[Redacted]

From: Sarah Boyack MSP <Sarah.Boyack.MSP@Parliament.scot>
Sent: 15 April 2021 11:49
To: Scottish Ministers
Subject: Letter from Sarah Boyack MPS re PFAS Chemicals (Case Ref: SB5333)

Categories: MICASE

Good morning,

I am writing to you on behalf of my constituent who has concerns regarding the potential use of PFAS chemicals. I will include his correspondence below:

"I am writing to encourage you to look into the contamination of our food and water by PFAS or "forever chemicals". These have come into public light over the recent few years and most government around the world are already testing for them in at least their water supply. The UK and Scotland remains ignorant of the dangers of these.

Please review the following and act accordingly:
https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fchemtrust.org%2Fpfas-food-packaging-uk%2F&data=04%7C01%7Csarah.boyack.msp%40parliament.scot%7C341c73b87fd74615d16008d8fed84dff%7Cd603c99ccfdd4292926800db0d0cf081%7C1%7C0%7C637539552288601667%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=3q2C6QY31lSXzrdvjhYDySD30hfkyX00JZuAtpGjhFs%3D&reserved=0

Data from ISD Scotland indicates that diseases linked to PFAS such as thyroid cancer continue to skyrocket:
https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.isdscotland.org%2FHealth-Topics%2FCancer%2FPublications%2Findex.asp%3F%232400&data=04%7C01%7Csarah.boyack.msp%40parliament.scot%7C341c73b87fd74615d16008d8fed84dff%7Cd603c99ccfdd4292926800db0d0cf081%7C1%7C0%7C637539552288601667%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=HhO5FFdnfFWWjmVl87Qnk8%2BnEkMbS4S5NgZOPYodS3U%3D&reserved=0

These chemicals are killing us."

I would appreciate your comment on this so that I can respond to my constituent.

Best wishes

Sarah

Sarah Boyack MSP
The Scottish Parliament
Edinburgh
EH99 1SP

Sarah Boyack MSP
Sarah.Boyack.MSP@Parliament.scot

Our Reference: 202100194413
Your Reference: Case Ref: SB5333

14 May 2021

Dear Sarah Boyack MSP,

Thank you for your email, dated 15 April 2021, to Scottish Government ministers. As an official with responsibility for environmental protection in the Scottish Government I have been asked to reply.

We are committed to maintaining or exceeding the high environmental and best practice standards represented by the EU. With the UK no longer being a member of the EU, new regulatory regimes for chemicals have been put in place and went live on 1 January 2021. The proposals set out in the recently announced UK REACH programme represent the priorities agreed by the Scottish, UK and Welsh Governments, and include work on lead ammunition and substances in tattoo inks and permanent make up as well as work on a Regulatory Management Options Appraisal (RMOA) in relation to PFAS.

PFAS are a group of over 9,000 different chemicals, some of which are already banned or highly restricted. In industry, these substances are used as stain repellents, coatings and fire-fighting foams. The chemicals in PFAS are extremely persistent in the environment; the substances can accumulate in animals and can also be toxic this means PFAS are of growing concern for both human health and environmental reasons. The Regulatory Management Options Appraisal will consider the risks posed by PFAS as a whole group and consider the best way to manage any identified risk.

PFAS has been included in the latest recast of the EU Drinking Water Directive. The Scottish Government is currently in the process of transposing this into Scottish drinking water regulations and we anticipate that this will be done within two years. Scottish drinking water will therefore be monitored for both total PFAS and the sum of individual PFAS compounds. Some preliminary monitoring has been undertaken in preparation, and this does not indicate that PFAS is a significant issue in Scottish Drinking waters.

Food Standards Scotland (FSS) has responsibility for food safety in Scotland which includes all packaging in contact with food or drink. Legislation is in place across the UK on Food Contact Materials (FCM) to ensure that the final material or article is not dangerous to health. Manufacturers have the option to use PFAS in FCM products; which must be safe in expected use and FSS understands that FCM manufacturers across the UK have moved away from using PFAS compounds.

FSS is aware of the latest draft of the European Food Safety Authority's (EFSA) opinion on the risk to human health related to the presence of PFAS in food (which includes its relevance to FCM such as paper and board); and of the opinion of the independent UK Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (CoT) which had initial discussions on PFAS in Dec 2020 and is due to discuss further in summer 2021. FSS will consider these, though current evidence does not indicate any issue regarding food safety for consumers in Scotland.

The Scottish Environment Protection Agency (SEPA) is working with partners across the UK to share data and work towards a common approach to the assessment and management of PFAS. This is recognised as a very challenging area based on the number of substances in this class (>4000) of which a great number are used commercially in a wide variety of applications. Under the new UK REACH Regulation, UK government has committed to an investigation of PFAS as part of the restriction work programme under the regime (see Restrictions under new chemical regime announced for first time - GOV.UK (www.gov.uk)).

The UK is a signatory to the Stockholm convention which lists PFOS and PFOA and precursor substances as Persistent Organic Pollutants. UK Government, and on behalf of the devolved administrations, is currently consulting on an updated UK National Implementation Plan for the Convention (see https://consult.defra.gov.uk/plan-for-persistent-organic-pollutants-pops-team/draft-update-to-uk-nip/). The Stockholm Convention does not permit the use of PFOA-containing fire fighting foams for training, and states that by end 2022 (and by the latest end 2025) use of these foams is restricted to sites were all releases can be contained. SEPA is supporting the Scottish Fire and Rescue Service, which is working to minimise the use of foams containing PFAS, only using fluorine foams for serious incidents where foam performance is critical and containment is achievable.

I hope this provides an overview of ongoing work on PFAS chemicals, and your constituent finds this useful.

Yours sincerely

[Redacted]
EQCE : Environmental Quality Unit

From[Redacted]
Environmental Quality Unit
21 February 2020

Cabinet Secretary for the Environment, Climate Change and Land Reform

DARK WATER FILM RELEASE AND POLY- AND PERFLUOROALKYL SUBSTANCES (PFAS)

Purpose
[Redacted]

Priority

[Redacted]

Background

1. [Redacted]
2. Redacted]
3. Redacted]

4. [Redacted]

5. [Redacted]

6. [Redacted]
7. SEPA are actively working with other regulators in the UK on the uses, sources and environmental presence of PFAS, and welcome the research by Fidra on the presence of PFAS in non-plastic food packaging materials. As far as SEPA and the Scottish Government are aware, there are no industrial manufacturing sites in Scotland of PFOA or other PFAS. SEPA are working with operators to move away from its use, where suitable alternatives exist, including with the Scottish Fire and Rescue Service on procuring fluorine free foams and other alternatives.

8. SEPA have carried out preliminary monitoring exercises looking for a number of fully fluorinated PFAS in surface waters, freshwater fish, groundwater and municipal sewage sludge that is spread to agricultural land. Although some areas show low levels of PFAS, the results to date do not indicate that there are any causes for concern to human health. SEPA will continue to monitor and provide Scottish Government officials with updates.

9. Scottish Water's monitoring evidence to date suggests that PFAS are unlikely to be present in significant quantities in Scottish drinking waters. The class of compounds has been added as a new parameter in the recently revised European Drinking Water Directive. This will be transposed into Scots law in the next two years.

Next Steps

10. [Redacted]

Recommendation

11. [Redacted]

[Redacted] 21 February 2020

[Redacted]

ANNEX D

[Redacted]

Environment Agency

Evidence

Overview of per- and polyfluoroalkyl substances (PFAS) in the UK

Internal discussion document (draft)

Authors:
[Redacted]

Dissemination status:
For internal use only

Project executives:
[Redacted]

Keywords:
Perfluorinated alkyl substances, perfluorooctanoic acid, perfluorooctanesulfonic acid, perfluorooctanesulfonate, PFAS, PFOA, PFOS

Executive summary

Poly- and perfluoroalkyl substances (PFAS) are a broad class of synthetic fluorinated organic chemicals. Almost 5,000 were recorded as being in worldwide use in 2018, although only around 100-150 are thought to be commercially significant.

Many PFAS are considered to have very long environmental half-lives. There is growing concern amongst the regulatory and academic communities that exposure of people and wildlife to this class of substance is widespread, long-term, continuous and irreversible, which may lead to impacts that cannot be detected in laboratory studies. Several are subject to strict regulation at an international level due to their persistent, bioaccumulative and toxic properties. Controls imposed on individual PFAS typically result in their replacement by similar substances that have very little (eco)toxicological data, which may lead to examples of “regrettable” substitution.

This report was initiated to provide the Environment Agency and other government stakeholders with a broad overview of the use and presence of PFAS in the UK. It presents information collected from regulatory authorities, academic literature and publicly available sources in a single place. It represents a first step in identifying the information required to gain sufficient understanding of the exposure and effects of PFAS, which may be used for future risk management action.

PFAS have oil, water and stain repellent properties, which make them useful in a range of processes and products. The 3 main applications are:

- in protective treatments – for example paper, packaging, and textiles such as waterproof clothing and carpets;
- in polymer manufacturing; and
- as surfactants – including aqueous film fire-fighting foams (AFFFs).

Around 120 PFAS have been registered for supply above 1 tonne/year in the European Union, and so might be on the UK market. Two primary manufacturers and a small number of companies that use these substances have environmental permits from the Environment Agency. However, many more companies are likely to rely on PFAS either in polymers, imported articles or in low quantities, and it is currently not possible to establish the scale of supply and use within the UK in any detail.

Compilation of a thorough emissions inventory for PFAS is therefore a major knowledge gap. Releases may occur during production, use, recycling or disposal as waste (e.g. to landfill). Incineration is the only way to ensure that PFAS are destroyed, provided that temperatures are high enough.

PFAS have been detected in air, surface water, groundwater (including drinking water), soil and food on an international scale. With a few exceptions, however, data on PFAS concentrations in environmental media in the UK are limited.

Contents

1	**Introduction**	**1**
2	**Regulatory information about PFAS on the UK market**	**2**
2.1	Classification and labelling inventory	2
2.2	REACH registrations	2
2.3	Other permitted sites	5
2.4	Other sites of potential interest	6
3	**Regulatory Risk Management of PFAS**	**7**
3.1	European risk management	7
3.2	Risk management outside Europe	12
4	**Sources and pathways of environmental exposure**	**13**
4.1	Introduction	13
4.2	Uses suggested from restricted PFAS	14
4.3	Uses mentioned in REACH registrations	15
4.4	Significant sources of release	16
5	**Monitoring data**	**23**
5.1	Introduction	23
5.2	Wastewater	23
5.3	Surface water and groundwater	24
5.4	Soil	31
5.5	Biota (including human foodstuffs)	32
5.6	People	36
6	**Conclusions and Recommendations**	**37**
6.1	Recommendations for further work	38
References		**40**
List of abbreviations		**47**
APPENDIX A: Definitions of PFAS		**49**
APPENDIX B: PFAS registrations under the REACH Regulation		**51**

List of tables and figures

Table 1.1	Examples of PFAS	1
Table 4.1	Number of substances claimed to be used for different applications in ECHA registration database	15
Table 4.2	PFAS applications identified from a general internet search	16
Table 4.3	Structures of PFOS and 2 alternatives used in chrome plating	21
Table 5.1	Proposed PFAS to be monitored in CIP Phase 3	24
Table 5.2	Groundwater and surface water monitoring data from England and Wales, 2006	26
Table 5.3	Environment Agency's LC-MS analytical suite	27
Table 5.4	Summary of recent groundwater and surface water monitoring data from Environment Agency's LC-MS analytical suite	28
Table 5.5	Summary of recent PFAS monitoring data in English groundwater (BGS, 2018)	28
Table 5.6	SEPA surface water monitoring data from 2017	29
Table 5.7	EU surface and groundwater monitoring data	30
Table 5.8	Surface monitoring data from the River Thames (Pan et al. 2018)	31
Table 5.9	Concentrations of PFAS found in selected foodstuffs by FERA	33
Table 5.10	PFAS concentrations found in selected fish by FERA	34
Table 5.11	Concentrations and frequency of detection of PFAS in stranded and by-caught harbour porpoises collected in 2012 to 2014 (Barber et al 2016)	35

Figure 4.1	Anthropogenic sources and pathways of PFAS into the environment	13
Figure 5.1	Distribution of groundwater monitoring for perfluorinated chemicals, 2006	25

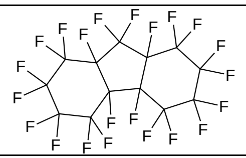
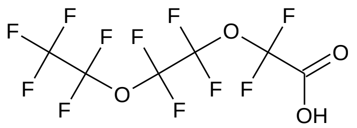
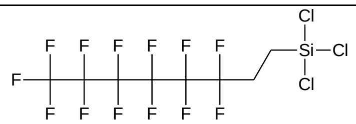
1 Introduction

A complex variety of fluorinated organic substances are synthesised for a broad range of commercial applications. They are not naturally occurring. The strong carbon–fluorine bond gives them stability and useful physical properties. However, this bond strength also brings disadvantages in terms of very high persistence. Environmental release can consequently lead to long-term continuous exposure of people and wildlife. Some of these substances can accumulate in biological tissues and/or be widely dispersed in the aquatic environment. These features have led to growing scientific concern about their potential impacts at a global level (Ritscher et al. 2018, OECD 2018).

We initiated this review of 2 major classes of fluorinated chemicals – known as per- and polyfluoroalkyl substances (PFAS) (ITRC 2018) – to provide a broad overview of their use and presence in the UK[1]. Our report presents information collected from regulatory authorities, academic literature and publicly available sources in a single place. It represents a first step in identifying information required to gain sufficient understanding of the exposure and effects of PFAS, which may be used for future risk management.

In 2018, the Organisation for Economic Co-operation and Development (OECD) published the results of efforts by OECD and the United Nations Environment Programme (UNEP) Global PFC Group to identify how many PFAS were on the global market; a total of 4,730 PFAS were believed to be in worldwide use (OECD 2018). These substances were defined as those that contain a perfluoroalkyl moiety with 3 or more carbon atoms ($–C_nF_{2n}–$, $n \geq 3$) or a perfluoroalkyl ether moiety with 2 or more carbon atoms ($–C_nF_{2n}OC_mF_{2m}–$, n and $m \geq 1$). This report has the same scope.

Table 1.1 Examples of PFAS

Type	Substance name	Chemical structure
Perfluorocyclo-alkyl substance	Docosafluorododeca-hydrofluorene	
Perfluoroalkyl substance	Difluoro[1,1,2,2-tetrafluoro-2-(pentafluoroethoxy)ethoxy]acetatic acid	
Polyfluoroalkyl substance	Trichloro(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-octyl) silane	

Section 2 summarises information about PFAS on the UK market based on regulatory sources. Section 3 describes current risk management activity at the international level. This is followed by a discussion of potential sources and pathways of environmental exposure from PFAS (Section 4), including information on uses. Section 5 summarises monitoring data collated on PFAS in the UK environment. Section 6 presents a conclusion of our findings. This work builds on an earlier investigation of the issues associated with this type of chemistry (Environment Agency 2001).

[1] The report does not consider inorganic fluorine compounds such as hydrogen fluoride, or fluorinated organic compounds that do not meet the definition of PFAS in OECD (2018), such as (trifluoromethyl)benzene (CAS no. 98-08-8).

2 Regulatory information about PFAS on the UK market

Note: The UK is leaving the European Union (EU) at the end of January 2020. However, the information collected by the European Chemicals Agency (ECHA) is currently the only readily accessible source of information about potential use of chemicals in the UK.

2.1 Classification and labelling inventory

Within the EU, manufacturers and importers have to notify hazard classification and labelling information on substances to ECHA in accordance with the Classification, Labelling and Packaging (CLP) Regulation (EC) No. 1272/2008. As well as substances with registration obligations under the REACH Regulation (see Section 2.2), a notification is required for any manufactured or imported substance if it is classified as hazardous, regardless of the quantity. In addition, importers of classified mixtures must provide information on the constituents leading to the hazard classification. Substances that a company does not think should be classified as hazardous and do not require REACH registration do not need to be notified.

From a comparison of the CAS numbers of PFAS included in OECD (2018) with those notified to ECHA in its Classification and Labelling (C&L) Inventory,[2] our review identified 640 individual PFAS that may be on the EU market. It is not possible to identify which companies provided the information.

2.2 REACH registrations

Within the EU, companies wishing to manufacture or import a substance for industrial or consumer use in quantities above 1 tonne per year have to submit a registration dossier of information to ECHA under the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) Regulation (EC) No. 1907/2006. A search of the ECHA public registration database on 23 November 2018 found 1,519 individual registrations of fluorinated compounds (ECHA, 2018a).

A comparison of the CAS numbers of PFAS included in the OECD database with those registered with ECHA identified 114 individual substances. Details of these substances are given in Appendix B.

Based on the information from the C&L Inventory (see Section 2.1), we assume that at least 530 additional substances may be supplied in the EU that do not have a registration obligation under REACH. Most of these are either on the market in small quantities or supply may have stopped before they were required to be registered.

Registration allows the Registrant to supply the entire EU and so any of the EU registered substances may potentially be supplied to the UK. Registration by a UK company does not necessarily mean that the substance is supplied to the UK market. An 'Only Representative' (OR) registers on behalf of a non-EU manufacturer; they can be based in any Member State, including ones with no active customers. In addition, there

[2] https://echa.europa.eu/information-on-chemicals/cl-inventory-database

is no registration requirement for polymers[3] or any substance supplied by a company in quantities below 1 tonne per year. It is therefore not possible to use the ECHA registration database to identify all the PFAS (including polymers) that are actually in commercial use within the UK, or the amounts involved.

However, the majority of non-polymeric PFAS are not supplied in large quantities by individual suppliers, with just 36 substances being supplied above 10 tonnes per year. These are highlighted in Appendix B.

Active ingredients in plant protection products, biocides, veterinary medicines, human pharmaceuticals and chemicals used offshore have different legislative requirements. From an inspection of the University of Hertfordshire's Pesticide Properties Database[4], only one PFAS (lufenuron or N-[2,5-dichloro-4-(1,1,2,3,3,3-hexafluoropropoxy)phenylaminocarbonyl]-2,6-difluorobenzamide, CAS no. 103055-07-8) is listed as a plant protection product, although there is no UK approval for its use (it is registered under REACH). We did not investigate these sources any further for this report.

2.2.1 REACH Registrants in the UK

There are currently 8 REACH Registrants of one or more PFAS in the UK:

- AGC Chemicals Europe Ltd
- AZ Electronic Materials Services Ltd
- BASF plc
- Cambridge Environmental Assessments (OR)
- Envigo Consulting Ltd (OR)
- F2 Chemicals Ltd
- ITS Testing Services (UK) Ltd (OR)
- Syngenta Ltd

The 3 ORs have legal responsibilities for their registrations, but are unlikely to process any substance themselves. It is not known if any UK companies source substances from them; Registrants are not required to keep customer lists that can be requested by ECHA or other regulatory bodies.

BASF and Syngenta had registrations under the pre-REACH Notification of New Substances (NONS) Regulations which are now listed as inactive. Although supply could restart at any time, it is assumed that their substances are no longer commercially relevant.

Three companies are currently actual importers/manufacturers of PFAS with REACH registrations in the UK. AZ Electronic Materials Services had registered one substance within the 1–10 tonnes per year band, but the company is now in the process of liquidation and the registration has been marked as inactive. AGC Chemicals Europe

[3] Their monomers must be registered, but the monomer registration dossier does not necessarily address the whole lifecycle of the polymer and will not describe the levels of any residual processing aids and other impurities.

[4] https://sitem.herts.ac.uk/aeru/ppdb/en/

and F2 Chemicals have a number of registrations in a range of tonnage bands (see Sections 2.2.2 and 2.2.3).

2.2.2 AGC Chemicals Europe Ltd

This company[5] has a manufacturing site at Thornton Cleveleys near Blackpool, Lancashire, with an environmental permit (ref: EPR/BU5453IY) under the Environmental Permitting (England and Wales) Regulations 2016. According to the permit, there are 2 main product streams:

- polytetrafluoroethylene (PTFE) with a capacity up to 4,000 tonnes per year
- ethylene-tetrafluoroethylene (ETFE) with a capacity up to 2,000 tonnes per year

Tetrafluoroethylene is made from chlorodifluoromethane and is polymerised to produce the finished product on site. The site also produces other types of fluoropolymers.

