Formulation, Industrial use and Wide-dispersive use

The approach to estimate releases from formulation of sealants, industrial use of sealant and wide-dispersive use of sealants is similar to that for manufacture and follows the approach in ECHA Guidance R.16. For formulation, the relevant ERC is ERC 2: Formulation into a mixture, for Industrial use, the relevant ERC is ERC 5: Use at industrial site leading to inclusion into/onto article, and for wide dispersive use the relevant ERC is ERC 8c: Widespread use leading to inclusion into/onto article (indoor).

The generic assessment assumes that 50% of the formulation occurs at one site at the regional scale, while the assumption is made that 10% of the tonnage for industrial use occurs at the largest site. For wide-dispersive use, the daily local amount is estimated according to ECHA Guidance, i.e.by applying a default factor of 0.0005 to the assessed tonnage and then increased by a factor of 4 to take into account geographical or temporal differences in the use.

Daily amounts used during formulation or use at a site are estimated as follows:

- Daily amount of substance in formulation (kg/day) = Annual amount of substance used at a formulation site (tonnes/year) × 1,000/number of production days.
- Daily amount of substance during industrial use (kg/day) = Annual amount of substance used during industrial use (tonnes/year) × 1,000/number of production days.
- Daily amount of substance during wide-dispersive use (kg/day) = Annual amount of substance used during wide-dispersive use (tonnes/year) × 1,000/number of production days.

The number of emission days for the formulation (300 days), industrial use (300 days) and wide-dispersive use (365 days) were taken from SPERC factsheets published by Association of the European Adhesive and Sealant Industry (FEICA) (ECHA, 2022m) and used for all FR classes.

Releases into the environment are estimated as follows:

- Initial emission to air/water/soil (Eair/Ewater/Esoi; kg/day) = daily amount produced (kg/day) × release fraction to air/water/soil.

Release factors to air, water and soil were obtained from FEICA SpERCs and are listed in Table A3.1. These release factors were used for all FR classes.

Use in coatings – Formulation, Industrial use and Wide-dispersive use

The approach to estimate releases from formulation of coatings, industrial use of coatings and wide-dispersive use of coatings is similar as described above for sealants. For formulation, the relevant ERC is ERC 2: Formulation into a mixture, for Industrial use, the relevant ERC is ERC 5: Use at industrial site leading to inclusion into/onto article, and for wide dispersive use the relevant ERC is ERC 8c: Widespread use leading to inclusion into/onto article (indoor).

The generic assessment assumes that 50% of the formulation occurs at one site at the regional scale, while the assumption is made that 10% of the tonnage for industrial use occurs at the largest site. For wide-dispersive use, the daily local amount is estimated according to ECHA Guidance, i.e.by applying a default factor of 0.0005 to the assessed tonnage and then increased by a factor of 4 to take into account geographical or temporal differences in the use.

Estimation of the daily amount used at a site are as described above; the number of emission days for formulation, industrial use and wide-dispersive use are taken from SPERCs published by European Council of the Paint, Printing Ink and Artists' Colours Industry (CEPE).

Releases into the environment are estimated as described above using release factors to air, water and soil taken from CEPE SPERCs (see Table A3.1). CEPE SPERCs for industrial and wide-dispersive uses contain scenarios for different applications, i.e. spray and non-spray scenarios. The highest release factors reported for either scenario was selected as a worst-case scenario. These release factors were used for all FR classes.

Use in polymers – Formulation and Industrial use

The approach to estimate releases from formulation of polymers and industrial use of polymers follows the approach in ECHA Guidance R.16. For formulation, the relevant ERC is ERC 2: Formulation into a mixture and for Industrial use, the relevant ERC is ERC 5: Use at industrial site leading to inclusion into/onto article.

The generic assessment assumes that 10% of the formulation occurs at one site at the regional scale, as well as that 10% of the tonnage for industrial use occurs at the largest site based on information stated in the OECD (2009) Emission Scenario Document on Plastic Additives.

Estimation of the daily amount used at a site are as described above; the number of emission days for formulation and industrial use are taken from OECD Emission Scenario Document on Plastic Additives.

Releases into the environment are estimated as described above using release factors to air, water and soil taken from OECD Emission Scenario Document on Plastic Additives (see Table A3.1). The release factors for formulation are the cumulative RF for compounding and conversion and the RFs for the highest vapour pressure band are selected as worst-case scenario. The OECD document reported on RFs during industrial use for additive and reactive brominated FRs, inorganic FR and organic FRs, the release factors to air and water for organic FRs were selected as a worst-case scenario. These release factors were used for all FR classes.

Use in textiles – Formulation and Industrial use

The approach to estimate releases from formulation of textiles and industrial use of textiles follows the approach in ECHA Guidance R.16. For formulation, the relevant ERC is ERC 2: Formulation into a mixture and for Industrial use, the relevant ERC is ERC 5: Use at industrial site leading to inclusion into/onto article.

The generic assessment assumes that 25% of the formulation occurs at one site at the regional scale as well as that 25% of the tonnage for industrial use occurs at the largest site[1].

Estimation of the daily amount used at a site are as described above; the number of emission days for formulation and industrial use are taken from a report entitled: Brominated flame retardants - risks to UK drinking water sources (BRE, 2009).

Releases into the environment are estimated as described above. Release factor to water during formulation and industrial use were taken from a report entitled: Brominated flame retardants - risks to UK drinking water sources[10]. Release factors to air during formulation and industrial use were taken from the formulation of coatings and industrial use of polymers, respectively. Release factors to soil during formulation (ERC2) and industrial use (ERC5) were taken from ECHA Guidance R.16. All release factors are stated in Table A3.1 and were used for all FR classes.

Service life of articles

Releases of FRs from articles during their service life are based on the methodology outlined in the ECHA Guidance R16. For uses of articles at industrial site the relevant ERC is ERC 12c: Use of articles at industrial sites with low release. For widespread uses of articles, the relevant ERCs are ERC 10a: Widespread use of articles with low release (outdoor) and ERC 11a: Widespread use of articles with low release (indoor).

As no information on releases of FRs were found from industry sector SPERCs, OECD emission Scenario Document or other sources that were not based on the generic service life methodology states in the ECHA Guidance R16, a single generic service life scenario was included in the lifecycle of the FRs.

The local assessment is based on a wastewater treatment plant service a population of 10,000 people and the local release is estimated by “scaling” from the regional release by taking into account the relative populations (20,000,000 people in the region compared with 10,000 people for the local assessment) but then increased by a factor of 4 to take into account geographical or temporal differences in the use.

Release factors were taken from ECHA Guidance R16 and the highest RFs from the above-mentioned service life ERCs were selected as a worst-case scenario and were 0.05% to air, 3.2% to water and 3.2% to soil. These release factors were for all FR classes.

The approach for service life does not take into account the possibility of exposure from dust ingestion. Ortiz and Harrad (2023) investigated the exposure of the general population to six organophosphate FRs (named in the paper as tri-n-butyl phosphate, tris(1,3-dichloroisopropyl) phosphate, 2-ethylhexyl diphenyl phosphate, tris(2-chloroethyl) phosphate, tris(2-chloroisopropyl) phosphate and triphenyl phosphate) via air inhalation, diet, drinking water and dust ingestion. Compared to the total daily intake from indoor air, diet and drinking water the intake from dust ingestion was relatively small (<2% of the total daily intake), showing that for the studied organophosphate FRs dust ingestion was a relatively minor route of exposure compared to other sources of exposure.

Waste - Landfill

A generic ES for disposal of all articles containing FRs has been developed based on ECHA (2012) Guidance R.18. This guidance document outlines generic approaches that can be used to estimate the potential releases to the environment from disposal by both incineration and landfill. For the purposes of the generic ES it is assumed that the highest potential for release to the environment comes from disposal of articles containing FRs in landfills and so this is the focus of the generic ES.

The starting point for the release estimation will be the amount of all articles disposed of each year. As a worst case has been assumed that 80% of this disposal occurs to landfill. Releases from landfills are continues with 365 emission days.

ECHA Guidance R.18 gives the following emission factors for release from landfills. According to ECHA Guidance R.18 the release estimation should consider the residence time of the substance/article in the landfill, as the amount of disposed articles containing the substance will build up over time until the landfill is closed. An average residence time of 20 years is used in the derived yearly emission factors.

- Emission factor to air = 0 for non-volatile organic compounds (non-VOCs)
- Emission factor to water = 0.032. This release factor is before any on-site wastewater treatment at the landfill. ECHA Guidance R.18 indicates that all leachate is collected and treated on-site and recommends a worst-case assumption of 50% removal for the on-site wastewater treatment for all substances.
- Emission factor to soil = 0.0016. This is the release factor from ERC 10a.

These release factors were for all FR classes.

Tonnage assessment

The tonnage information obtained in Section 3.1.4 included a range of the registered tonnage (min-max) or a single value. The maximum tonnage was used for the environmental assessment. For substances where only a single tonnage value was available, the upper limit of the UK REACH registration band was used as a maximum value. This maximum tonnage value was used to estimate releases for ES1: manufacturing.

The maximum tonnage was split over the four assessed uses (use in sealants, use in coatings, use in polymers and use in textiles) according to the split reported in Section 3.1.3. These tonnages were used to estimate releases during the formulation exposure scenarios (ES2, 5, 8 and 10) as well as for the industrial use in polymers and textiles (ES9 and 11). For use in sealants and coatings, the formulated tonnage was split 50/50 over the industrial and wide-dispersive use scenarios (ES3&4 and ES6&7). For FRs listed as additive FR, 100% of the tonnage was assessed. For FRs listed as reactive FR, it was assumed that only a small amount of unreacted FR will be present in the article (0.3%) (BRE, 2009), and therefore, the tonnage for these FRs was adjusted accordingly. When no information was available on whether a FR was used as an additive or reactive FR, the assumption was made that it was used as an additive FR.

