Environment Agency

# Environmental risk evaluation report: Hexafluoropropene [HFP]

# (CAS no. 116-15-4)

## Chief Scientist’s Group report

April 2023

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Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

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Email: research@environment-agency.gov.uk

Author(s):
Chemicals Assessment Unit, Environment Agency

Keywords:
Perfluorinated alkyl substances, PFAS, PFC, perfluoroalkenes, hexafluoropropene, perfluoropropene, HFP

Environment Agency’s Project Executive:
Steve Dungey

Citation:
Environment Agency (2023) Environmental risk evaluation reports: Hexafluoropropene [HFP] (CAS no. 116-15-4). Environment Agency, Bristol

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Dr Robert Bradburne
**Chief Scientist**

# Acknowledgements

The co-operation and additional information provided by the sole UK supplier, F2 Chemicals Ltd, is acknowledged.

# Executive summary

There is growing regulatory concern at international level about the emissions of per- and polyfluoroalkyl substances (PFAS) to the environment. This is due to their extreme persistence, which could lead to long-term exposure of both people and wildlife. High levels of exposure to certain PFAS have also been shown to cause harmful effects in humans and some have been declared to be ‘Persistent Organic Pollutants’ (POPs) under the United Nations Environment Programme (UNEP) Stockholm Convention.

The UK Government is developing an action plan to address the concerns arising from PFAS. As a contribution to this work, the Environment Agency informally reviewed several PFAS that are known to be made or used at two UK production facilities. The substance reviewed in this evaluation report is hexafluoropropene or HFP (CAS no. 116-15-4).

HFP is a PFAS belonging to the group of perfluoroalkenes and it is a gas at standard environmental temperatures and pressures. It is produced predominantly as a raw material for manufacture of other PFAS (see Section 2 for further details).

The Environment Agency has identified publicly available information on the regulatory status, uses, physico-chemical properties, environmental fate and (eco)toxicity of HFP and has reviewed this information for reliability. Further information has also been sought from the UK users. The data have then been used to conduct an environmental hazard and risk assessment. Human health hazards have only been reviewed in so far as they are relevant for the environmental assessment. Potential risks to people following environmental exposure have not been addressed.

HFP is not readily biodegradable and there is no evidence that it significantly degrades via abiotic mechanisms such as hydrolysis. HFP therefore screens as Persistent (P) or very Persistent (vP). However, there is evidence to show that HFP photolytically degrades in the atmosphere. There are no valid experimental aquatic bioconcentration data and also no experimental log $K_{OW}$ data for HFP itself. In the absence of better information and based on Quantitative Structure-Activity Relationship (QSAR) approaches, the indicative log $K_{OW}$ for HFP of around 2 (Section 5.4) suggests that it does not screen as potentially Bioaccumulative (B) in aquatic organisms. HFP is also a gas and so this might not be a relevant trigger. There are some indications of retention in mammalian tissues (which is possibly non-lipid mediated) but also of elimination by exhalation of high vapour pressure perfluorocarbons in mammalian studies.

There are no measured ecotoxicity data on HFP itself to determine whether it meets the ‘T’ criteria for ecotoxicity. However, as HFP is a gas its high volatility could make testing difficult. Whilst there are some uncertainties with the assumptions made, the information considered in Section 7 indicates overall that HFP is unlikely to exhibit significant toxicity to aquatic or soil-dwelling organisms.

Draft criteria have been proposed by the EU to identify chemicals that are persistent, mobile and toxic (PMT) or very persistent and very mobile (vPvM). HFP screens as P/vP and vM and human health self-classifications indicate it might also be T. Based on these draft criteria therefore, it could pose a concern for groundwaters. However, HFP is a gas and the influence of volatility is not currently considered under these criteria.

The substance is expected to partition predominantly to air. Available information suggests that HFP also has the potential for long-range transport. It is not a greenhouse gas and is expected to have a low global warming potential (GWP), with a 100-year GWP in the order of <1 (see Section 9.5). No data are available on effects on plants via aerial exposure.

HFP is used as a raw material in the production of other substances at a single site, and is expected to be mostly consumed in the reaction process. However, given the physico-chemical properties of HFP, a small proportion of the overall production volume could eventually end up in the atmosphere (unless specific measures are taken to recover or destroy this).

Overall, the Environment Agency considers that the direct risk to the aquatic and terrestrial environment from HFP is likely to be low. Risks via atmospheric exposure cannot be assessed due to lack of information.

A number of recommendations are made to the UK supplier to improve the data package to allow a more robust assessment of the environmental hazards, exposure and risks posed by HFP. In particular these relate to supporting and improving the scientific justifications for the data waivers in the physico-chemical properties, ecotoxicity and mammalian toxicity sections of their dossier. Further information on the expected emissions of HFP would also provide a more robust exposure assessment.

This report, along with others in this series, will be used by the Environment Agency to inform the UK Government action plan on PFAS and the PFAS Regulatory Management Options Analysis (RMOA) being conducted under the UK REACH Regulations.

# Introduction

There is growing international concern about the emissions of per- and polyfluoroalkyl substances (PFAS) to the environment. This is principally due to their extreme persistence, which could lead to long-term irreversible exposure of both people and wildlife. High levels of exposure to certain PFAS have also been shown to cause harmful effects in humans and some have been declared to be 'Persistent Organic Pollutants' (POPs) under the United Nations Environment Programme (UNEP) Stockholm Convention.

The UK Government is developing an action plan to address the concerns arising from PFAS. As a contribution to this work, the Environment Agency informally reviewed several substances that are made or used at two known production facilities in the UK, namely AGC Chemicals Europe Ltd of Thornton Cleveleys, Lancashire and F2 Chemicals Ltd of Preston, Lancashire.  Based on information provided by these companies, a provisional list of PFAS for further consideration was drawn up. This was narrowed down to the following eight substances which were, at the time, registered at more than 1 tonne per year under the EU REACH Regulation[1] and subsequently also under UK REACH. Additionally a potential substitute for perfluoroctanesulfonic acid (PFOS, which is a known POP) was included that had been identified from UK surface water monitoring. All the substances chosen for further evaluation are listed below, initially using their EU-registered name:

- Ammonium difluoro[1,1,2,2-tetrafluoro-2-(pentafluoroethoxy)ethoxy]acetate - also known as perfluoro(2-ethoxy-2-fluoroethoxy)acetic acid ammonium salt or EEA-$NH_4$ (CAS no. 908020-52-0)
- Trideca-1,1,1,2,2,3,3,4,4,5,5,6,6-fluorohexane - also known as 1H-perfluorohexane or 1H-PFHx (CAS no. 355-37-3)
- 3,3,4,4,5,5,6,6,6-Nonafluorohexene - also known as perfluorobutylethylene or PFBE (CAS no. 19430-93-4)
- 1,1,1,2,2,3,3-Heptafluoro-3-[(trifluorovinyl)oxy]propane - also known as perfluoro(propyl vinyl ether) or PPVE (CAS no. 1623-05-8)
- 1,1,1,2,2,3,3,4,5,5,5-Undecafluoro-4-(trifluoromethyl)pentane - also known as perfluoroisohexane or PFiHx (CAS no. 355-04-4)
- Perflunafene - also known as perfluorodecalin or PFD (CAS no. 306-94-5)

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[1] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) - see: https://ec.europa.eu/environment/chemicals/reach/reach_en.htm

- **Hexafluoropropene or HFP (CAS no. 116-15-4)**
- Octafluoropropane - also known as perfluoropropane or PFP (CAS no. 76-19-7)

The additional substance also being considered is:

- 6:2 Chlorinated polyfluorinated ether sulfonate, 6:2 Cl-PFESA - also known as 'F-53B' (CAS no. 73606-19-6)

This report summarises the evaluation of the substance highlighted above in **bold** (i.e. HFP), to address the following questions:

- What data are currently available, and are they sufficiently reliable to assess the environmental hazards and risks from this substance?
- Can we establish numerical exposure limits for assessing environmental impacts (e.g. for use under permitting regimes)?
- Is this substance potentially able to reach remote environments and what is its groundwater contamination potential?
- Is this substance a potential candidate for future risk management?
- What information gaps remain, relative to the registered tonnage of this substance and, if required, what is the most appropriate way of obtaining this information?

The Environment Agency has performed a literature review on this substance (Appendix A). As the substance was, at the time of writing, registered under EU REACH, information on the properties and uses substance was obtained from the European Chemicals Agency (ECHA) public dissemination website (ECHA, 2020). Unless otherwise stated, this website is the main source of information used in this report. Full scientific study reports have generally not been reviewed by the Environment Agency, only the publicly available literature and EU REACH dossier information have been consulted at this stage.

This report describes the substance and its structural analogues, its analytical chemistry, manufacture and use, regulatory status and then various environmentally relevant properties. This is followed by an environmental hazard assessment in Section 9, then an exposure and risk assessment. The final section summarises the findings of this review. Although the focus of this evaluation is on environmental hazards and risks, there is a brief summary of mammalian toxicology information where available and relevant to the environmental assessment. This report is however not intended to provide a consideration of the hazards, exposure and risks to human health. This is not a formal UK REACH Evaluation.

# 1 Substance identity

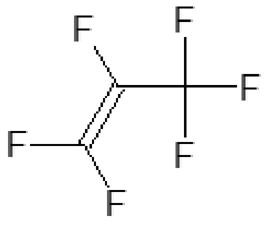
## 1.1 Name and other identifiers

**Table 1.1 Substance Identifiers**

| | |
|---|---|
| **Public name** | Hexafluoropropene |
| **IUPAC name** | 1,1,2,3,3,3-Hexafluoro-1-propene |
| **Abbreviated name and acronym** | Hexafluoropropene or [HFP]* |
| **EC number** | 204-129-5 |
| **CAS number** | 116-15-4 |
| **Index number in Annex VI of the CLP Regulation** | 602-061-00-4 |
| **Molecular formula** | $C_3F_6$ |
| **Molecular weight** | 150 g/mol |
| **SMILES code** | F\C(F)=C(/F)C(F)(F)F |
| **Synonyms** | Hexafluoropropylene;<br>perfluoropropene: perfluoropropylene |
| **Type of substance** | Mono-constituent |

*The substance is referred to as HFP for the purposes of this report.
SMILES - Simplified Molecular Input Line Entry System

**Figure 2.1 Structural formula**

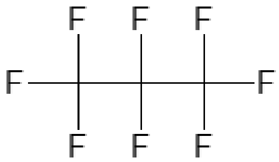


## 1.2 Structurally related substances

HFP is a perfluoroalkene. It is an example of a perfluorocarbon (PFC), containing only carbon and fluorine atoms. Substances in the perfluoroalkene category contain at least 2 fluorinated unsaturated carbon atoms and lack functional groups such as the acids, ethers or alcohols that characterize other PFAS categories (OECD, 2018).

The US EPA CompTox Chemicals database (US EPA, 2020a; US EPA, 2020b) was used to identify structural analogues of HFP. The carbon-fluorine bond is very strong (up to 546 kJ/mol in tetrafluoromethane ($CF_4$)) and so PFCs are much less reactive than their hydrocarbon analogues. Although no close perfluoroalkene analogues were identified as registered in EU REACH, there are perfluoroalkane analogues of similar molecular weight such as octafluoropropane (or PFP).

**Table 1.2 Substance identifiers for octafluoropropane**

| | |
|---|---|
| **Public name** | Octafluoropropane |
| **IUPAC name** | 1,1,2,3,3,3-Hexafluoro-1-propene |
| **CAS number** | 76-19-7 |
| **EC number** | 200-941-9 |
| **Structural formula** |  |
| **Molecular formula** | $C_3F_8$ |
| **Molecular weight** | 188 g/mol |
| **SMILES code** | C(C(F)(F)F)(C(F)(F)F)(F)F |
| **Synonyms** | Freon 218; C3F8-gas; perfluoropropane or PFP; perflutren; propane, octafluoro-; |
| **Relationship to HFP** | Both have a 3 carbon-fluorine chain, but HFP has an unsaturated group and a slightly lower molecular weight. PFP is a saturated structural analogue to HFP. |

## 1.3 Transformation products

HFP contains an unsaturated alkene group. The electron density available in the pi bonds of alkenes may make HFP susceptible to photochemical or addition reactions.

For example, there is the potential for photolysis of the carbon double bond and formation of perfluorocarbon radicals which may be scavenged by hydroxyl radicals in the atmosphere with subsequent formation of perfluoroalkyl alcohols (Section 6). These in turn might transform to trifluoroacetic acid (TFA).

Since HFP is used as a chemical intermediate (Section 3), the emission to atmosphere is likely to be very low. Transformation products are therefore not considered further for the purposes of this report.

# 2 Analytical chemistry

## 2.1 Regulatory and academic methods

It is understood from F2 Chemicals Ltd that they use Gas Chromatography (GC) to determine the concentration of HFP in air, which is calibrated against a known standard.

The Environment Agency searched the academic literature for analytical methods for the detection of HFP in the following environmental matrices: water, fresh and marine; soil; sediment; sludge; and air (see Appendix A). No environmental monitoring methods for HFP were identified.