The company has registered the following PFAS under REACH (see Appendix B for further details):

- trifluoro(trifluoromethoxy)ethylene (CAS no. 1187-93-5)
- 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluorotetradecane (CAS no. 133331-77-8)
- 1,1,1,2,2,3,3-heptafluoro-3-[(trifluorovinyl)oxy]propane (CAS no. 1623-05-8) – used by the company as a monomer for polymer manufacture (the combined EU registration band is 100–1,000 tonnes per year, but the company's usage is much smaller)
- 3,3,4,4,5,5,6,6,6-nonafluorohexene (CAS no. 19430-93-4)
- 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate (CAS no. 2144-53-8)
- 4-(1,1,1,2,3,3,3-heptafluoropropan-2-yl)-2-methylaniline (CAS no. 238098-26-5)
- 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooct-1-ene (CAS no. 25291-17-2)
- trideca-1,1,1,2,2,3,3,4,4,5,5,6,6-fluorohexane (CAS no. 355-37-3)
- N-(2-methylsulfinyl-1,1-dimethyl-ethyl)-N'-{2-methyl-4-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]phenyl}phthalamide (CAS no. 371771-07-2)
- 1,1,1,2,3,3,3-heptafluoro-2-iodopropane (CAS no. 677-69-0)
- 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluorooctane (CAS no. 80793-17-5)
- ammonium difluoro[1,1,2,2-tetrafluoro-2-(pentafluoroethoxy)ethoxy]acetate (CAS no. 908020-52-0)

One of the substances registered by this company – ammonium difluoro[1,1,2,2-tetrafluoro-2-(pentafluoroethoxy)ethoxy] acetate (EEA-NH_4) – is currently subject to a formal Substance Evaluation by Germany under REACH. Evaluation of all the substances registered by AGC Chemicals Europe Ltd could be a useful exercise to establish their properties and hazards, which may be of benefit to local site management (e.g. in any review of the site permit).

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[5] www.agcce.com

2.2.3 F2 Chemicals Ltd

This company[6] has an environmental permit (ref: EPR/BU3485IS) under the Environmental Permitting (England and Wales) Regulations 2016 for its manufacturing plant near Preston in Lancashire. It produces a range of liquid and gaseous perfluorocarbon substances, with a product capacity of around 400 tonnes per year.

The substances registered under REACH by this company are:

- nonafluoro(trifluoromethyl)cyclopentane (CAS no. 1805-22-7)
- perfluoroperhydrophenanthrene (CAS no. 306-91-2)
- perflunafene (CAS no. 306-94-5)
- docosafluorododecahydrofluorene (CAS no. 307-08-4)
- perfluorooctane (CAS no. 307-34-6)
- 1,1,2,2,3,3,4,5,5,6-decafluoro-4,6-bis(trifluoromethyl)cyclohexane (CAS no. 335-27-3)
- perfluoro(methylcyclohexane) (CAS no. 355-02-2)
- 1,1,1,2,2,3,3,4,5,5,5-undecafluoro-4-(trifluoromethyl)pentane (CAS no. 355-04-4)
- (E)-1,1,1,2,3,4,5,5,5-nonafluoro-4-(trifluoromethyl)pent-2-ene (CAS no. 3709-71-5)
- octafluoropropane (CAS no. 76-19-7)

Evaluation of all the substances registered by F2 Chemicals Ltd could be a useful exercise to establish their properties and hazards, which may be of benefit to local site management (e.g. in any review of the site permit).

2.3 Other permitted sites

Two further sites in England are known to handle PFAS.

2.3.1 MacDermid plc

MacDermid plc has a formulation site in Small Heath, Birmingham which is subject to an environmental permit (ref: EPR/VP3531XV) under the Environmental Permitting (England and Wales) Regulations 2016. This is for the formulation of mixtures used in metal treatment and waste transfer operations for waste copper and nickel solutions from its customers.

The company produces chromium (VI) plating solutions and a mist suppressant containing 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonic acid (CAS no. 27619-97-2). This is a replacement for perfluorooctane sulfonic acid (PFOS) (see Section 2.5.1).

[6] www.f2chemicals.com

2.3.2 Angus Fire Ltd

This company[7] produces synthetic aqueous film-forming foam (AFFF) concentrates for fire-fighting applications at its production facility in Bentham, North Yorkshire. These concentrates contain a combination of hydrocarbon and fluorochemical surface active agents. The fluoroprotein foam concentrates contain unspecified six-carbon chain length (C6) PFAS.

The company blends (formulates) mixtures but also operates a production facility, which is subject to an environmental permit (ref: EPR/XP3832NV) under the Environmental Permitting (England and Wales) Regulations 2016. The production process does not involve PFAS and all the fluorinated fire-fighting foams are formulated in the non-permitted area of the site.

2.4 Other sites of potential interest

Other companies may supply, formulate or distribute mixtures that contain PFAS without the need for a permit under the Environmental Permitting (England and Wales) Regulations 2016. For example, a search for UK fluorinated chemical manufacturers and suppliers using online search engines and for 'fluorochemical' on Companies House[8] suggests that Sigma-Aldrich Company Ltd (now Merck)[9] and Fluorochem Ltd[10] supply a range of PFAS on a small scale primarily for laboratory use or research and development. JRD Fluorochemicals Ltd[11] also manufacture fluorochemicals. Atotech UK Ltd[12] formulates metal plating solutions and mist suppressants that may contain PFAS. These companies do not have any REACH registrations – either they source substances from other Registrants (including ORs) or the quantities are below the registration threshold of 1 tonne/year.

There is no information on the customers of these companies or other UK companies that may import PFAS from EU REACH Registrants. These are all 'downstream users' of PFAS and, with one or two exceptions, the number and location of these sites are currently unknown. Further information on specific uses is given in Section 3.3.

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7 www.angusfire.co.uk

8 https://beta.companieshouse.gov.uk/

9 https://www.sigmaaldrich.com/united-kingdom/customer-service.html

10 http://www.fluorochem.co.uk/

11 http://www.jrdfluoro.co.uk/

12 https://www.atotech.com/united-kingdom/

3 Regulatory Risk Management of PFAS

3.1 European risk management

Several PFAS are subject to significant regulatory scrutiny. Perfluorooctane sulfonic acid (PFOS) (see Section 3.1.1) and perfluorooctanoic acid (PFOA) (see Section 3.1.2) have attracted the most academic and regulatory attention. This is because they commonly constitute a high proportion of environmental PFAS contamination due to their significant historical usage (e.g. Zareitalabad et al. 2013).

Many PFAS can partially degrade in the environment to very stable terminal transformation products, termed ‘arrowhead substances’. For example, perfluorooctane sulfonyl fluoride (POSF) and N-methyl perfluorooctane sulfonamidoethanol (MeFOSE) both degrade to PFOS through hydrolysis and biotransformation (e.g. Martin et al. 2010). The chemical of regulatory interest is often the arrowhead substance (such as PFOS) and the precursor substances usually need to be grouped together for risk management purposes.

Various risk management initiatives have reduced (or will reduce in the near future) the commercial applications of PFOS and PFOA. Consequently, replacement substances are growing in significance and these are often less well studied. Some of these have also been subject to risk management to minimise the risk of ‘regrettable’ substitution (that is, replacing one substance of concern with another of similar or different concerns). The European Commission is currently considering a strategy for the wider risk management of PFAS which is likely to lead to further risk management proposals in the EU over the next few years.

3.1.1 Perfluorooctane sulfonic acid (PFOS)

Use of PFOS has been in decline since 3M (a major manufacturer of fluorochemicals in the USA) voluntarily ceased its production in the early 2000s. It is highly persistent, bioaccumulative in air-breathing organisms and toxic (Beach et al. 2006). The UK was the first European country to propose a national ban in 2004 (Environment Agency 2019). Subsequently, the marketing and use of PFOS and its derivatives were restricted in the EU at the end of 2006 under Directive 2006/122. Nevertheless, there were some exemptions, specifically for photolithography, photographic applications, mist suppressants for hard chromium plating and hydraulic fluids for aviation. In 2009, this restriction was incorporated by Commission Regulation (EC) No 552/2009 into Annex XVII of the REACH Regulation.

PFOS and its derivatives were subsequently listed in Annex B to the Stockholm Convention as a persistent organic pollutant (POP) (Conference of the Parties 2009). This decision was implemented in the EU in 2010 by Commission Regulation (EU) No 757/2010. The threshold allowed in products that were not exempt was lowered from the previous level of 0.005% to 0.001% by weight (10 mg/kg). The restriction in the REACH Regulation was rescinded by Commission Regulation (EU) No 207/2011. Use in fire-fighting foam was permitted if the foam had been placed on the market before 27 December 2006 and was used by 27 June 2011; hence there should be no more foam containing PFOS in the UK.

This is a good example of the time typically taken between recognition of a problem and achieving phase out, which can be 10 years or more. In fact, PFOS-related substances are still allowed to be used in some limited applications in 2019 (for example, chrome plating).

Two substances that can degrade to PFOS are registered under REACH (see Appendix B):

- heptadecafluorooctanesulfonyl fluoride (CAS no. 307-35-7)
- tetraethylammonium heptadecafluorooctane sulfonate (CAS no. 56773-42-3)

All remaining uses of PFOS-related substances are being reviewed under the Stockholm Convention and are likely to be stopped in the near future, some 20 years after 3M's decision.

Further information on PFOS in the UK is provided in Environment Agency (2019).

3.1.2 Perfluorooctanoic acid (PFOA)

PFOA and its ammonium salt (APFO) were identified as substances of very high concern (SVHC) under the REACH Regulation in July 2013 because of their persistent, bioaccumulative and toxic (PBT) properties. They will be restricted in the EU after 4th July 2020, with some time-limited exemptions such as for protective textiles and fire-fighting foams (ECHA, 2018b). PFOA and its derivatives were subsequently listed in Annex A to the Stockholm Convention as a persistent organic pollutant (POP) (Conference of the Parties 2019). This decision will be implemented in due course in the EU.

Four PFOA-related substances are currently registered under REACH (see Appendix B). All have the potential to degrade to PFOA. The only company known to produce PFOA in the EU (Miteni SpA in Italy) reportedly ceased production and commercialisation of PFOA in 2010 (ECHA, 2018b) and filed for bankruptcy in October 2018 (Eurofound 2018).

ECHA (2018b) identified a range of potential alternatives to PFOA and PFOA-related substances for most uses. These are generally shorter chain length PFAS with less than 7 fully fluorinated carbon atoms. The details of many of these substitutes are confidential, but a few examples are presented below:

- Fire-fighting foam:
  - dodecafluoro-2-methylpentan-3-one (CAS no. 756-13-8)
  - carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) sulfonyl]amino]propylammonium hydroxide (CAS no. 34455-29-3)
  - N-[3-(dimethylamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonamide N-oxide (CAS no. 80475-32-7)
- Fluoropolymer production/ fluorotelomer manufacturing:
  - 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonic acid (CAS no. 27619-97-2)
  - ammonium 2,2,3-trifluoro-3-(1,1,2,2,3,3-hexafluoro-3-trifluoro-methoxypropoxy) propionate (ADONA)[13]

[13] There is some confusion about the CAS number used for this substance. It is registered under REACH using CAS no. 480-310-4. CAS no. 1280222-90-3 and 958445-44-8 have been used in other literature (EFSA 2011; ECHA 2018d).

Some of these alternatives may still contain PFOA and/or PFOA-related substances as trace impurities because of the way they are made.

3.1.3 Longer chain perfluorocarboxylic acids (PFCAs)

Five PFCAs were identified as SVHCs under REACH due to their very persistent and very bioaccumulative (vPvB) properties in 2012 with a further one added in 2017:

- perfluorononanoic acid (CAS no. 375-95-1)
- perfluorodecanoic acid (CAS no. 335-76-2)
- perfluoroundecanoic acid (CAS no. 2058-94-8)
- perfluorododecanoic acid (CAS no. 307-55-1)
- perfluorotridecanoic acid (CAS no. 72629-94-8)
- perfluorotetradecanoic acid (CAS no. 376-06-7)

These PFCAs mainly occur as unavoidable by-products during the manufacture of PFAS containing a carbon chain with fewer than 9 carbon atoms such as PFOA. No intentional manufacturing or use has been identified in the EU, although one article (semi-conductors) that contains them is known to be imported, and other articles might be on the market (ECHA 2018c).

The European Commission is currently reviewing a proposal to restrict the manufacture, use and import of the 6 PFCAs listed above, including their salts and precursors (ECHA 2018c). The recommended transition period is 18 months from entry into law, and so it is likely to take effect during late 2021. The restriction was intended to prevent regrettable substitution of PFOA by these substances. Alternatives exist for most uses, and these are often shorter chain length PFAS. Fluorine-free alternatives are also available for some uses (ECHA 2018c).

3.1.4 Perfluorohexanoic acid (PFHxA)

Germany proposed PFHxA as an SVHC under REACH in September 2018, arguing that it poses an equivalent level of concern to substances with PBT/vPvB properties (ECHA 2018e). This is primarily because it is very persistent, highly mobile in the aquatic environment and difficult to remove from wastewater with most treatment methods. The proposal was withdrawn in December 2018. Germany submitted a restriction proposal in December 2019, and this will be processed by ECHA in due course.

Thirty-one PFAS registered under REACH have the potential to degrade to PFHxA, as summarised in Appendix B. Many of these are likely to have been used as replacements for PFOA (and potentially PFOS) and related compounds.

3.1.5 Perfluorohexane sulfonic acid (PFHxS)

PFHxS was identified as an SVHC under REACH in 2017 due to its vPvB properties and a restriction proposal was submitted in April 2019 (ECHA 2019a). PFHxS, its salts and related compounds are currently under review for listing as a POP under the Stockholm Convention.

PFHxS may have similar uses to PFOS (POPRC 2016). It is also a potential impurity in commercial PFOS products. Reported applications from outside Europe include (POPRC 2019):

- in AFFFs
- metal plating
- textiles and leather
- polishing and cleaning/washing agents
- coatings including for impregnation/damp-proofing
- the manufacturing of electronics and semiconductors

It is not registered under REACH, and none of the other REACH-registered substances appear to have the potential to degrade to it, suggesting that it is not a major commercial product in the EU. The REACH restriction proposal is primarily intended to avoid regrettable substitution.

3.1.6 Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1)

This substance is also known as FRD-902; GEN-X or hexafluoropropylene oxide dimer acid, ammonium salt, HFPO-DA). Although further data have been requested under Substance Evaluation (see Section 3.1.8), HFPO-DA, its salts and its acyl halides were identified as an SVHC and added to the Candidate List in July 2019 as they are considered to have probable serious effects to human health and environment (ECHA 2019b). This is because it is very persistent, highly mobile in the aquatic environment and difficult to remove from wastewater with most treatment methods, can be accumulated in plants, and has signs of significant toxicity. This substance is now subject to a Risk Management Options Analysis (RIVM 2018).

3.1.7 Perfluorobutanesulfonic acid (PFBS)

PFBS was identified as an SVHC under REACH in December 2019 as it is considered to have probable serious effects to human health and environment (ECHA 2019c). This is because it is very persistent, highly mobile in the aquatic environment and difficult to remove from wastewater with most treatment methods, can be accumulated in plants, and has signs of significant toxicity.

3.1.8 Public Activities Co-ordination Tool (PACT)

PACT (https://echa.europa.eu/pact) provides an overview of the substance-specific activities that EU regulatory authorities are working on under the REACH and CLP Regulations. Work on PFAS has been co-ordinated by the PFAS Working Group of the EU Risk Management Expert Group (RIME).[14] Fifteen substances were being considered under various work streams by EU regulators as of 10 December 2018; these are flagged in Appendix B and mentioned below.

[14] The PFAS Working Group is a forum for interested EU Member State regulators to draw up strategies for considering the risk management of PFAS. Up to 40 substances were within scope during 2018, including substances that have already been restricted such as PFOA. The PFAS Working Group has highlighted 'short-chain PFAS' (that is, <C6 perfluoroalkyl sulfonic acids and <C7 perfluoroalkyl carboxylic acids) as substances of concern due to their very high persistence, mobility in water, low adsorption potential to organic matter and enrichment in plants.

Dossier Evaluation

A Dossier Evaluation is a review by ECHA of an individual registration to either check that it is compliant with REACH requirements, or that testing proposed by a Registrant is appropriate. Five PFAS have been evaluated:

- ethene, 1,1,2-trifluoro-2-(trifluoromethoxy)-)- (CAS no. 1187-93-5)
- 1-propene, 1,1,2,3,3,3-hexafluoro-, oxidised, polymerised, polymerised reduced, fluorinated (CAS no. 161075-00-9)
- 1-hexene, 3,3,4,4,5,5,6,6,6-nonafluoro- (CAS no. 19430-93-4)
- 3-pentanone, 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)- (CAS no. 756-13-8)
- silane, trimethoxy(3,3,4,4,5,5,6,6,6-nonafluorohexyl)- (CAS no. 85877-79-8)

Substance Evaluation

A Substance Evaluation is a review by the Competent Authority of an EU Member State of all registrations of a substance in order to clarify specific concerns. Nine substances are currently undergoing substance evaluation:

- 2-propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester (CAS no. 17527-29-6)
- 2-propenoic acid, 2-methyl-, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester (CAS no. 2144-53-8)
- hexane, 3-ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl)- (CAS no. 297730-93-9)
- 1-propanamine, 1,1,2,2,3,3,3-heptafluoro-N,N-bis(1,1,2,2,3,3,3-hepta-fluoropropyl)- (CAS no. 338-83-0)
- phosphinic acid, P,P-bis(1,1,2,2,3,3,4,4,4-nonafluorobutyl)- (CAS no. 52299-25-9)
- propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1) (FRD-902; GEN-X or hexafluoropropylene oxide dimer acid, ammonium salt, HFPO-DA) (CAS no. 62037-80-3)
- 2-propenoic acid, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)-sulfonyl]- amino]-ethyl ester (CAS no. 67584-55-8)
- acetic acid, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,2-pentafluoro- ethoxy)-ethoxy]-, ammonium salt (1:1) (CAS no. 908020-52-0)
- ammonium 2,2,3-trifluoro-3-(1,1,2,2,3,3-hexafluoro-3-trifluoro-methoxy-propoxy) propionate (ADONA) (CAS no. 958445-44-8)

The principal concerns listed on the Community Rolling Action Plan (CoRAP)[15] are their ability to degrade to arrowhead substances that may have endocrine disrupting and/or PBT properties, or in some cases their high mobility in the aquatic environment.

[15] https://echa.europa.eu/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table

3.1.9 Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)

OSPAR is a mechanism by which 15 national governments and the EU co-operate to protect the marine environment. Much of OSPAR's work on chemicals is now being addressed by REACH activities.

The only PFAS on the List of Chemicals for Priority Action adopted in 2002 is PFOS.[16] Six PFAS are included in the List of Substances of Possible Concern:[17]

- hexadecafluoroheptane (CAS no. 335-57-9)
- tetradecafluorohexane (CAS no. 355-42-0)
- 1-hexanesulfonyl fluoride, 1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro (CAS no. 423-50-7)
- 1-butanesulfonyl fluoride, 1,1,2,2,3,3,4,4,4-nonafluoro- (CAS no. 375-72-4)
- 1,1,1,2,2,3,3,4,4,5,5,6,6- tridecafluoro-6-iodo-hexane (CAS no. 355-43-1)
- 1-octanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8 -heptadecafluoro-N-[2-(phosphonooxy)ethyl]-, diammonium salt (CAS no. 67969-69-1)

3.2 Risk management outside Europe

While the EU has been particularly active in seeking to phase out some PFAS, the global attention on PFAS has stimulated regulatory activity in other jurisdictions, notably in North America (see, for example, Environment and Climate Change Canada 2018). In particular, the US Environmental Protection Agency (USEPA) is planning to carry out tiered toxicity and toxicokinetic testing for a range of PFAS in the near future (Patlewicz et al. 2019). This will help to address the limited availability of public information concerning the toxic profile of the vast majority of compounds.

In addition, regulatory action has been taken in Australia including the phasing out of fire-fighting foams containing PFAS by some states (see, for example, Queensland Government 2018).

[16] www.ospar.org/work-areas/hasec/chemicals/priority-action

[17] www.ospar.org/work-areas/hasec/chemicals/possible-concern/list

4 Sources and pathways of environmental exposure

4.1 Introduction

International studies published between 2009 and 2019 have reported the detection of more than 400 individual PFAS in air, surface water, fish, sediments, wastewater, sewage sludge and soils, as well as in products such as AFFFs and fluoropolymer surfactants (see, for example: Danish EPA 2013, Xiao 2017, Environment Agency 2019).

PFAS have a broad range of physicochemical properties, which affects their environmental partitioning. Some are non-volatile, ionic or ionisable and soluble in water, whereas some are gases, and others are neutral and hydrophobic. Many PFAS are considered to have very long environmental half-lives.

The aquatic environment is likely to be the ultimate sink for many of these chemicals (Xiao 2017). Where groundwater has been contaminated by PFAS and is used as a source of potable water, high levels of human exposure to PFAS can be anticipated (ATSDR 2018a). The most important exposure routes are shown in Figure 4.1.