For the estimation of releases during the service life of the articles (ES12), the combined tonnage of the FR from all the industrial and wide-dispersive uses was used.

For the estimation of releases from the articles in a landfill (ES13), a worst case assumption was made that 80% of the waste disposal occurs to landfill.

Appendix 4 - Ranking of FRs based on regional scale risk characterisation.

Table A4.1: Ranking of FR based on RCRs in Regional scale Freshwater using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater*
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	10 - 100
12251-53-5	235-487-0	Aluminate (Al(OH)41-), sodium, (T-4)-	Group (a)	Inorganic	1 - 10
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	1 - 10
1302-42-7	215-100-1	Aluminium sodium dioxide	Group (a)	Inorganic	1 - 10
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	0.1 - 1
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	0.1 - 1
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.1 - 1
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	Group (a)	Organophosphorus	0.1 - 1
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	0.1 - 1

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater*
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Group (b)	Organophosphorus	0.1 - 1
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Group (a)	Nitrogen-based	0.1 - 1
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.01 - 0.1
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.01 - 0.1
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.001 - 0.01
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.001 - 0.01
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.001 - 0.01

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater*
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Group (b)	Organophosphorus	0.001 - 0.01
115-77-5	204-104-9	Pentaerythritol	Group (b)	Other	0.001 - 0.01
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.001 - 0.01
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.0001 - 0.001
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.0001 - 0.001
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.0001 - 0.001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.0001 - 0.001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.0001 - 0.001
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Group (b)	Chlorinated organic	0.0001 - 0.001
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.00001 - 0.0001
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.00001 - 0.0001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Table A4.2: Ranking of FR based on RCRs in Regional scale Marine water using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine water*
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	10 - 100
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	1 - 10
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	1 - 10
12251-53-5	235-487-0	Aluminate (Al(OH)41-), sodium, (T-4)-	Group (a)	Inorganic	1 - 10
1302-42-7	215-100-1	Aluminium sodium dioxide	Group (a)	Inorganic	1 - 10
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.1 - 1
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	Group (a)	Organophosphorus	0.1 - 1
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	0.1 - 1
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	0.1 - 1
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Group (a)	Nitrogen-based	0.01 - 0.1
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine water*
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.01 - 0.1
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.01 - 0.1
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.01 - 0.1
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.01 - 0.1
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Group (b)	Organophosphorus	0.01 - 0.1
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Group (b)	Organophosphorus	0.001 - 0.01
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.001 - 0.01
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.001 - 0.01

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine water*
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.001 - 0.01
115-77-5	204-104-9	Pentaerythritol	Group (b)	Other	0.001 - 0.01
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.0001 - 0.001
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.0001 - 0.001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.0001 - 0.001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.0001 - 0.001
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Group (b)	Chlorinated organic	0.00001 - 0.0001
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.00001 - 0.0001
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.00001 - 0.0001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Table A4.3: Ranking of FR based on RCRs in Regional scale Freshwater sediment using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater sediment*
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	100 – 1,000
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	10 - 100
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	10 - 100
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	10 - 100
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	1 - 10
12251-53-5	235-487-0	Aluminate (Al(OH)41-), sodium, (T-4)-	Group (a)	Inorganic	1 - 10
1302-42-7	215-100-1	Aluminium sodium dioxide	Group (a)	Inorganic	1 - 10
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	Group (a)	Organophosphorus	0.1 - 1
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.1 - 1
84852-53-9	284-366-9	1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	Group (a)	Brominated organic	0.1 - 1
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Group (b)	Organophosphorus	0.1 - 1

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater sediment*
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Group (a)	Nitrogen-based	0.01 - 0.1
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.01 - 0.1
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.01 - 0.1
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.01 - 0.1
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.01 - 0.1
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.01 - 0.1
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and	0.001 - 0.01

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Freshwater sediment*
				brominated, mainly phosphate esters)	
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Group (b)	Organophosphorus	0.001 - 0.01
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Group (b)	Chlorinated organic	0.001 - 0.01
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.001 – 0.01
115-77-5	204-104-9	Pentaerythritol	Group (b)	Other	0.001 - 0.01
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.0001 - 0.001
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.0001 - 0.001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.0001 - 0.001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.0001 - 0.001
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.00001 - 0.0001
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.00001 - 0.0001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Table A4.4: Ranking of FR based on RCRs in Regional scale Marine sediment using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine sediment*
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	100 – 1,000
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	10 - 100
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	10 - 100
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	10 - 100
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	1 - 10
12251-53-5	235-487-0	Aluminate (Al(OH)41-), sodium, (T-4)-	Group (a)	Inorganic	1 - 10
1302-42-7	215-100-1	Aluminium sodium dioxide	Group (a)	Inorganic	1 - 10
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	Group (a)	Organophosphorus	0.1 - 1
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.1 - 1
84852-53-9	284-366-9	1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	Group (a)	Brominated organic	0.1 - 1
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Group (a)	Nitrogen-based	0.01 - 0.1

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine sediment*
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.01 - 0.1
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.01 - 0.1
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.01 - 0.1
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.01 - 0.1
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.01 - 0.1
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Group (b)	Organophosphorus	0.01 - 0.1
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Group (b)	Organophosphorus	0.001 - 0.01

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine sediment*
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.001 - 0.01
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.001 – 0.01
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Group (b)	Chlorinated organic	0.001 - 0.01
115-77-5	204-104-9	Pentaerythritol	Group (b)	Other	0.001 - 0.01
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.0001 - 0.001
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.0001 - 0.001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	No Group (b)	Organophosphorus	0.0001 - 0.001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.0001 - 0.001
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.00001 - 0.0001

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Marine sediment*
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.00001 - 0.0001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Table A4.5: Ranking of FR based on RCRs in Regional scale Soil using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Soil*
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	100 – 1,000
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	10 - 100
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	10 - 100
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	10 - 100
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	0.1 - 1
12251-53-5	235-487-0	Aluminate (Al(OH)41-), sodium, (T-4)-	Group (a)	Inorganic	0.1 - 1
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.01 - 0.1
359406-89-6	436-230-7	Phosphonium, tetrakis(hydroxymethyl)-, chloride (1:1), reaction products with 1-tetradecanamine and urea	Group (a)	Organophosphorus	0.01 - 0.1
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.01 - 0.1
84852-53-9	284-366-9	1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene] (DBDPE)	Group (a)	Brominated organic	0.01 - 0.1
1302-42-7	215-100-1	Aluminium sodium dioxide	Group (a)	Inorganic	0.01 - 0.1

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Soil*
55566-30-8	259-709-0	Tetrakis(hydroxymethyl)phosphonium sulphate(2:1)	Group (b)	Organophosphorus	0.01 - 0.1
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.01 - 0.1
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.01 - 0.1
108-78-1	203-615-4	1,3,5-Triazine-2,4,6-triamine	Group (a)	Nitrogen-based	0.001 - 0.01
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.001 - 0.01
139189-30-3	432-770-2	Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	Group (b)	Organophosphorus	0.001 - 0.01
115-77-5	204-104-9	Pentaerythritol	Group (b)	Other	0.001 - 0.01
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.0001 - 0.001

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Soil*
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.0001 - 0.001
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.0001 – 0.001
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.0001 - 0.001
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.00001 - 0.0001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.00001 - 0.0001
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.000001 - 0.00001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.000001 - 0.00001
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.000001 - 0.00001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Table A4.6: Ranking of FR based on RCRs in Regional scale Humans via Environment (oral) using generic exposure scenarios

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Humans via Environment oral*
68937-41-7	273-066-3	Phenol, isopropylated, phosphate (3:1)	Group (a)	Organophosphorus	100 – 1,000
25155-23-1	246-677-8	Trixylyl phosphate	Group (a)	Organophosphorus	10 - 100
85535-85-9	287-477-0	Chloroalkanes, C14-17	Group (a)	Chlorinated organic	1 - 10
79-94-7	201-236-9	2,2',6,6'-Tetrabromo-4,4'-isopropylidenediphenol (TBBPA)	Group (a)	Brominated organic	0.1 - 1
115-27-5	204-077-3	4,7-Methanoisobenzofuran-1,3-dione, 4,5,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-	Group (b)	Chlorinated organic	0.1 - 1
29761-21-5	249-828-6	Isodecyl diphenyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
126-73-8	204-800-2	Tributyl phosphate	Group (b)	Organophosphorus	0.01 - 0.1
57583-54-7	260-830-6	Tetraphenyl m-phenylene bis(phosphate)	Group (a)	Organophosphorus	0.001 - 0.01
1241-94-7	214-987-2	Phosphoric acid, 2-ethylhexyl diphenyl ester (2EHDPP)	Group (b)	Organophosphorus	0.001 - 0.01
7722-76-1	231-764-5	Ammonium dihydrogenorthophosphate	Group (a)	Inorganic	0.001 - 0.01
7783-28-0	231-987-8	Diammonium hydrogenorthophosphate	Group (a)	Inorganic	0.001 - 0.01

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Humans via Environment oral*
38051-10-4	253-760-2	Phosphoric acid, P,P′-[2,2-bis(chloromethyl)-1,3-propanediyl] P,P,P′,P′-tetrakis(2-chloroethyl) ester (V6)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.001 - 0.01
7783-20-2	231-984-1	Ammonium sulphate	Group (a)	Inorganic	0.001 - 0.01
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.0001 - 0.001
1244733-77-4	807-935-0	Reaction products of phosphoryl trichloride and 2-methyloxirane (TCIPP, TCPP)	Group (a)	Halogenated organophosphorus (chlorinated and brominated, mainly phosphate esters)	0.0001 - 0.001
5945-33-5	425-220-8	(1-Methylethylidene)di-4,1-phenylenetetraphenyl diphosphate	Group (a)	Organophosphorus	0.0001 - 0.001
181028-79-5	425-220-8	Phosphoric trichloride, reaction products with bisphenol A and phenol	Group (b)	Organophosphorus	0.0001 - 0.001
63449-39-8	264-150-0	Paraffin waxes, chloro	Group (a)	Chlorinated organic	0.00001 - 0.0001