The Environment Agency considers that the description of a robust analytical method will typically include the following details:

- Instruments and consumables including chromatographic column, temperature, mobile phase composition, flow rates, gradient or isocratic separation and the detector optimisation and configuration.
- Certified reference standards, calibration range and sensitivity, limit of detection, limit of quantification, column recoveries, stability and reproducibility.
- The use of procedural blanks and control samples in both sample preparation and analysis.
- Sample preparation including clean-up consumables, concentration techniques and use of internal standards (plus justification for choice) for validation and recoveries, etc.
- Identification and discussion of technical limitations.

Analytical monitoring of HFP environmental matrices does not appear to be performed as part of national or international programmes. In particular, it is not present in the following PFAS databases accessed via the NORMAN network (https://www.norman-network.com/nds/susdat/ last accessed 12 February 2021).

- PFASTRIER list; and
- PFASNTREV19

HFP was included in a KEMI PFAS list but no associated analytical methods were presented.

Internationally validated LC/MS/MS methods for the analyses of specific PFAS generally include several methods used by the US EPA, none of which were found to include HFP.

It is recommended that the UK supplier publishes details of their analytical methodology for measuring HFP (and related PFC) emissions to air.

# 3 Import, manufacture and uses

Although the UK left the European Union (EU) at the end of January 2020, European legislation in place by December 2020 has been retained and transposed in to UK law. The European Chemicals Agency (ECHA) public databases are however still a relevant source of information about industrial chemicals on the UK market at the time of writing.

HFP is registered in the EU at an aggregated supply level of 10 000 to 100 000 tonnes/year (ECHA, 2020a). Several companies have submitted a registration for HFP in EU REACH (ECHA, 2020a). One of the EU REACH Registrants at the time was based in the UK; i.e. F2 Chemicals Ltd (www.f2chemicals.com), which has a manufacturing site near Preston in Lancashire. F2 Chemicals Ltd has an environmental permit (ref: EPR/BU3485IS) under the Environmental Permitting (England and Wales) Regulations 2016. It produces a range of liquid and gaseous PFC substances, with a total production capacity of around 400 tonnes per year.

According to the ECHA website (ECHA, 2020a), HFP is generally used as a chemical intermediate, as presented in Table 3.1. Personal communication with F2 Chemicals Ltd indicates that they use HFP in the production of octafluoropropane and also perfluoro-4-methyl-2-pentene (PFMP).

**Table 3.1 Overview of uses**

| Life cycle stage | Use(s) |
|---|---|
| **Manufacture** | **Manufacture of substance**<br>ERC1: Manufacturing<br>PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions<br>**Intermediate use in industrial manufacture of another substance under strictly controlled conditions**<br>ERC1: Manufacturing<br>ERC6a: Use of intermediate<br>PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions<br>PROC 8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities<br>PROC 9: Transfer of substance or mixture into small containers (dedicated filling line, including weighing) |

| Life cycle stage | Use(s) |
|---|---|
| **Formulation** | None identified in registration dossier |
| **Uses at industrial sites** | ERC4: Use of non-reactive processing aid at industrial site (no inclusion into or onto article)<br>ERC5: Use at industrial site leading to inclusion into/onto article<br>ERC6a: Use of intermediate<br>ERC6b: Use of reactive processing aid at industrial site (no inclusion into or onto article)<br>ERC6c: Use of monomer in polymerisation processes at industrial site (inclusion or not into/onto article)<br>ERC7: Use of functional fluid at industrial site<br>PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions<br>PROC 2: Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment condition<br>PROC 3: Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment conditions<br>PROC 15: Use as laboratory reagent |
| **Uses by professional workers** | ERC 0: Other: The substance is a monomer within an imported polymer, and hence is not available for exposure in the neat form<br>PROC 1: Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions |
| **Consumer uses** | None identified in registration dossier |
| **Article service life** | None identified in registration dossier |

Source: REACH registration dossier (ECHA, 2020a).

# 4 Summary of relevant regulatory activities

## 4.1 Regulatory activity inside Europe

### 4.1.1 European Chemicals Agency (ECHA)

The Public Activities Co-ordination Tool (PACT) (https://echa.europa.eu/pact accessed July 2020) provides an overview of the substance-specific activities that EU regulatory authorities are working on under the EU REACH and CLP Regulations. HFP has been identified on PACT and is listed on the EU Community Rolling Action Plan (CoRAP) (https://echa.europa.eu/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table accessed July 2020) as being under evaluation by Italy in 2017. The concerns for its inclusion in the CoRAP were suspected carcinogenic, mutagenic and reprotoxic (CMR) substance (https://www.echa.europa.eu/documents/10162/208654a0-0a2d-bf27-2bb0-9756fc3c07e4 accessed July 2020). A decision letter was issued to the EU REACH Registrant(s) by ECHA on 7 July 2017, requesting information on an *In vitro* mammalian cell micronucleus test (OECD 487 /EU B.49) with a deadline of 15 October 2018.

Between May and July 2020, the national authorities of Germany, the Netherlands, Norway, Sweden, and Denmark invited interested parties to send in evidence and information on the use of PFAS in preparation for a joint REACH restriction proposal (see https://www.rivm.nl/en/pfas/pfas-restriction-proposal accessed July 2020). The current scope of the work is wide, and includes all substances that contain at least one aliphatic -$CF_2$- or -$CF_3$ element, HFP is therefore within scope of this initiative (see ECHA Registry of Restriction Intentions: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b, accessed October 2021).

### 4.1.2 European Food Standards Agency (EFSA)

EFSA provides scientific advice on safety of food additives, enzymes, flavourings, processing aids and other substances intentionally added to food, safety of food packaging and other food contact materials.

A search of EFSA (http://www.efsa.europa.eu/ accessed July 2020) did not identify HFP as being evaluated in any published scientific opinions.

### 4.1.3 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 marine resources. Much of OSPAR's work on chemicals is now being addressed by REACH activities.

HFP is not on the OSPAR List of Substances of Possible Concern https://www.ospar.org/work-areas/hasec/hazardous-substances/possible-concern (accessed July 2020), nor on the list of Chemicals for Priority Action adopted in 2002 https://www.ospar.org/work-areas/hasec/hazardous-substances/priority-action (accessed July 2020).

## 4.2 Regulatory activity outside Europe

### 4.2.1 United States

The US EPA is planning to carry out tiered toxicity and toxicokinetic testing for a range of PFAS in the near future (Patlewicz *et al.,* 2019). HFP is not listed in the Patlewicz *et al.* study. The US EPA have a PFAS Strategic Roadmap which sets out their commitments to action for the period 2021-2024 (https://www.epa.gov/pfas/pfas-strategic-roadmap-epas-commitments-action-2021-2024 accessed October 2021)).

HFP is not listed as one of the substances undergoing risk evaluation as part of the US EPA's existing chemical initiative under the Toxic Substances Control Act (TSCA) to determine whether they present an unreasonable risk to public health or the environment under the conditions of use (https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/chemicals-undergoing-risk-evaluation-under-tsca accessed July 2020; https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/low-priority-substances-under-tsca accessed July 2020).

### 4.2.2 Canada

A search did identify HFP as being under assessment under the Prohibition of Certain Toxic Substances Regulations, 2012 (https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/substances-list/toxic.html accessed July 2020). However, the assessment does not appear to have been progressed further as no Australian use, import, or manufacture was reported at their Tier 1 level (https://www.nicnas.gov.au/chemical-information/imap-assessments/imap-assessments/human-health-assessments#cas-A_116-15-4 last accessed July 2020).

### 4.2.3 Australia

A search did not identify HFP as being under assessment under the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) (https://www.industrialchemicals.gov.au/chemical-information/search-assessments accessed July 2020).

### 4.2.4 New Zealand

A search did not identify HFP as being under assessment under the Hazardous Substances and New Organisms Act 1996 (https://www.epa.govt.nz/industry-areas/hazardous-substances/chemical-reassessment-programme/screened-chemicals-list/ accessed July 2020).

### 4.2.5 Japan

Industrial chemicals are managed under the Chemical Substances Control Law (CSCL), most recently amended in 2009 (https://www.nite.go.jp/chem/jcheck/list3.action?category=141&request_locale=en accessed July 2020). Under the Act there are 3 lists:

- Class I Specified Chemicals - 28 substances (persistent, bioaccumulative, toxic) https://www.nite.go.jp/chem/jcheck/list6.action?category=211&request_locale=en accessed July 2020)
- Class II Specified Chemicals - 23 substances (toxic and high risk) (https://www.nite.go.jp/chem/jcheck/list6.action?category=212&request_locale=en accessed July 2020)
- Priority Assessment Chemical Substance (PACS), currently 226 substances (https://www.nite.go.jp/chem/jcheck/list7.action?category=230&request_locale=en accessed July 2020)

HFP is not on any of the above lists.

## 4.3 Other international agreements

### 4.3.1 United Nations Stockholm Convention on Persistent Organic Pollutants (POPs)

HFP is not identified as a POP and is not currently under evaluation (http://chm.Pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx accessed July 2020).

### 4.3.2 Greenhouse gases

Fluorinated gases (‘F-gases’) may contribute to climate change due to their global warming potential and they are often used as substitutes for ozone-depleting substances, because they do not damage the atmospheric ozone layer (EC, 2015). F-gases are regulated under the Ozone-Depleting Substances and Fluorinated Greenhouse Gases (Amendment etc.) (EU Exit) Regulations (2019) (https://www.legislation.gov.uk/uksi/2019/583/contents/made accessed 12 February 2021) which aims to reduce the emission of these gases into the environment. Annexes I and II list the F-gases subject to the Regulation and HFP is not included.

# 5 Physico-chemical properties

This evaluation focusses on vapour pressure, water solubility and n-octanol-water partition coefficient, because they are the key physico-chemical end points for the environmental assessment of most organic chemicals. Surface tension and dissociation constant are also considered. The available information is discussed in this section and a conclusion is drawn about which value the Environment Agency considers most suitable for the further evaluation of this substance.

The source of this information is the publicly available EU REACH registration database (ECHA, 2020a), unless otherwise indicated. The reliability scores provided in the full registration for individual studies are cited. These scores have presumably been generated in accordance with the ECHA R.4. Guidance Document (ECHA, 2011). An independent evaluation has not been possible since original study reports were not available, and the REACH registration dossiers generally lack sufficient supporting information. The Environment Agency is therefore not in a position to assign its own reliability scores (except in the case of data presented in academic journals or obtained using quantitative structure-activity relationship (QSAR) models).

Where an endpoint value is missing from the registration dossier, or an initial review raised questions around the validity of an experimentally derived value, the assessment has been supplemented with information from analogues (see Section 1) and openly available in silico QSAR models. REACH registration data for the analogues are taken at face value, although preference is given to regulatory reviews (if available). QSAR models are generally considered to be a screening-level tool and measured values are preferable provided that they are sufficiently reliable. Further information is provided in Appendix B.

An overview of physico-chemical data provided in the EU REACH registration or generated by the Environment Agency is presented in Table 5.1.

## 5.1 Vapour pressure

### 5.1.1 Measured data

No experimentally derived vapour pressure value was presented in the EU REACH registration dossier for HFP (ECHA, 2020a).

According to REACH Guidance R7a (ECHA, 2017a), vapour pressure testing is not required for substances with a standard boiling point of < 30 ºC, as these substances will have vapour pressures above the limit of laboratory measurement $10^5$ Pa (100 kPa).

The US EPA CompTox dashboard contain a measured vapour pressure of 653 kPa ($4.9 \times 10^3$ mmHg) for HFP (US EPA, 2020a). No details were provided.

Table 5.1 Summary of physico-chemical properties

| Property | Value(s) | Reliability | Reference |
|---|---|---|---|
| **Physical state at 20 °C and 101.3 kPa** | Gas | Registrant: 2 (key study) | Registration dossier |
| **Melting / freezing point** | Data waiver | | Registration dossier |
| **Boiling point** | Data waiver | | Registration dossier |
| **Relative density** | Data waiver | | Registration dossier |
| **Vapour pressure** | 587 kPa at 25 °C (software prediction using MPBPWIN v1.43) | Registrant: 2 (key study) | Registration dossier |
| **Surface tension** | Data waiver | | Registration dossier |
| **Water solubility** | 82 mg/L at 28 °C (unknown method, non-GLP compliant) | Registrant: 2 (key study) | Registration dossier |
| **n-Octanol/water partition coefficient (log $K_{OW}$)** | 1.95 (software prediction using Toxmatch V1.6) | Registrant: 2 (key study) | Registration dossier |
| **n-Octanol/air partition coefficient (log $K_{OA}$)** | -0.22 (software prediction using KOAWIN v1.10) | Environment Agency: 4 | Environment Agency |
| **Particle size distribution** | Data waiver | | Registration dossier |
| **Stability in organic solvents and identity of relevant degradation products** | Data waiver | | Registration dossier |
| **Dissociation constant** | Data waiver | | Registration dossier |

### 5.1.2 Predicted data

A vapour pressure of 588 kPa (4.4 x $10^3$ mmHg) at 25 °C was reported in the EU REACH registration, which was estimated with the MPBPWIN (v1.43) model (modified Grain method) (ECHA, 2020a). This was reported as the key study rated as Klimisch score 2 (reliable with restrictions) in the EU REACH registration.