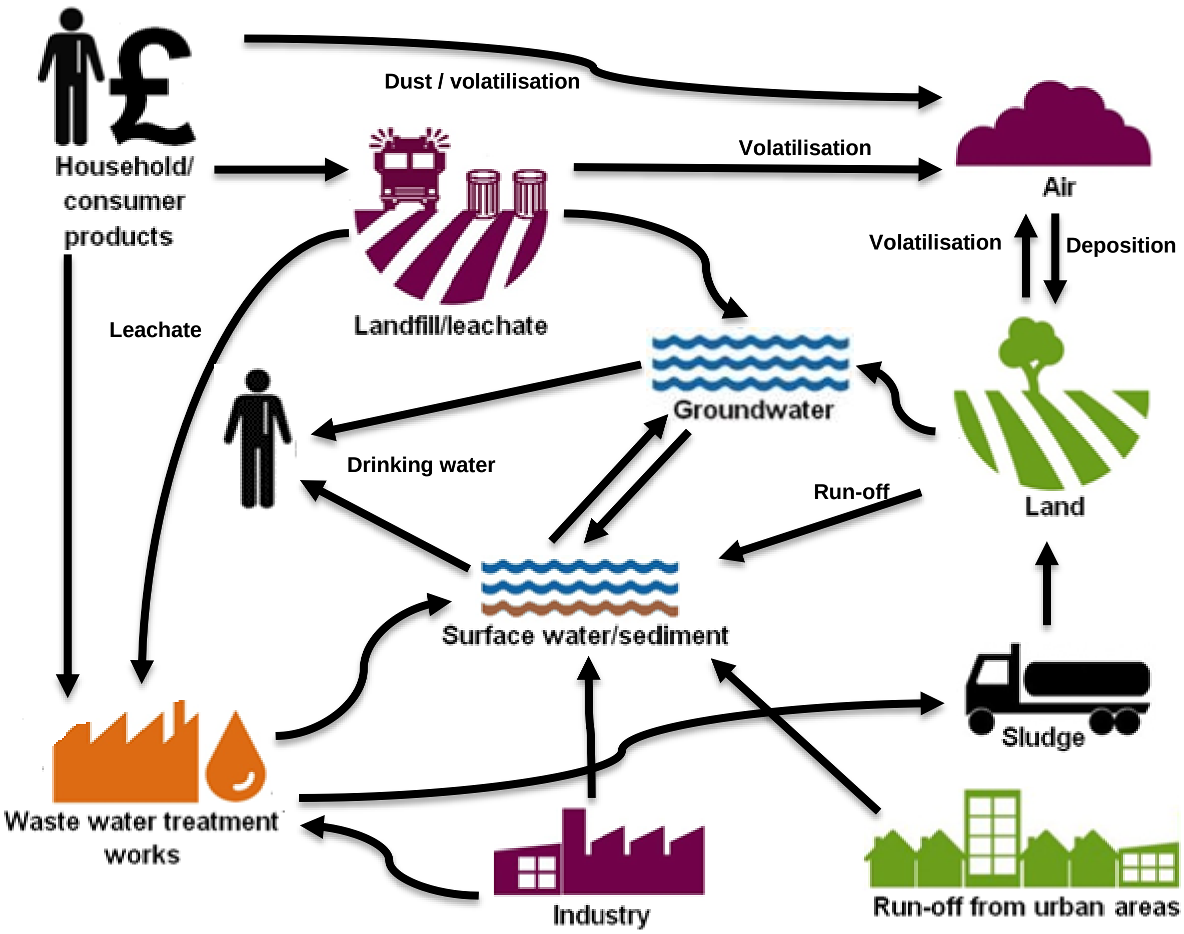


Figure 4.1 Anthropogenic sources and pathways of PFAS into the environment

Source: Environment Agency

4.2 Uses suggested from restricted PFAS

The most detailed published information about the use of PFAS comes from previous work to restrict PFOS and PFOA (and related substances). The documentation provides some quantitative information on likely emissions and pathways in the environment, though this may involve a large number of assumptions since information about precursors (particularly polymers) is often lacking.

PFOS-related substances were used to impart oil and water resistance to a range of materials such as:

- textiles (including carpets) and leather goods
- paper/packaging – including food contact materials[18] such as fast food packaging (see, for example, Schaider et al. 2017)
- general coatings (primarily as polymers)

Another important use was in mist suppressants for metal plating applications involving chromium (VI) ions (see Section 3.4.6).

Other uses included (Environment Agency 2004, POPRC 2016, Environment Agency 2019):

- in photoresists or antireflective coatings for photolithography processes
- photographic coatings
- hydraulic fluids for aviation
- in fire-fighting foams

Environmental emissions were predicted to be highest from textile, paper and chrome plating applications (Environment Agency 2004).

Applications of PFOA (and longer chain PFCA analogues) and its derivatives are diverse (ECHA, 2018b, 2018c). They include:

- as processing aids/emulsifying agents for the manufacture of fluoropolymers, fluoroelastomers and side-chain fluorinated polymers – which in turn have multiple uses such as in ski waxes and vehicle parts
- in printing inks
- coatings for mobile phone screens
- in photographic plates
- membranes for water treatment and filtration
- surfactants in the semiconductor industry
- coatings for the paper industry
- building products
- water and oil proofing agents for textiles (including outdoor and protective clothing)

[18] https://www.rivm.nl/publicaties/per-and-polyfluoroalkyl-substances-pfass-in-food-contact-material

- AFFFs for fire-fighting

All of these applications may take place legally in the UK; the EU restriction of PFOA-related substances does not come into force until July 2020 and even then it will be possible to continue use of some product types (for example, AFFFs) for a fixed time period.

Although there are many uncertainties, the largest emissions of PFOA to the environment are thought to be from textiles, AFFFs, imported polymers and fluoropolymer production; releases from other uses are likely to be substantially lower (ECHA, 2018b).

4.3 Uses mentioned in REACH registrations

The main uses for non-polymeric PFAS registered under REACH are provided in Appendix B, which is based on information on the public ECHA registration database (ECHA 2018a). Broadly speaking, the number of substances claimed to be used for specific applications are given in Table 4.1.

Table 4.1 Number of substances claimed to be used for different applications in ECHA registration database

Application	Number of substances
Chemical intermediate (including monomers for polymers)	60
Processing aid in the manufacture of other chemicals (including catalysts)	22
Functional fluid at industrial sites (for example, heat transfer)	12
Electronics manufacture	9
Laboratory/equipment calibration	6
Coatings (including paints and inks)	6
Metal working	5
Fire-fighting foam	5
Non-metal surface treatment	4
Washing and cleaning products	2
Cosmetics	2
Miscellaneous (solvent, refrigerant, insulation foams, cover gas, automotive)	6
Not clearly stated	6
Confidential	16

Note: A substance can have more than one use.

The ECHA database usually only provides a brief summary of general use areas, and the exact use and function of the substance is not always clear. A general internet search was therefore performed for all PFAS registered above 10 tonnes per year in March 2019. A number of uses were found that may be relevant in the UK. These are summarised in Table 4.2.

Table 4.2 PFAS applications identified from a general internet search

Application	CAS No.	Use
Cleaning	34455-29-3	Floor finish sold in USA[1]
Coatings	85857-16-5	Non-metal surface treatment, water and dirt repellence on glass[2,3]
Cosmetics	1805-22-7	Shaving foam[3]
	306-91-2	Eye cream, facial cream, mask, anti-aging products[4]
	306-94-5	Nail polish/nail care, cleansing wipes, cream/lotion, hair spray, moisturiser, anti-aging, facial cream, facial cleansing, eye cream, lip balm, acne treatment, mask, scrub[4]
	335-27-3	Eye cream, facial cream, mask, anti-aging products[4]
	51851-37-7	Liquid foundation[4]
	85857-16-5	Powder, foundation[4]
Fire-fighting chemicals	34455-29-3	Fire-fighting foam (professional and consumer)[5]
	80475-32-7	Fire-fighting foam[6]
Flame retardant	29420-49-3	Flame retardant for polycarbonate[7]
Textile treatment	2144-53-8	Used to make polymers to provide water and dirt repellence[8]

Notes:
[1] https://www.lgcstandards.com/GB/en/N-carboxymethyl-N-N-dimethyl-3-perfluorohexyl-ethyl-sulfonyl-amino-hydroxide-inner-salt/p/DRE-C11041300

[2] http://www.powerchemical.net/silanes/PC9756%20[85857-16-5].html; https://co-formula.blogspot.com/2019/02/cfs-a98-titanium-dioxide-dispersant-co.html

[3] http://www2.mst.dk/Udgiv/publications/2018/10/978-87-93710-94-8.pdf

[4] https://www.rodial.co.uk/makeup/face/foundation?___SID=U

[5] http://angusfire.co.uk/wp-content/uploads/TridolC6-S1-Zero-v1.1_EN.pdf

[6] http://www.solbergfoam.com/getattachment/61aa0da7-3b58-4052-80fd-47388182802a/SDS_600_ATC_Safety_Data_ENG.aspx

[7] http://www.unibrom.com/Public/Uploads/EcoFlame-S-338(1).pdf

[8] http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC11CO-SUBM-PFOS-Fluorocouncil-20160616.En.docx

The Danish EPA has published a report on PFAS found in a wide range of cosmetics, and similar products are likely to be on the UK market (Danish EPA 2018). The Danish study included a risk assessment for direct human exposure but did not attempt to estimate emissions to the environment. This would be worthwhile to do.

The remaining substances not included in table 4.2 above are generally used as monomers for manufacturing a range of polymers.

4.4 Significant sources of release

PFAS can be emitted to the environment from both direct (manufacture, use and disposal of products containing PFAS) and indirect sources (degradation of precursor substances) (OECD/UNEP Global PFC Group 2013). Potentially significant sources include:

- use and disposal of imported articles and polymers
- releases of PFAS containing AFFF used in fire-fighting at:
    - training sites
    - civil airports
    - military sites
    - major installations (for example, power stations, oil refineries and chemical works)
- disposal of waste containing PFAS to landfill – leading to volatile emissions and leakage of leachate
- spreading of materials containing PFAS to land (for example, municipal compost, paper pulp and sewage sludge)
- discharge to rivers and groundwater of treated sewage effluent (for example, from large water company owned waste water treatment works (WWTWs) or small sewage effluent discharges such as those from domestic septic tanks)
- point source releases of products containing PFAS to air, water and land from manufacturing facilities and downstream user sites, including chromium (VI) plating sites
- release to the environment and degradation of PFAS precursors such as polymers

The 3 most significant sources of PFAS in the environment are likely to be:

- sites that store and use AFFFs
- landfill sites
- the spreading of waste to land

It is anticipated that there will also be:

- localised sources around manufacturing and formulation sites
- more diffuse sources from use in:
    - consumer products such as textiles – from washing as well as general wear and tear (see, for example, Commission for Environmental Cooperation 2017)
    - coatings including anti-graffiti paints (Scheeder et al. 2005)
    - cosmetics

Further information on some of these sources is provided below.

4.4.1 Imported articles and polymers

There is no mechanism to collect information on individual PFAS present in articles or polymers that are imported into the UK or EU markets unless a substance is added to the Candidate List of Substances of Very High Concern under the REACH Regulation (which addresses some specific hazard classes).

OECD (2018) suggests that very large numbers of substances might have been imported which are yet to be registered under REACH; for example, because of the low volumes involved, but potentially due to lack of knowledge on the part of the importers. This is an area of significant uncertainty in terms of estimating environmental risk.

The lifecycle of imported articles and polymers may result in diffuse releases to the environment, but will typically end with reuse, recycling or disposal as waste to landfill or waste-to-energy installations (incinerators). Assuming that temperatures are high enough, incineration is the only way to ensure that PFAS are destroyed.

4.4.2 Aqueous film-forming foams (AFFFs)

AFFF products are used for fire-fighting; see Environment Agency (2003) for a review of the environmental impact of these products.

Many AFFFs contain surfactants made using PFAS. For example, 10 different fluorochemical classes were identified in US military-certified AFFF formulations by Place and Field (2012), including anionic, cationic and zwitterionic surfactants with perfluoroalkyl chain lengths ranging from 4 to 12. These types of foam are typically used to control class B fires (large volatile fuel fires).

Of the substances registered under REACH above 10tonnes per year, the following are specifically for use in fire-fighting foams:

- carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) sulfonyl]amino]propylammonium hydroxide (CAS no. 34455-29-3)
- N-[3-(dimethylamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonamide N-oxide (CAS no. 80475-32-7)

The UK Fire and Rescue Service is currently revising its National Foam Procurement Process. It is expected that fluorinated foams will only be recommended for the most serious scenarios such as oil refinery fires, where full containment of foam would be part of risk management measures (Environment Agency internal records).

The Department for the Environment, Food and Rural Affairs (Defra) is currently undertaking a research project to investigate which PFAS are used in foams in the UK, with a focus on PFOA and related substances (Defra 2019). The European Commission and ECHA are also carrying out similar projects, which are expected to be completed during 2020.

The historic use of AFFF products is known to have caused soil pollution and associated groundwater, surface water and drinking water contamination near to some fire training areas, airports and sites of major incidents in the USA (ATSDR 2018b).

In the UK, for example, PFOS-containing foam was used at the major fire at the Buncefield Oil Storage Depot in Hertfordshire in December 2005 (internal Environment Agency data). Unintentional releases of AFFF have been reported at civil airports around the world, including at Schiphol Amsterdam Airport in 2008 (Kwadijk et al. 2014). At Jersey Airport, past operations at the fire training ground have resulted in contamination of the groundwater beneath the site with PFOS (Jersey Airport 2017). Another UK site with identified PFAS contamination is a small airfield for which fire training practice involved pouring fuel across the ground or over structures, igniting it and then extinguishing it using fire-fighting foam (internal Environment Agency data).

It is therefore highly likely that local soil and groundwater contamination will have occurred at any UK site that has allowed uncontrolled release of AFFF products containing PFAS in the past. This could include the Fire Service College in Moreton-in-Marsh, Gloucestershire, as well as a large number of small airfields and larger installations. There are no publically available monitoring data for such sites in the UK, but site operators may possess further information if they have conducted their own investigations. Further consultation with these stakeholders is desirable, and risk assessment of sites where fire-fighting foams have been used is recommended.

4.4.3 Landfill sites

Disposal to landfill is often the end of the lifecycle for consumer products containing PFAS (Eggen et al. 2010). Discarded textiles (including carpets and clothing) that are not suitable for recycling provide one example (Lang et al. 2016). Industrial waste and sewage sludge from wastewater treatment facilities can also be a significant source of PFAS in landfills, particularly those works that accept waste from the production or application of PFAS (ITRC 2018). Landfill leachate can be transferred to WWTWs directly or via a tanker system; consequently, PFAS may be transferred from landfill leachate via WWTWs to sewage sludge or surface water.

PFAS are not commonly measured at UK landfill sites. Internationally, PFOA is one of the most frequently detected PFCAs in landfill leachate, although only a limited number of substances are monitored for. Short-chain PFCAs (C4 to C7) can be more abundant than longer chain ones, possibly reflecting their greater mobility and increasing use (Hamid et al. 2018).

Various studies of the PFAS composition of landfill leachate have been carried out in many countries. PFOA and PFHxS were the most commonly detected PFAS in leachate samples from northern Spain (Fuertes et al. 2017), whereas PFHxA was found to be the major contaminant in Australian landfill leachate (Gallen et al. 2017).

Defra will shortly be commissioning a study to sample POPs in landfill leachate, which will increase our understanding of levels of some PFAS (particularly PFOS, PFHxS and PFOA).

The introduction of PFAS monitoring and risk assessment at landfill sites could be considered. An initial phase of risk screening would flag up which landfills should be within scope. This screening could:

- consider which landfills have accepted PFAS-contaminated waste (such as large quantities of furniture or soils contaminated with fluorinated fire-fighting foam)
- assess the potential impact to surface water and groundwater from the leaching

Internal Environment Agency records show that at least one hazardous landfill site in England has accepted PFAS-contaminated soils from Buncefield as a waste.

4.4.4 Spreading of materials on land

The spreading of materials to land is regulated through the Environmental Permitting Regulations (England and Wales) 2016; the Environment Agency is the key regulatory body in England.

There has been a significant increase in the volume of material spread on land for agricultural benefit in recent decades. This is in response to the desire of successive governments for the UK to adopt a more sustainable approach to waste management. However, there is concern that spreading materials on land could be a growing source of PFAS contamination, particularly in groundwater.

An example of PFAS contamination arising from the spreading of waste materials to land comes from Rastatt in Baden-Wuerttemberg, Germany (Brendel et al. 2018). A large area of arable land has been affected following a long period of application of compost mixed with sludge from paper production. The paper sludge was contaminated with various PFAS, which degraded to short-chain PFAS in the soil and were subsequently detected in groundwater at significant concentrations. This has led to the closure of some abstraction points for drinking water, as well as the loss of crop growing potential as plants were found to exceed recommended maximum concentrations. It is not known if this scenario also occurs in the UK, but it cannot be ruled out. This would make investigation of the PFAS used in paper, or specific controls on the use of paper waste, a priority.

Data from a project in England showed that some materials spread on land contain PFAS (Environment Agency 2017). More work is needed to better understand and substantiate the risks to the water environment from land spreading.

4.4.5 Waste Water Treatment Works (WWTWs and spreading of sewage sludge to land

PFAS are commonly detected in influents, effluents and sludges from WWTWs around the world. They originate from releases from products currently on the market, as well as old products still in use such as surface-treated carpets (Houtz et al. 2016).

PFOS and PFOA have been included in monitoring at UK WWTWs as part of the UK water industry's Chemicals Investigations Programme, which is being expanded to include additional PFAS (see Section 4.2). The Environment Agency has also carried out research to better understand the concentrations of PFAS in waste materials being spread to land (Environment Agency 2017). Regulatory controls for PFOS/PFOA emissions have been proposed in the environmental permitting regime (that is, for land spreading deployment activities).

Concentrations of PFAS in WWTW effluents are likely to be variable and dependant on the type of treatment involved and the level of partitioning to sludge during secondary and tertiary treatment (Earnshaw et al. 2014). Some types of PFAS are very difficult to remove using conventional wastewater and drinking water treatment processes. This is due to their resistance to degradation as well as low sorption to solids. These properties also make the remediation of contaminated sites difficult (Ross et al. 2018). Expensive tertiary treatment such as granular activated carbon (GAC) has been implemented in Switzerland in response to concerns around PFAS and other toxic chemicals entering surface water.

Further research could be performed to identify those WWTWs most likely to produce sludges containing PFAS, with subsequent sampling and measurement of PFAS in sewage sludge intended to be spread to land. This may be one outcome of monitoring already performed or being planned by the UK water industry (see Section 4.2). It is also important to identify the sources of any PFAS found.

4.4.6 Chrome plating

There are approximately 100 metal treatment sites in the UK currently using chromium (VI) compounds for chrome plating (personal communication in December 2018 with the Surface Engineering Association). PFAS are used as mist suppressants in some processes to reduce worker exposure to toxic chromium (VI) ions. This is a derogated use of PFOS under the POPs Regulation.

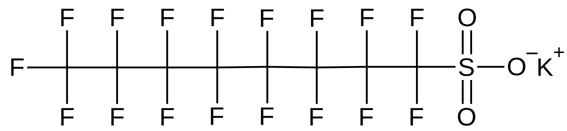
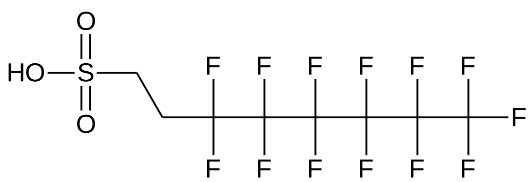
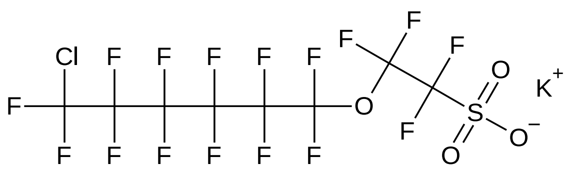
Although a recent survey by the Surface Engineering Association reported that there were no sites still using PFOS in the UK, recent work by the Environment Agency has identified 13 user sites in England. This discrepancy may be because some companies are not members of the Surface Engineering Association or perhaps there was an incomplete response to their survey. There could also be an additional site in Scotland (personal communication in March 2019 from the Scottish Environment Protection Agency).