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Humans via Environment oral*
91-76-9	202-095-6	1,3,5-Triazine-2,4-diamine, 6-phenyl-	Group (b)	Nitrogen-based	0.00001 - 0.0001
18824-74-3	242-604-9	Dipotassium 3,4,5,6-tetrabromophthalate	Group (b)	Brominated organic	0.00001 – 0.0001
78-40-0	201-114-5	Triethyl phosphate	Group (a)	Organophosphorus	0.00001 - 0.0001
115-86-6	204-112-2	Triphenyl phosphate	Group (a)	Organophosphorus	0.000001 - 0.00001
3296-90-0	221-967-7	2,2-Bis(bromomethyl)propane-1,3-diol	Group (a)	Brominated organic	0.000001 - 0.00001
101-02-0	202-908-4	Phosphorous acid, triphenyl ester (TPP)	Group (b)	Organophosphorus	0.000001 - 0.00001
1271172-98-5 **	690-512-6	Reaction products of 1,3,5-triazine-2,4,6-triamine and zinc bis(dihydrogen phosphate)	Group (a)	Nitrogen-based	0.000001 - 0.00001

CAS number	EC number	Substance name	GB-relevant FR?	FR type	Estimated RCR Regional Humans via Environment oral*
78-51-3	201-122-9	Tris(2-butoxyethyl) phosphate (TBOEP)	Group (b)	Organophosphorus	0.0000001 - 0.000001

* For confidentiality reasons, the actual value of the highest RCR is not provided but replaced by a range.

** As the Koc for this substance cannot be predicted reliably, its environmental fate in this model is subject to significant uncertainty.

Appendix 5 - Summary of FR concentrations from EA monitoring data

Table A5.1: FR concentrations from EA monitoring data

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
Phosphoric acid, 2-ethylhexyl diphenyl ester - 1241-94-7	Freshwater	2018	2560	105	0.006	2.3	0.4	0.05
	Freshwater	2019	2645	53	0.004	0.126	0.026	0.017
	Freshwater	2020	606	5	0.005	0.485	0.106	0.014
	Freshwater	2021	1469	36	0.003	0.128	0.024	0.016
	Groundwater	2018	1720	26	0.005	1.4	0.287	0.014
	Groundwater	2019	1460	25	0.004	0.262	0.021	0.01
	Groundwater	2020	231	19	0.003	0.049	0.018	0.012
	Groundwater	2021	68	5	0.007	0.024	0.016	0.019
	Marine water	2018	204	3	0.006	1.4	0.472	0.009

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Marine water	2019	169	2	0.005	0.008		
	Marine water	2020	36	0				
	Marine water	2021	270	2	0.007	0.012		
	Sewage discharge	2018	9	4	0.018	19	4.773	0.038
tributyl phosphate - 126-73-8	Freshwater	2018	2560	219	0.007	2.5	0.095	0.038
	Freshwater	2019	2645	255	0.007	1.5	0.08	0.027
	Freshwater	2020	606	79	0.007	0.398	0.053	0.028
	Freshwater	2021	1469	149	0.005	0.555	0.045	0.022
	Groundwater	2018	1720	5	0.01	0.219	0.062	0.023
	Groundwater	2019	1460	8	0.004	0.044	0.013	0.007
	Groundwater	2020	231	2	0.009	0.014		

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Groundwater	2021	68	0				
	Marine water	2018	204	18	0.013	0.095	0.034	0.028
	Marine water	2019	169	14	0.008	0.063	0.026	0.022
	Marine water	2020	36	4	0.01	0.098	0.034	0.014
	Marine water	2021	270	76	0.004	0.068	0.021	0.017
	Sewage discharge	2018	9	4	0.018	0.031	0.025	0.026
Triphenyl phosphate - 115-86-6	Freshwater	2018	2560	525	0.055	85	1.182	0.8
	Freshwater	2019	2645	387	0.28	3.5	0.755	0.551
	Freshwater	2020	606	75	0.3	2.6	0.718	0.6
	Freshwater	2021	1469	296	0.3	9.7	0.732	0.562
	Groundwater	2018	1720	152	0.3	7.2	0.979	0.755

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Groundwater	2019	1460	87	0.3	4.8	0.692	0.49
	Groundwater	2020	231	21	0.32	4	0.96	0.43
	Groundwater	2021	68	11	0.302	1.3	0.633	0.561
	Marine water	2018	204	27	0.3	2	0.887	0.8
	Marine water	2019	169	12	0.31	0.9	0.468	0.403
	Marine water	2020	36	1	0.43	0.43		
	Marine water	2021	270	70	0.0566	579[17]	9.275	0.8
	Sewage discharge	2018	9	3	0.45	20	7.027	0.63
trixylyl phosphate - 25155-23-1	Freshwater	2018	678	677		0.0055		
	Freshwater	2019	417	416		0.07		

[17] This value is very high and could be a reporting error.

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Freshwater	2020	116	0				
	Freshwater	2021	380	0				
	Groundwater	2018	452	0				
	Groundwater	2019	248	0				
	Groundwater	2020	114	0				
	Groundwater	2021	21	0				
	Marine water	2018	175	0				
	Marine water	2019	65	0				
	Marine water	2021	24	0				
	Sewage discharge	2018	8	0				
1,3,5-Triazine-2,4,6-triamine -	Freshwater	2019	410	181	0.0058	13	0.883	0.28

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
108-78-1	Freshwater	2020	116	34	0.029	3.9	0.454	0.155
	Freshwater	2021	380	117	0.012	4.9	0.401	0.17
	Groundwater	2019	248	40	0.0034	1.2	0.103	0.028
	Groundwater	2020	114	10	0.014	2.5	0.342	0.089
	Groundwater	2021	21	5	0.011	0.12	0.049	0.036
	Marine water	2019	65	6	0.0081	0.39	0.163	0.11
	Marine water	2021	24	1	0.068	0.068		
hexachlorocyclopentadiene - 77-47-4	Freshwater	2019	2560	0				
	Freshwater	2020	2645	0				
	Freshwater	2021	606	0				
	Groundwater	2018	1469	0				
	Groundwater	2019	1720	5	0.002	0.031	0.016	0.02

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Groundwater	2020	1460	4	0.001	0.008	0.005	0.006
	Groundwater	2021	231	0				
	Marine water	2018	204	0				
	Marine water	2019	169	0				
	Marine water	2020	36	0				
	Marine water	2021	270	0				
	Sewage discharge	2018	9	0				
tris(1,3-dichloro-2-propyl) phosphate (TDCPP) - 13674-87-8	Freshwater	2019	2645	665	0.004	0.841	0.042	0.029
	Freshwater	2020	606	121	0.008	0.292	0.036	0.029
	Freshwater	2021	1478	278	0.003	0.889	0.041	0.026
	Freshwater	2022	1259	422	0.006	0.724	0.043	0.026

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Groundwater	2019	1231	23	0.014	0.464	0.06	0.034
	Groundwater	2020	201	4	0.012	0.057	0.027	0.02
	Groundwater	2021	61	2	0.062	0.086		
	Groundwater	2022	28	1	0.015	0.015		
	Marine water	2019	169	16	0.01	0.04	0.022	0.02
	Marine water	2020	36	0				
	Marine water	2021	270	40	0.008	0.166	0.036	0.029
	Marine water	2022	463	126	0.006	0.089	0.023	0.02
2,4,6-Tribromophenol - 118-79-6	Freshwater	2019	2645	244	0.001	0.756	0.017	0.01
	Freshwater	2020	606	15	0.003	0.082	0.012	0.006
	Freshwater	2021	1478	318	0.002	0.066	0.014	0.012
	Freshwater	2022	1259	313	0.003	0.182	0.016	0.011

Name - CAS	Environmental compartment	Year	Samples analysed	Samples >LOD	Min. (µg/L)	Max. (µg/L)	Mean (µg/L)	Median (µg/L)
	Groundwater	2019	1231	7	0.004	0.067	0.022	0.014
	Groundwater	2020	201	1	0.04	0.04		
	Groundwater	2021	61	0				
	Groundwater	2022	28	1	0.004	0.004		
	Marine water	2019	169	5	0.002	0.012	0.008	0.01
	Marine water	2020	36	1	0.196	0.196		
	Marine water	2021	270	31	0.002	0.026	0.009	0.007
	Marine water	2022	463	79	0.003	0.03	0.011	0.009

Note: Concentrations of isodecyl diphenyl phosphate (CAS 29761-21-5) were below the detection limit of 0.01 µg/L in all samples. Dimethyl phosphonate (CAS 868-85-9) was not detected although the detection limit for this substance was not evaluated.

Appendix 6 - Additional substances identified by the Advisory Group

Table A6.1 lists substances that were identified by the Advisory Group over the course of the project, but did not meet the criteria for selection for this project as described in Section 3.1. Information from an Advisory Group member states these substances were detected in the EU and/or UK. However, these substances were not UK REACH registered and DUINs had not been submitted for them. None of these substances were EU REACH registered.

Other substances identified by the Advisory Group that have DUINs but were not registered under UK REACH are included in Appendix 7. Advisory Group members have indicated several of these substances with DUINs are believed to be relevant in GB and/or expected to be registered under UK REACH in future. Several of these other substances with DUINs identified by the Advisory Group were incorporated into the project as "Group (c)" substances in 2023 (see Section 1.2).