The ChemSpider database and the US EPA CompTox dashboard contain predicted vapour pressures for HFP generated from EPISuite™, TEST, ACD/Labs and OPERA software (RSC, 2020a) (US EPA, 2020a). Median predicted values are presented in Table 5.2. The Environment Agency converted the values from mmHg to kPa.

**Table 5.2 Predicted vapour pressures for HFP**

| Source | Details | Vapour pressure at 25 °C |
|---|---|---|
| **ACD/Labs** | N/A | 636 kPa<br>[4.77 x $10^3$ mmHg] |
| **EPISuite™ estimation programme**<br>**MPBPVP v 1.42** | Mean of Antoine and Grain methods<br>BP = -26.0°C<br>MP = -152.8°C | 586.6 kPa<br>[4.4 x $10^3$ mmHg] |
| **EPISuite™ estimation programme**<br>**MPBPVP v 1.42** | exp. database<br>BP = -29.6°C<br>MP = -156.5°C | 653.3 kPa<br>[4.9 x $10^3$ mmHg] |
| **TEST** | N/A | 785.3 kPa<br>[5.83 x $10^3$ mmHg] |
| **OPERA** | Global applicability domain: Inside<br>Local applicability domain index: 0.998<br>Confidence interval 0.939 | 652 kPa<br>[4.89 x $10^3$ mmHg] |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- For the ACD/labs models this information was not available. Therefore no assessment of the applicability could be performed.
- Guidance provided with the MPBPWIN v1.42 model indicated that the relationship between the experimental and predicted vapour pressure values for a test set of 1,642 compounds was good, with an $R^2$ of 0.949, standard deviation of 0.59 and an

average deviation of 0.32. The training set contained several PFCs (see Appendix B) and it is likely that the predicted value for HFP falls within the applicability domain of the model. The Environment Agency notes that the values predicted by MPBPWIN and ACD/Labs models are the closest to the measured value.

- For the OPERA model, PFCs were included in both the training set and external test sets (including HFP). HFP is considered inside the global applicability domain and has a high local applicability domain index (> 0.6), therefore the prediction is considered reliable based on the OPERA model applicability domain criteria.
- For the TEST model, perfluorcarbons were included in both the training set and external test sets (e.g. perfluoroethane). Therefore, predicted values from TEST could be considered within the applicability domain of the model.

### 5.1.3 Data from structural analogues

Our evaluation of octafluoropropane recommended using the EU REACH registration's measured value for vapour pressure of 767 kPa at 20 °C (ECHA, 2020b).

### 5.1.4 Additional resources

No additional relevant information was reviewed as part of this investigation.

### 5.1.5 Recommended value

For HFP no experimental vapour pressure value is available in the registration dossier, with a predicted value of 588 kPa at 25 °C provided instead (ECHA, 2020a).

A measured value for HFP of 653 kPa (at 25°C) is available in the US EPA CompTox dashboard (US EPA, 2020a). *In silico* predicted values range from 586.6 to 785.3 kPa (at 25°C; US EPA, 2020a and RSC, 2020a).

The Environment Agency considers that the measured value for HFP at **653 kPa (at 25°C)** should be treated cautiously, but will take the value forward to derive conclusions and as part of the exposure and risk assessment. This is because it is within the range of *in silico* values from the available models. The measurement by far exceeds that within the limits of laboratory measurement, and there is no guidance about how to proceed with data exceeding 100 kPa.

## 5.2 Surface tension

### 5.2.1 Measured data

No experimentally data was presented in the EU REACH registration for the surface tension of HFP (ECHA, 2020a).

### 5.2.2 Predicted data

No *in silico* predictive data were presented in the EU REACH registration for this endpoint but they made a statement of “no surface activity predicted based on structural examination”.

The ChemSpider database (RSC, 2020a) and US EPA CompTox dashboard (US EPA, 2020a) include predictions of surface tension generated from ACD/Labs software at 9.6 mN/m (US EPA, 2020a). The Environment Agency believes that this represents the surface tension of the substance itself, rather than an aqueous solution. QSARs have therefore not been considered further.

### 5.2.3 Data from structural analogues

There is no measured data available for perfluoropropane (ECHA, 2020c).

### 5.2.4 Additional sources

Chernyshev and Skliar (2014) reported a small decrease in the surface tension of deionised water in the presence of perfluorocarbon vapours in an experiment using perfluoropentane and perfluorohexane at 20 °C. The surface tension of the water reduced from 72 mN/m to 64.6 mN/m in presence of perfluoropentane and 66.7 mN/m in the presence of perfluorohexane. Evidence from Chernyshev and Skliar (2014) for perfluorohexane suggests that there is some potential for the formation of a separate HFP layer at the water-air interface in aqueous solution.

As part of this evaluation, the Environment Agency reviewed data for perfluorophenanthrene (CAS no. 306-91-2). It is reported to have a minimal effect on the surface tension of water. Whilst not a close analogue of HFP, the lack of hydrophilic functional groups means that PFCs generally are unlikely to be surface active in water.

### 5.2.5 Recommended value

Surface tension in water is important because it affects the measurement and interpretation of other physico-chemical properties such as water solubility and partition coefficients. Although there is a predicted surface tension of 9.6 mN/m at 25 °C for HFP, the Environment Agency considers that this is the surface tension of the neat substance rather than that of an aqueous solution and so is not relevant for this evaluation (Chernyshev and Skliar, 2014).

The Environment Agency notes that HFP does not have any hydrophilic structural groups that can form hydrogen or Van der Waals bonds in water. This suggests that it is unlikely to be significantly surface active in aqueous solutions. This hypothesis of “not surface active” will be used in this assessment. The Environment Agency recommends that the robust study summary for this end point is updated.

## 5.3 Water solubility

### 5.3.1 Measured data

The water solubility is reported to be 82 mg/L at 28 °C in the EU REACH registration dossier (ECHA 2020). HFP was mixed with water to equilibrium in a closed vial and the concentration of HFP was then measured in the water phase. This study is dated 2001 (rated reliability 2, non-guideline method and non-GLP). The value can be converted to one at 25 °C using the calculation method in R.16 (ECHA, 2016) given a water solubility of 77.8 mg/L. There was no discussion in the testing information regarding colloid formation or attempts to minimise losses due to volatilisation other than the vessel is closed vial.

### 5.3.2 Predicted data

The ChemSpider database and US EPA CompTox dashboard contained predicted water solubility endpoint values generated from EPISuite™, TEST and OPERA software (RSC, 2020a; US EPA, 2020a). These values are presented in Table 5.3. Values were converted by the Environment Agency from mol/L to mg/L using a molecular weight of 150 g/mol.

**Table 5.3 Predicted water solubility values for HFP**

| Model | Details | Water solubility |
|---|---|---|
| **EPISuite™ water solubility estimate from log KOW (WSKOW v1.41)** | log $K_{OW}$ used: 2.12 (estimated) | 1 167 mg/L at 25 °C |
| **EPISuite™ water solubility estimate from fragments (v1.01 est.)** | - | 1 006.5 mg/L |
| **TEST** | Predicted value: $2.1 \times 10^{-3}$ mol/L | 315 mg/L |
| **OPERA** | Predicted value: $1.45 \times 10^{-4}$ mol/L<br>Global applicability domain: Inside<br>Local Applicability domain index: 0.561. Confidence Interval 0.630 | 21.8 mg/L |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- Guidance provided with the WSKOWWIN model indicates that the relationship between the experimental and predicted values for a training set of 1 450 compounds was good, with an $R^2$ of 0.97, standard deviation of 0.409 and an average deviation of 0.313. The validation set contained several perfluorocarbons (see Appendix B) and it is likely that the predicted value for HFP falls within the applicability domain of the model, but the value should be treated with caution.
- For the OPERA model, structural analogues of HFP were included in both the training set and external test sets (including perfluoropropane). HFP is considered inside the global applicability domain and has a high local applicability domain index (~0.6) and therefore the prediction is considered reliable based on the OPERA model applicability domain criteria.
- For the TEST model, no close structural analogues of HFP were included in both the training set and external test sets. Therefore, predicted values from TEST are considered to be outside the applicability domain of the model.

The predicted water solubility values for HFP vary across 2 orders of magnitude and therefore the actual water solubility is highly uncertain as unsaturated perfluorocarbons such as HFP are not listed within the training / validation sets of these predictive models.

### 5.3.3 Data from structural analogues

The analogue octafluoropropane has a measured water solubility of 5.7 mg/L at 15 °C. HFP has an unsaturated group, is slightly lower molecular weight, compared to octafluoropropane, and so there is likely to be some difference in water solubility.

### 5.3.4 Additional sources

Tsai *et al*. (2002) and Tsai (2009) roughly estimated the water solubility of several PFCs from measured water solubility of tetrafluoromethane. The estimation was performed using a regression equation derived from plotting water solubility against octanol-water partition co-efficient. These values are summarised in Table 5.4.

The Environment Agency does not consider this to be a reliable approach, given the uncertainties in the octanol-water partition coefficients used in this study (see Section 5.4.4).

### 5.3.5 Recommended value

The key water solubility value of HFP in the EU REACH registration dossier is a measured value of 82 mg/L at 28 °C (ECHA, 2020a).

The Environment Agency notes that according to Chernyshev and Skliar (2014), PFCs such as perfluorohexane form colloids in water, which may involve “liquid droplets, vapour bubbles or a combination of both phases simultaneously”. The substance is likely to partition from water to air (see Section 6.2), so controls to limit losses due to volatility may also be required during measurement. Both factors complicate the measurement of aqueous solubility.

**Table 5.4 Summary of estimated water solubility of perfluorocarbon analogues**

| Substance | Molecular weight (g/mol) | Water solubility (mol/L) | Water solubility (mg/L) | Measured/ Estimated | Reference |
|---|---|---|---|---|---|
| **Perfluoromethane** | 88 | $1.7 \times 10^{-4}$ | 15.0 | Not stated | Tsai *et al.* (2002) |
| **Perfluoromethane** | 88 | $2.1 \times 10^{-4}$ | 18.5 | Measured† | Tsai (2009) |
| **Perfluoropentane** | 288 | $1.9 \times 10^{-5}$ | 5.5 | Estimated | Tsai (2009) |
| **Perfluorohexane** | 338 | $1.0 \times 10^{-5}$ | 3.4 | Estimated | Tsai (2009) |
| **Perfluoroheptane** | 388 | $5.7 \times 10^{-6}$ | 2.2 | Estimated | Tsai (2009) |
| **Perfluorooctane** | 438 | $3.1 \times 10^{-6}$ | 1.4 | Estimated | Tsai (2009) |
| **Perfluorononane** | 488 | $1.7 \times 10^{-6}$ | 0.8 | Estimated | Tsai (2009) |

†measured at 25 °C

*In silico* predictions for the water solubility of HFP were between 21.8 and 1 167 mg/L (RSC, 2020a; US EPA, 2020a). These are considerably different to the values predicted for the structurally similar perfluoropropane. The studies of Tsai *et al*, 2002 and Tsai, 2009 suggest a water solubility of HFP could lie between 5.5 mg/L (perfluoropentane) and 18.5 mg/L (perfluoromethane), but the reliability is low.

The Environment Agency considers that the water solubility of HFP is probably > 1 mg/L, although there is uncertainty in the actual value. Ideally the water solubility should be measured using a standard method, taking care to minimise colloid formation and volatilisation. In the absence of better information, the measured water solubility value of **82 mg/L at 28 °C** will be used in the assessment. This equates to approximately 78 mg/L at 25 °C.

## 5.4 Partition co-efficient (n-octanol/water; log $K_{OW}$)

### 5.4.1 Measured data

No experimentally derived log $K_{OW}$ value was presented in the EU REACH registration dossier of HFP (ECHA, 2020a).

### 5.4.2 Predicted data

The key data in the registration refers to a predicted log $K_{OW}$ value of approximately 1.95 at 25 °C generated in the EU REACH registration using the Toxmatch v1 platform (ECHA, 2020a). The Registrant assessed the data reliability as Klimisch score 2.

The Environment Agency generated a predicted log $K_{OW}$ value of 2.12 using KOWWIN v1.68 as part of EPISuite$^{TM}$ software. The ChemSpider database and US EPA CompTox dashboard contained estimated log $K_{OW}$ values from EPISuite™, ACD/Labs and OPERA software (RSC, 2020a; US EPA, 2020a). Values are presented in Table 5.5.