An alternative substance is now being used by a large number of the Surface Engineering Association's members. This is 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonic acid (CAS no. 27619-97-2), also known as 1H,1H,2H,2H-perfluorooctanesulfonic acid. This has been registered under REACH in the 10-100 tonnes per year band and is not currently subject to any evaluation activities. However, this substance is likely to be within scope of the planned restriction proposal for PFHxA from Germany (see Section 2.5.4).

F-53B (6:2 chlorinated polyfluorinated ether sulfonate, 6:2 Cl-PFESA, CAS no. 73606-19-6) has structural similarities to PFOS and is reported to be used as an alternative to PFOS in China in the chrome plating industry (Wang et al. 2013). Although it has not been registered under REACH, this may be because it is imported in quantities below 1 tonne per year by individual companies. It has been identified in surface water, wastewater and municipal sewage sludge in China and has been claimed to show similar resistance to degradation as PFOS, have strong bioaccumulation potential, and be moderately toxic (Wang et al. 2013, Deng et al. 2018). F-53B may be a high priority for evaluation if it is registered under REACH in the future as it has already been detected in surface water in the River Thames in one study, although at very low levels (Pan et al. 2018) (see Section 4.3).

Table 4.3 shows the structures of all 3 substances.

Table 4.3 Structures of PFOS and 2 alternatives used in chrome plating

Substance	CAS no.	Chemical structure
PFOS (potassium salt)	2795-39-3 [a]	
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctanesulfonic acid	27619-97-2	
F-53B (6:2 chlorinated polyfluorinated ether sulfonate) (potassium salt)	73606-19-6	

Note: [1] Different CAS numbers may be available for a substance if it is ionic. For example, CAS no. 1763-23-1 is used for PFOS in its fully protonated form.

All users of chromium (VI) compounds for chrome plating should be subject to authorisation decisions under the REACH Regulation within the next year or two. Although the focus of authorisation is the use of chromium (VI) compounds, the applications may provide some insights into releases of PFAS that are used in the same processes. The Environment Agency is interested to know more about the fate of any PFAS-containing effluents and wastes. Further dialogue with the metal treatment industry would help to clarify this.

4.4.7 Contaminated land

Elevated concentrations of PFAS in either soil, groundwater and/or surface water can occur at sites on or adjacent to any of the potential source types noted above. For example, discussions with one of the Environment Agency's Area Groundwater and Contaminated Land teams has identified a case study site contaminated with PFAS where adjacent land uses include an airfield with a former fire-fighting training area and an historic landfill site that accepted industrial (including chemical) waste. Both the landfill site and the fire-fighting training area are potential sources of PFAS in the local area.

In the USA, the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) – commonly known as Superfund – provides the federal government with the authority to address a release or threatened environmental releases of dangerous substances in some circumstances. This is managed by the USEPA, which is considering designating PFOA and PFOS as 'hazardous substances' under Superfund (USEPA, undated). No similar provisions currently exist in the UK, although a similar approach could be useful to help mitigate existing PFAS contamination. Regulation of contaminated land in the UK is undertaken through either the local authority planning system for land development or via Part 2A of the Environmental Protection Act 1990.

PFAS are not routinely measured during contaminated land investigations in the UK. A recent technical bulletin (CLAIRE 2019) on managing the risks of PFAS at contaminated land sites discusses emerging technologies for remediation, including granular activated carbon (GAC), which is more efficient at removing long-chain substances than short-chain ones. PFAS can be destroyed on GAC surfaces at temperatures of 700°C during the GAC reactivation process (Ross et al. 2018). Further awareness raising in this sector might be beneficial.

5 Monitoring data

5.1 Introduction

A limited number of sampling sites, sample types and range of PFAS have been investigated in surface water, groundwater and soil in the UK. PFOS and PFOA are the most commonly monitored and reported PFAS substances.

PFOS is a Water Framework Directive priority hazardous listed in Annex I of the Environmental Quality Standards Directive (EQSD) (2008/105/EC) as amended by the Priority Substances Directive (2013/39/EU). It is the only PFAS with environmental quality standards and the Environment Agency has monitored it in surface waters and biota (freshwater and marine fish, and blue mussels) since 2016. PFOS is a widespread environmental contaminant that is frequently detected in surface waters across England. Further information on the available monitoring data for PFOS is provided in Environment Agency (2019).

Most monitoring activities have typically focused on a relatively small number of arrowhead substances that are known or suspected to be hazardous and may be formed from several different precursor substances over time. Some of the target analytes are also constituents of widely used substances that have been (or will shortly be) extensively banned, but are still in the environment from historical sources. This presents a complex challenge in terms of:

- identifying the most appropriate substances
- identifying their lifecycle stages for further risk management
- tracking the declines in concentrations once control measures have been introduced

An analytical technique known as the Total Oxidisable Precursors (TOP) Assay has been developed to quantify the sum of different types of PFAS (Houtz and Sedlak 2012). It uses simple hydroxyl radical chemistry to break down precursor substances to stable arrowheads, which can then be directly measured. This technique may be a useful addition to a future monitoring programme to help identify the presence and levels of precursors in the environment. Miyake et al. (2007) developed a more comprehensive mass balance method to quantify the sum of total organic fluorine (TOF) in individual samples. This method can be used for PFAS that do not degrade to the arrowhead substances, but is costly and not widely used because of the high level of background contamination in laboratory blank samples.[19]

5.2 Wastewater

The Chemicals Investigations Programme (CIP) is a major monitoring programme led by the UK water industry.[20] Phase 2 collected samples of WWTW effluent and up- and downstream river water at over 600 locations in England, Wales and Scotland up to

[19] A Nordic Council of Ministers screening study (Kärrman et al. 2019) analysed a list of 99 target PFAS together with an extractable organic fluorine (EOF) method in a variety of media. It found that using mass balance between the two it was possible to get an indication of how much of the total organic fluorine could be identified. The results ranged from an average of 9% in the sewage sludge to 68% in bird eggs.

[20] https://ukwir.org/the-chemicals-investigation-programme-phase-2,-2015-2020

December 2017. Measurements of PFOS and PFOA concentrations were made in all samples. Detailed interpretation of the CIP data for PFOA falls outside the scope of this report although the highest concentrations measured were likely to be sourced from an industrial site or a landfill site.

Further monitoring will be undertaken as part of CIP Phase 3, which is scheduled to begin in April 2020. This will include the measurement of a wider range of PFAS in water and sewage sludge at a smaller number of WWTWs. This will assist further priority setting. The proposed list of PFAS to be measured is shown in Table 5.1.

Table 5.1 Proposed PFAS to be monitored in CIP Phase 3

Substance	CAS No.	Sludges	Water
Perfluorobutane sulfonic acid (PFBS)	375-73-5	Y	Y
Perfluorohexane sulfonic acid (PFHxS)	355-46-4	Y	Y
Perfluorooctane sulfonic acid (PFOS)	1763-23-1	Y	Y
Perfluorooctane sulfonamide (PFOSA)	754-91-6	Y	Y
Perfluorohexanoic acid (PFHxA)	307-24-4	Y	Y
Perfluorooctanoic acid (PFOA)	335-67-1	Y	Y
Perfluorononanoic acid (PFNA)	375-95-1	Y	Y
Perfluorodecanoic acid (PFDA)	335-76-2	Y	Y
Perfluoroundecanoic acid (PFUnDA)	2058-94-8	Y	Y
Perfluorododecanoic acid (PFDoDA)	307-55-1	Y	Y
Perfluorotridecanoic acid (PFTrDA)	72629-94-8	Y	-
Perfluorotetradecanoic acid (PFTeDA)	376-06-7	Y	Y
10:2 Fluorotelomer alcohol (10:2 FTOH)	1262446-14-9	Y	-
8:2 Fluorotelomer alcohol (8:2 FTOH)	678-39-7	Y	-

5.3 Surface water and groundwater

The Environment Agency routinely collects water samples around England from coastal and estuarine waters, rivers, lakes, ponds, canals and groundwater as part of the national monitoring network. Samples are taken for different purposes including routine monitoring to assess compliance against discharge permits, and for water body classification required by the Water Framework Directive (WFD). We also investigate pollution incidents. We have only limited monitoring data for PFAS but are collecting semi-quantitative data for 14 of them in both surface water and groundwaters (the substances are shown in Table 5.3).

5.3.1 Surface and ground water monitoring

The Environment Agency carried out an investigation in 2006 to measure a limited number of PFAS in surface water and groundwater (Environment Agency 2007). The surface water sites included 42 Surface Water Abstraction Directive sites and 39 other monitoring sites. There were 202 groundwater sites in England and 17 in Wales. The sampling locations were located close to urban/industrial areas and airfields as well as rural areas. The results are presented in Figure 5.1 and Table 5.2.

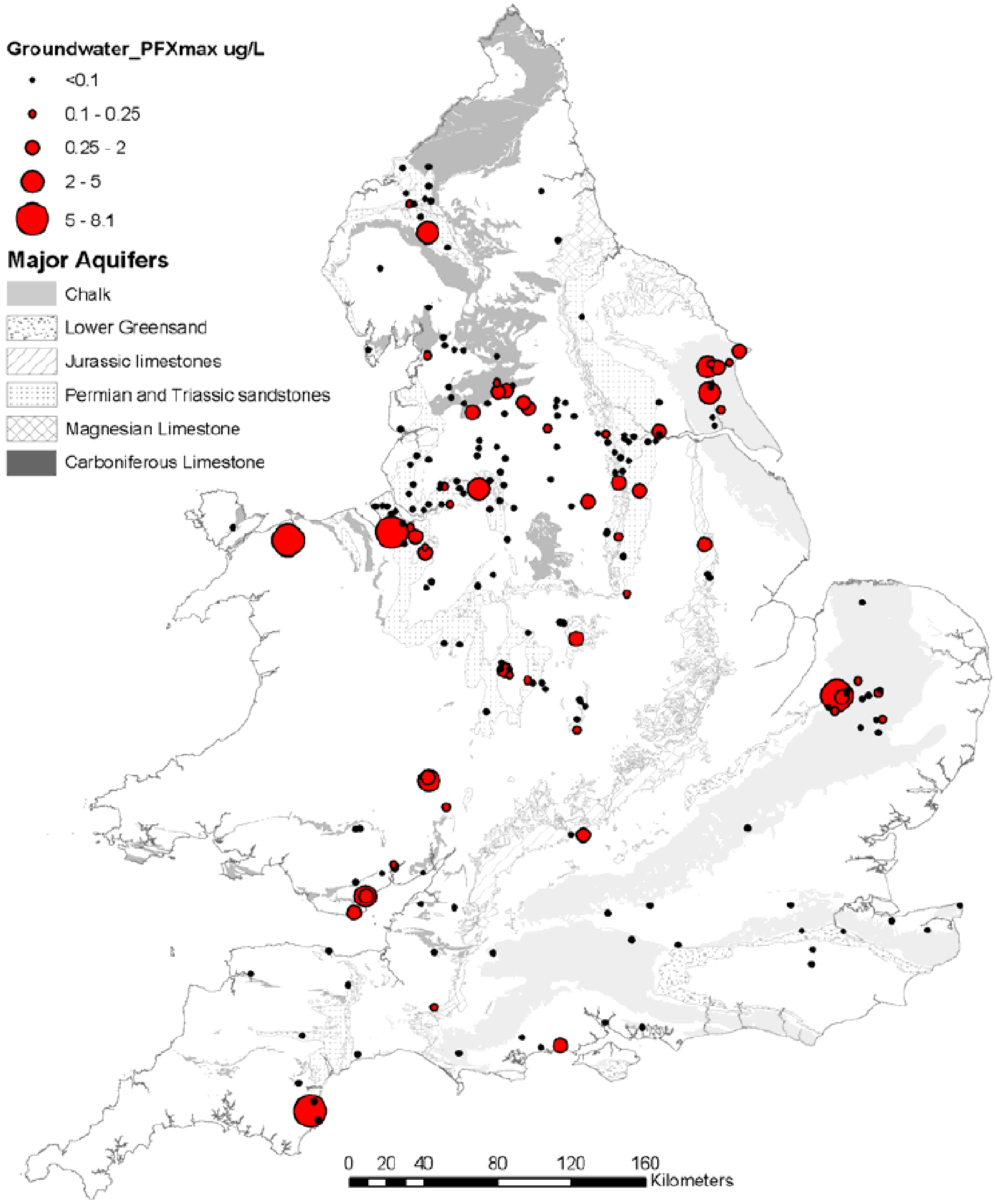


Figure 5.1 Distribution of groundwater monitoring for perfluorinated chemicals, 2006

Source: Environment Agency (2008)

All the PFAS were detected at one site at least. The substance detected at the highest concentrations in both surface water and groundwater was PFOS. It was also the most frequently detected substance in groundwater (at approximately 14% of the 219 sites sampled). PFAS were detected at 52% of the Surface Water Abstraction Directive sites and at 67% of the other monitoring sites.

Table 5.2 Groundwater and surface water monitoring data from England and Wales, 2006

Substance	CAS no.	Concentration (µg/L)			
		Surface water		Groundwater	
		Min.	Max.	Min.	Max.
PFOS	1763-23-1	<0.1	33.9	<0.1	6.30
Perfluoropentanoic acid (PFPeA)	2706-90-3	<0.1	2.0	<0.1	0.46
PFHxA	307-24-4	<0.1	3.0	<0.1	0.61
Perfluoroheptanoic acid (PFHpA)	375-85-9	<0.1	1.5	<0.1	0.7
PFOA	335-67-1	<0.1	2.0	<0.1	0.6
PFNA	375-95-1	<0.1	0.35	<0.1	0.42
PFDA	335-76-2	<0.1	0.40	<0.1	0.82
PFUnDA	2058-94-8	<0.1	2.4	<0.1	0.76
PFDoDA	307-55-1	<0.1	2.4	<0.1	1.04
PFTeDA	376-06-7	<0.1	0.6	<0.1	4.00

The Drinking Water Inspectorate (England and Wales) commissioned a study of levels of PFOS and PFOA in raw and treated drinking water samples collected from 20 sites (5 control sites and 15 perceived higher risk sites) in England and Wales during 2007 (Atkinson et al. 2008). PFOA levels were frequently below the detection limit (0.024 µg/L), although higher levels were obtained on one sampling occasion at several sites (up to 0.26 µg/L). The Drinking Water Inspectorate (England and Wales) is currently planning an assessment of the likelihood of PFAS levels in drinking water exceeding the draft standard proposed in the recast of the Drinking Water Directive.[21]

The Environment Agency's National Laboratory Service (NLS) has since developed a liquid chromatography–mass spectrometry (LC-MS) method for the semi-quantitative analysis of a broad range of organic compounds in water samples. The suite includes 14 PFAS as shown in Table 5.3; heptafluorobutanoic acid (HFBA) or perfluorobutanoic acid (PFBA) was added to the method as recently as December 2018.

The NLS also has an accredited analytical method for PFOS (limit of detection: 0.09 ng/L) and PFOA (limit of detection: 0.6 ng/L) in surface water. The range of PFAS analysed by the NLS is broadly comparable with those included in the USEPA analytical method for water (Shoemaker et al. 2008).

[21] A proposal to set a total limit value of 0.1 µg/L for several PFAS in drinking water is currently under discussion at EU level. Further details are beyond the scope of this report, although it may provide an additional driver for action.

Table 5.3 Environment Agency's LC-MS analytical suite

Substance	CAS no.	Limit of detection (LOD) (µg/L)
PFBA (HFBA)	375-22-4	0.001
PFBS	375-73-5	0.005
PFPeA	2706-90-3	0.005
PFHxA	307-24-4	0.005
PFHxS	355-46-4	0.005
PFHpA	375-85-9	0.005
PFOS	1763-23-1	0.01
PFOSA	754-91-6	0.005
PFOA	335-67-1	0.005
PFNA	375-95-1	0.005
PFDA	335-76-2	0.01
PFUnDA	2058-94-8	0.1
PFDoDA	307-55-1	0.1
PFTeDA	376-06-7	0.1

Measurements have been taken using the NLS LC-MS suite method in samples of surface water and groundwater obtained from the Environment Agency's national monitoring network (circa 2012 to 2019) and the data are summarised in Table 5.4.

Given the semi-quantitative nature of the LC-MS method, the values should be treated with a degree of caution. The surface water sampling locations include 8 monitoring points, across a variety of different catchment sizes with differing proportions of agricultural land, as part of a specific project on countryside stewardship and catchment sensitive farming. In general, the sampling locations are non-targeted with respect to potential sources of PFAS. The results do not therefore reflect levels in urban or highly contaminated locations, and are instead considered to provide a limited, high level regional profile of PFAS concentrations in surface water and groundwater.

Table 5.4 Summary of recent groundwater and surface water monitoring data from Environment Agency's LC-MS analytical suite

Substance	CAS no.	Concentration (µg/L)			
		Surface water		Groundwater	
		Minimum	Maximum	Minimum	Maximum
PFBA	375-22-4	<LOD	0.04	<LOD	0.018
PFBS	375-73-5	<LOD	8.3	<LOD	1.1
PFPeA	2706-90-3	<LOD	0.1	<LOD	0.25
PFHxA	307-24-4	<LOD	0.1	<LOD	0.16
PFHxS	355-46-4	<LOD	1.4	<LOD	8.6
PFHpA	375-85-9	<LOD	0.066	<LOD	0.035
PFOS	1763-23-1	<LOD	0.088	<LOD	0.71
PFOSA	754-91-6	<LOD	<LOD	<LOD	<LOD
PFOA	335-67-1	<LOD	0.16	<LOD	0.1
PFNA	375-95-1	<LOD	0.03	<LOD	0.0076
PFDA	335-76-2	<LOD	0.011	<LOD	<LOD
PFUnDA	2058-94-8	<LOD	<LOD	<LOD	<LOD
PFDoDA	307-55-1	<LOD	<LOD	<LOD	<LOD
PFTeDA	376-06-7	<LOD	<LOD	<LOD	<LOD

Detailed interpretation of this monitoring dataset falls outside the scope of this report. However, a recent study by the British Geological Survey (BGS) has identified the top 50 of the most frequently detected emerging substances by the LC-MS method from the groundwater measurements obtained from the Environment Agency's national monitoring network for 2012 to 2017. This dataset included 5 PFAS. A provisional summary of the monitoring data prepared by the BGS is presented in Table 5.5 (for further details, see Lapworth et al. 2018).

Table 5.5 Summary of recent PFAS monitoring data in English groundwater (BGS, 2018)

Substance	Concentration (ng/L)[1]					No. of analyses	No. of positive detections	% analyses with positive detections
	Limit of detection	Median	Mean	95th percentile	Maximum			
PFOS	10	0.28	2.92	12	440	267	80	30.0
PFPeA	5	1.8	2.63	6.88	80	267	60	22.5
PFHxA	5	1.45	2.31	5.35	130	267	60	22.5
PFHpA	5	–	–	5	30	267	50	18.7
PFOA	5	0.65	1.6	6	50	267	106	39.7

Note: [1] Most of the reported concentrations were below the limits of detection. The median/means are statistically derived based on the data distribution.
[2] The data are from BGS (2018) and may be subject to change in the final published report.

Given the semi-quantitative nature of the LC-MS method, the values should be treated with a degree of caution. Not all aquifers are monitored and there is a bias towards some regions, so it is unclear how representative the data are of the national situation. The data are not truly comparable with the earlier 2006 survey. However, it is particularly notable that PFAS contamination appears to be fairly widespread in groundwater at ng per litre (ng/L) levels in areas that are not likely to be subject to significant point source pollution.

In 2017, the Scottish Environmental Protection Agency (SEPA) carried out a project to identify the presence of PFOS and other PFAS in Scottish surface water samples taken from higher risk Water Framework Directive classification sites on a monthly basis for 3 months. A summary of the results is presented in Table 5.6.

Table 5.6 SEPA surface water monitoring data from 2017

Substance	Concentration (ng/L)		
	LOD	**Minimum**	**Maximum**
PFBS	0.13	<LOD	10.7
PFHxS	0.07	<LOD	1.16
Perfluoroheptane sulfonic acid (PFHpS)	0.1	<LOD	0.35
PFOS	0.08	<LOD	3.11
PFHxA	1.86	<LOD	18.2
PFHpA	0.5	<LOD	4.17
PFOA	0.44	<LOD	4.37
PFNA	0.35	<LOD	1.05
PFDA	0.56	<LOD	0.78

SEPA plans to conduct a further investigation of PFAS emitted from landfill sites and measure PFAS concentrations in groundwater.

A more detailed review of the Environment Agency’s data is recommended.

5.3.2 Academic studies

A pan-European survey collected over 100 surface water samples and 164 groundwater samples from 27 and 23 European countries respectively (Loos et al. 2009, 2010). PFAS concentrations for UK sample locations are not presented, but the dataset provides a broad overview of PFAS concentrations across Europe. The maximum concentrations are presented in Table 5.7.