Table A6.1: Additional FRs identified by the Advisory Group

Substance name	CAS number	Chemical group	Notified EU CLP?
1,2-Bis(2,4,6-tribromophenoxy) ethane	37853-59-1	Brominated organic	Yes
2-Ethylhexyl 2,3,4,5-tetrabromobenzoate	183658-27-7	Brominated organic	Yes
Hexabromobenzene	87-82-1	Brominated organic	Yes
2,3,4,5,6-Pentabromoethylbenzene	85-22-3	Brominated organic	Yes
Pentabromotoluene	87-83-2	Brominated organic	Yes
1,2-Dibromo-4-(1,2-	3322-93-8	Brominated organic	Yes

Substance name	CAS number	Chemical group	Notified EU CLP?
dibromoethyl)cyclohexane			
2,3,5,6-Tetrabromo-p-xylene	23488-38-2	Brominated organic	Yes
2,3,4,5-Tetrabromo-6-chlorotoluene	39569-21-6	Brominated organic, chlorinated organic	No

Appendix 7 - DUINs list

Table A7.1 provides a list of potential FRs that have UK Downstream User Import Notifications, based on analysis that became available after the main phase of this screening review was completed. During this analysis, the complete list of substances that were classed as potential FRs in the project inventory was compared with the UK REACH DUIN database as of January 2023. In total, 152 substances were found to have a DUIN but no other UK REACH activity and these were listed by Bevington *et al.* (2022).

Table A7.1: Potential FRs with DUIN but no other UK REACH activity

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
4-Bromobiphenyl	92-66-0	Brominated organic	Yes	Intermediate use only
1,2-Dibromo(phenyl)ethane	93-52-7	Brominated organic	Yes	No data
2,3-Dibromopropanol	96-13-9	Brominated organic	Yes	Intermediate use only
2,4,6-Tribromophenol	118-79-6	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE)	1163-19-5	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
3-Bromo-2,2-bis(bromomethyl)propanol	1522-92-5	Brominated organic	Yes	No data
2,2'-[(1-Methylethylidene)bis[(2,6-dibromo-4,1-phenylene)oxymethylene]]bis[oxirane]	3072-84-2	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
1,2,5,6,9,10-Hexabromocyclododecane	3194-55-6	Brominated organic	Yes	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate	20566-35-2	Brominated organic	Yes	No longer valid
Tetrabromobisphenol a-bis(2,3-dibromopropyl ether)	21850-44-2	Brominated organic	Yes	≥ 1,000 to < 10,000 tonnes
Hexabromocyclododecane	25637-99-4	Brominated organic	Yes	Cease manufacture
2,4,6-Tris-(2,4,6-tribromophenoxy)-1,3,5-triazine	25713-60-4	Brominated organic	Yes	≥ 1,000 to < 10,000 tonnes
Bisphenol a-epichlorohydrin-2,2',6,6'-tetrabromobisphenol a copolymer	26265-08-7	Brominated organic	Yes	No data
Dibromostyrene	31780-26-4	Brominated organic	Yes	No data
1,2-Bis(tetrabromophthalimido)ethane	32588-76-4	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
Tribromoneopentyl alcohol	36483-57-5	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
3,5,3',5'Tetrabromobisphenol a, epichlorohydrin polymer	40039-93-8	Brominated organic	Yes	≥ 1,000 to < 10,000 tonnes
(Pentabromophenyl)methyl acrylate	59447-55-1	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
Poly(pentabromobenzyl acrylate)	59447-57-3	Brominated organic	No	No data
Nonabromodiphenyl ether	63936-56-1	Brominated organic	Yes	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
2-Butyne-1,4-diol, polymer with 2-(chloromethyl)oxirane, brominated, dehydrochlorinated, methoxylated	68441-62-3	Brominated organic	Yes	≥ 1,000 to < 10,000 tonnes
2,2'-[(1-Methylethylidene)bis[(dibromo-4,1-phenylene)oxymethylene]]bis[oxirane]-4,4'-(1-methylethylidene)bis[2,6-dibromophenol] copolymer	68928-70-1	Brominated organic	Yes	No data
Diphenyl ether, heptabromo derivative	68928-80-3	Brominated organic	No	No data
Phenol, 4,4'-(1-methylethylidene)bis[2,6-dibromo-, polymer with carbonic dichloride, bis(2,4,6-tribromophenyl) ester	71342-77-3	Brominated organic	Yes	No data
Tetrabromophthalic acid mixed esters with diethylene glycol and propylene glycol	77098-07-8	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
Benzene, ethenyl-, homopolymer, brominated	88497-56-7	Brominated organic	Yes	No data
1,1'-(Isopropylidene)bis(3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene)	97416-84-7	Brominated organic	Yes	≥ 1,000 to < 10,000 tonnes
(+/-)-α-Hexabromocyclododecane	134237-50-6	Brominated organic	Yes	No data
(+/-)-Beta-hexabromocyclododecane	134237-51-7	Brominated organic	Yes	No data
(+/-)-Gamma-hexabromocyclododecane	134237-52-8	Brominated organic	Yes	No data
Brominated epoxy resin end-capped with tribromophenol	135229-48-0	Brominated organic	No	No data
4,4'-(1-Methylethylidene)bis[2,6-dibromophenol] polymer with (chloro-methyl)oxirane and 2,4,6-tribromophenol	158725-44-1	Brominated organic	Yes	≥ 100 to < 1,000 tonnes

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
2,2-Bis(chloromethyl)-1,3-propanediyl tetrakis(1-chloro-2-propanyl) bis(phosphate)	1047637-37-5	Brominated organic	Yes	≥ 100 to < 1,000 tonnes
Chlorendic acid	115-28-6	Chlorinated organic	Yes	No data
Tetrachlorophthalic anhydride	117-08-8	Chlorinated organic	Yes	≥ 100 to < 1,000 tonnes
Polyvinylidene chloride	9002-85-1	Chlorinated organic	No	No data
Dechlorane plus	13560-89-9	Chlorinated organic	Yes	Cease manufacture
Vinyl acetate ethylene copolymer	24937-78-8	Chlorinated organic	Yes	Tonnage data confidential
Chloroalkanes	61788-76-9	Chlorinated organic	Yes	No data
Alkenes, C12-24, chloro	68527-02-6	Chlorinated organic	Yes	No data
C10-13 chloro alkanes	85535-84-8	Chlorinated organic	Yes	No longer valid
C18-28 chloroalkanes	85535-86-0	Chlorinated organic	Yes	No data
Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[2, 6-dibromophenol] and phenol	94334-64-2	Chlorinated organic	Yes	No data
Alkanes, C18-20, chloro	106232-85-3	Chlorinated organic	No	No data
Alkanes, C22-40, chloro	106232-86-4	Chlorinated organic	No	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
C10-12 chloroalkanes	108171-26-2	Chlorinated organic	No	No data
Dechlordane plus (syn isomer)	135821-03-3	Chlorinated organic	No	No data
Anti-dechlorane plus	135821-74-8	Chlorinated organic	No	No data
Tetradecane, chloro derivs.	198840-65-2	Chlorinated organic	No	No data
Alkanes, C14-16, chloro	1372804-76-6	Chlorinated organic	Yes	No data
Alkanes, C24-28, chloro	1402738-52-6	Chlorinated organic	No	No data
Alkanes, C21-34-branched and linear, chloro	1417900-96-9	Chlorinated organic	No	No data
Alkanes, C20-28, chloro	2097144-43-7	Chlorinated organic	No	No data
Slack wax (petroleum), chloro	2097144-44-8	Chlorinated organic	No	No data
Alkanes, C20-24, chloro	2097144-45-9	Chlorinated organic	No	No data
Hexacosane, chloro derivs.	2097144-46-0	Chlorinated organic	No	No data
Octacosane, chloro derivs.	2097144-47-1	Chlorinated organic	No	No data
Octadecane, chloro derivs.	2097144-48-2	Chlorinated organic	No	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Tris(2-chloroethyl) phosphate	115-96-8	Halogenated organophosphorus	Yes	Cease manufacture
Tris(2-chloroisopropyl)phosphate	13674-84-5[18]	Halogenated organophosphorus	Yes	No data
Bis(2-chloro-1-methylethyl) 2-chloropropyl phosphate	76025-08-6	Halogenated organophosphorus	No	No data
(2-Chloro-1-methylethyl) bis(2-chloropropyl) phosphate	76649-15-5	Halogenated organophosphorus	No	No data
Tris(2-chloropropyl) phosphate	6145-73-9	Halogenated organophosphorus	Yes	No data
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	Halogenated organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Tris(tribromoneopentyl)phosphate	19186-97-1	Halogenated organophosphorus	Yes	No data

[18] Please see also Reaction products of phosphoryl trichloride and 2-methyloxirane, EC no: 807-935-0; CAS no: 1244733-77-4, which was assessed in this project.