**Table 5.5 Predicted log $K_{OW}$ values for HFP**

| Model | Details | Log $K_{OW}$ |
|---|---|---|
| **ACD/Labs** | ACD/LogP<br>ACD/LogD (pH 5.5) | 1.88<br>1.92 |
| **EPISuite™** | KOWWIN v 1.67 estimate | 2.12 |
| **OPERA** | Global applicability domain: Inside<br>Local applicability domain index: 0.418<br>Confidence interval 0.508 | 1.63 |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- This information was not available for the ACD/labs model, so no assessment of the applicability can be performed.
- Guidance provided with the WSKOWWIN model indicates that the relationship between the experimental and predicted values for a training set of 1 450 compounds was good, with an $R^2$ of 0.97, standard deviation of 0.409 and an average deviation of 0.313. The validation set contained several perfluorocarbons (see Appendix B) and it is likely that the predicted value for HFP falls within the applicability domain of the model but the value should be treated with caution.
- For the OPERA model, structural analogues of HFP were included in both the training set and external test sets (e.g. perfluoroethane). HFP is considered inside the global applicability domain and has a local applicability domain index of 0.4 to 0.6 and therefore the prediction should be considered with caution.

### 5.4.3 Data from structural analogues

There are no measured log $K_{OW}$ values for the analogue perfluoropropane (ECHA, 2020c), but in the evaluation by the Environment Agency a log $K_{OW}$ of 2.8 was recommended.

### 5.4.4 Additional sources

Tsai (2009) estimated the log $K_{ow}$ of several PFCs using a fragment constant approach as summarised below in Table 5.6.

**Table 5.6 Summary of estimated log $K_{OW}$ of perfluoroalkane analogues**

| Substance | Molecular weight (g/mol) | Log $K_{OW}$ |
|---|---|---|
| **Perfluoropentane** | 288 | 1.53 |
| **Perfluorohexane** | 338 | 1.79 |
| **Perfluoroheptane** | 388 | 2.05 |
| **Perfluorooctane** | 438 | 2.31 |
| **Perfluorononane** | 488 | 2.57 |

The Environment Agency notes that the predicted value for these PFCs is much lower than those estimated using other models. The reliability of these values is therefore highly uncertain but they indicate a general trend of increasing hydrophobicity with longer chain length PFCs. From reviewing the data in Table 5.6, HFP would likely have a log $K_{OW}$ <1.53 but this remains uncertain.

### 5.4.5 Recommended value

No experimental log $K_{OW}$ values are available for HFP. The Environment Agency notes that according to Chernyshev and Skliar (2014), PFCs such as perfluorohexane form colloids in water, which may involve “liquid droplets, vapour bubbles or a combination of both phases simultaneously”. The substance is likely to partition from water to air (see Section 6.2), so controls to limit losses due to volatility may also be required during measurement.

*In silico* predictions for the log $K_{OW}$ of HFP were in the range from 1.63 to 2.12 (US EPA, 2020a and RSC, 2020a), although the reliability of these values is unknown.

There are no measured data for the analogue perfluoropropane (ECHA, 2020c).

There is significant uncertainty in the log $K_{OW}$ of HFP. In the absence of better information, the Environment Agency recommends a **log $K_{OW}$ of 2.0 at 25 °C** for modelling purposes (with a range of **1.5 to 2.5 for the purposes of sensitivity analysis**).

## 5.5 Octanol-air partition co-efficient ($K_{OA}$)

The log $K_{OA}$ is a non-standard endpoint under REACH used to predict the partitioning behaviour of organic compounds between air and environmental matrices such as soil, vegetation, and aerosol particles (Meylan and Howard, 2005).

### 5.5.1 Measured data

No experimental log $K_{OA}$ values were presented in the EU REACH registration (ECHA, 2020a).

### 5.5.2 Predicted data

The Environment Agency has estimated an n-octanol-air partition coefficient ($K_{OA}$) using the dimensionless HLC ($K_{AW}$) of 2.72 (see Section 6.2.2) and a log $K_{OW}$ value of 2.0 (Section 5.4.5) ($K_{OA} = K_{OW}/K_{AW}$). The resulting log $K_{OA}$ is -0.72. As noted in Section 5.4.5, the Environment Agency recommends that the uncertainty in the $K_{OW}$ value should be addressed using sensitivity analysis. If a log $K_{OW}$ value of 2.5 is assumed, the log $K_{OA}$ would be -0.22. As there is uncertainty in the HLC ($K_{AW}$), the reliability of these resulting $K_{OA}$ values is unknown.

The US EPA CompTox dashboard and ChemSpider database contained predicted $K_{OA}$ values for HFP generated from KOAWIN v1.10 and OPERA software (RSC, 2020a, US EPA, 2020a). These values are presented in Table 5.7.

**Table 5.7 Predicted log $K_{OA}$ for HFP**

| Source | Details | Log $K_{OA}$ |
|---|---|---|
| **EPISuite™ Estimation programme KOAWIN v1.1** | Log $K_{OA}$ (log $K_{OW}$ used: 2.12 and $K_{AW}$ used: 2.34 estimated)<br>Log $K_{OA}$ (experimental database): None | -0.566 |
| **OPERA** | Global applicability domain: Inside<br>Local Applicability domain index: 0.914<br>Confidence Interval: 0.760 | 0.556 |
| **Calculation** | Calculated from log $K_{AW}$ of 2.72 and a log $K_{OW}$ value of 2.0 ($K_{OA} = K_{OW}/K_{AW}$) | -0.72 |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- For the KOAWIN v1.1 model this information was not available. Therefore no assessment of the applicability can be performed. It is not known whether the training set contained structurally similar substances of HFP.
- For the OPERA model, no close structural analogues of HFP were included in the training and external test sets. HFP is considered inside the global applicability domain and has a high local applicability domain index (> 0.6), therefore the prediction is considered reliable based on the OPERA model applicability domain criteria.

These values can be used in the assessment of bioaccumulation in air breathing organisms, and the low values suggest mammalian bioaccumulation is unlikely to be significant for HFP.

### 5.5.3 Data from structural analogues

There are no measured data for structural analogues.

### 5.5.4 Additional sources

No relevant references were identified in the literature search.

### 5.5.5 Recommended value

No log $K_{OA}$ values were presented in the EU REACH registration dossier (ECHA, 2020a).

Predicted values from the open literature and derived by the Environment Agency suggest a log $K_{OA}$ in the range -0.72 to 0.556, although the reliability of these predictions is uncertain. They also depend on the log $K_{OW}$ value chosen.

The Environment Agency does not consider it appropriate to choose a single value from the estimated data range. This is considered further in the assessment of bioaccumulation in air breathing organisms (Section 6.3.2).

## 5.6 Dissociation constant

No experimental dissociation constants were presented for HFP in the EU REACH registration (ECHA, 2020a), and the endpoint entry states ‘does not dissociate’. The Environment Agency agrees a dissociation constant is irrelevant for HFP as it has no ionisable functional groups. It will remain as a neutral compound at environmentally relevant pH.

# 6 Environmental fate properties

## 6.1 Degradation

### 6.1.1 Abiotic degradation

#### 6.1.1.1 Hydrolysis

In the publicly available information from the registration dossier, the hydrolysis study is waived with the justification “study scientifically not necessary / other information available” (ECHA, 2020a).

Several articles describing organo-fluorine chemistry are cited in the Chemical Safety Report (CSR) to justify why hydrolysis will not occur, principally based on the strength of the carbon-fluorine bond and resulting increased strength of the surrounding carbon-carbon bonds. A further argument was that the high volatility means that water is not a relevant environmental compartment for HFP.

The Environment Agency notes that the structure of the substance suggests that hydrolysis is unlikely to be a significant degradation pathway. In any case, the measured water solubility of HFP is below 1 mg/L (see Section 5.3.5), which is the threshold for conducting the test in the OECD TG 111 (OECD, 2004b).

#### 6.1.1.2 Phototransformation in air

The CSR included three studies to fulfil the endpoint. Acerboni *et al.* (2001) investigated vapour phase reactions of three perfluoroalkenes, HFP, perfluoroethene and perfluorobuta-1,3-diene, with OH, $NO_3$ and $O_3$. The experiments were performed at 298 K and 740 Torr (98,659 Pa) in purified air using long-path Fourier Transform infrared detection. They determined the OH reaction rate constant for HFP to be 2.6 x 10-12 $cm^3$ $molecules^{-1}s^{-1}$. This was noted by the authors to be similar to values in three other published papers: McIlroy and Tully (1993); Orkin *et al*. (1997) and Mashino *et al*. (2000) (these have not been further reviewed by the Environment Agency).

The reaction with ozone was stated by Acerboni *et al*. (2001) to be “slow”, with a rate constant of $6.2 \times 10^{-22}$ $cm^3$ $molecules^{-1}s^{-1}$. Again the authors noted that the value is in good agreement with the value determined by Mashino *et al*. (2000). The $NO_3$ reaction was noted to be “very slow” (<3 x 10-15 $cm^3$ $molecules^{-1}s^{-1}$). Using the OH rate constant the chemical lifetime for reaction with OH was roughly estimated by Acerboni *et al*. (2001) to be “a few days” using an OH concentration of $1 \times 10^{-6}$ molecules $cm^{-3}$. A more precise estimate was calculated using the Oslo CTM2 (Chemistry Transport Model). This simulates chemical turnover and distribution in the atmosphere with variable OH concentration and estimated the “global and yearly averaged lifetime” to be 6 days for HFP. Lifetime is not defined (e.g. $DT_{50}$, $DT_{90}$ etc), but for the purpose of this assessment the Environment Agency assumes that this was a half-life. The authors comment that the saturated perfluoroalkanes are much more stable in the atmosphere in comparison to these perfluoroalkenes.

Acerboni *et al.* (2001) also assessed global warming potential (GWP) using an emissivity/absorptivity thermal infrared broadband model. Using the infrared spectra at 298 K using wavelengths of 100 – 2600 $cm^{-1}$ the radiative forcing was modelled with either the distribution from the Oslo CTM2 model, or a constant vertical profile (through the atmosphere). The authors concluded that the GWP value (0.25) was very low compared to CFC-11, and below the value of one for carbon dioxide. Results for the other two perfluoroalkenes indicated similar results. Overall negligible GWP was shown.

One further consideration is the photodegradation products of HFP. Acerboni *et al.* (2001) summarise these as $CF_2O$ and $CF_3CFO$, which are rapidly incorporated into raindrop and aerosols in 5-10 days. This means that they are removed from the atmosphere and therefore were not considered by Acerboni *et al.* (2001) to be significant for GWP compared to CFC-11. In water, $CF_2O$ slowly degrades to HF and $CO_2$, and $CF_3CFO$ slowly degrades to HF and $CF_3COOH$ (TFA).

The second study is Atkinson & Carter (1984), which only assesses the reaction of HFP with ozone. The Environment Agency has not been able to access the full article, and there is only a limited description of the study in the CSR. The experiment measured concentrations of HFP, ozone and oxygen using infrared absorption spectroscopy to follow the reaction, but information such as the frequency of measurement or test duration were not provided in the summary. A rate constant for the reaction with ozone of 7.7 x 10-20 $cm^3$ $molecules^{-1}s^{-1}$ was determined. The EU REACH registration states that “any rate constant less than 10-20 to 10-21 is considered to be unreactive to ozone”. A $DT_{50}$ of >1 year is stated in the registration, which appears to be an extrapolation from the rate constant.

The third entry for the endpoint is a QSAR calculating the pseudo first order rate constant for degradation in air ($k_{DEGAIR}$). This was equation R16-18 from the ECHA Environmental Exposure guidance (ECHA, 2016):

$k_{DEGAIR} = k_{OH} \cdot OH_{CONC\text{-}AIR} \cdot 24 \cdot 3600$

The CSR uses a value of $k_{OH}$ (specific degradation rate constant with OH-radicals) of 2.6 x $10^{-12}$ $cm^3.molec^{-1}.s^{-1}$ based on the work of Acerboni *et al*., (2001) described above. The OHCONC-AIR (concentration of OH-radicals in atmosphere) of 5 x $10^5$ $molec.cm^{-3}$ is stated to be the “global annual average OH-radical concentration” in R16. Using the equation and these values, the CSR determines $k_{DEGAIR}$ = 0.11 $d^{-1}$ and the $DT_{50}$ as 6.2 days.

### 6.1.1.3 Further information

Tokuhashi *et al.* (2000) measured the rate constants for the reactions of OH radicals with HFP and trifluoromethyl trifluorovinyl ether in experiments using four sources of OH radicals. The sources were one using flash photolysis (direct photolysis of water) and three using laser photolysis (indirect photolysis of water using $N_2O$, a water-free method using methane, and photolysis of hydrogen peroxide). The OH radical concentration was monitored using a laser-induced fluorescence technique, with the test substances detected using gas chromatography equipped with a FID detector. Measurements were made over a temperature range 250–430 K, with results converted to 298 K using the Arrhenius equation. Tokuhashi *et al.* (2000) determine the rate constant for HFP to be $2.12 \times 10^{-12}$ $cm^3$ $molecules^{-1}s^{-1}$. This value is consistent with those in the Acerboni *et al.* (2001) paper.

The US EPA CompTox dashboard and ChemSpider database contained predicted photodegradation half-life values for HFP generated from AOPWIN v1.92 and OPERA software (RSC, 2020a, US EPA, 2020a). These values are presented in Table 6.1.