Table 5.7 EU surface and groundwater monitoring data

Substance	Maximum concentration (µg/L)	
	Surface water (Loos et al. 2009)	Groundwater (Loos et al. 2010)
PFBS	–	0.025
PFHxS	–	0.019
PFOS	1.371	0.135
PFHxA	0.109	–
PFHpA	0.027	0.021
PFOA	0.174	0.039
PFNA	0.057	0.01
PFDA	0.007	0.011
PFUnDA	0.003	–

Pan et al. (2018) analysed PFAS in 6 surface water samples collected from the River Thames in southern England in 2016 – as well as a large number of sites worldwide. A summary is presented in Table 5.8. The reliability and representiveness of the findings are unknown, but a number of interesting findings may need to be followed up. For example, GEN-X (see Section 3.1.6) has been widely detected in the aquatic environment in the Netherlands where it was linked to a site that imports it for manufacturing fluorinated polymers (RIVM 2018). The UK source is not known. F-53B was also found at low concentrations (see Section 4.4.6).

Table 5.8 Surface monitoring data from the River Thames (Pan et al. 2018)

Substance	Concentration (ng/L)		
	Mean	Minimum	Maximum
PFBA	6.96	4.62	9.79
PFPeA	15.7	10.1	19.9
PFHxA	12.2	7.32	15
PFHpA	4.1	2.58	5.19
PFOA	8.51	5.56	11.7
PFNA	1.18	0.77	1.71
PFDA	0.86	0.52	1.22
PFUnDA	0.07	0.03	0.1
PFDoDA	0.04	<LOD	0.05
Perfluorotridecanoic acid (PFTriA)	<LOD	<LOD	<LOD
PFTeDA	<LOD	<LOD	<LOD
GEN-X (HFPO-DA)	1.12	0.7	1.58
Hexafluoropropylene oxide trimer acid (HFPO-TA)	0.14	0.05	0.21
ADONA	<LOD	<LOD	<LOD
PFBS	5.06	3.26	6.75
PFHxS	7.14	4.96	11.3
PFOS	13.8	8.12	18.8
4:2 chlorinated polyfluorinated ether sulfonate (4:2 Cl-PFESA)	<LOD	<LOD	<LOD
6:2 Cl-PFESA (F-53B)	0.05	0.01	0.08
8:2 chlorinated polyfluorinated ether sulfonate (8:2 Cl-PFESA)	<LOD	<LOD	<LOD
6:2 polyfluorinated ether sulfonic acid (6:2 HPFESA)	<LOD	<LOD	<LOD
4:2 fluorotelomer sulfonate (4:2 FTSA)	0.04	<LOD	0.11
6:2 fluorotelomer sulfonate (6:2 FTSA)	6.75	2.25	13.9
8:2 fluorotelomer sulfonate (8:2 FTSA)	0.09	0.06	0.19

5.4 Soil

Soil organic carbon, pH and clay content have a significant effect on sorption for some PFAS (Li et al. 2018). Pereira et al. (2018) suggested that many long-chain PFAS are preferentially bound to the humic fraction of soil organic matter, whereas shorter chain PFAS may also bind to the humic and fulvic acids.

The Environment Agency has previously performed a review of PFOS and PFOA present in wastes spread to agricultural land (Environment Agency 2017) (see Section 4.4.4). This highlighted the uncertainty in ambient levels of these 2 substances in UK soils and the existing level of contamination as a result of previous waste applications such as biosolids. Further research was recommended to establish the levels of PFAS precursor compounds such as fluorotelomer alcohols, polyfluoroalkyl phosphates and perfluorooctane sulfonamides in waste streams. These can break down into shorter chain length PFAS during treatment and following application to land (Environment Agency 2017).

The Environment Agency does not routinely perform monitoring of soil samples in England. Data on PFAS concentrations in soil are likely to be limited to individual sites where sampling and analysis have been carried out as part of contaminated land investigation work or where a significant pollution incident involving PFAS has occurred. Various UK commercial laboratories offer PFAS measurements for soils and other media for this purpose.

5.5 Biota (including human foodstuffs)

Houde et al. (2011) provided a review of monitoring data from international studies of biota concentrations. PFOS was considered the predominant PFAS detected with high concentrations in invertebrates, fish, reptiles and marine mammals worldwide.

Since many PFAS tend to have high water solubility but generally do not degrade through biological mechanisms, they may accumulate in plant tissues (see, for example, Stahl et al. 2009). Significant crop contamination has been found in some parts of the world where high amounts of PFAS were present in sludges applied to soil (see, for example, Brendel et al. 2018).

In animals, PFAS may sometimes accumulate more in protein-rich tissues such as blood than in fatty tissues. Gill-breathing organisms tend not to accumulate some types of PFAS as much as air-breathing ones due to their ability to eliminate them via water.

Data for PFOS in fish and mussels are provided in Environment Agency (2019). The limited additional information found for PFAS measurements in biota in the UK from a literature search is summarised below.

Following earlier surveys in 2006, 2008 and 2009 (FSA 2006, Central Science Laboratory 2008, FSA 2009), the Food and Environment Research Agency investigated the levels of 11 PFAS in a variety of retail foods on sale in the UK as part of a Total Diet Survey (Fernandes et al. 2012). Table 5.9 presents selected results to provide an indication of levels in plants and animals.

Table 5.9 Concentrations of PFAS found in selected foodstuffs by FERA

PFAS	Concentration (µg/kg whole weight)												
	Carcass meat	Offal	Meat products	Poultry	Fish	Eggs	Green vegetables	Potatoes	Other vegetables	Fresh fruit	Fruit products	Milk and dairy	Nuts
PFHxA	NQ	0.79	0.5	0.23	1.85	0.16	2.8	0.41	1.13	1.74	0.76	0.54	0.86
PFHpA	NQ	2.45	0.88	0.43	3.89	0.32	1.27	0.85	0.12	1.05	0.98	1.22	0.59
PFOA	0.17	0.62	0.2	0.21	1.51	0.11	0.22	0.12	0.18	0.2	0.17	0.08	0.54
PFNA	0.18	0.44	0.22	0.23	0.6	0.21	0.25	0.12	0.17	1.1	0.17	0.08	0.72
PFDA	0.31	0.98	0.16	0.23	0.81	0.17	0.36	0.09	0.14	0.21	0.1	0.06	0.22
PFUnDA	0.17	1.75	0.34	0.56	1.24	0.71	0.27	0.05	0.22	0.23	0.48	0.18	0.56
PFDoDA	0.15	0.75	0.2	0.08	1.31	0.28	0.21	0.05	0.11	0.06	0.07	0.12	0.12
PFBS	0.04	0.95	0.16	0.28	2.47	0.1	0.07	0.04	0.05	0.08	0.03	0.04	0.16
PFHxS	0.13	1.3	0.23	0.25	2.41	0.1	0.17	0.07	0.1	0.18	0.08	0.06	0.09
PFOS	0.22	2.66	0.17	0.16	0.96	0.31	0.1	0.05	0.04	0.07	0.02	0.06	0.1
PFOSA	0.05	0.64	0.03	0.24	1.33	0.05	0.1	0.03	0.06	0.01	0.03	0.08	0.05
Total	**1.4**	**13.3**	**3.1**	**2.9**	**18.4**	**2.5**	**5.8**	**1.9**	**2.3**	**5**	**2.9**	**2.5**	**4**

Notes: NQ = not quantifiable
Source: Fernandes et al. (2012, Table 3.12)

In a further study, FERA analysed 50 fish samples (Fernandes et al. 2015) and found PFAS in every one (Table 5.10). PFOS was often found at the highest concentrations.

Similarly, SEPA measured PFOS and PFOA in 20 individual freshwater fish collected in Scotland during 2016 and 2017. PFOS was found in the range <1.0 to 13.5 µg/kg wet weight, whereas PFOA was below the LOD of 1.0 µg/kg wet weight in all samples.

Table 5.10 PFAS concentrations found in selected fish by FERA

Substance	Concentration (µg/kg wet weight)	Sardines (n = 8)	Mackerel (n = 12)	Herring (n = 9)	Mullet (n = 7)	Sprat (n = 9)	Sea bass (n = 5)
PFOA	Range	0.06–0.92	0.06–0.35	0.08–1.17	0.01–0.26	0.13–3.82	0.05–0.24
	Mean	0.34	0.2	0.34	0.13	1.48	0.13
PFNA	Range	0.01–0.27	0.04–0.23	0.02–0.45	0.02–0.19	0.05–0.69	0.04–0.16
	Mean	0.16	0.1	0.1	0.07	0.26	0.07
PFDA	Range	0.04–0.94	0.07–1.07	0.02–0.87	0.14–0.58	0.05–0.45	0.06–0.33
	Mean	0.37	0.4	0.3	0.27	0.25	0.18
PFUnDA	Range	0.04–2.29	0.13–1.89	0.06–0.58	0.15–0.84	0.22–1.09	0.12–0.59
	Mean	0.78	0.4	0.16	0.39	0.51	0.3
PFDoDA	Range	0.02–0.51	0.01–2.04	0.03–0.64	0.13–1.34	0.05–0.64	0.02–0.48
	Mean	0.26	0.35	0.17	0.42	0.25	0.17
PFBS	Range	0.03–0.35	0.01–0.1	0.01–0.6	0.02–0.15	0.02–0.5	0.01–0.08
	Mean	0.07	0.02	0.12	0.08	0.11	0.04
PFHxS	Range	0.01–0.12	0.01–0.14	0.04–0.06	0.01–0.08	0.02–0.15	0.01–0.1
	Mean	0.03	0.02	0.02	0.02	0.08	0.03
PFOS	Range	0.78–3.59	0.22–4.92	0.16–1.84	0.37–12.83	1.51–9.44	1.28–10.79
	Mean	2.18	1.12	0.59	2.58	3.94	3.82
PFOSA	Range	0.06–3.4	0.04–0.39	0.02–0.89	0.29–0.67	0.08–3.0	0.43–2.13
	Mean	0.92	0.22	0.38	0.36	0.85	0.84

Source: Fernandes et al. (2015, Table 3.6)

The Predatory Bird Monitoring Scheme[22] is a long-term national monitoring programme that quantifies the concentrations of a variety of contaminants in the livers and eggs of predatory birds in the UK. It is operated by the Centre for Ecology and Hydrology (CEH). Although PFAS are not routinely measured, a range of PFAS were detected in sterile eggs of the northern gannet (*Morus bassanus*), a colonial marine species feeding primarily on fish. A total of 54 eggs were collected from the Ailsa Craig colony (Irish Sea/eastern Atlantic) and 57 eggs from the Bass Rock colony (North Sea) between 1977 and 2014 (Walker et al. 2015). The analytes were C4 and C8–14 PFCAs (PFBA, PFOA, PFNA, PFDA, PFUnA, PFDoDA, PFTriDA and PFTeDA), PFHxS, PFOS and perfluoro-1-decanesulfonate (PFDS). Concentrations of perfluoroalkylsulfonic acids appeared to

[22] https://pbms.ceh.ac.uk/

have peaked in the mid-1990s, but levels of the PFCAs had increased steadily by approximately 10-fold since 1977 with no sign of plateauing.

Some PFAS have recently been measured in tissue samples from Eurasian otters *Lutra* as part of the Cardiff University Otter Project,[23] but the results have not yet been published (E Chadwick, personal communication, January 2019). CEH also has a tissue archive for fish. It would be interesting to investigate PFAS levels in samples collected from sites where otters are contaminated, especially for any substances that are not currently under risk management.

The Centre for Environment, Fisheries and Aquaculture Science (Cefas) carries out monitoring in the marine environment, including sediment and biota such as stranded cetaceans. One published study focused on PFOA and PFOS in the livers of harbour porpoises around the UK between 1992 and 2003 (Law et al. 2008). Concentrations of PFOS ranged from <16 to 2,420 µg/kg wet weight; the concentrations of PFOA were less than the LOD in all 58 porpoise liver samples.

In a more recent study of livers of harbour porpoises around the UK from 2012-2014 (Barber et al., 2016), a suite of 15 PFAS were analysed, of which 6 were ubiquitous as summarised in Table 5.11. The mean PFOS concentration for 2012-14 (178 ng/g wet weight) is approximately one third of that for 2001-03 (600 ng/g wet weight), indicating that a decrease in concentrations has occurred. This work is continuing, with PFAS levels currently being determined in livers of 100 animals from 13 different UK marine mammal species.

Table 5.11 Concentrations and frequency of detection of PFAS in stranded and by-caught harbour porpoises collected in 2012 to 2014 (Barber et al 2016)

Substance	Concentration (ng/g wet weight)		
	Mean	Minimum	Maximum
PFPeA	0.19	<0.05	0.51
PFHxA	0.095	<0.05	0.16
PFHpA	0.17	<0.05	0.43
PFOA	0.26	<0.05	0.82
PFNA	2.7	0.087	19
PFDeA	9.1	0.54	81
PFUnA	16	1.5	88
PFDoDA	2.8	<0.1	15
PFTrDA	7.4	1.0	50
PFTeDA	1.6	<0.2	7.1
PFBS	0.10	<0.05	0.13
PFHxS	1.0	<0.05	4.6
PFOS	178	6.6	1144
PFDcS	0.74	<0.1	5.84
PFOSA	18	0.21	90

[23] www.otterproject.cf.ac.uk

Some PFAS have also been measured by Cefas in samples of sediment (n=58) and fish (pooled dab and plaice livers, n=119 and 10, respectively) collected around England and Wales under the Clean Seas Environmental Monitoring Programme (CSEMP) in 2014-15, but the data are not yet published.

Several studies have reported levels of PFAS in wildlife in the north-west Atlantic or North Sea areas, and these are likely to be relevant for UK waters too. For example, while most studies have only investigated concentrations of PFOS and long-chain PFCAs, van de Vijver et al. (2005) reported levels of PFBS in tissues of common (harbour) seals (*Phoca vitulina*) from the Dutch Wadden Sea where it was detected in spleen tissue at around 2 ng/g wet weight. In contrast, PFBA could not be detected.

5.6 People

In the early 2000s, the Worldwide Fund for Nature (WWF) commissioned a series of biomonitoring studies that reported levels of a variety of chemicals in human blood. These included PFOS and PFOA – and, in some cases, additional long-chain PFCAs or PFOSA.

One of these studies analysed blood from 33 people living in the UK (WWF 2004a), while 2 others reported levels in government officials (WWF 2004b) and families (WWF 2005) from across the EU. These studies are likely to be broadly representative of the general public in the UK, although overall sample sizes were small. One or more PFAS were present in a high proportion of the samples; they were found in children as well as adults, with indications of higher levels in older generations. For example, the median summed concentration of 8 PFAS reported in WWF (2005) was 3.8 ng/g (parts per billion) of blood, with a maximum of 37 ng/g blood in one individual.

The general public are exposed to PFAS via their diet and drinking water, from contact with materials in homes and offices (such as treated carpets) and indoor air (including dusts). Not all PFAS are as bioaccumulative as those investigated by WWF, though some appear to take a long time to be cleared from the human body. A large project, Human Biomonitoring for the EU,[24] is underway that will gather additional information on current levels of additional PFAS in human tissues. Public Health England is the lead organisation in the UK for this project.

[24] https://www.hbm4eu.eu/

6 Conclusions and Recommendations

The term ‘PFAS’ represents a very large number of synthetic organic compounds that are used in a wide range of applications. Due to their persistence they have the potential to cause widespread environmental contamination. The impact of this on people and wildlife is not currently known. Some PFAS are well-characterised and known to have properties of very high concern (for example, being persistent, bioaccumulative and toxic); others are highly mobile in the aquatic environment. However, little hazard information is available for the majority of PFAS, often because they are supplied in relatively small quantities.

Information on the actual substances and amounts on the UK market is not currently available. The Environment Agency is aware of 2 UK manufacturing companies with active PFAS registrations under the REACH Regulation. It also has some limited information from a small number of site permits and other intelligence gathered for this report. However, well over a hundred PFAS are registered for supply to the EU in annual quantities of 1 tonne or more under the REACH Regulation and nearly 5,000 are reported to be in use worldwide. Many of these could be used in the UK. The Environment Agency has no information on polymeric PFAS, non-polymeric PFAS used in quantities below 1 tonne per year and PFAS present in imported articles.

Most academic and regulatory attention has focused on a very small list of PFAS (mainly related to PFOS and PFOA), although the inclusion of precursor substances in risk management decisions has captured many more. As one chemical is subjected to international controls, it is typically replaced by similar substances with unknown or sometimes even additional concerns.

PFAS therefore present a major regulatory challenge. To ensure that the risks posed by these substances are managed effectively in the future, it is important to consider new ways of working to engage with the relevant industry sectors so that they take full responsibility for minimising the long-term environmental impacts of the chemicals they sell. This could include:

- identifying the major contributors to environmental exposure (including precursors);
- the prevention of releases where possible (for example, using product stewardship initiatives); and
- further scientific information about the impacts of the likely substitutes.

Additional risk management measures such as tighter permit controls or further restrictions are also an option.

There are many case studies from other countries which demonstrate that PFAS are present in surface water, groundwater, landfill leachate, soils and biota. Data on PFAS concentrations in environmental media in the UK are much more limited, but widespread low level contamination by some PFAS is already apparent.

6.1 Recommendations for further work

A range of activities could be carried out to improve the understanding of the emissions and risks of PFAS in the UK. The review team has identified the following projects as being important. Note that they are not listed in any order of priority or feasibility.

The suggested tasks will involve further consultation with industry and/or wider stakeholder engagement, and so will all require a significant amount of resource. The Environment Agency will continue to develop its approach to this group of chemicals, which might contribute to a future chemicals strategy in collaboration with other government bodies.

6.1.1 Work with industry

Specific industrial sectors should be evaluated to identify the range of PFAS they use and to determine the amounts and routes of release to the environment so that exposure can be modelled (if possible). The Environment Agency could recommend additional monitoring if necessary, and work with relevant industry stakeholders to assess the environmental risk and potential need for additional control measures or remediation.

One example could involve work with the Surface Engineering Association to assess the scale of emissions of PFAS from chrome plating sites, including better understanding of the control measures currently in place. Another example could involve consultation with major users of AFFFs (including civilian and military airports, fire stations, fire-fighting colleges and major industrial installations) to find out what PFAS monitoring data they hold. This could build on work already commissioned (Defra 2019).

Based on information for PFOS and PFOA, other candidate sectors for investigation include the textile industry, paper industry (including printing inks) and consumer products (for example, cosmetics, cleaning products, paints).

The Environment Agency could also work with the water companies to understand the potential for PFAS to be emitted to the environment from WWTWs via both effluent discharge and sewage sludge.

6.1.2 Review existing data

- Identify priority substances for inclusion in routine environmental monitoring programmes and analyte suites, ideally with better targeting of relevant sampling sites as part of an early warning system. As well as the Environment Agency, this may be relevant for other stakeholders such as national environmental regulators in the Devolved Administrations, CEH and Cefas.
- Perform a detailed analysis of Environment Agency and CIP monitoring data for surface water and groundwater – and in future WWTW sludge – to identify potential sources of PFAS and priority sites for more detailed investigations. This could include a repeat of the Environment Agency (2007) groundwater study to include a wider group of substances and find out how levels have changed.

6.1.3 Collaborate with other regulators and stakeholders

- Increase the awareness of national environmental regulators of the hazards and risks of PFAS. This could cover environmental permitting, water quality and contaminated land.

- Work with other government bodies to investigate how PFAS are used offshore (for example, in North Sea oil fields) and as active ingredients in plant protection products, biocides, veterinary medicines and human pharmaceuticals.
- Co-operate more closely with other environmental regulators outside the UK. The emphasis would be on co-ordinating efforts to improve understanding of the fate and transport of PFAS in the environment (including the importance of degradation pathways), hazard properties and sources. Engagement with manufacturers and importers will also be important.
- Liaise with stakeholders such as Public Health England and the Drinking Water Inspectorate about human health hazards and risk via environmental exposure.

6.1.4 Perform further research

- Keep a watching brief on evolving treatment techniques to remove PFAS from environmental media such as soil, sediment and groundwater.
- Undertake a project to establish the levels of PFAS precursor compounds in waste streams. This would enable the Environment Agency to better assess the environmental risk of PFAS contamination from recycling operations and spreading materials to land.
- Undertake an evaluation of the substances registered by UK companies or detected by Pan et al. (2018).
- A monitoring programme similar to the Nordic Council of Ministers screening study (Kärrman et al. 2019) could be undertaken, which would give an indication of the levels of a wider range of PFAS in the UK environment.