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Bentonite	1302-78-9	Inorganic	Yes	No data
Borax ($B_4Na_2O_7.10H_2O$)	1303-96-4	Inorganic	Yes	No data
Zinc sulfide	1314-98-3	Inorganic	Yes	≥ 100,000 to < 1,000,000 tonnes
Vermiculite	1318-00-9	Inorganic	Yes	No data
Antimony oxide (Sb_2O_4)	1332-81-6	Inorganic	Yes	No data
Zinc carbonate	3486-35-9	Inorganic	Yes	≥ 10 to < 100 tonnes
Magnesium carbonate hydroxide ($Mg_5(CO_3)_4(OH)_2$)	7760-50-1	Inorganic	Yes	No data
Aluminum hypophosphite	7784-22-7	Inorganic	Yes	≥ 100 to < 1,000 tonnes
Calcium phosphinate	7789-79-9	Inorganic	Yes	≥ 100 to < 1,000 tonnes
Antimony trichloride	10025-91-9	Inorganic	Yes	≥ 10 to < 100 tonnes
Calcium sulfate dihydrate	10101-41-4	Inorganic	Yes	No data
Crude natural boric acid	11113-50-1	Inorganic	Yes	Cease manufacture
Calcium borate	12040-58-3	Inorganic	Yes	No data
Disodium stannate	12058-66-1	Inorganic	Yes	≥ 0 to < 10 tonnes
Ammonium bromide	12124-97-9	Inorganic	Yes	≥ 1,000 to < 10,000 tonnes
Boron sodium oxide pentahydrate	12179-04-3	Inorganic	Yes	No data
Disodium octaborate tetrahydrate	12280-03-4	Inorganic	Yes	No data
Boron phosphate ($B(PO_4)$)	13308-51-5	Inorganic	Yes	≥ 100 to < 1,000 tonnes
Sodium tungsten oxide (Na_2WO_4)	13472-45-2	Inorganic	Yes	≥ 1,000 to < 10,000 tonnes

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Aluminum phosphate ($Al(H_2PO_4)_3$)	13530-50-2	Inorganic	Yes	≥ 1,000 to < 10,000 tonnes
Barium metaborate	13701-59-2	Inorganic	Yes	≥ 100 to < 1,000 tonnes
Zinc molybdate(VI) ($ZnMoO_4$)	13767-32-3	Inorganic	Yes	≥ 10 to < 100 tonnes
Ammonium fluoroborate	13826-83-0	Inorganic	Yes	≥ 10 to < 100 tonnes
Phosphate	14265-44-2	Inorganic	Yes	No data
Sodium antimonate	15432-85-6	Inorganic	Yes	≥ 100 to < 1,000 tonnes
Huntite	19569-21-2	Inorganic	No	No data
Aluminium hydroxide oxide	24623-77-6	Inorganic	Yes	No data
Sodium hexahydroxyantimonate(1-)	33908-66-6	Inorganic	Yes	≥ 1,000 to < 10,000 tonnes
Calcium magnesium hydroxide oxide	58398-71-3	Inorganic	Yes	≥ 100,000 to < 1,000,000 tonnes
Calcium borate silicate	59794-15-9	Inorganic	No	No data
Ammonium polyphosphates	68333-79-9	Inorganic	Yes	≥ 10,000 to < 100,000 tonnes
Zinc borate 2335	138265-88-0	Inorganic	Yes	No data
Zinc borate	1332-07-6	Inorganic	Yes	≥ 10 to < 100 tonnes
Cyanuric acid	108-80-5	Nitrogen-based	Yes	≥ 10,000 to < 100,000 tonnes
Tris(2-hydroxyethyl) isocyanurate	839-90-7	Nitrogen-based	Yes	≥ 10,000 to < 100,000 tonnes

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Melem 1,3,4,6,7,9,9b-heptaazaphenalene-2,5,8-triamine	1502-47-2	Nitrogen-based	Yes	Tonnage data confidential
1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde	9003-08-1	Nitrogen-based	Yes	No data
Diammonium tetraborate	12007-58-8	Nitrogen-based	Yes	No data
Diphosphoric acid, compd. with 1,3,5-triazine-2,4,6-triamine (1:?)	15541-60-3	Nitrogen-based	Yes	≥ 100 to < 1,000 tonnes
1,3,5-Triazine-2,4,6(1h,3h,5h)-trione, compd. with 1,3,5-triazine-2,4,6-triamine (1:1)	37640-57-6	Nitrogen-based	Yes	≥ 100 to < 1,000 tonnes
Quaternary ammonium compounds, bis(hydrogenated tallow alkyl)dimethyl, salts with bentonite	68953-58-2	Nitrogen-based	Yes	No data
1,3-Propanediamine, n1,n1'-1,2-ethanediylbis- , reaction products with cyclohexane and peroxidized n-butyl-2,2,6,6-tetramethyl-4-piperidinamine-2,4,6-trichloro-1,3,5-triazine reaction products	191680-81-6	Nitrogen-based	Yes	≥ 100 to < 1,000 tonnes
Tris(4-methylphenyl) phosphate	78-32-0	Organophosphorus	Yes	No data
Tris(4-tert-butylphenyl) phosphate	78-33-1	Organophosphorus	Yes	No data
Diethyl ethylphosphonate	78-38-6	Organophosphorus	Yes	≥ 100 to < 1,000 tonnes
Tris(2-ethylhexyl) phosphate	78-42-2	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Myo-inositol hexakisphosphate	83-86-3	Organophosphorus	Yes	≥ 1 to < 10 tonnes
Bis(p-tert-butylphenyl) phenyl phosphate	115-87-7	Organophosphorus	No	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Triisobutyl phosphate	126-71-6	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Bis(2-ethylhexyl) phosphate	298-07-7	Organophosphorus	Yes	≥ 100 to < 1,000 tonnes
Trimethyl phosphate	512-56-1	Organophosphorus	Yes	≥ 10 to < 100 tonnes
Dimethyl methylphosphonate	756-79-6	Organophosphorus	Yes	Intermediate use only
Triphenylphosphine oxide	791-28-6	Organophosphorus	Yes	≥ 1 to < 10 tonnes
Diethylphosphinic acid	813-76-3	Organophosphorus	No	No data
Dimethyl phosphate	813-78-5	Organophosphorus	Yes	No data
Diphenyl phosphate	838-85-7	Organophosphorus	Yes	No data
Tris(methylphenyl) phosphate	1330-78-5	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Dibutyl phenyl phosphate	2528-36-1	Organophosphorus	Yes	No data
Butyl diphenyl phosphate	2752-95-6	Organophosphorus	Yes	No data
Diethyl (n,n-bis(2-hydroxyethyl)amino)methanephosphonate	2781-11-5	Organophosphorus	Yes	≥ 100 to < 1,000 tonnes
1,3,2-Dioxaphosphorinane, 2,2'-oxybis[5,5-dimethyl-, 2,2'-disulfide	4090-51-1	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Diphosphoric acid--1,3,5-triazinane-2,4,6-triimine (1/2)	13518-93-9	Organophosphorus	Yes	≥ 1 to < 10 tonnes
3-[Hydroxy(phenyl)phosphoryl]propanoic acid	14657-64-8	Organophosphorus	Yes	Tonnage data confidential
1,2-Ethanediamine, phosphate	14852-17-6	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Bis(2ethylhexyl) phenyl phosphate	16368-97-1	Organophosphorus	Yes	No data
Dimethyl propylphosphonate	18755-43-6	Organophosphorus	Yes	Intermediate use only
Dimethyl (3-((hydroxymethyl)amino)-3-oxopropyl)phosphonate	20120-33-6	Organophosphorus	Yes	No data
Cresyl diphenyl phosphate	26444-49-5	Organophosphorus	Yes	No data
Phosphoric acid, bis(methylphenyl) phenyl ester	26446-73-1	Organophosphorus	Yes	No data
6H-dibenzo[c,e][1,2]oxaphosphinine 6-oxide	35948-25-5	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
(5-Ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl dimethyl phosphonate p-oxide	41203-81-0	Organophosphorus	Yes	No data
1,3,5-Triazine-2,4,6-triamine, phosphate	41583-09-9	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Bis((5-ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl) methyl phosphonate p,p'-dioxide	42595-45-9	Organophosphorus	Yes	No data
Tert-butylphenyl diphenyl phosphate	56803-37-3	Organophosphorus	Yes	No data

Substance name	CAS number	Chemical group	Notified EU CLP?	EU REACH registered tonnage band
Antiblaze 19	61840-22-0	Organophosphorus	No	No data
Bis(tert-butylphenyl)phenyl phosphate	65652-41-7	Organophosphorus	Yes	No data
Diphosphoric acid, compd. With piperazine (1:1)	66034-17-1	Organophosphorus	Yes	≥ 100 to < 1,000 tonnes
Diphenyl methylphosphonate--4,4'-(propane-2,2-diyl)diphenol (1/1)	68664-06-2	Organophosphorus	No	No data
Carbonic acid, diphenyl ester, polymer with diphenyl p-methylphosphonate and 4,4'-(1-methylethylidene)bis[phenol]	77226-90-5	Organophosphorus	No	No data
3,3'-[(2-Methylpropyl)phosphoryl]di(propan-1-ol)	147768-39-6	Organophosphorus	No	No data
Phosphoric acid, triethyl ester, polymer with oxirane and phosphorus oxide (P_2O_5)	184538-58-7	Organophosphorus	Yes	No data
Melapur 200 1,3,5-triazine-2,4,6-triamine, phosphate	218768-84-4	Organophosphorus	Yes	No data
Aluminum diethylphosphinate	225789-38-8	Organophosphorus	Yes	≥ 1,000 to < 10,000 tonnes
Phosphinic acid, p,p-diethyl-, zinc salt (2:1)	284685-45-6	Organophosphorus	Yes	Tonnage data confidential
Dicumyl peroxide	80-43-3	Other organic	Yes	≥ 1,000 to < 10,000 tonnes
Benzenesulfonic acid, 3,3'-sulfonylbis-, potassium salt (1:2)	63316-33-6	Other organic	Yes	No data
Potassium 3-(phenylsulfonyl)benzenesulfonate	63316-43-8	Other organic	Yes	No data

Appendix 8 - GB monitoring studies list

Advisory Group members provided this list of FR detections in Great Britain that have been reported in published scientific literature.