**Table 6.1 Predicted photodegradation half-life values for HFP**

| Source | Atmospheric hydroxylation rate constant | Half-life (days) |
|---|---|---|
| **EPISuite™**<br>**Estimation programme**<br>**AOPWIN v1.92** | $0.7742 \times 10^{-12}$ $cm^3$/molecule-sec | 13.815<br>2.07[1] |
| **OPERA** | $2.2 \times 10^{-12}$ $cm^3$/molecule-sec<br>Global applicability domain: Inside<br>Local Applicability domain index: 0.998<br>Confidence Interval: 0.841 | 7.29[1] |

[1] calculated by the Environment Agency using EUSES (v2.03) (ECHA, 2020d)

- AOPWIN predictions are based on reactions of specific chemicals bonds – in this case the reaction of the carbon double bond. There is no recognition of the influence of the carbon-fluorine bonds, either in terms of their own degradation potential, or their effect on the energy of the double bond. The predicted half-life is therefore likely to be of low reliability.
- For the OPERA model, a close structural analogue of HFP was included in the training and external test sets i.e. 1,1,2,3,3,3-hexafluoro-1-propene. HFP is considered inside the global applicability domain and the local applicability domain > 0.6, therefore the prediction can be considered reliable.

The Environment Agency notes that the measured and reliable prediction data both suggest that the photodegradation half-life of HFP is around 6 to 7 days.

Overall, the $DT_{50}$ value of **6.2 days** used in the EU REACH registration will be used in Environment Agency assessment.

#### 6.1.1.4 Phototransformation in water

No relevant information is available in the registration dossier.

#### 6.1.1.5 Phototransformation in soil

No relevant information is available in the registration dossier.

### 6.1.2 Biodegradation in water

#### 6.1.2.1 Measured data

There is no ready biodegradation study for HFP in the registration dossier, and the endpoint is waived as not being scientifically necessary on account of the fluorinated structure, which is not expected to degrade. The CSR includes a statement that the physical chemical properties for this substance are similar to other HFCs that have been found to be not inherently biodegradable, based on Berends *et al*. (1999). This is a review article of HFCs and HCFCs (the Environment Agency has not been able to access the journal article).

The CSR also cites Boethling *et al*. (1994) (who considered the predicted degradation of different molecular fragments to build a biodegradation QSAR), highlighting that the authors identified minimal degradation of fluorinated structural fragments. The Environment Agency has not been able to access the paper but notes it is referenced in the BIOWIN (v4.10) help files of the EPISUITE programme. Within the help files, the available fluorinated fragments are the CF3 group and aromatically bound fluorine. However, the different QSAR validation and training sets do not include any perfluorinated alkyl substances, and the fluorinated fragments are part of other more complex substances such as pesticides, or chlorofluoro chemicals.

The CSR provides further argument that as HFP is highly volatile, biodegradation in the water and soil compartments, and sewage treatment plants, is not a relevant pathway.

No simulation test is available, and the endpoint is waived in the EU REACH registration dossier based on the exposure assessment in the CSR (which principally relies on HFP being a gas).

#### 6.1.2.2 Predicted data

There is no relevant information is available in the registration dossier.

The Environment Agency is not aware of a biodegradation QSAR for which HFP is within the applicability domain.

#### 6.1.2.3 Data from structural analogues

There is no relevant information available in the registration dossier.

There are no close, relevant structural analogues with measured data. Measured biodegradation data are available for perfluoroisohexane (PFiHx, CAS 355-42-0). PFiHx is a fully saturated perfluorocarbon with twice the number of carbon atoms as HFP and it is a liquid at room temperature. Therefore while providing some guide to the potential for perfluorocarbon mineralisation, it is not a direct analogue.

A modern ready biodegradation test was performed in 2018 using PFiHx. It was conducted according to OECD TG 301F and GLP, with 0% biodegradation observed after 28 days. Results were calculated from oxygen uptake and the EU REACH registration considered the study to be reliable without restriction. The Environment Agency reviewed the study in the assessment of PFiHx (Environment Agency, 2023b) and agrees that the substance is ‘not inherently biodegradable’ based on the study results, although further information is needed to demonstrate the validity of the test.

#### 6.1.2.4 Recommended value

The Environment Agency considers that HFP is not inherently biodegradable.

### 6.1.3 Biodegradation in sediment

No relevant information is available in the EU REACH registration dossier as the endpoint is waived. The substance is a gas, and the justification provided is that direct and indirect exposure of the substance to sediment is unlikely due to the substance properties (i.e. low log $K_{ow}$ and high vapour pressure and HLC).

### 6.1.4 Biodegradation in soil

No relevant information is available in the EU REACH registration dossier as the endpoint is waived. The substance is a gas, and the justification provided is that direct and indirect exposure of the substance to soil is unlikely due to the substance properties (i.e. low log $K_{ow}$ and high vapour pressure and HLC).

### 6.1.5 Summary and discussion on degradation

There are no measured hydrolysis data for HFP in the registration dossier. Based on the structure, the Environment Agency considers hydrolysis will not be a significant degradation pathway.

The available information for photodegradation suggests that HFP is much more reactive to OH (radical) degradation than saturated perfluorocarbon substances. This means that atmospheric photodegradation is likely to be the main degradation pathway for HFP. Nevertheless, an atmospheric half-life around 6 to 7 days (as predicted in the EU REACH information) is relatively long, given that a half-life greater than 2 days is used as a guide for a substance with potential for long-range transport. The available data suggest that HFP is unreactive to ozone, and therefore is unlikely to be an ozone depleting substance. Based on the conclusion of Acerboni *et al.* (2001), HFP has a GWP below carbon dioxide.

There are no biodegradation data for HFP itself in the EU REACH registration dossier. The Environment Agency considers that the substance is not inherently biodegradable due to its perfluorinated structure, gaseous state at room temperature and very high Henry's Law Constant (see Section 6.2.2.2). The longer chain length and less volatile substance PFiHx exhibits no biodegradation in tests (Environment Agency, 2023b), providing further support for this conclusion.

## 6.2 Environmental distribution

### 6.2.1 Adsoprtion/desorption

#### 6.2.1.1 Measured data

There are no measured data in the EU REACH registration dossier. A waiver is provided using the column 2 adaption that the log $K_{OW}$ of HFP is below 3 and therefore it has a low potential for adsorption.

#### 6.2.1.2 Predicted data

Despite the waiver, a predicted log $K_{OC}$ of 1.68 was provided in the EU REACH registration dossier using the QSARs in Toxmatch based on a log $K_{OW}$ of 1.95. The prediction was stated to be within the model domain. No further information is provided regarding the prediction, and the Environment Agency has not been able to determine whether any PFCs are in the training set of the QSAR. Without further justification, the Environment Agency does not consider the prediction to be valid as it is not known whether HFP is within the applicability domain. Nevertheless, the value is very close to the one predicted using EUSES below.

The Environment Agency has predicted the log $K_{OC}$ for HFP using the preferred log $K_{OW}$ value of 2.0. This was done in EUSES v2.03 using the 'Predominantly hydrophobics" chemical class (the equation is: log $K_{OC}$ = 0.81 log $P_{OW}$ + 0.10).

The calculated log $K_{OC}$ was 1.72.

There is uncertainty in the $K_{OW}$ value, which is likely to lie in the log $K_{OW}$ range of 1.5 to 2.5 (see Section 5.4); the log $K_{OC}$ range could therefore be between 1.31 and 2.12 using the same equation. According to the published paper for the QSAR (Sabljic *et al*., 1995), it is suitable for chemicals containing fluorine (despite none of the 81 chemicals in the training set containing fluorine). The log $K_{OW}$ value of HFP means that it is within the applicability domain.

The US EPA CompTox dashboard and ChemSpider database contained predicted log $K_{OC}$ values for HFP generated from KOCWIN v1.66 and OPERA software (RSC, 2020a, US EPA, 2020a). The Environment Agency have generated a predicted $K_{OC}$ values for HFP using KOCWIN v2.0 as ChemSpider does not report whether this prediction is based on the Molecular Connectivity Index (MCI) method or on the log $K_{OW}$ method. These values are presented in Table 6.2.

**Table 6.2 Predicted log $K_{OC}$ for HFP**

| Source | Details | Log $K_{OA}$ |
|---|---|---|
| **EPISuite™**<br>**Estimation programme**<br>**KOCWIN v1.66** | ChemSpider does not report whether this prediction is based on the Molecular Connectivity Index (MCI) method or on the Log $K_{OW}$ method | 2.67 |
| **EPISuite™**<br>**Estimation programme**<br>**KOCWIN v2.0** | Molecular Connectivity Index (MCI) method<br>$K_{OC}$ = 406.4 L/kg<br>Log $K_{OW}$ method (estimated log $K_{OW}$ = 2.12)<br>$K_{OC}$ = 69.1 L/kg | 2.61<br>1.84 |
| **OPERA** | Global applicability domain: Inside<br>Local Applicability domain index: 0.506<br>Confidence Interval: 0.626 | 2.26 |
| **EUSES model calculation from Log $K_{OW}$** | Log $K_{OW}$ = 2 and 'predominantly hydrophobics" equation | 1.72 |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- For the KOCWIN v2.0 model, the training and validation sets contained no perfluorocarbons (see Appendix B) and it is likely that the predicted value for HFP does not fall within the applicability domain of the model and the value should be treated with caution.
- For the OPERA model, no close structural analogues of HFP were included in both the training set and external test sets. HFP is considered inside the global applicability domain and has a local applicability domain index of 0.4 to 0.6 and therefore the prediction should be considered with caution.

#### 6.2.1.3 Data from structural analogues

There are no measured data available for relevant analogues.

#### 6.2.1.4 Recommended value

There is significant uncertainty in the log $K_{OC}$ of HFP. In the absence of better information, the Environment Agency recommends a **log $K_{OC}$ of 1.72 at 25 °C** for modelling purposes (with a range of **1.31 to 2.22 for the purposes of sensitivity analysis**). The high volatility of the substance (Section 6.2.2) means that the significance of the uncertainty in the log $K_{OC}$ value is reduced, as only a small fraction will be partitioned between water and organic carbon compared to the much larger fraction partitioned to air.

### 6.2.2 Volatilisation

#### 6.2.2.1 Measured data

No measured data was presented in the EU REACH registration dossier (ECHA, 2020a).

#### 6.2.2.2 Predicted data

In the registration dossier, the Henry's law constant (HLC) has been calculated as 1.08 x $10^6$ Pa $m^3$/mol at 25 °C. This is stated to have been estimated using the water solubility of 82 mg/L at 28 °C and a vapour pressure of 588 kPa at 25 °C.

A HLC of 1.24 x $10^6$ Pa $m^3$/mol was calculated by the Environment Agency using EUSES (v2.03) and the recommended values of water solubility of 82 mg/L at 28 °C (78.8 mg/L at 25 °C) and vapour pressure of 653 kPa at 25 °C (see Sections 5.3.5 and 5.1.5).

The US EPA CompTox dashboard and ChemSpider database contained predicted HLC values for HFP generated from OPERA software (RSC, 2020a, US EPA, 2020a). These values are presented in Table 6.3. The Environment Agency converted the value from atm $m^3$/mol to Pa $m^3$/mol.

**Table 6.3 Predicted Henry's Law constant for HFP**

| Source | Details | HLC (Pa $m^3$/mol) |
|---|---|---|
| **EPISuite™**<br>**Estimation programme**<br>**HENRYWIN v3.1** | Bond Method: 5.34 atm $m^3$/mol<br>Group Method: Incomplete | 1.86 x $10^9$ Pa $m^3$/mol |
| **EPISuite™**<br>**Estimation programme**<br>**HENRYWIN v3.1** | Vapour pressure/water solubility estimate using EPISuite™ derived values: 1.286 x $10^{-1}$ atm $m^3$/mol | 1.3 x $10^4$ Pa $m^3$/mol |
| **OPERA** | Predicted value: 6.59 x $10^{-4}$ atm $m^3$/mol<br>Global applicability domain: outside | 6.68 x $10^1$ Pa $m^3$/mol |

| Source | Details | HLC (Pa $m^3$/mol) |
|---|---|---|
|  | Local Applicability domain index: 0.242<br>Confidence Interval: 0.384 |  |
| **EUSES** | Calculated from water solubility of 82 mg/L at 28 °C and vapour pressure of 653 kPa at 25 °C | $1.24 \times 10^6$ Pa $m^3$/mol |

*In silico* predicted values should always be treated cautiously where substances in the training set and external test set are not visible.

- For the HENRYWIN v3.1 model, the training and validation sets contained several perfluorocarbons (see Appendix B) and it is likely that the predicted value for HFP falls within the applicability domain of the model.
- For the OPERA model, no close structural analogues of HFP were included in both the training set and external test sets. HFP is considered outside the global applicability domain and has a low local applicability domain index (< 0.4), therefore the prediction is not considered to be reliable.

#### 6.2.2.3 Data from structural analogues

In the evaluation of perfluoropropane (PFP), the Environment Agency recommended a HLC of $2.25 \times 10^7$ Pa $m^3$/mol calculated from the preferred water solubility value (6.4 mg/L) and vapour pressure (767 kPa) (Environment Agency, 2023a).

#### 6.2.2.4 Recommended value

The Environment Agency recommends a HLC of $1.24 \times 10^6$ Pa $m^3$ $mol^{-1}$ for modelling purposes calculated from the preferred water solubility value (82 mg/L) and vapour pressure (653 kPa).