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List of abbreviations

4:2 Cl-PFESA	4:2 Chlorinated polyfluorinated ether sulfonate
6:2 Cl-PFESA	6:2 chlorinated polyfluorinated ether sulfonate
ADONA	ammonium 2,2,3-trifluoro-3-(1,1,2,2,3,3-hexafluoro-3-trifluoro-methoxy-propoxy) propionate
AFFF	aqueous film fire-fighting foam
BGS	British Geological Survey
CAS	Chemical Abstracts Service
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEH	Centre for Ecology and Hydrology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIP	Chemicals Investigation Programme
C&L	Classification and Labelling [Inventory]
CLP	Classification, Labelling and Packaging [Regulation]
ECHA	European Chemicals Agency
EQS	Environmental Quality Standard
FASAs	perfluoroalkanesulfonamides
FEP	fluorinated ethylene propylene
g	Gram
GAC	granular activated carbon
GEN-X [HFPO-DA]	propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1)
HFBA	heptafluorobutanoic acid
HFPO-TA	hexafluoropropylene oxide trimer acid
kg	Kilogram
L	Litre
LOD	limit of detection
NLS	National Laboratory Service [Environment Agency]
NONS	Notification of New Substances Regulations 1993
OECD	Organisation for Economic Co-operation and Development
OR	Only Representative
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PACT	Public Activities Co-ordination Tool

PASFs	perfluoroalkane sulfonyl fluorides
PBT	persistent, bioaccumulative and toxic
PFAS	per- and polyfluorinated alkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFC	perfluorocarbon
PFCAs	perfluoroalkyl carboxylic acids
PFDA	perfluorodecanoic acid
PFDoDA	perfluorododecanoic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid
PFHpA	perfluoroheptanoic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctane sulfonamide
PFPeA	perfluoropentanoic acid
PFTriA	perfluorotridecanoic acid
PFTeDA	perfluorotetradecanoic acid
PFTrDA	perfluorotridecanoic acid
PFUnDA	perfluoroundecanoic acid
POP	persistent organic pollutant
PTFE	polytetrafluoroethylene
PVDF	polyvinylidene fluoride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals [Regulation]
RIME	EU Risk Management Expert Group
RMOA	Risk Management Option Analysis [REACH]
SEPA	Scottish Environment Protection Agency
SVHC	Substance of Very High Concern
USEPA	US Environmental Protection Agency
VOCs	volatile organic compounds
vPvB	very persistent, very bioaccumulative
WWF	Worldwide Fund for Nature
WWTW	wastewater treatment works

APPENDIX A: Definitions of PFAS

OECD (2018) identified 4,730 PFAS believed to be in worldwide use. That study focused on substances that contain a perfluoroalkyl moiety with 3 or more carbon atoms (–CnF2n–, n ≥ 3) or a perfluoroalkyl ether moiety with 2 or more carbon atoms (–CnF2nOCmF2m−, n and m ≥ 1). The same scope has been used for this report, supplemented by the classification methodologies of Buck et al. (2011) and Wang et al. (2017). Further details are provided below.

A.1 Non-polymeric PFAS

A.1.1 Perfluoroalkyl substances

Perfluoroalkyl substances are characterised by a fully fluorinated carbon chain where all hydrogen atoms in the alkyl chain are replaced by fluorine atoms (C_nF_{2n+1}).[25] They have been manufactured for more than 50 years. Examples include perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA).

A.1.2 Polyfluoroalkyl substances

Polyfluoroalkyl substances are aliphatic substances in which all hydrogen atoms attached to at least one (but not all) of the carbon atoms have been replaced by fluorine atoms in such a manner that they contain the perfluoroalkyl moiety.

Polyfluoroalkyl substances have the potential to be transformed into perfluoroalkyl compounds under appropriate conditions. Examples include fluorotelomer substances such as 8:2 fluorotelomer alcohol (8:2 FTOH), which has 8 fully fluorinated carbon atoms and 2 terminal carbon atoms with no fluorine atoms attached (Buck et al. 2011) and 10:2 fluorotelomer alcohol (10:2 FTOH).

A.2 Polymeric PFAS

Fluorinated polymers are considered to be PFAS if they contain per- or polyfluoroalkyl moieties. Polymeric PFAS are made from one or more PFAS monomers or involve the use of a fluorosurfactant processing aid (Buck et al. 2011).

There are 2 main types. Both can be a source of lower molecular weight PFAS due to degradation of poly/perfluorinated side chains, or the presence of residual manufacturing impurities (such as processing aids) that are PFAS themselves.

A.2.1 Fluoropolymers

‘Fluoropolymers’ are typically made by the (co)polymerisation of unsaturated monomers – at least one of which contains fluorine atoms bound to one or both of the unsaturated carbon atoms – to form a carbon-only polymer backbone with fluorine atoms directly attached (Buck et al. 2011). Examples include:

- polytetrafluoroethylene (PTFE)

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[25] Perfluorocarbons (PFCs) consist only of fluorine and carbon atoms.

- polyvinylidene fluoride (PVDF)
- fluorinated ethylene propylene (FEP)
- perfluoroalkoxyl polymer (PFA)

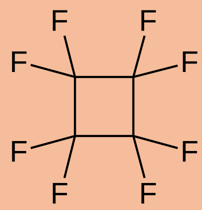
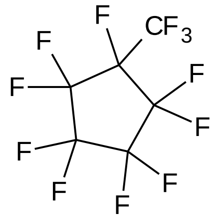
Henry et al. (2018) argued that fluoropolymers are distinctly different from other polymeric and non-polymeric PFAS due to their thermal, chemical, photochemical, hydrolytic, oxidative and biological stability. They have negligible residual monomer and oligomer content and low to negligible leachability. Fluoropolymers have very high molecular weights, are practically insoluble in water and are not subject to long-range transport (Henry et al. 2018).

A.2.2 Side-chain fluorinated polymers

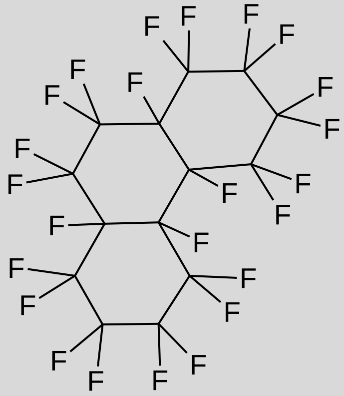
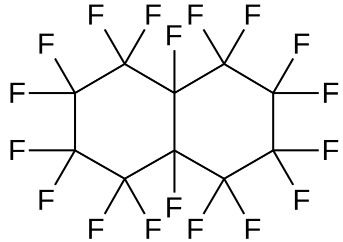
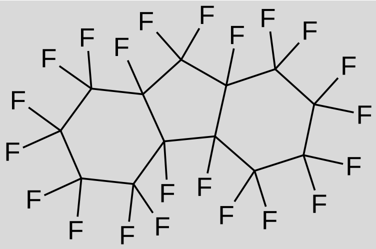
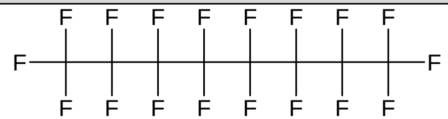
Side-chain fluorinated polymers have a non-fluorinated polymer backbone with fluorinated side chains, ending in $–C_nF_{2n+1}$. Examples are polymers derived from 8:2 FTOH.

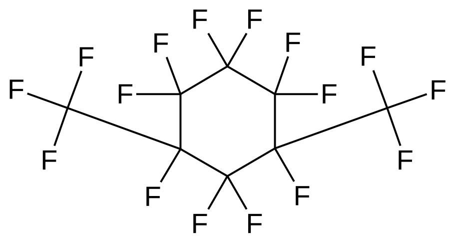
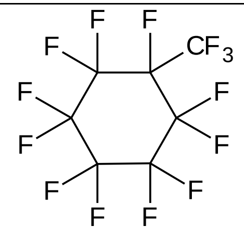
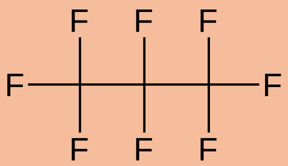
APPENDIX B: PFAS registrations under the REACH Regulation

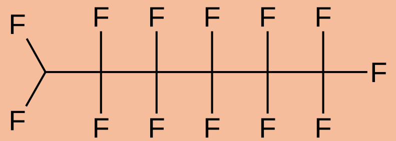
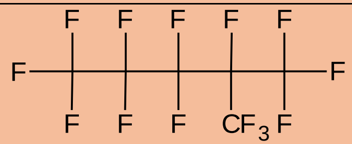
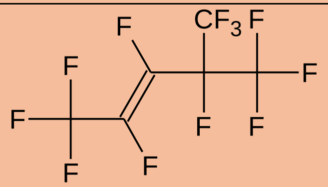
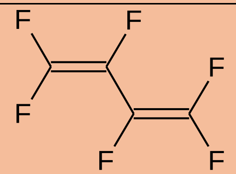
The substances listed below were registered on the ECHA public dissemination website[26] as of 23 November 2018. Those highlighted in grey are former ‘new substances’ under pre-REACH legislation. Substances supplied at 10 tonnes per year or more are highlighted in orange. The substances are presented in general accordance with PFAS family groups set out in Buck et al. (2011).

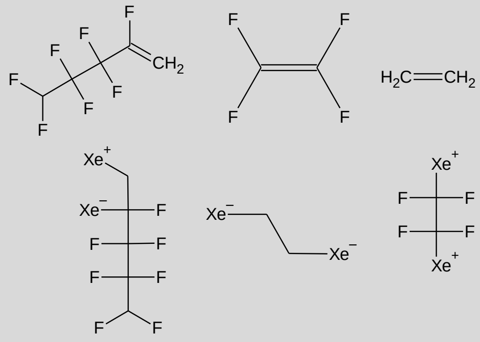
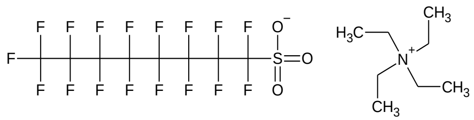
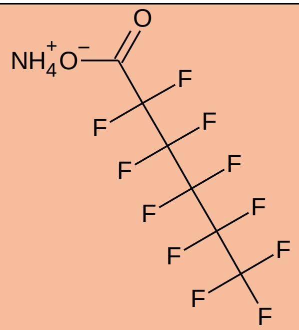
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Perfluorocarbons (PFCs)						
Octafluorocyclobutane	115-25-3	10–100		–	Formulation into mixtures Electronic component manufacture Use for the calibration of analysis equipment	–
Nonafluoro(trifluoromethyl)cyclo-pentane	1805-22-7	0–10		–	Manufacture of the substance	–

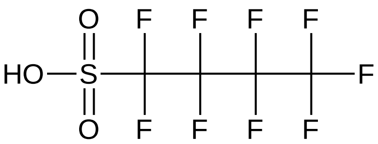
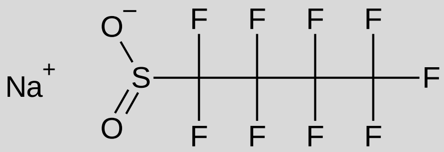
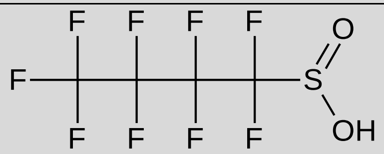
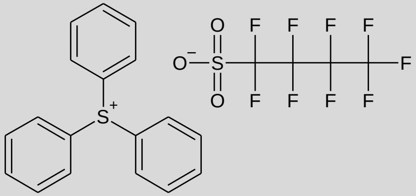
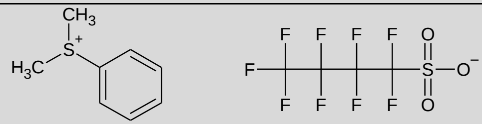
[26] https://echa.europa.eu/information-on-chemicals/registered-substances

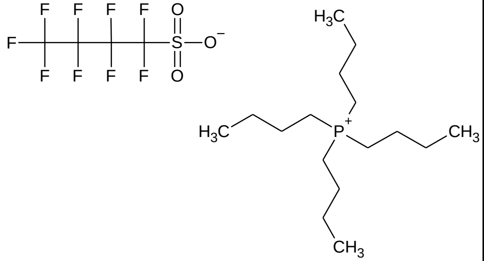
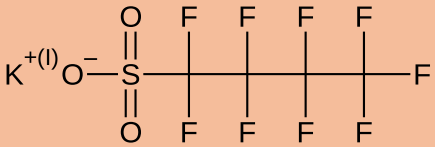
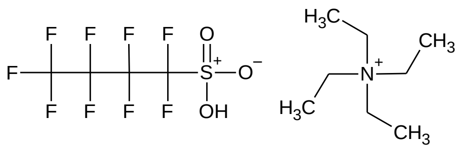
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Perfluoroperhydrophenanthrene	306-91-2	Confidential		–	–	–
Perflunafene	306-94-5	0–10		–	Manufacture of the substance Laboratory chemicals Pharmaceuticals	–
Docosafluorododecahydrofluorene	307-08-4	Confidential		–	–	–
Perfluorooctane	307-34-6	0–10		–	Manufacture of the substance	–

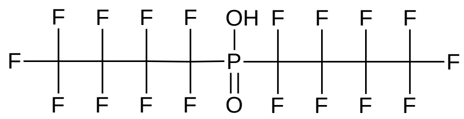
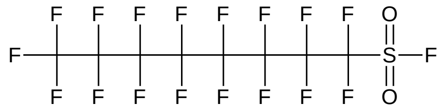
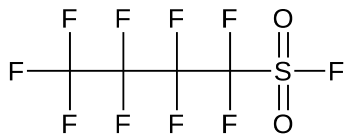
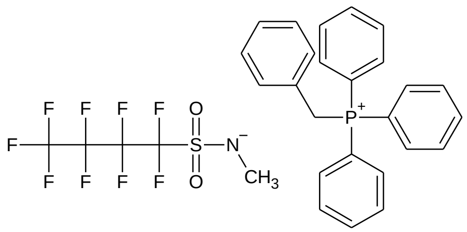
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,1,2,2,3,3,4,5,5,6-Decafluoro-4,6-bis(trifluoromethyl)cyclohexane	335-27-3	0–10		–	Manufacture of the substance Use of non-reactive processing aid at industrial site Manufacture of bulk, large scale chemicals (including petroleum products)	–
Perfluoro(methylcyclohexane)	355-02-2	0–10		–	Manufacture of the substance	–
Octafluoropropane	76-19-7	10–100		–	Manufacture of the substance Processing agent Coolant and detector fluid Calibration of analysis equipment Refrigerant Use as intermediate Solvent in polymerisation process	–

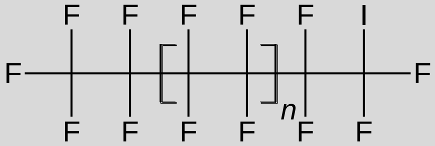
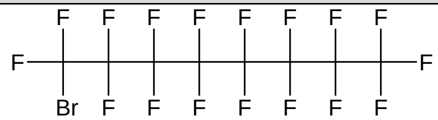
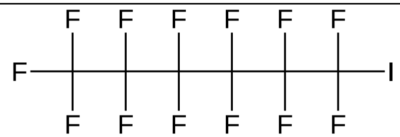
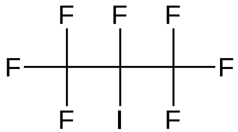
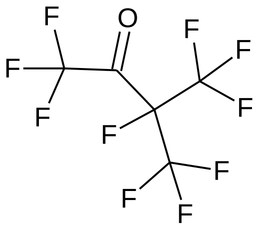
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
					Use for electronic component manufacture Industrial use as cleaning/etching	
Trideca-1,1,1,2,2,3,3,4,4,5,5,6,6-fluorohexane	355-37-3	10–100		–	Formulation into mixtures Use as non-reactive processing aid at industrial site (no inclusion into or onto articles)	–
1,1,1,2,2,3,3,4,5,5,5-Undecafluoro-4-(trifluoromethyl)pentane	355-04-4	100–1,000		–	Manufacture of the substance	–
(E)-1,1,1,2,3,4,5,5,5-Nonafluoro-4-(trifluoromethyl)pent-2-ene [5]	3709-71-5	100–1,000		–	Manufacture of the substance Industrial use in insulation foams	–
1,1,2,3,4,4-Hexafluorobuta-1,3-diene	685-63-2	10–100		–	Manufacture of the substance (directly exported)	Appears to be a structural analogue to a known POP (hexachloro–butadiene)

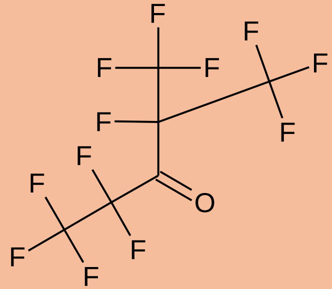
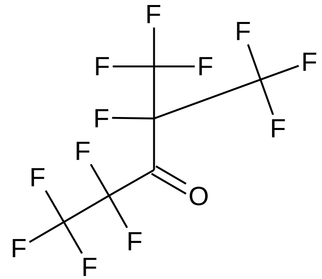
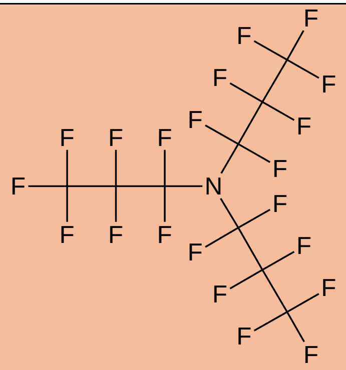
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Poly(1-pentene-2,3,3,4,4,5,5-heptafluoro-co-ethene-co-tetrafluoroethene)	94228-79-2	Confidential		–	–	–
Perfluoroalkyl acids (PFAAs)						
Tetraethylammonium heptadecafluorooctanesulfonate	56773-42-3	0–10		PFOS	Manufacture of the substance Manufacture of fabricated metal products, chromium (VI) metal plating	Addressed by ongoing activity under Stockholm Convention for PFOS
Ammonium undecafluorohexanoate [perfluorohexanoic acid (PFHxA), ammonium salt]	21615-47-4	10–100		PFHxA	Manufacture of polymers	SVHC proposal in 2018 for concerns over drinking water contamination was withdrawn; restriction proposal expected 2019

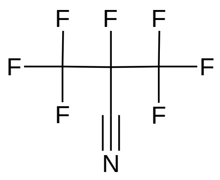
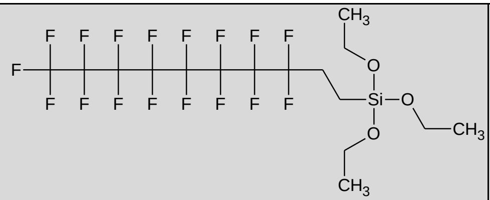
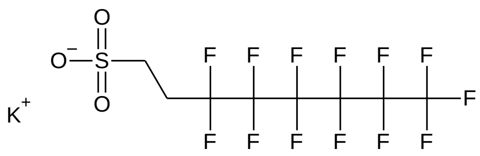
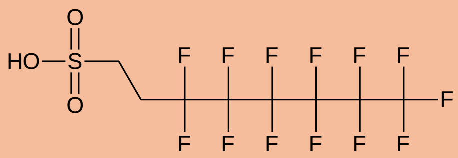
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,1,2,2,3,3,4,4,4-Nonafluorobutane-1-sulfonic acid [perfluorobutane sulfonate, PFBS]	375-73-5	0–10		PFBS	Manufacture of the substance Chemical intermediate Catalyst	RMOA by Norway, 2018 (SVHC identification and restriction proposal likely)
Sodium 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfinate	102061-82-5	Confidential		PFBS	–	See CAS no. 375-73-5
Perfluorobutanesulfinic acid	34642-43-8	Confidential		PFBS	–	See CAS no. 375-73-5
Triphenylsulfonium perfluoro-1-butanesufonate	144317-44-2	Confidential		PFBS	–	See CAS no. 375-73-5
Dimethyl(phenyl)sulfanium nonafluorobutane-1-sulfonate	220133-51-7	Confidential		PFBS	–	See CAS no. 375-73-5