Table A8.1: FR detections in Great Britain based on published scientific literature

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,1'-(Ethane-1,2-diyl)bis[pentabromo benzene] (decabromodiphenyl ethane) (84852-53-9)	DBDPE	BFR	Detected in classrooms in the West Midlands, England (Ali *et al.*, 2011). Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021).	Group (a)	EU CoRAP for PBT concern	Yes	≥ 10,000 to < 100,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				
Ethylhexyl diphenyl phosphate (1241-94-7)	EHDPP	OPFR	Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015). Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023).	Group (b)		Yes	≥ 1,000 to < 10,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023).				
Tetrabromobisphenol-A (2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol) (79-94-7)	TBBPA	BFR	Detected in human breast milk samples from Birmingham, England (Abdallah and Harrad, 2011). Detected in indoor air and dust in Birmingham, England (Abdallah *et al.*, 2008). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in water, sediment and fish from English Lakes (Harrad *et al.*, 2009). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010).	Group (a)	EU CoRAP	Yes	≥ 10,000 to < 100,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Predominant in UK WEEE plastic (Stubbings *et al.*, 2021).				
Tris(2-butoxyethyl) phosphate (78-51-3)	TBOEP	OPFR	Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023). Detected in water samples from the River Thames at Gabriel's Pier in Central London collected between October 2020 and January 2021 (Rapp-Wright *et al.*, 2023).	Group (b)		Yes	≥ 1,000 to < 10,000 tonnes
Bis(2-ethylhexyl)-3,4,5,6-tetrabromophthalate (26040-51-7)	TBPH	BFR	Detected in classrooms in the West Midlands, England (Ali *et al.*, 2011).	Group (a)		Yes	≥ 100 to < 1,000 tonnes
Tri-n-butyl-phosphate (126-73-8)	TnBP	OPFR	Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015).	Group (b)		Yes	≥ 1,000 to < 10,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023).				
Triphenyl phosphate (115-86-6)	TPHP	OPFR	Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015). Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of	Group (a)	EU CoRAP	Yes	≥ 100 to < 1,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023).				
Dipotassium 3,4,5,6-tetrabromophthalate (18824-74-3)	BEH-TEBP	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).	Group (a)	EU REACH ARN identified a need for further regulatory risk management if suspected vPvB properties confirmed.	Yes	≥ 10 to < 100 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				
2,4,6-Tribromophenol (118-79-6)	TBP	BFR	Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019).	Group (c)	Substance identified as potential PBT/vPvB under EU REACH but the SEv is not further pursued either due to depriorit isation or because	Yes	≥ 100 to < 1,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
					it is not possible to acquire further data from the registrant.		
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene] (DecaBDE), decabromodiphenyl ether (1163-19-5)	BDE-209	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Dominant PBDE congener in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in human breast milk samples from Birmingham, England (Harrad and Abdallah, 2015).	Group (c)	POP. PBT under EU REACH.	Yes	≥ 100 to < 1,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Predominant in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017).Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				
1,2-Dibromo-4-(2,4-dibromophenoxy)be	BDE-66	BFR	Detected in indoor dust samples from primary school and daycare centre	No	POP	Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
nzene (189084-61-5)			classrooms in the West Midlands, England (Harrad *et al.*, 2010).				
1,2,3-Tribromo-4-(2,4-dibromophenoxy)benzene (182346-21-0)	BDE-85	BFR	Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016).	No	POP	Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,2,4-Tribromo-5-(2,4,5-tribromophenoxy)benzene (68631-49-2)	BDE-153	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in human breast milk samples from Birmingham, England (Harrad and Abdallah, 2015). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016).	No	POP.	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,2,4-Tribromo-5-(2,4,6-tribromophenoxy)benzene (207122-15-4)	BDE-154	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021).	No	POP	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,2,3,5-Tetrabromo-4-(2,4,5-tribromophenoxy)benzene (207122-16-5)	BDE-183	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No	POP	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
2,2’,4,4’-Tetrabromodiphenyl ether (5436-43-1)	BDE-47	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in human breast milk samples from Birmingham, England (Harrad and Abdallah, 2015). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021).	No	POP	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
2,2',4,4',5-Pentabromodiphenyl ether (60348-60-9)	BDE-99	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in human breast milk samples from Birmingham, England (Harrad and Abdallah, 2015). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021).	No	POP	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
Hexabromocyclododecane (25713-60-4, 3194-55-6, etc)	HBCDD	BFR	Detected in human breast milk samples from Birmingham, England (Abdallah and Harrad, 2011). Detected in indoor air and dust in Birmingham, England (Abdallah *et al.*, 2008). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in water, sediment and fish from English Lakes (Harrad *et al.*, 2009). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in human breast milk samples from Birmingham, England (Harrad and Abdallah, 2015). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016).	No	POP. Included in an Advisory Group member's list of 21 FRs registered at the highest volumes under EU REACH	Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Note different isomers and degradation products were measured in several of these studies.				

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,2-Bis(2,4,6-tribromophenoxy)ethane (37853-59-1)	BTBPE	BFR	Detected in classrooms in the West Midlands, England (Ali *et al.*, 2011). Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).	No	PBT under EU REACH	Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
Anti/syn-dechlorane plus (13560-89-9)	anti-/syn-DP	Cl FR	Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Syn and anti isomers detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No	PBT under EU REACH and under assessment as a POP	Yes	Cease manufacture
1,2,3,5-Tetrabromo-4-(2,3,4,6-tetrabromophenoxy) benzene (117964-21-3)	BDE-197	BFR	Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		Yes	No data
1,2,3,4,5-Pentabromo-6-(2,4,5-tribromophenoxy)benzene (337513-72-1)	BDE-203	BFR	Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
2,4,4'-Tribromodiphenyl ether (41318-75-6)	BDE-28	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in silicone wristbands worn by occupants (as passive samplers of	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			exposure) in office buildings in the UK (Young *et al.*, 2021).				
Tetrabromoethylcyclohexane (3322-93-8)	DBE-DBCH	BFR	α and β isomers detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). α and β isomers detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No		Yes	No data
Hexabromobenzene (87-82-1)	HBB; or HBBz	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a).	No		Yes	No data
Pentabromobenzene (608-90-2)	PBBz	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).				
Pentabromoethylbenzene (85-22-3)	PBEB	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a).	No		Yes	No data
Pentabromotoluene (87-83-2)	PBT	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a).	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
2-Ethylhexyl-2,3,4,5-tetrabromobenzoate (183658-27-7)	TBB; or EH-TBB	BFR	Detected in classrooms in the West Midlands, England (Ali *et al.*, 2011). Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).	No		Yes	No data
Tetrabromo-3,6-dimethylbenzene (23488-38-2	TBX	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
Tri-m-tolyl phosphate (563-04-2)	TMTP	OPFR	Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023).	No		Yes	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
1,3,5-Tribromo-2-(2,4-dibromophenoxy)benzene (189084-64-8)	BDE-100	BFR	Detected in indoor dust from floors and elevated surfaces in homes in Birmingham, England (Al-Omran and Harrad, 2018). Detected in dust samples from homes in Birmingham, England (Drage *et al.*, 2020). Detected in dust samples from homes, offices and cars in Birmingham, England (Harrad *et al.*, 2008). Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011). Detected in kitchen and living room dust from homes in the West Midlands, England (Kuang *et al.*, 2016). Detected in UK WEEE plastic (Stubbings *et al.*, 2021). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No		No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in eggs laid by gulls breeding adjacent to a landfill in Scotland, UK (Tongue *et al.*, 2021). Detected in dust from inside and outside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).				
2,2',3,3',4,4',5,6'-Octabromodiphenyl ether (446255-39-6)	BDE-196	BFR	Detected in indoor dust samples from primary school and daycare centre classrooms in the West Midlands, England (Harrad *et al.*, 2010). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		No	No data
2,2′,3,3′,5,5′,6,6′-Octabromodiphenyl ether (67797-09-5)	BDE-202	BFR	Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
2,2',3,3',4,4',5,5',6-Nonabromodiphenyl ether (63387-28-0)	BDE-206	BFR	Detected in sediments of the River Thames, England, UK (Ganci *et al.*, 2019). Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		No	No data
2,2',3,3',4,4',5,6,6'-Nonabromodiphenyl ether (437701-79-6)	BDE-207	BFR	Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		No	No data
2,2',3,3',4,5,5',6,6'-Nonabromodiphenyl ether (437701-78-5)	BDE-208	BFR	Detected in dust samples from cars in the West Midlands, England (Harrad and Abdallah, 2011).	No		No	No data
Tetrabromo-o-chlorotoluene (39569-21-6)	TBCT	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	No		No	No data
2,3-Dibromopropyl 2,4,6-tribromophenyl ether (35109-60-5)	TBP-DBPE; or DPTE	BFR	Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016). Detected in dust from inside of UK e-waste recycling facilities (Ma *et al.*, 2023a). Detected in food samples from Birmingham, England (Ma *et al.*, 2023b).	No		No	No data
Tris-(2-chloroethyl)-phosphate (115-96-8)	TCEP	Cl-OPFR	Dermal uptake from UK fabrics observed in an in vitro study (Abdallah and Harrad, 2022). Detected in living room, office, car and classroom dust samples from the West	No	SVHC under EU REACH due to reprotox	Yes	Cease manufacture

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Midlands, England (Brommer and Harrad, 2015). Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023). Detected in water samples from the River Thames at Gabriel's Pier in Central London collected between October 2020 and January 2021 (Rapp-Wright *et al.*, 2023).		icity. Included on the EU REACH Authorisation list.		
Tri - hexaBDEs (BDE-28, -47, -99, -	tri - hexaBDEs	BFR	Sum of tri - hexaBDEs measured in food samples and human milk samples from Birmingham, England (Tao *et al.*, 2017).	No	Includes POPs	No	No data

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
100, -153, -154, -183) (NA)							
Tetrabromobisphenol a–bis(2,3-dibromopropyl ether) (21850-44-2)	TBBPA–BDBPE; or TBBPA-DBPE	BFR	Detected in classrooms in the West Midlands, England (Ali *et al.*, 2011). Detected in indoor air and dust samples from homes and offices in Birmingham, England (Tao *et al.*, 2016).	Group (c)	Included in an Advisory Group member's list of 21 FRs registered at the highest volumes under EU REACH. EU REACH ARN identified a need for further regulatory risk management if ED and PBT	Yes	≥ 1,000 to < 10,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
					properties of TBBPA confirmed.		
Tris(2-chloroisopropyl) phosphate (13674-84-5)	TCIPP	Cl-OPFR	Dermal uptake from UK fabrics observed in an in vitro study (3). Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015). Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).	Group (a)	Included in an Advisory Group member's list of 21 FRs registered at the highest volumes under EU REACH. An EU REACH restriction proposa	Yes	≥ 1,000 to < 10,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
			Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023). Detected in water samples from the River Thames at Gabriel's Pier in Central London collected between October 2020 and January 2021 (Rapp-Wright *et al.*, 2023).		l on chlorinated organophosphates in childcare articles and residential upholstered furniture has been paused while the US review of carcinogenicity in an NTP study is underway.		