This value has been used to derive the dimensionless HLC or air-water partition coefficient i.e. a log $K_{AW}$ of 2.72 which is used in modelling the prediction of long-range transport of HFP (see Section 6.2.4 below).

### 6.2.3 Distribution modelling

The EU REACH registration dossier includes the output of a Level III Fugacity Model from EPISuite™ v4.0 using initial input to air only and the following assumptions:

- Vapour pressure: 4 410 mm Hg (587 952 Pa)
- Water solubility: 82 mg/L
- Henry's Law Constant: 10.6 atm $m^3$/mole ($1.08 \times 10^6$ Pa $m^3$/mol)
- Log $K_{OW}$: 1.95

- Soil $K_{OC}$: 47.5

This gave the following distribution:

| | |
|---|---|
| Air (%): | 100.0 |
| Water (%): | 0 |
| Soil (%): | 0.004 |
| Sediment (%): | 0 |

The Environment Agency considers that although some caution is required as most of the input data are predicted, the substance is a gas under environmentally relevant conditions and so release into the atmosphere will result in partitioning almost exclusively to air. Any substance present in sediment or soil will volatilise, due to the very high vapour pressure and HLC.

Fugacity modelling predicts how a substance may be distributed in the environment following a release to a specific compartment (i.e. air, water, or soil). The potential environmental distribution of HFP has been assessed by the Environment Agency using EPI Suite (US EPA 2020c, version 4.11) and is summarised in Table 6.4. This program contains a Level III multimedia fugacity model and predicts partitioning of chemicals to air, soil, sediment, and water under steady state conditions for a generic model "environment”. A fixed temperature of 25 °C is assumed. Mass transport between the compartments via volatilization, diffusion, deposition, and runoff are modelled.

The model was run four times with a nominal release rate of 1,000 kg/hour initially entering the air, soil or water compartments and the same release to all three compartments using substance properties as per Table 6.6.

**Table 6.4 Results of generic level III fugacity model for HFP**

| Compartment (percent distribution at steady state) | Emission rate (1,000 kg/h) to air | Emission rate (1,000 kg/h) to water | Emission rate (1,000 kg/h) to soil | Emission rate (1,000 kg/h) to air: water: soil equally |
|---|---|---|---|---|
| **Amount in air (%)** | 100.0 | 10.3 | 95.8 | 33.5 |
| **Amount in water (%)** | <0.1 | 89.3 | <0.1 | 65.6 |
| **Amount in soil (%)** | <0.1 | <0.1 | 4.2 | 0.57 |
| **Amount in sediment (%)** | <0.1 | 0.39 | <0.1 | 0.29 |

The Environment Agency has used the SimpleTreat model in EUSES (v2.03) to predict the following partitioning of HFP in a wastewater treatment plant. The sensitivity of changing the log $K_{OC}$ value is summarised in Table 6.5 below.

**Table 6.5 Predicted partitioning of HFP in a wastewater treatment plant**

| Fraction of emission to compartment / degraded | Log $K_{OC}$ 1.5 | Log $K_{OC}$ 2.0 | Log $K_{OC}$ 2.5 |
|---|---|---|---|
| **Air** | 94.9 % | 94.6 % | 93.9 % |
| **Water** | 4.95 % | 4.94 % | 4.91 % |
| **Sludge** | 0.19 % | 0.47 % | 1.19 % |
| **Biodegradation** | 0.0 % | 0.0 % | 0.0 % |

This model predicts that a significant fraction will partition to air and sludge, with a small fraction emitted to effluent. The reliability of this prediction for this type of substance is unknown, and the uncertainties in the physico-chemical input parameters also mean that this distribution might not be fully reliable.

### 6.2.4 Long-range transport potential

The REACH Guidance (Chapter R.7b, Section R.7.9.4.3) indicates that long-range transport can be considered on a case-by-case basis, but there is no guidance about how to use the information in the overall assessment (ECHA, 2017c).

The OECD has produced a decision support tool for estimating the long-range transport potential (LRTP) of organic chemicals at a screening level. It is a steady state non-equilibrium model in a standardised evaluative environment and predicts three characteristics that can be used to provide an indication of the LRTP of a substance: Characteristic Travel Distance, Transfer Efficiency and overall persistence ($P_{OV}$). To estimate the LRTP of HFP, the Environment Agency has performed calculations using the input parameters for the substance indicated in Table 6.6

The OECD LRTP screening tool predicts the following outputs, also included in Table 6.6:

- Overall persistence ($P_{OV}$).
- Characteristic Travel Distance (CTD): a transport oriented LRTP indicator. It quantifies the distance from the point of release to the point at which the concentration has dropped to 1/e, or about 37% of its initial value; and

- Transfer Efficiency (TE): is a target oriented LRTP indicator originally applied to quantify the deposition of chemicals transported from different regions to the North American Great Lakes.

The sensitivity of changing the log $K_{OW}$ value was investigated but due to the very long degradation half-lives used in the input parameters for air, water and soil compartments, negligible change in the output was recorded from altering the log $K_{OW}$ value over the range of 1.5 to 2.5.

**Table 6.6 Estimated long-range transport potential of HFP**

| Input Parameter | Value |
|---|---|
| **Molecular mass** | 150 g/mol |
| **Log $K_{AW}$** [a] | 2.72 |
| **Log $K_{OW}$** | 2.0 (range of 1.5 to 2.5) |
| **Half-life in air (hours)** | 144 |
| **Half-life in water (hours)**[b] | $2.4 \times 10^{41}$ |
| **Half-life in soil (hours)** | $2.4 \times 10^{41}$ |
| **Characteristic Travel Distance (km)** | 2 984 |
| **Transfer Efficiency (%)** | 0.005 |
| **$P_{OV}$ (days)** | 148 |

Note: a - This is the log of the dimensionless HLC.
b - The upper bound value for biodegradation of a non-readily biodegradable substance in EUSES is $1 \times 10^{40}$ days to represent infinity (equivalent to $2.4 \times 10^{41}$ hours).

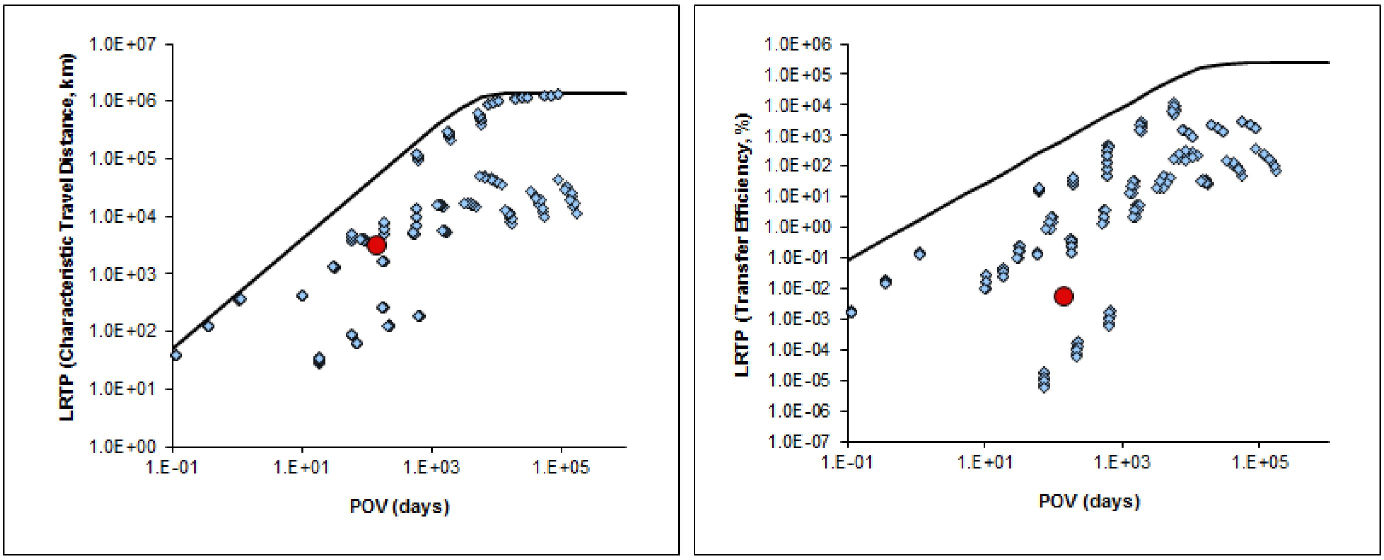
The OECD LRTP screening tool allows comparisons of these three characteristics for a range of substances, provided in Figure 6.1 Long-range transport potential of HFP (log $K_{OW}$ of 2.0).

Based on this screening tool, it appears that HFP may be capable of long-range transport.

Wet and dry deposition, which is important for the atmospheric fate of perfluorinated acids, are less relevant for HFP due to its different physico-chemical characteristics (HFP is considerably more volatile and less water soluble than PFAS such as PFOA). Due to its low water solubility, removal of HFP from the atmosphere through precipitation is not likely to be a significant process and rainwater concentrations are likely to be low.

Evidence of occurrence (or not) of HFP in the Arctic and other remote regions also needs to be taken into account (noting the proximity of industrial activity and population centres). This is beyond the scope of this evaluation.

**Figure 6.1 Long-range transport potential of HFP (log $K_{OW}$ of 2.0)**



Note: In the left hand graph the x axis is overall persistence in days (Pov) and the y axis is the Characteristic Travel Distance (km). In the right hand graph the x axis is overall persistence in days (Pov) and the y axis is the Transfer Efficiency (%).

# 6.3 Bioaccumulation

## 6.3.1 Bioaccumulation in aquatic organisms

### 6.3.1.1 Screening data

The likely low log $K_{OW}$ of HFP (2, range 1.5 to 2.5; see Section 5) means that it does not screen as potentially bioaccumulative in aquatic organisms. For example, the ECHA guidance for environmental exposure assessment uses a threshold of log $K_{OW}$ ≥3 as a trigger for the secondary poisoning assessment (ECHA, 2016).

### 6.3.1.2 Measured data

There are no fish bioaccumulation data for HFP in the EU REACH registration dossier, and the endpoint is waived based on the log $K_{OW}$ value being below 3. An additional argument is that the very high vapour pressure, together with “limited or no aqueous exposure” result in low bioaccumulation potential.

There are no measured fish bioaccumulation data on relevant analogues.

## 6.3.2 Terrestrial bioaccumulation

The EU REACH registration does not assess the potential for terrestrial bioaccumulation as this is not a standard information requirement. The endpoint is waived using a similar justification as for the aquatic bioaccumulation endpoint – that the high volatility and low log $K_{ow}$ together with the use pattern limits exposure to terrestrial organisms.

### 6.3.2.1 Screening data

In terms of bioaccumulation in air breathing organisms, the screening criteria are log $K_{OW}$ > 2 and log $K_{OA}$ > 5. Section 5.5 discusses the available estimates for $K_{OA}$, which range from -0.72 to 0.556 with a value of -0.72 derived using a log $K_{OW}$ value of 2.0.

These values suggest that HFP does not meet the screening criteria for bioaccumulation in air breathing organisms.

There is no measured information on the bioaccumulation of HFP in earthworms.

The Environment Agency has predicted a BCF for HFP for earthworms using the preferred log $K_{OW}$ value of 2.0. This was done in EUSES v2.03 using the “Predominantly hydrophobics” chemical class. The calculated BCF was 2 L/kg ww. It is unlikely that perfluoroalkanes are within the applicability domain of this QSAR which was derived on a small number of organochlorine compounds and this value remains uncertain.

### 6.3.2.2 Other information

No relevant information is available.

## 6.3.3 Summary and discussion of bioaccumulation

The estimated range of log $K_{OW}$ of HFP indicates that it does not screen as being bioaccumulative in aquatic species. There are no measured data for aquatic bioaccumulation of the substance.

The assumption that hydrophobic and lipophilic interactions between compound and substrate (as modelled by the log $K_{OW}$) are the main mechanisms governing bioaccumulation behaviour may not be applicable for this type of substance due to the oleophobic repellency of the perfluorinated alkyl chain.

There is some evidence from studies in mammals that PFCs may have a long elimination half-life. There are no data available for HFP (see Section 6.3.2), but the Environment Agency notes that the predicted log $K_{OA}$ range of HFP suggests that air-elimination would be favoured for mammals, rather than bioaccumulation. As discussed above however, there is some uncertainty in the log $K_{OA}$ values.

Overall, the available data do not suggest that bioaccumulation is a significant concern for HFP. However it should be noted that this conclusion relies solely on predicted data, most of which is subject to a degree of uncertainty.

# 7 Ecotoxicity

The same comments about sources of data, reliability scoring and use of supplemental information apply as for Section 5.