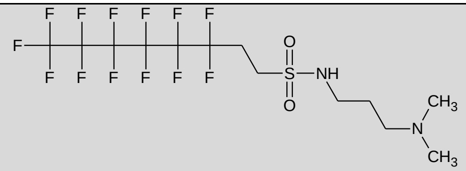
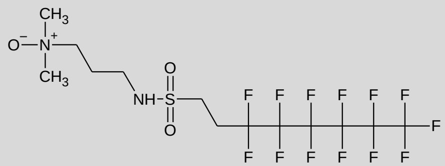
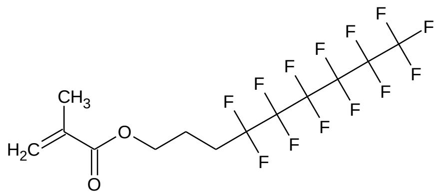
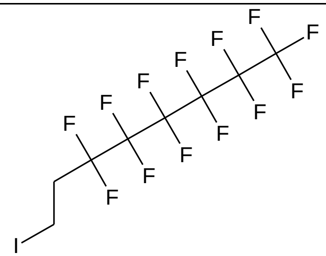
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Tetrabutyl-phosphonium nonafluoro-butane-1-sulfonate [6]	220689-12-3	1+		PFBS	Manufacture of the substance Manufacture of polymer preparations Production of plastic articles	See CAS no. 375-73-5
Potassium 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate	29420-49-3	10–100		PFBS	Manufacture of the substance Formulation of polymer preparations Use as an additive/reactant in polymerisation process Laboratory use Manufacture of plastic articles Chemical intermediate	See CAS no. 375-73-5
N,N,N,-Triethylethanaminium 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate	25628-08-4	0–10		PFBS	Manufacture of the substance Manufacture of fabricated metal products, except machinery and equipment	See CAS no. 375-73-55

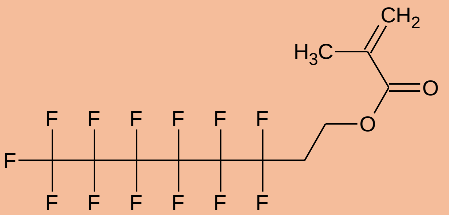
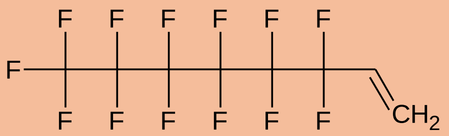
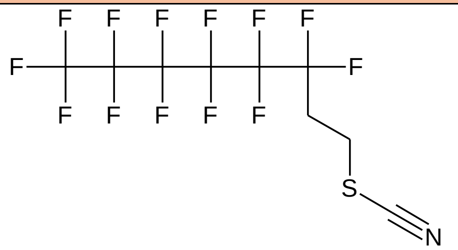
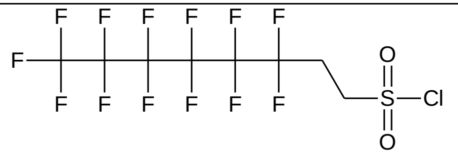
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Bis(nonafluorobutyl)phosphinic acid	52299-25-9	0–10		–	Manufacture of the substance Metal surface treatment chemical Laboratory chemical Chemical intermediate	Substance Evaluation by Germany, 2018 (PBT/vPvB concern)
Perfluoroalkane sulfonyl fluorides (PASFs)						
Heptadecafluorooctanesulfonyl fluoride	307-35-7	–		PFOS	Chemical intermediate	See CAS no. 56773-42-3
1,1,2,2,3,3,4,4,4-Nonafluorobutane-1-sulfonyl fluoride	375-72-4	–		PFBS	Chemical intermediate	See CAS no. 375-73-55
Perfluoroalkane sulfonamides (FASAs)						
Triphenyl(phenylmethyl)phosphonium 1,1,2,2,3,3,4,4,4-nonafluoro-N-methyl-1-butanesulfonamide (1:1)	332350-93-3	Confidential		PFBS	–	See CAS no. 375-73-5

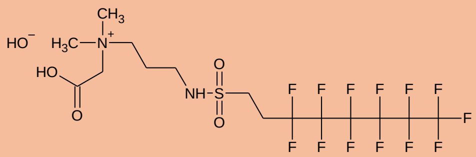
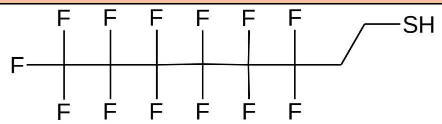
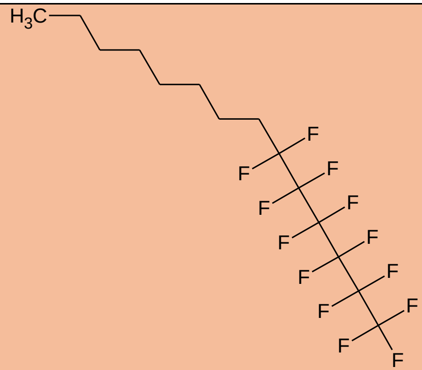
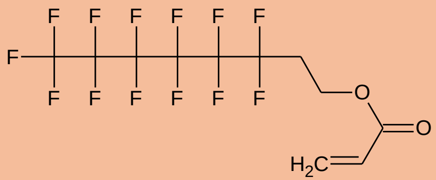
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Perfluoroalkyl iodides (PFAIs) and perfluoroalkyl bromides (PFABs)						
Alkyl iodides, C6-18, perfluoro	90622-71-2	–	 n=1-7	PFOA and long-chain PFCAs	Chemical intermediate	Exempt from EU PFOA restriction??
1-Bromoheptadecafluorooctane	423-55-2	0–10		PFOA	Processing aid in the manufacture of pharmaceuticals	Addressed by EU PFOA restriction
1,1,1,2,2,3,3,4,4,5,5,6,6-Tridecafluoro-6-iodohexane	355-43-1	–		PFHxA?	Chemical intermediate	–
1,1,1,2,3,3,3-Heptafluoro-2-iodopropane	677-69-0	–		–	Chemical intermediate	–
Other perfluoroalkyl substances						
1,1,1,3,4,4,4-Heptafluoro-3-(trifluoromethyl)butan-2-one	756-12-7	0–10		–	Use of substance as an insulator in closed electrical/ electronic equipment Closed heat transfer agent in thermal management systems	–

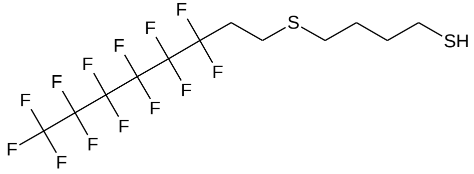
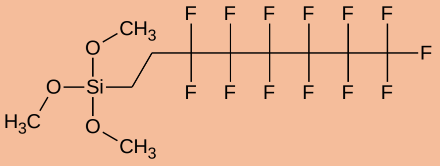
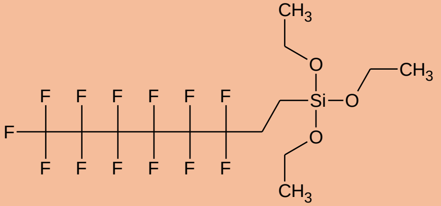
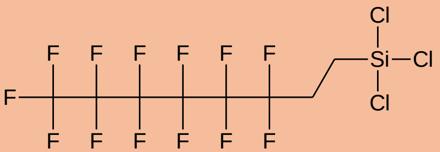
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,1,1,2,2,4,5,5,5-Nonafluoro-4-(trifluoromethyl)-3-pentanone	756-13-8	1,000+		–	Formulation into mixtures Use as a cover gas Use as a functional fluid in a closed system	Dossier Evaluation on a testing proposal. ECHA Decision dated 14 September 2011
1,1,1,2,2,4,5,5,5-Nonafluoro-4-(trifluoromethyl)-3-pentanone	756-13-8	0–10		–	Gaseous fire suppression Use as a functional fluid in a closed system	Dossier Evaluation on a testing proposal. ECHA Decision dated 14 September 2011
1-Propanamine, 1,1,2,2,3,3,3-heptafluoro-N,N-bis(1,1,2,2,3,3,3-heptafluoropropyl)- [Perfluamine]	338-83-0	100–1,000		–	Manufacture of the substance Formulation of mixtures Functional fluid at industrial sites Non-reactive processing aid at industrial sites	Substance Evaluation by Belgium, 2020 (suspected PBT/vPvB)

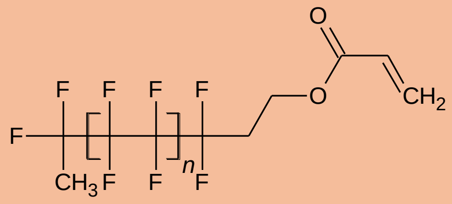
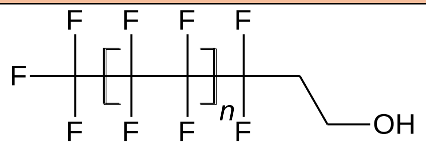
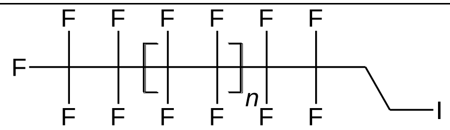
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
2,3,3,3-Tetrafluoro-2-(trifluoromethyl)propanenitrile	42532-60-5	0–10		–	Functional fluid (insulator on manufacture of computer, electronic and optical products, electrical equipment; electricity, steam, gas water supply; and sewage treatment)	–
Polyfluoroalkyl substances						
Triethoxy(3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)silane	101947-16-4	Confidential		PFNA/PFOA	–	Addressed by restriction of PFOA and higher homologues
Potassium 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonate	59587-38-1	0–10		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Manufacture of plastics products, including compounding and conversion	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctanesulfonic acid	27619-97-2	10–100		PFHpA/PFHxA, 6:2 FTOH	Formulation for metal treatment Industrial use as fluoropolymer and fluoroelastomer processing aid	See CAS no. 21615-47-4

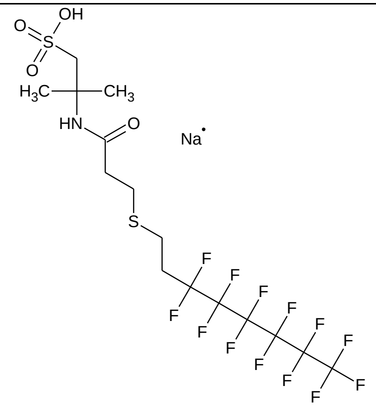
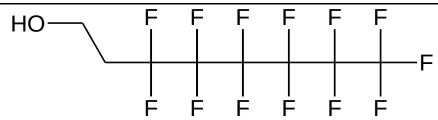
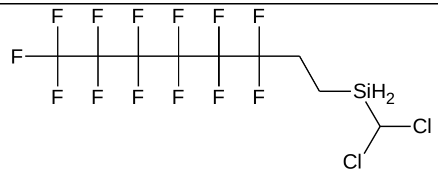
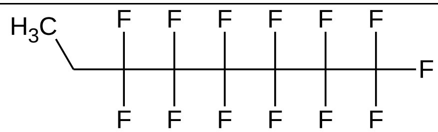
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
N-[3-(Dimethylamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-octane-1-sulfonamide	34455-22-6	–		PFHpA/PFHxA, 6:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4
N-[3-(Dimethylamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonamide N-oxide	80475-32-7	10–100		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Formulation into mixtures Industrial use in paint Professional use in fire-fighting foams	See CAS no. 21615-47-4
4,4,5,5,6,6,7,7,8,8,9,9,9-Tridecafluorononyl methacrylate	1228350-17-1	0–10		PFHpA/PFHxA 6:2 FTOH	Manufacture of the substance Manufacture of fine chemicals	See CAS no. 21615-47-4
1,1,1,2,2,3,3,4,4,5,5,6,6-Tridecafluoro-8-iodooctane	2043-57-4	–		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Chemical intermediate	See CAS no. 21615-47-4

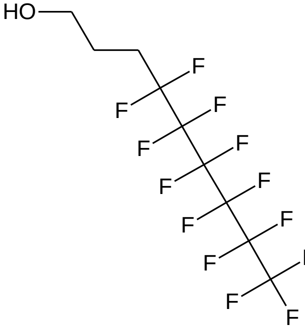
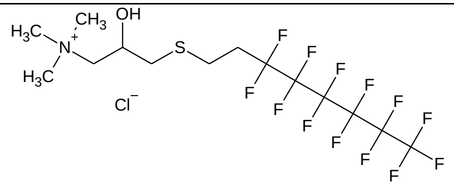
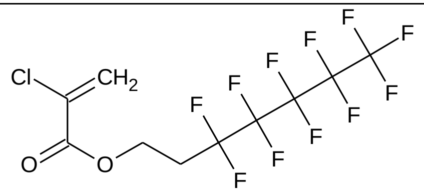
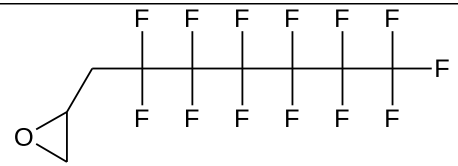
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl methacrylate	2144-53-8	100–1,000		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Monomer for manufacture of polymers	Substance Evaluation by Germany, 2016 (endocrine disruption and PBT concerns) See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooct-1-ene	25291-17-2	10–100		PFHpA/PFHxA	Manufacture of intermediate Monomer in polymerisation processes Non-metal surface treatment products	See CAS no. 21615-47-4
Thiocyanic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	26650-09-9	–		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance for use as an isolated intermediate	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctanesulfonyl chloride	27619-89-2	–		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance for use as an isolated intermediate	See CAS no. 21615-47-4

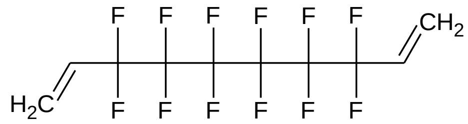
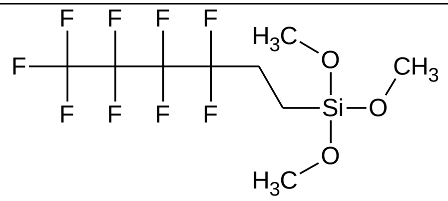
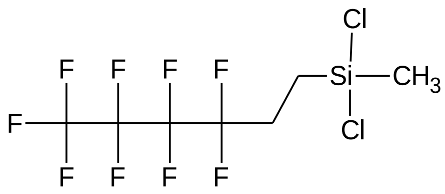
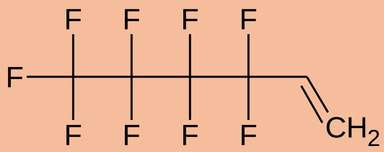
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]propylammonium hydroxide	34455-29-3	100–1,000		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Formulation into mixtures Industrial use in inks and films Professional use in fire-fighting foams Consumer use in portable fire extinguishers	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-thiol	34451-26-8	0–10		PFHpA/PFHxA, 6:2 FTOH	Use as intermediate	See CAS no. 21615-47-4
1,1,1,2,2,3,3,4,4,5,5,6,6-Tridecafluorotetradecane [6]	133331-77-8	10–100		PFHpA/PFHxA 6:2 FTOH	Manufacture of the substance Use at industrial sites leading to inclusion into/onto article	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl acrylate	17527-29-6	100–1,000		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Monomer for manufacture of polymers	Substance Evaluation by Germany, 2016 (endocrine disruption and PBT concerns)

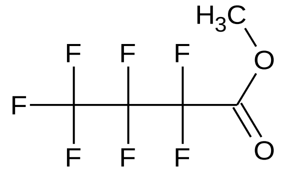
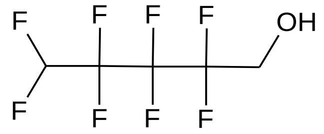
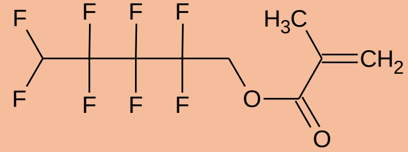
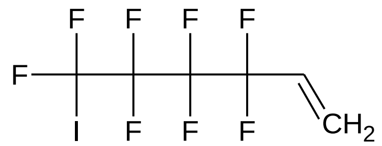
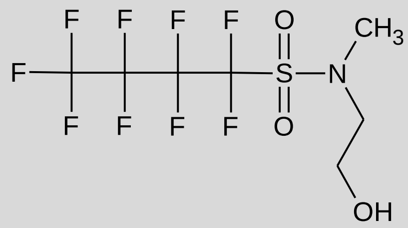
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
						See CAS no. 21615-47-4
4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl)thio]butane-1-thiol	36097-07-1	0–10		PFHpA/PFHxA, 6:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4
Trimethoxy(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane	85857-16-5	10–100		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Formulation into mixtures Non-metal surface treatment Laboratory chemical	See CAS no. 21615-47-4
Triethoxy(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane	51851-37-7	10–100		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Preparation of pre-treatment solutions Use of non-metal surface treatments Use as a chemical intermediate at the production site	See CAS no. 21615-47-4
Trichloro(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane	78560-45-9	10–100		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Non-metal surface treatment agent Use as an intermediate at production site and by downstream users	See CAS no. 21615-47-4

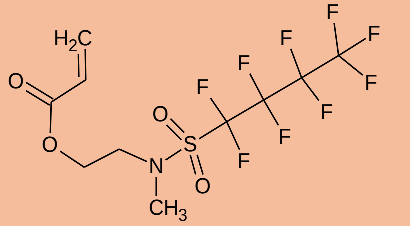
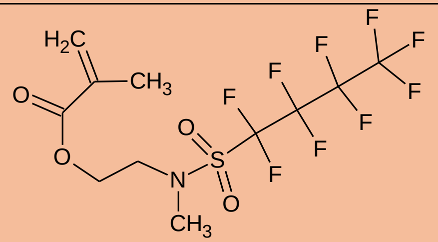
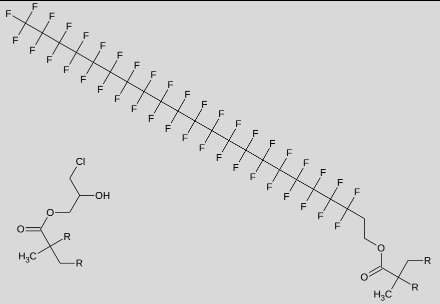
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
2-Propenoic acid, γ-ω-perfluoro-C8-14-alkyl esters	85631-54-5	100–1,000	 n=2-5	PFHpA/PFHxA, 6:2 FTOH and higher homologues	Manufacture of the substance Formulation and re-packing Monomer in polymerisation processes at industrial sites	See CAS no. 21615-47-4
Alcohols, C8-14, γ-ω-perfluoro	68391-08-2	–	 n=2-5	PFHpA/PFHxA, 6:2 FTOH and higher homologues	Manufacture of the substance Chemical intermediate	See CAS no. 21615-47-4
Alkyl iodides, C8-14, γ-ω-perfluoro	85995-91-1	–	 n=1-4	PFHpA/PFHxA, 6:2 FTOH and higher homologues	Chemical intermediate	See CAS no. 21615-47-4 and PFOA restriction

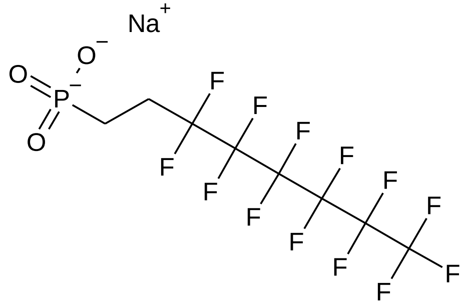
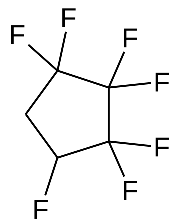
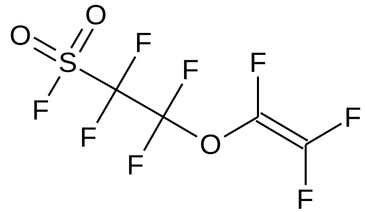
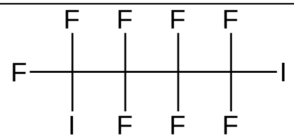
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
2-Methyl-2-[(1-oxo-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]propyl)amino]-1-propanesulfonic acid, sodium salt	62880-93-7	0–10		PFHpA/PFHxA, 6:2 FTOH	Use in fire-fighting foams Use in coatings and paints, thinners, paint removers	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctan-1-ol [6:2 fluorotelomer alcohol, 6:2 FTOH]	647-42-7	–		PFHpA/PFHxA, 6:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4
Dichloromethyl(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane [5]	73609-36-6	0–10		PFHpA/PFHxA, 6:2 FTOH	Manufacture of the substance Chemical intermediate	See CAS no. 21615-47-4
1,1,1,2,2,3,3,4,4,5,5,6,6-Tridecafluorooctane	80793-17-5	0–10		PFHpA/PFHxA, 6:2 FTOH	Used as a solvent Used as a heat transfer fluid	See CAS no. 21615-47-4