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
Tris-(1,3-dichloropropyl)-phosphate (13674-87-8)	TDCPP	Cl-OPFR	Dermal uptake from UK fabrics observed in an in vitro study (Abdallah and Harrad, 2022). Detected in food samples collected from Birmingham, England (Gbadamosi *et al.*, 2022). Detected in soft furnishings entering the UK waste stream (Stubbings *et al.*, 2016). Detected in drinking water samples from the West Midlands, England (Gbadamosi *et al.*, 2023). Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021). Detected in indoor and outdoor air in Birmingham, UK (Ortiz and Harrad, 2023). Detected in freshwater sediment collected from four locations in the UK during 2019-2021 (Onaja *et al.*, 2023).	Group (c)	Included in an Advisory Group member's list of 21 FRs registered at the highest volumes under EU REACH. An EU REACH restriction proposal on chlorinated organophosphates in childcare articles	Yes	≥ 1,000 to < 10,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
					and residential upholstered furniture has been paused while the US review of carcinogenicity in an NTP study is underway.		
Tris(2-ethylhexyl) phosphate (78-42-2)	TEHP	OPFR	Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).	Group (c)		Yes	≥ 1,000 to < 10,000 tonnes
Triethyl phosphate (78-40-0)	TEP	OPFR	Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).	Group (a)		Yes	≥ 10,000 to < 100,000 tonnes

Substance name (CAS number)	Abbreviation	FR type	Occurrence	Assessed in this project?	POPs & EU REACH status	Notified EU CLP?	EU REACH registered tonnage band
Tri-iso-butyl-phosphate (126-71-6)	TiBP	OPFR	Detected in silicone wristbands worn by occupants (as passive samplers of exposure) in office buildings in the UK (Young *et al.*, 2021).	Group (c)		Yes	≥ 1,000 to < 10,000 tonnes
Tri-cresylphosphate (1330-78-5)	TMP	OPFR	Detected in living room, office, car and classroom dust samples from the West Midlands, England (Brommer and Harrad, 2015).	Group (c)	Included in an Advisory Group member's list of 21 FRs registered at the highest volumes under EU REACH	Yes	≥ 1,000 to < 10,000 tonnes

Appendix 9 - Findings related to tonnages of flame retardants in GB

The analysis of the UK FR market at a tonnage level relies on data at a tonnage band level and the assumption of 100% use of a substance as an FR. There are significant differences suggested between the GB market and other markets, and it is difficult to discern if this is consequence of the form of the UK data or an actual difference. Due to this uncertainty, this part of the analysis has been placed in an appendix, rather than the main body of the report, and caution should be used when relying on the volume aspects of the data.

Applications of flame retardants

To avoid disclosing confidential market information on specific substances, findings are presented here for aggregated substance groups. Following the approach set out in Section 3.1, 73 substances were screened in as FRs relevant to GB. The combined annual GB tonnage of this FR inventory is 82,000 - 826,000 tonnes/year, with inorganic substances accounting for almost 80%, organophosphorus FRs representing 11% of the tonnage, and other FR types each making up no more than 4% (see Figure A9.1).

Figure A9.1 Proportion of total inventory tonnage by flame retardant type

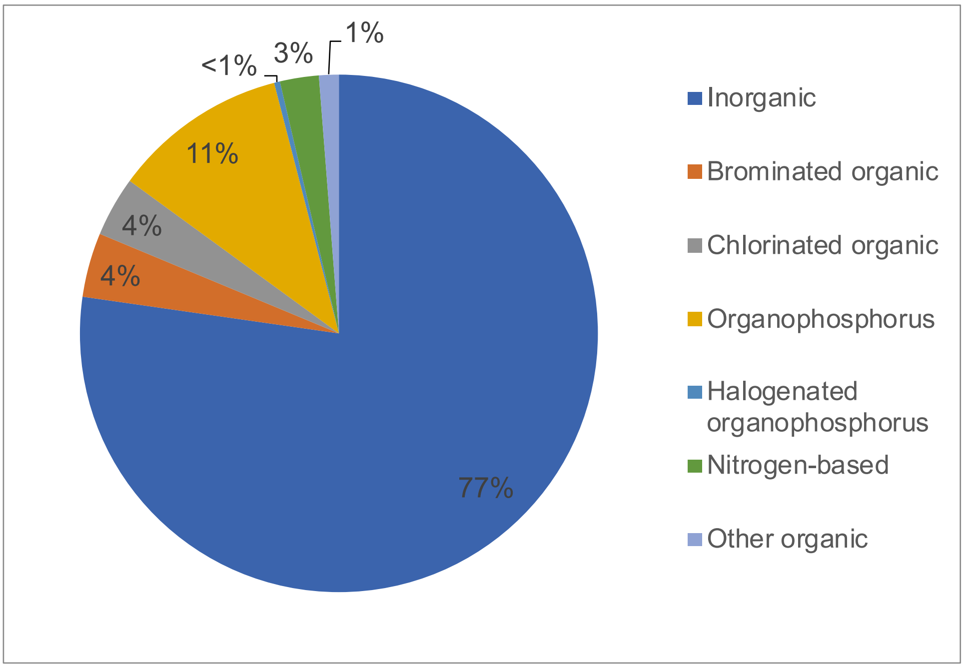
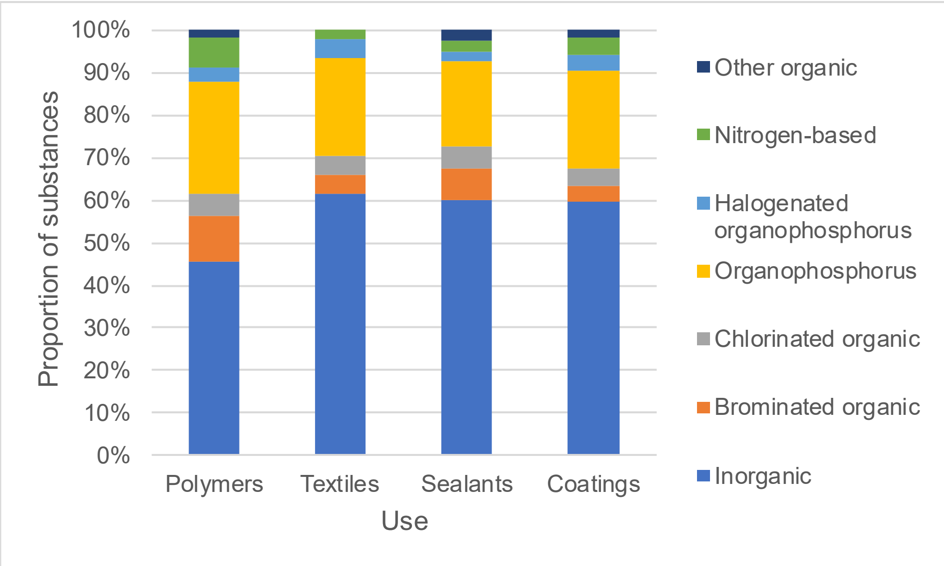


Figure A9.2 shows the proportions of substances by substance types used across the four use categories. Inorganic substances are the most frequently used FRs in textiles, sealants and coatings, and account for just under half of FR substances used in polymers. Organophosphorus FRs represent at least 20% of FR substances used in each of the four categories. This is based on the number of substances identified as having uses in a particular use class.

Textiles, sealants, and coatings display a similar substance profile, where flame retardancy is provided primarily by inorganic and organophosphorus substances, followed by smaller shares of other substance types. By contrast, polymers are more varied in the use of FR types, with a greater share of brominated and halogenated organophosphorus substances being used in these sectors to provide flame retardancy.

Figure A9.2 Proportion of FR substance types in different use categories



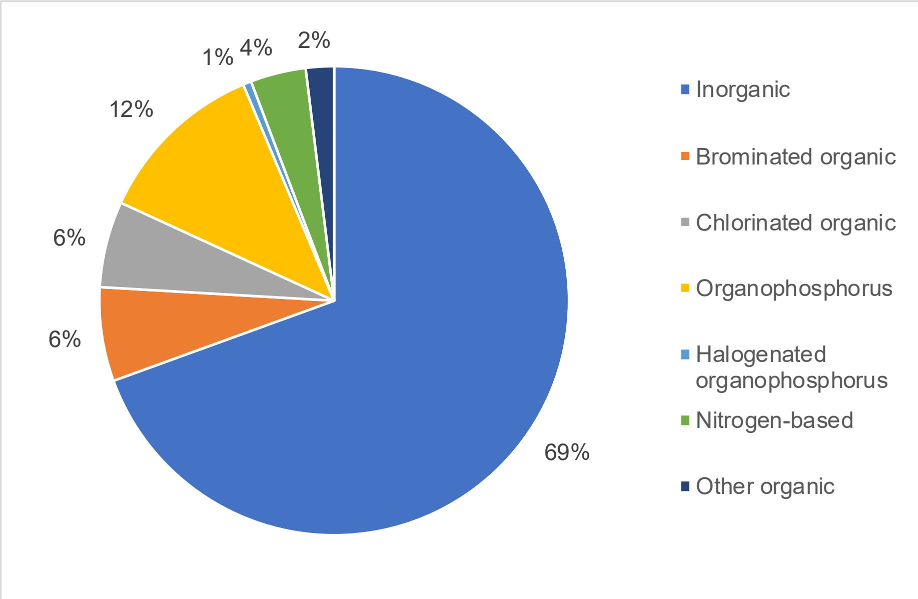
Key industrial sectors for FR life cycles in GB

Plastics

Of the 73 substances identified as GB-relevant FRs, 57 (78%) are used in polymers. Of these 57 substances 26 (46%) were inorganic, 15 (26%) organophosphorus, and 6 (11%) brominated organic.