## 7.1 Aquatic compartment (including sediment)

### 7.1.1 Fish

#### 7.1.1.1 Short-term (acute) toxicity

**Table 7.1 Summary of acute toxicity to fish**

| Method | Species | Analytical method | Results | Reliability | Reference |
|---|---|---|---|---|---|
| **ECOSAR v1.00 prediction with log $K_{OW}$ 1.948** | N/A | N/A | 96-h $LC_{50}$ 128.5 mg/L<br>mortality endpoint | Registrant: 2 (supporting study) | Unnamed (2009) cited in ECHA (2020a) |

Acute toxicity to fish is a standard information requirement under REACH Annex 8 for substances registered at 10 tonnes/year or more. The EU REACH registration (ECHA, 2020a) waives this requirement due to a limited potential for aqueous exposure based on the high vapour pressure and use pattern of the substance, indicating that aquatic toxicity is unlikely.

As supporting information, the registration includes a predicted 96-h $LC_{50}$ value of 128.5 mg/L for fish generated using ECOSAR v1.00 and an estimated log $K_{OW}$ of 1.948 (Unnamed, 2009; cited in ECHA, 2020a). This is claimed to be reliable with restrictions (Klimisch 2) because it was said to be derived from a valid QSAR model with adequate and reliable documentation and because HFP was claimed to fit within the applicability domain.

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.3 and 5.4), the Environment Agency calculated a 96-h $LC_{50}$ of 123.3 mg/L for fish in ECOSAR v1.11 (part of EPISuite$^{TM}$ software). To account for the uncertainty associated with the log $K_{OW}$ for HFP (see Section 5.4.5), this input parameter was varied from 1.5 to 2.5, which led to 96-h $LC_{50}$ values of 346.6 mg/L and 43.8 mg/L, respectively. However, no PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear that HFP lies within the applicability domain. Consequently these values should be treated with caution.

The Environment Agency generated a predicted 96-h $LC_{50}$ value of 742.75 mg/L for Fathead Minnow using the 'nearest neighbour' method in the US EPA T.E.S.T. software (the other three models did not produce a prediction). This estimate is the average of experimental toxicity values for 1,1,1,3,3,3-hexafluor-2-propanol (CAS 920-66-1), ethyl trifluoroacetate (CAS 383-63-1) and 2,2,2-trifluoroethanol (CAS 75-89-8) which are the three chemicals in the training set that are most similar to the test chemical. A disadvantage of the nearest neighbour method is that it does not use a QSAR model to correlate the differences between the test compound and the nearest neighbour. It was also shown to achieve the worst prediction results during external validation of the T.E.S.T. methods (US EPA, 2016). In addition, no PFCs are included in the training sets used for any of the T.E.S.T. models and consequently, these values should be treated with caution (US EPA, 2020d).

No further predicted data were available on ChemSpider or US EPA CompTox for HFP.

In addition, no acute fish toxicity data are included in the REACH registration for perfluoropropane (ECHA, 2020c) identified as an analogue substance in this evaluation (see Section 1.2). A study has been waived for this substance because it is claimed to be highly insoluble in water and unlikely to cross biological membranes, hence indicating that aquatic toxicity is unlikely to occur. Available testing of related substances is also said to indicate that the substance is non-toxic.

*Summary*

The two predicted 96-h $LC_{50}$ values for HFP both exceed 1 mg/L and the water solubility limit. However, there is uncertainty regarding the suitability of the QSAR models to predict toxicity for PFCs.

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) suggest that HFP will mostly volatilise to air and there is little to no potential for aqueous exposure to aquatic organisms (see Section 10.1).

The Environment Agency therefore considers that acute toxicity is unlikely to be expressed in fish. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

#### 7.1.1.2 Long-term (chronic) toxicity

Long-term fish toxicity tests are not available. This is a standard information requirement under REACH Annex 9 for substances registered at 100 tonnes/year or more. The EU REACH registration (ECHA, 2020a) refers to data waiving due to exposure considerations, although no further details on this are available online. The CSR claims there is limited potential for aqueous exposure based on the high vapour pressure and use pattern of the substance, indicating that aquatic toxicity is unlikely.

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.4 and 5.3), the Environment Agency calculated a Maximum Acceptable Toxicant Concentration (MATC) of 12.0 mg/L for fish using ECOSAR v1.11. To account for the uncertainty associated with the log $K_{OW}$ for HFP (see Section 5.4.5), this input parameter was varied to 1.5 and 2.5, which led to MATC values of 32.1 mg/L and 4.5 mg/L, respectively. MATC values are the geometric mean of the NOEC and LOEC and so the NOEC would be lower than these values. No PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear whether HFP is within the applicability domain. Consequently, these values should be treated with caution.

*Summary*

Despite the uncertainties with the model predictions, predicted MATC values were >1 mg/L indicating that HFP is unlikely to be chronically toxic to fish at a level that would trigger a hazard classification (see Section 9.1).

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) suggest that HFP will mostly volatilise to (and remain in) air and there is little potential for exposure to aquatic organisms (see Section 10.1).

The Environment Agency therefore considers that chronic toxicity is unlikely to be expressed in fish. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

## 7.1.2 Aquatic invertebrates

### 7.1.2.1 Short-term (acute) toxicity

**Table 7.2 Summary of acute toxicity to aquatic invertebrates**

| Method | Species | Analytical method | Results | Reliability | Reference |
|---|---|---|---|---|---|
| **ECOSAR v1.00 prediction with log $K_{OW}$ 1.13** | Daphnid | N/A | 48-h $LC_{50}$ 71.9 mg/L<br>mortality endpoint | Registrant: 2 (supporting study) | Unnamed (2009) cited in ECHA (2020a) |

Acute toxicity to invertebrates is a standard information requirement under REACH Annex 7 for substances registered at 1 tonne/year or more. The EU REACH registration (ECHA, 2020a) waives this requirement due to a limited potential for aqueous exposure based on the high vapour pressure and use pattern of the substance, indicating that aquatic toxicity is unlikely.

As supporting information, the EU REACH registration (ECHA, 2020a) includes a predicted 48-h $LC_{50}$ value of 71.9 mg/L for daphnids generated using ECOSAR v1.00 and an estimated log $K_{OW}$ of 1.13 (Unnamed 2009, cited in ECHA 2020a). This is claimed to be reliable with restrictions (Klimisch 2) because it was said to be derived from a valid QSAR model with adequate and reliable documentation and because HFP was claimed to fit within the applicability domain.

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.4 and 5.3) as input parameters for ECOSAR v1.11, the Environment Agency calculated a 48-h $LC_{50}$ of 70.0 mg/L for daphnids. To account for the uncertainty associated with the log $K_{ow}$ for HFP (see Section 5.4.5), this input parameter was varied to 1.5 and 2.5, which led to 48-h $LC_{50}$ values of 187.9 mg/L and 26.1 mg/L, respectively, for daphnids. However, no PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear whether HFP is within the applicability domain. Consequently these values should be treated with caution.

The Environment Agency also generated *Daphnia magna* 48-h $LC_{50}$ values (and prediction toxicity intervals) of 40.4 mg/L (≥ 1.01; ≤ 1 620), 60.8 (≥ 21.2; ≤ 175) and 40.4 mg/L (≥ 1.01; ≤ 1617) with the hierarchical clustering model, FDA model and single model methods, respectively, in the US EPA T.E.S.T. v4.2.1 software. The average of these predicted results is a 48-h $LC_{50}$ of 46.30 mg/L for *Daphnia magna* calculated using the consensus method. The consensus method was shown to achieve the best prediction results during external validation of the T.E.S.T. methods (US EPA, 2016). The nearest neighbour and group contribution methods in the software were not able to predict toxicity values. High uncertainty with the predicted toxicity values is indicated by the large prediction toxicity intervals for the hierarchical and single models. In addition, no PFCs are included in the training sets used for any of the T.E.S.T. models (US EPA, 2020d) and consequently, these values should be treated with caution.

No further predicted data were available on ChemSpider or US EPA CompTox for HFP.

In addition, no acute invertebrate toxicity data are included in the REACH registration for the analogue substance perfluoropropane (ECHA, 2020c). A study has been waived for this substance because it is claimed to be highly insoluble in water and unlikely to cross biological membranes, hence indicating that aquatic toxicity is unlikely to occur. Available testing of related substances is also said to indicate that the substance is non-toxic.

*Summary*

The predicted 48-h $EC_{50}$ values for HFP all exceed 1 mg/L. However, there is uncertainty regarding the suitability of the QSAR models to predict toxicity for PFCs.

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) suggest that HFP will mostly volatilise to air and there is little to no potential for aqueous exposure to aquatic organisms (see Section 10.1).

The Environment Agency therefore considers that acute toxicity is unlikely to be expressed in invertebrates. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

#### 7.1.2.2 Long-term (chronic) toxicity

Long-term toxicity tests on aquatic invertebrates are not available. This is a standard information requirement under REACH Annex 8 for substances registered at 100 tonnes/year or more. The EU REACH registration (ECHA, 2020a) refers to data waiving although no further details are available online. The CSR justifies the data waiving for the same reasons as the chronic fish toxicity end point (see Section 7.1.1.2).

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.4 and 5.3), the Environment Agency calculated a MATC of 6.8 mg/L for daphnids in ECOSAR v1.11. To account for the uncertainty associated with the log $K_{OW}$ for HFP (see Section 5.4.5), this input parameter was varied to 1.5 and 2.5, which led to MATC values of 16.1 mg/L and 2.9 mg/L, respectively, for daphnids. MATC values are the geometric mean of the NOEC and LOEC and so the NOEC would be lower than these values. No PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear whether HFP is within the applicability domain. Consequently, these values should be treated with caution.

*Summary*

Despite the uncertainties with the model predictions, predicted MATC values were >1 mg/L indicating that HFP is unlikely to be chronically toxic to invertebrates at a level that would trigger a hazard classification (see Section 9.1).

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) suggest that HFP will mostly volatilise to (and remain in) air and there is little potential for exposure to aquatic organisms (see Section 10.1).

The Environment Agency therefore considers that chronic toxicity is unlikely to be expressed in invertebrates. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

### 7.1.3 Algae and aquatic plants

**Table 7.3 Summary of toxicity to algae**

| Method | Species | Analytical method | Results | Reliability | Reference |
|---|---|---|---|---|---|
| **ECOSAR v1.00 prediction with log $K_{OW}$ 1.948** | Algae | N/A | 96-h EC50 33.4 mg/L<br>growth rate or biomass endpoint (according to the ECOSAR methodology document (Mayo-Bean *et al.*, 2012)) | Registrant: 2 (supporting study) | Unnamed (2009) cited in ECHA (2020a) |

Toxicity to algae and aquatic plants is a standard information requirement under REACH Annex 7 for substances registered at 1 tonne/year or more. The EU REACH registration (ECHA, 2020a) waives this requirement although no further details are available online. The CSR justifies the data waiving for the same reasons as the acute invertebrate toxicity test endpoint (see Section 7.1.2.1).

As supporting information, the EU REACH registration (ECHA, 2020a) includes a predicted 96-h $EC_{50}$ value of 33.4 mg/L for algae generated using ECOSAR v1.00 and an estimated log $K_{OW}$ of 1.948 (Unnamed 2009, cited in ECHA 2020a). Effects are based on growth rate or biomass (Mayo-Bean *et al.*, 2012). This is claimed to be reliable with restrictions (Klimisch 2) because it was said to be derived from a valid QSAR model with adequate and reliable documentation and because HFP was claimed to fit within the applicability domain. A NOEC or $EC_{10}$ value was not provided.

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.4 and 5.3), the Environment Agency calculated a 96-h $EC_{50}$ of 52.1 mg/L and a MATC of 13.7 mg/L based on the growth rate or biomass of green algae in ECOSAR v1.11. To account for the uncertainty associated with the log $K_{OW}$ for HFP (see Section 5.4.5), this input parameter was varied to 1.5 and 2.5, which led to 96-h $EC_{50}$ values of 115.7 mg/L and 23.5 mg/L, respectively, for green algae. MATC values were 27.3 mg/L based on the log $K_{OW}$ of 1.5 and 6.8 mg/L based on the log $K_{OW}$ of 2.5. However, no PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear whether HFP is within the applicability domain. Consequently these values should be treated with caution.

No further predicted data were available on ChemSpider or US EPA CompTox for HFP.

In addition, no aquatic plant toxicity data are included in the REACH registration for the analogue substance perfluoropropane (ECHA, 2020c). A study has been waived because it is claimed that available testing of related substances indicates that it is non-toxic.

*Summary*

Despite the uncertainties with the model predictions, the data indicate that the substance has a low short-term and long-term toxicity to algae with all predicted $EC_{50}$ and MATC values for HFP being above the water solubility limit or above 1 mg/L.

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) suggest that HFP will mostly volatilise to (and remain in) air and there is little potential for exposure to aquatic organisms (see Section 10.1).

The Environment Agency therefore considers that growth inhibition of algae and aquatic plants is unlikely. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

### 7.1.4 Sediment organisms

REACH Annex 10 requirements note sediment toxicity testing may be required at this level of supply. The CSR justifies data waiving according to REACH Annex 10 because the substance is a gas with a high vapour pressure and a low log $K_{OW}$ and so there is limited potential for exposure to sediment organisms.