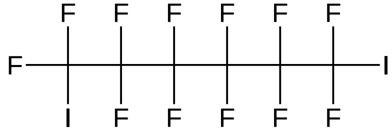
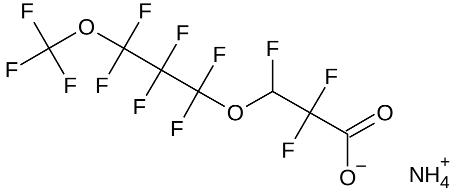
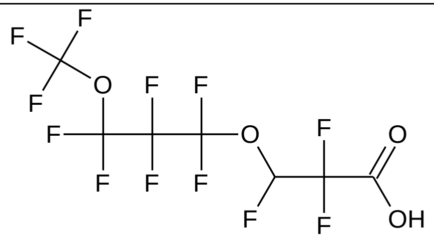
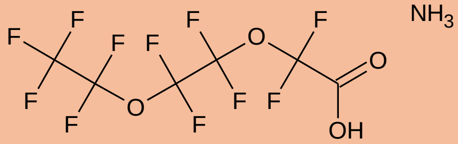
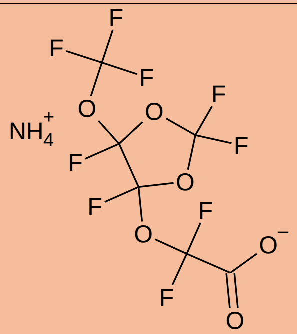
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
4,4,5,5,6,6,7,7,8,8,9,9,9-Tridecafluorononan-1-ol	80806-68-4	–		PFHpA/PFHxA, 6:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4
2-Hydroxy-N,N,N-trimethyl-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]propan-1-aminium chloride	88992-45-4	0–10		PFHpA/PFHxA, 6:2 FTOH	Use in fire-fighting foams Use in coatings and paints, thinners, paint removers	See CAS no. 21615-47-4
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl 2-chloroacrylate	96383-55-0	0–10		PFHxA, 5:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4
(2,2,3,3,4,4,5,5,6,6,7,7,7-Tridecafluoroheptyl)oxirane	38565-52-5	-		PFHpA/PFHxA, 6:2 FTOH	Chemical intermediate	See CAS no. 21615-47-4

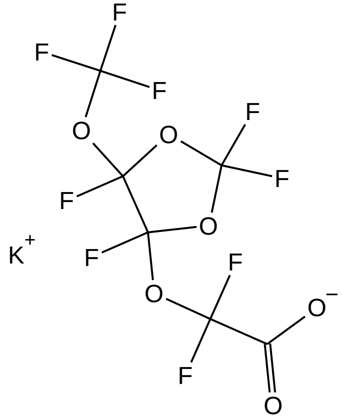
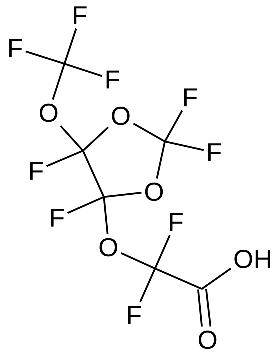
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
3,3,4,4,5,5,6,6,7,7,8,8-Dodecafluorodeca-1,9-diene	1800-91-5	0–10		–	Manufacture of the substance Manufacture of rubber products for the automotive industry	–
Silane, trimethoxy(3,3,4,4,5,5,6,6,6-nonafluorohexyl)-	85877-79-8	Confidential		PFPeA 4:2 FTOH	-	Dossier Evaluation concluded
Dichloromethyl(3,3,4,4,5,5,6,6,6-nonafluorohexyl)silane	38436-16-7	0–10		PFPeA 4:2 FTOH	Substance is manufactured and used as a monomer in polymer production outside the EU. The polymer does not contain the registered substance as it reacts fully during polymerisation	–
3,3,4,4,5,5,6,6,6-Nonafluorohexene	19430-93-4	100–1,000		PFPeA	Monomer for manufacture of (imported) polymers Chemical intermediate	Dossier Evaluation on a testing proposal. ECHA Decision dated 11 January 2016

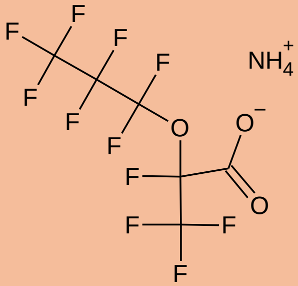
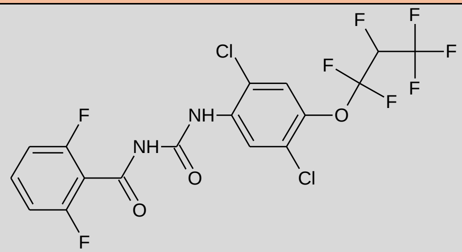
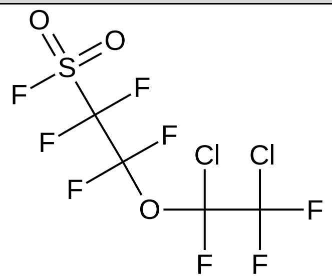
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Methyl heptafluorobutyrate	356-24-1	–		PFBA	Chemical intermediate	–
2,2,3,3,4,4,5,5-Octafluoropentan-1-ol	355-80-6	–		–	Chemical intermediate	–
2,2,3,3,4,4,5,5-Octafluoropentyl methacrylate	355-93-1	10–100		CAS no. 355–80–6	Manufacture of the substance Formulation into cosmetic products	–
3,3,4,4,5,5,6,6-Octafluoro-6-iodohex-1-ene	203929-12-8	–		–	Chemical intermediate Use as chain transfer agent in polymerisation reactions	–
1,1,2,2,3,3,4,4,4-Nonafluoro-N-(2-hydroxyethyl)-N-methylbutane-1-sulfonamide	34454-97-2	10–100		PFBS	Manufacture of the substance Use as intermediate or monomer in form of flakes or liquid substance Monomer in imported polymers	See CAS no. 375-73-5

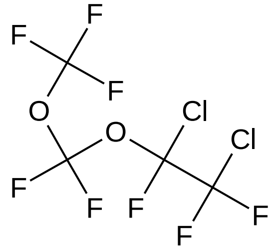
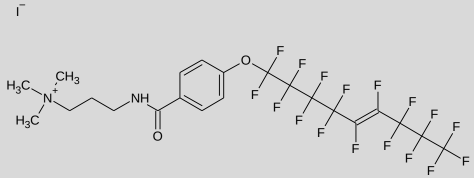
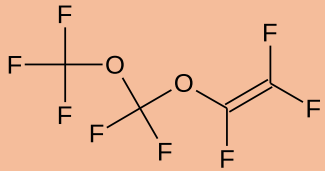
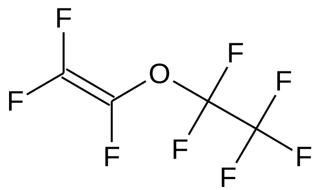
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
2-[Methyl[(nonafluorobutyl)-sulfonyl]amino]ethyl acrylate	67584-55-8	100–1,000		PFBS	Manufacture of the substance Monomer in polymerisation processes at industrial sites	See CAS no. 375-73-5
2-[Methyl[(nonafluorobutyl)-sulfonyl]amino]ethyl methacrylate	67584-59-2	10–100		PFBS	Manufacture of the substance Monomer for (imported) polymers (inclusion or not into/onto article)	See CAS no. 375-73-5
Poly(α-fluoro-ω-methacryloyloxyethylpoly(difluoro-methylene)-co-3-chloro-2-hydroxypropylmethacrylate)	101896-32-6	Confidential		Unknown	–	–

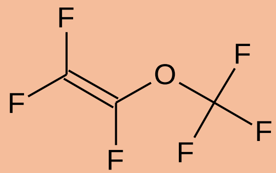
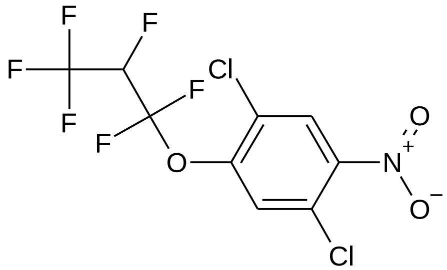
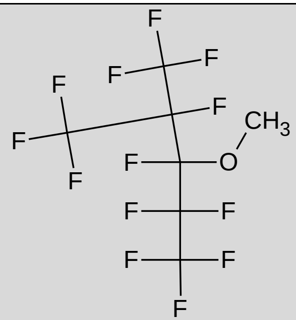
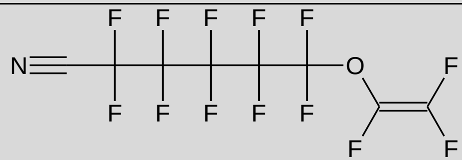
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Tridecafluorooctyl-phosphonic acid sodium salt (1:1)	1189052-95-6	0–10		C8–PFPA (perfluorooctyl phosphonic acid)	Fragrance and cosmetics	–
1,1,2,2,3,3,4-Heptafluorocyclopentane[6]	15290-77-4	0–10		–	Semiconductors Washing and cleaning product Manufacture of computer, electronic and optical products, electrical equipment	–
1,1,2,2-tetrafluoro-2-[(trifluorovinyl)oxy]ethanesulfonyl fluoride	29514-94-1	0–10		–	Manufacture of the substance Manufacture of plastics products, including compounding and conversion	–
1,1,2,2,3,3,4,4-Octafluoro-1,4-diiodobutane	375-50-8	–		–	Chemical intermediate	–

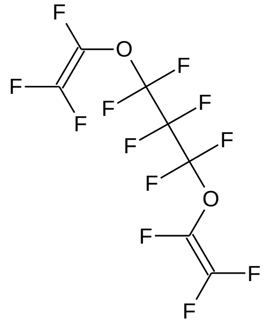
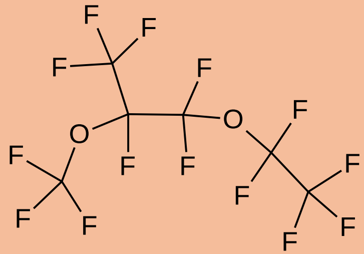
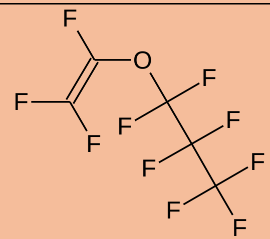
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,6-Diiodoperfluorohexane	375-80-4	–		–	Chemical intermediate	–
ammonium 2,2,3 trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluormethoxypropoxy), propionate (ADONA)	–	0–10		–	Use as a non-reactive processing aid at industrial sites Used in polymer production	Substance Evaluation by Germany, 2017 (PBT concern)
2,2,3-Trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)-propoxy]propanoic acid	919005-14-4	–		–	Chemical intermediate	–
Ammonium difluoro[1,1,2,2-tetrafluoro-2-(pentafluoroethoxy)ethoxy]acetate	908020-52-0	10–100		–	Use as a non-reactive processing aid at industrial sites	Substance Evaluation by Germany, 2017 (PBT concern)
Ammonium difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy}acetate	1190931-27-1	10–100		–	Manufacture of the substance Polymerisation aid in fluoropolymer production	–

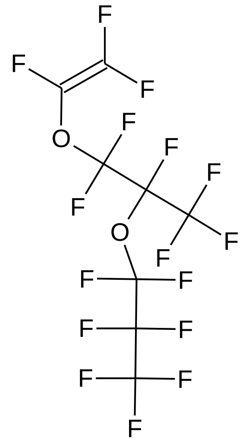
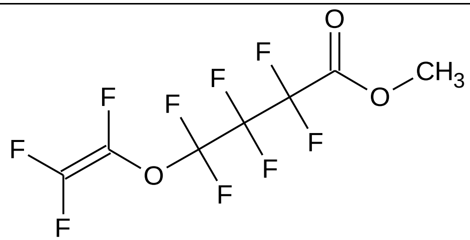
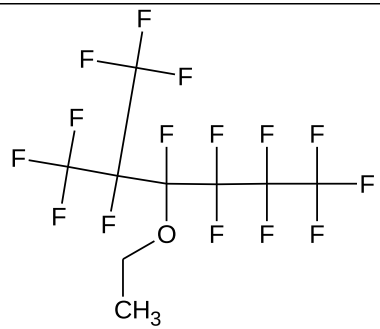
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Potassium difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy}acetate	1190931-39-5	–		–	Chemical intermediate	–
Difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy}acetic acid	1190931-41-9	–		–	Chemical intermediate	–

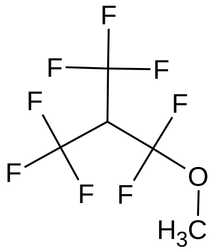
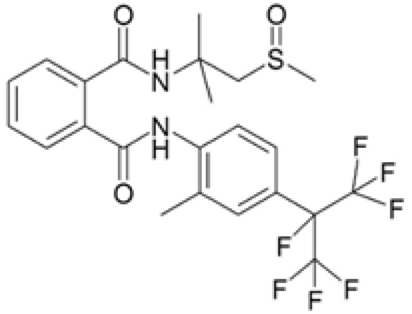
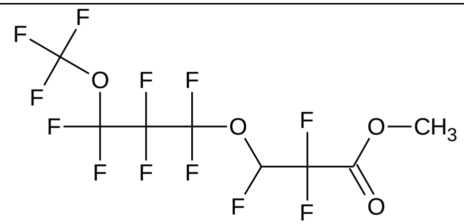
Substance[1] (trade name if available)	**CAS no.**	**Annual tonnage band**	**Chemical structure (example)**	**Potential terminal transformation product of concern[2]**	**Use according to registration[3]**	**Regulatory activity[4]**
Ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate (FRD-902 or GEN-X)	62037-80-3	10–100		–	Processing aid for polymerisation	Substance Evaluation by Germany and Netherlands, 2017 (PBT concerns) RMOA by Netherlands, 2018
N-[2,5-Dichloro-4-(1,1,2,3,3,3-hexafluoropropoxy)-phenyl-aminocarbonyl]-2,6-difluorobenzamide (Lufenuron)	103055-07-8	Confidential		–	(Known to be used as a pesticide but no approvals in UK)	–
2-(1,2-Dichloro-1,2,2-trifluoroethoxy)-1,1,2,2-tetrafluoroethanesulfonyl fluoride	144728-59-6	–		–	Chemical intermediate	–

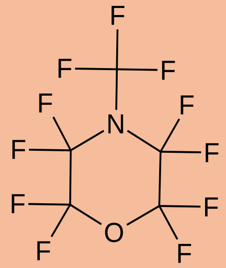
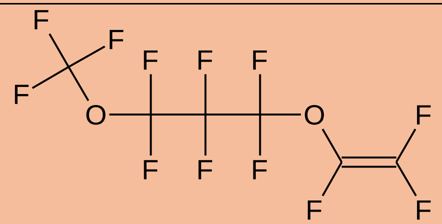
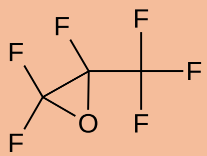
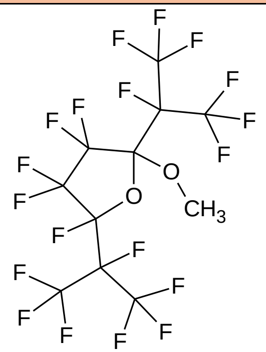
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,2-Dichloro-1-[difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoroethane,	874288-98-9	–		–	Chemical intermediate	–
1-[3-[4-((Heptadecafluorononyl)oxy)-benzamido]propyl]-N,N,N-trimethylammonium iodide	59493-72-0	Confidential		–	–	–
{Difluoro[(1,2,2-trifluoroethenyl)oxy]-methoxy}trifluoromethane	700874-87-9	10–100		–	Manufacture of the substance Monomer in polymerisation processes	–
Trifluoro(pentafluoroethoxy)ethylene	10493-43-3	0–10		–	Import in another monomer Intermediate Polymer preparations and compounds Manufacture of plastics products, including compounding and conversion	–

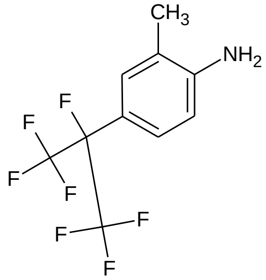
Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
Trifluoro(trifluoromethoxy)ethylene	1187-93-5	100–1,000		–	Monomer for manufacture of (imported) polymers	Dossier Evaluation on a testing method proposal. ECHA Decision dated 25 November 2014
1,4-Dichloro-2-(1,1,2,3,3,3-hexafluoropropoxy)-5-nitrobenzene[6]	130841-23-5	–		–	Manufacture of the substance Chemical intermediate	–
1,1,1,2,2,3,4,5,5,5-Decafluoro-3-methoxy-4-(trifluoromethyl)pentane	132182-92-4	Confidential		–	–	–
2,2,3,3,4,4,5,5,6,6-Decafluoro-6-trifluorovinyloxyhexanenitrile	120903-40-4	Confidential		–	–	–

Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,1,2,2,3,3-Hexafluoro-1,3-bis[(trifluorovinyl)oxy]propane	13846-22-5	–		–	Chemical intermediate	–
Hexafluoropropene, oxidised, oligomers, reduced, fluorinated	161075-00-9	10–100		–	Manufacture of the substance Formulation into mixtures Heat transfer fluid at industrial sites	Dossier Evaluation on a testing proposal ECHA Decision concluded
1,1,1,2,2,3,3-Heptafluoro-3-[(trifluorovinyl)oxy]propane	1623-05-8	100–1,000		–	Manufacture of the substance Monomer for manufacture of (imported) polymers	–

Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
1,1,1,2,3,3-Hexafluoro-2-(heptafluoropropoxy)-3-[(trifluorovinyl)oxy]propane	1644-11-7	0–10		–	Manufacture of the substance Monomer for manufacture of polymers	–
Methyl 2,2,3,3,4,4-hexafluoro-4-[(1,2,2-trifluoroethenyl)oxy]butanoate	19190-61-5	0–10		–	Monomer bound within an imported polymer	–
3-Ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl)-hexane[6]	297730-93-9	0–10		–	Use of functional fluid at industrial site and in motor vehicles	Substance Evaluation by Spain, 2018 (suspected PBT/vPvB)

Substance[1] (trade name if available)	**CAS no.**	**Annual tonnage band**	**Chemical structure (example)**	**Potential terminal transformation product of concern[2]**	**Use according to registration[3]**	**Regulatory activity[4]**
2-[Difluoro(methoxy)methyl]-1,1,1,3,3,3-hexafluoropropane	382-26-3	–		–	Chemical intermediate	–
N-(2-Methylsulfinyl-1,1-dimethyl-ethyl)-N'-{2-methyl-4-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]phenyl}-phthalamide	371771-07-2	–		–	Chemical intermediate	–
Methyl 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]propanoate	958445-54-0	-		–	Manufacture of the substance Chemical intermediate	–

Substance[1] (trade name if available)	CAS no.	Annual tonnage band	Chemical structure (example)	Potential terminal transformation product of concern[2]	Use according to registration[3]	Regulatory activity[4]
2,2,3,3,5,5,6,6-Octafluoro-4-(trifluoromethyl)morpholine	382-28-5	100–1,000		–	Manufacture of the substance Formulation of mixtures Use of functional fluid at industrial sites	–
1,1,2,2,3,3-Hexafluoro-1-trifluoromethoxy-3-trifluorovinyloxypropane	40573-09-9	10–100		–	Manufacture of the substance Monomer in polymerisation	–
Trifluoro(trifluoromethyl)oxirane	428-59-1	100–1,000		–	Manufacture of the substance Monomer for (imported) polymers Chemical intermediate	–
2,3,3,4,4-Pentafluoro-2,5-bis(1,1,1,2,3,3,3-heptafluoropropan-2-yl)-5-methoxytetrahydrofuran	957209-18-6	0–10		–	Functional fluid on industrial sites	–

Substance[1] (trade name if available)	**CAS no.**	**Annual tonnage band**	**Chemical structure (example)**	**Potential terminal transformation product of concern[2]**	**Use according to registration[3]**	**Regulatory activity[4]**
4-(1,1,1,2,3,3,3-Heptafluoropropan-2-yl)-2-methylaniline	238098-26-5	–		–	Manufacture of the substance Chemical intermediate Manufacture of fine chemicals	–

Notes:

[1] Substances highlighted in grey are former 'new substances' under pre-REACH legislation. Substances supplied at 10 tonnes per year or more are highlighted in orange.
[2] This is an additional consideration to any potential intrinsic hazard of an individual substance which may aid grouping or targeted assessment. It is based on the chemical structure of the substance rather than any specific evidence of degradation. For example, a fully fluorinated C8 carbon chain attached to another carbon atom may degrade to a C9 carboxylic acid (PFNA) or potentially a C8 carboxylic acid (PFOA).
[3] Chemical Safety Reports have not been evaluated for this report. The information presented is publicly available.
[4] ECHA, PACT search dated 10 December 2018 ()
[5] Two registrations are listed for this substance.
[6] Also listed under NONS.