Based on minimum and maximum substance tonnages reported in the UK REACH system, and assumptions on how tonnages are split by use (see Section 3.1.4), the total tonnage of FRs used in polymers across the 73 screened substances is estimated to be between 44,000 - 446,000 tonnes/year. Approximately 69% of this tonnage is attributable to inorganic substances, (see Figure A9.3). Organophosphorus and BFRs account for most of the remaining tonnage, at 12% and 6% respectively.

Figure A9.3 Percentage of total tonnage of FRs used in polymers, split by substance type

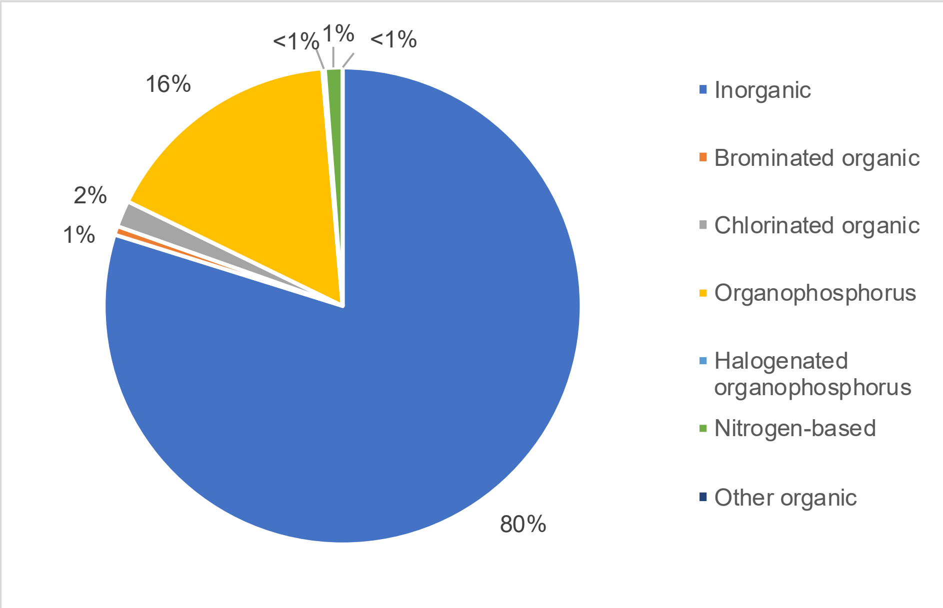


Textiles

44 of the 73 substances identified as UK-relevant FRs are said to be used in textiles. 27 (61%) of the 44 substances are inorganic, 10 (23%) organophosphorus and 2 (5%) halogenated organophosphorus, chlorinated organic, and brominated organic substances.

Based on minimum and maximum tonnages reported in UK REACH, the total tonnage of GB-relevant FRs used in textiles is estimated to be between 17,000 – 168,000 tonnes/year. Around 80% of this tonnage is attributable to inorganic FRs, as seen in Figure A9.4. Organophosphorus FRs represent the majority (16%) of the remaining tonnage relevant to use in textiles.

Figure A9.4 Percentage of total tonnage of FRs used in textiles, split by substance type

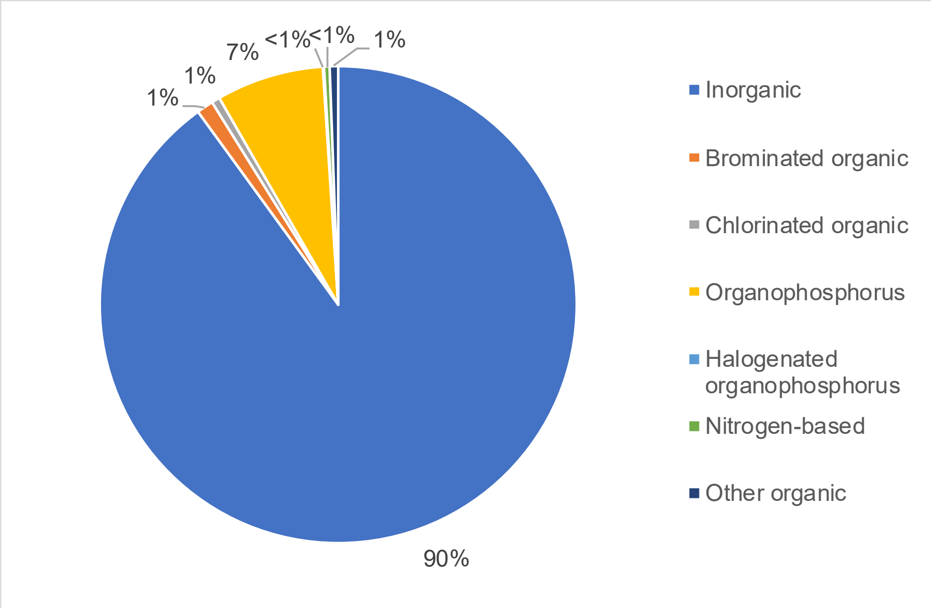


Coatings

Coatings are listed as a use for 52 out of the 73 substances identified as GB-relevant FRs. Of the 52 substances, 31 (60%) are inorganic and 12 (23%) are organophosphorus FRs. The remaining substance types each represent a smaller proportion of the total FR database.

Based on minimum and maximum substance tonnages reported under UK REACH, the total tonnage of GB-relevant FRs used in coatings is estimated to be between 13,000 – 133,000 tonnes/year. Approximately 90% of this comes from inorganic FRs (Figure A9.5). Of the remaining tonnage, organophosphorus FRs account for the greatest share at 7%.

Figure A9.5 Percentage of total tonnage of FRs used in coatings, split by substance type

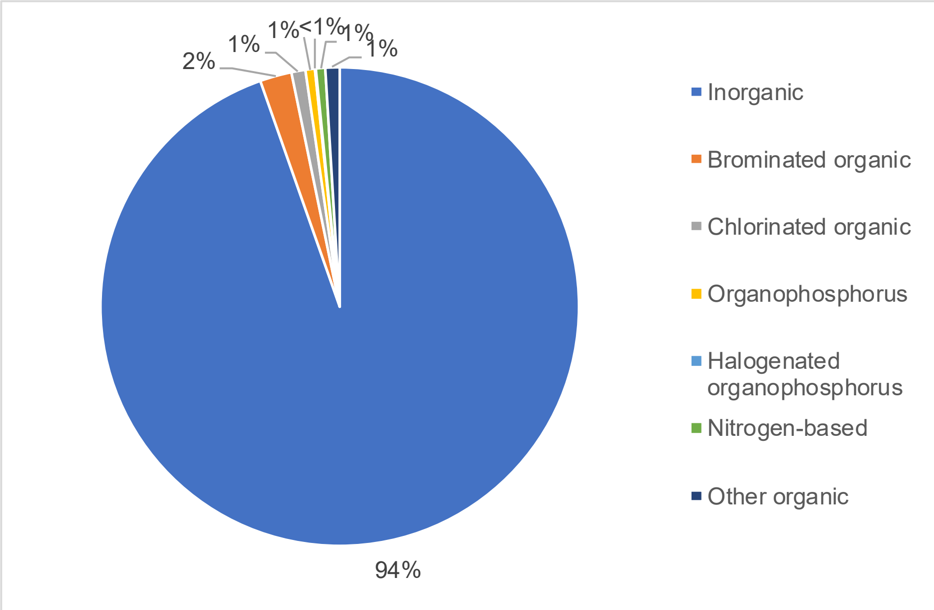


Sealants and Adhesives

Sealants were identified as a use for 40 out of the 73 substances identified as GB-relevant FRs. Out of the 40 substances, 24 (60%) are inorganics, while 8 (20%) are organophosphorus FRs. The remaining substance types each account for up to 7% of the substances used in sealants/adhesives.

Based on minimum and maximum substance tonnages reported in the UK REACH, the total tonnage of GB-relevant FRs used in adhesives/sealants is estimated to be between 8,000 – 79,000 tonnes/year. Approximately 94% of this tonnage is attributable to inorganic FRs, as seen in Figure A9.6. BFRs account for 2% of the remaining tonnage, with other substance groups making up smaller fractions.

Figure A9.6 Percentage of total tonnage of FRs used in sealants/adhesives, split by substance type



Comparison of UK trends with global and EU trends

A comparison of important aspects of the FRs markets globally, in Europe, and in GB (based on the assessed inventory of substances) is provided in Table A9.1.

Table A9.1 Comparison of global, EU, and GB trends in FRs use

Parameter	Global market	European market	GB trend
Annual FRs consumption	2.17 million tonnes (2019) – 3.18 million tonnes (2020) (Flame Retardants Online, n.d., Pinfa, 2021)	452,000 tonnes (2015; Pinfa, 2017)	82,000 to 826,000 tonnes for scoped-in substances (see Figure A9.1)
Market value	USD 8.63 billion (2022; Grand View Research, n.d.)	USD 1.98 billion (2023; Mordor Intelligence, n.d.)	No data
Key FRs uses	85% in plastics. Textiles, rubber products, wood and timber account for most of the rest (Pinfa, 2021)	No data	54% by tonnage in polymers, 20% in textiles, 16% in coatings, 10% in sealants (see Figure A9.2)
Key FRs types	Inorganics (aluminium hydroxide 38%; antimony oxides 9%), organophosphorus (18%) (see Figure 3.3). Regional variation based on regulatory requirements (e.g. brominated FRs use more prevalent in Asia than North America) (Ceresana, 2022)	Aluminium hydroxide accounts for over half of consumption (51%), phosphorus FRs account for a further 18% (Pinfa, 2017).	Inorganic FRs (77% by tonnage), organophosphorus (11%) (see Figure A9.1)

Note: Tonnage figures reported in imperial tons in the referenced sources for the global and European markets have been converted to metric tonnes to ensure consistency with other values cited in this report.

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