The Environment Agency notes that the range of possible log $K_{OW}$ values from 1.5-2.5 (see Section 5.4.5) and log $K_{OC}$ of 1.31-2.22 (see Section 6.2.1) are below the trigger value of ≥3 for sediment effects assessment under REACH (ECHA, 2017b). The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) also suggest that HFP will mostly be present in air and there is little to no potential for exposure to sediment organisms (see Section 10.1).

The Environment Agency therefore considers that toxicity to sediment organisms is unlikely and that testing for this endpoint is not required. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

### 7.1.5 Other aquatic organisms

No other relevant information is available.

## 7.2 Terrestrial compartment

REACH Annex 9 and 10 requirements note terrestrial toxicity testing may be required at this level of supply. The EU REACH registration (ECHA, 2020a) refers to data waiving because direct and indirect exposure to the soil compartment is unlikely. The CSR added the high volatility of the substance to the justification for the data waiving (HFP is a gas).

### 7.2.1 Predicted data

As supporting information, the EU REACH registration (ECHA, 2020a) includes a predicted 14-d $LC_{50}$ value of 264.1 mg/kg for earthworms generated using ECOSAR v1.00 and an estimated log $K_{OW}$ of 1.948 (Unnamed 2009, cited in ECHA 2020a). This is claimed to be reliable with restrictions (Klimisch 2) because it was said to be derived from a valid QSAR model with adequate and reliable documentation and because HFP was claimed to fit within the applicability domain.

Using the log $K_{OW}$ of 2.0 and water solubility of 82 mg/L recommended in this evaluation (see Sections 5.4 and 5.3), the Environment Agency calculated a 14-d $LC_{50}$ of 261 mg/kg for earthworms in ECOSAR v1.11. To account for the uncertainty associated with the log $K_{OW}$ for HFP (see Section 5.4.5), this input parameter was varied to 1.5 and 2.5, which led to 14-d $LC_{50}$ values of 293.9 mg/kg and 231.5 mg/kg, respectively, for earthworms. However, no PFCs are included in the model training set (US EPA, 2020c) and it is therefore not clear whether HFP is within the applicability domain. Consequently these values should be treated with caution.

No further predicted data were available on ChemSpider or US EPA CompTox for HFP.

### 7.2.2 Data from structural analogues

No terrestrial toxicity data are included in the EU REACH registration for the analogue substance perfluoropropane (ECHA, 2020c). A study has been waived for this substance because it is claimed that it is not scientifically necessary.

### 7.2.3 Recommendations

Despite a lack of certainty over the applicability of the QSAR models for PFCs, the data suggest that the substance is likely to have a low acute toxicity to earthworms with all predicted $LC_{50}$ values for HFP being above 100 mg/kg.

The high HLC (see Section 6.2.2) and the distribution modelling (see Section 6.2.3) also suggest that HFP will mostly be present in the air and there is little potential for direct exposure to soil (see Section 11.1). The log $K_{OC}$ between 1.31 and 2.22 (see Section 6.2.1) also indicates relatively low soil sorption potential.

The Environment Agency therefore considers that no information on toxicity to soil-dwelling organisms is required. The Environment Agency suggests that the REACH registration dossier could be updated to provide additional information on the levels of exposure to help support the justification for data waiving.

## 7.3 Microbiological activity in sewage treatment systems

This is a standard information requirement under REACH Annex 8 for substances registered at 10 tonnes/year or more. The EU REACH registration refers to data waiving because there is no emission to a sewage treatment plant.

Information from the environmental permit and use pattern for F2 Chemicals Ltd suggest that emissions to wastewater is unlikely (see Section 10.1). The Environment Agency notes that microbial toxicity is unlikely because the substance is a gas and is expected to partition from water to air (see Section 6.2.3).

The Environment Agency recommends that the data waiver in the registration dossier is updated to reflect this additional justification.

## 7.4 Atmospheric effects

The Environment Agency notes that HFP is a gas. No data about biotic effects (e.g. to plants) from aerial exposure are available in the EU REACH registration (ECHA, 2020a), but this is not a standard information requirement.

The available data in the EU REACH registration dossier suggest that HFP is unreactive to ozone, and therefore is unlikely to be an ozone depleting substance.

Based on the conclusion of Acerboni et al (2001), HFP has a GWP lower than carbon dioxide, and the photodegradation products were also of low concern for GWP. The greenhouse gas hazard is considered further in Section 9.5.

# 8 Mammalian toxicology

The following information is taken directly from the ECHA public dissemination website entry for HFP (ECHA, 2021a). The focus is on those longer-term endpoints which are potentially relevant for determination of the substance as Toxic ('T') according to the REACH Annex 13 criteria (see Section 9.3) or for a wildlife secondary poisoning. No human health hazard assessment has been undertaken. The study details and their reliability (Klimisch) scores are as presented by in the public EU REACH registration dossier and the Environment Agency has not evaluated this information. The same comments about sources of data, reliability scoring and use of supplemental information apply as for Section 5.

## 8.1 Toxicokinetics

Three toxicokinetic studies are available and are summarised in the following table.

**Table 8.1 Summary of mammalian toxicokinetic studies**

| Method and test substance | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| **Equivalent or similar to OECD TG 417**<br>**GLP status not specified** | Rat | Administered via inhalation at 800 ppm for 1 hour in an *in-vivo* test. Rat liver microsomes and cytosol incubated with 1 mM HFP for 1 hour in an *in-vitro* test. | Urinary metabolite N-Ac-HFPC was identified *in-vivo*. Results suggested that HFP may be exclusively metabolised by GST *in-vivo* in an addition-reaction to give S-hexafluoropropyl-glutathione (HFPG).<br>Two metabolites, HFPG and S-pentafluoropropenyl-glutathione (PFPG) were formed *in-vitro*. | Registrant: 2 (key study) | Koob and Dekant (1990) cited in ECHA (2020a) |
| **Equivalent or similar to OECD TG 417**<br>**Non-GLP** | Rat | Administered via inhalation at 2,600 ppm for 30 minutes | Significant increase of urinary fluoride the first day after exposure and the 4-6 day post-exposure period. Significant increase in urine output following HFP exposure. | Registrant: 2 (supporting study) | Dilley, Carter and Harris (1974) cited in ECHA (2020a) |
| **Equivalent or similar to OECD TG 417**<br>**GLP status not specified** | Rat | Administered via inhalation at 380 (380 ± 27.0), 470 (467 ± 72.0), 660 (660 ± 191.0), and 1200 (1180 ± 60.0) ppm for 4 hours | Cellular necrosis of the proximal renal tubules was observed in rats within 24 hrs following exposure to each concentration of HFP. Urinary excretion of fluoride increased proportionally with the concentration of HFP up to 660 ppm. This apparent maximum urinary fluoride excretion was considered to potentially reflect | Registrant: 2 (supporting study) | Potter *et al.* (1981) cited in ECHA (2020a) |

| | | | | | |
|---|---|---|---|---|---|
| | | | renal failure following exposure to higher concentrations. | | |

## 8.2 Repeated dose toxicity

A number of repeated dose toxicity studies are mentioned in the registration dossier:

**Table 8.2 Summary of mammalian repeated dose toxicity endpoints**

| Method and test substance | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| **Repeated dose inhalation toxicity, US EPA Fluoro-alkenes Final Test Rule**<br>**GLP** | Mouse | Administered via inhalation at mean measured concentrations of 10.1± 0.3, 50.1 ± 1.1 and 150 ± 2.7 ppm for 6 hours per day, 5 days a week over 92 days. | NOAEL 10 ppm (nominal); based on microscopic lesions observed in the kidneys after 90 days of repeated exposure to 50 or 150 ppm of HFP and 28 days of recovery. Kidney lesions included regeneration of the inner cortical tubules, cytomegaly of tubular epithelium, and tubular epithelial necrosis. | Registrant: R1 (key study) | Unnamed (1989), cited in ECHA (2020a) |
| **US EPA Fluoroalkenes Final Test Rule**<br>**GLP** | Rat | Administered via inhalation at measured concentrations of 10.1± 0.3, 50.1 ± 1.1 and 150 ± 2.7 ppm for 6 hours per day, 5 days a week over 90 days. | NOAEL 10 ppm (nominal); based on diuresis indicated by significantly elevated urine volumes and low urine osmolality in male and female rats after 90 days of repeated exposure to 50 or 150 ppm of HFP. Diuresis was not significant after the 28 day recovery period leading to a NOAEL of 150 ppm. | Registrant: R1 (supporting study) | Unnamed (1989), cited in ECHA (2020a) |
| **Equivalent or similar to OECD TG 412, Subacute Inhalation Toxicity,** | Rat | Administered via inhalation at measured concentrations of 0, 213.5 ± | NOAEL ≥324 ppm (mean measured); based on no adverse effects on mortality, weight, urine, gross pathology or histopathology | Registrant: R2 (supporting study) | Unnamed (1976), cited in ECHA (2020a) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **28-day study**<br>**GLP status not specified** |  | 81.65 and 324 ± 180.05 ppm for 4 hours per day, 5 days a week over 2 weeks. | attributable to the test substance. |  |  |
| **Equivalent or similar to OECD TG 412, Subacute Inhalation Toxicity, 28-day study**<br>**GLP status not specified** | Rat | Administered via inhalation at measured concentrations of 10 ± 0.74, 50 ± 3.6 and 200 ± 12 ppm for 6 hours per day, 5 days a week over 2 weeks. | NOAEL 50 ppm (nominal); based on mild nephrosis in the kidneys of rats exposed to 200 ppm of HFP. This effect was absent after 14 days recovery. | Registrant: R2 (supporting study) | Unnamed (1985), cited in ECHA (2020a) |
| **Equivalent or similar to OECD TG 412, Subacute Inhalation Toxicity, 28-day study**<br>**GLP** | Mouse | Administered via inhalation at measured concentrations of 5.2 ± 1.4, 20 ± 3.2 and 74 ± 11 ppm for 6 hours per day, 5 days a week over 2 weeks. | NOAEL 20 ppm (nominal); based on regeneration of epithelial cells in the kidney cortical tubules of mice exposed to 75 ppm of HFP. | Registrant: R2 (supporting study) | Unnamed (1988), cited in ECHA (2020a) |

## 8.3 Mutagenicity

Both *in vitro* and *in-vivo* genetic toxicity studies are mentioned in the EU registration dossier (ECHA 2020a), as follows:

**Table 8.3 Summary of mutagenicity endpoints**

| Method | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| **Bacterial Reverse Mutation Assay, OECD TG 471**<br>**GLP** | *Salmonella typhimurium* and *Escherichia coli* strains | Exposure at 0, 0.026, 0.078, 0.23, 0.69, 2.8, 8.3 and 25 mmoles/L, both in absence and presence of metabolic activation. | Negative (no adverse effects reported at these concentrations).<br>The test article is not mutagenic with or without metabolic activation under the test conditions. | Registrant: R1 (key study) | Unnamed (2010), cited in ECHA (2020a) |
| **Mammalian Cell Gene Mutation Test, EPA Agency Final Test Rule on the Fluoroalkenes**<br>**GLP** | Chinese hamster ovary (CHO) BH4 clone of the CHO-K1 cell line. | Exposure of cell plates at atmospheric concentrations of 0.05, 0.15, 0.20, 0.30 and 0.35 % in the absence of metabolic activation and 0.10, 0.25, 0.5, 1.0 and 1.5 % in the presence of metabolic activation. | Negative (no adverse effects reported at these concentrations).<br>The test substance is not mutagenic under the study conditions. | Registrant: R2 (key study) | Unnamed (1988), cited in ECHA (2020a) |
| ***In-vitro* Mammalian Cell Micronucleus Test, OECD TG 487**<br>**GLP** | Human lymphoblastoid cells (TK6) | Exposure of cell plates at atmospheric concentrations of 15, 17.5, 20 and 30% in the absence of metabolic activation and 1, 3.75, 5 and 7.5 % in the presence of metabolic activation for 4 hours. | No induction of micronuclei in TK6 cells in the 27-hour treatment without metabolic activation or 4-hour treatments with and without metabolic activation, under the study conditions. | Registrant: R1 (key study) | Unnamed (2018), cited in ECHA (2020a) |

| Method | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| | | Exposure at 0.01, 0.2, 0.8 and 1% in the absence of metabolic activation for 27-hours. | | | |
| **Equivalent or similar to *in-vitro* Mammalian Chromosome Aberration Test, OECD TG 473**<br>**GLP** | Chinese hamster ovary (CHO) | Exposure of cell plates at atmospheric concentrations of 0.01, 0.02, 0.10, 0.17, 0.29, 0.43 and 0.59 % in the absence of metabolic activation and 0.09, 0.17, 0.33, 0.46, 0.55, 0.67, 0.85 and 1.40 % in the presence of metabolic activation. | Positive: The test substance exhibited clastogenic activity in CHO cells both with and without metabolic activation. The concentrations where clastogenic activity was observed (≥0.13% without metabolic activation and ≥0.49% with metabolic activation) were considered markedly cytotoxic based on cell cycle delay. | Registrant: R3 (supporting study) | Unnamed (1986), cited in ECHA (2020a) |
| **Non-guideline**<br>**bacterial reverse mutation assay**<br>**GLP status not specified** | *Salmonella typhimurium* strains | Exposure at atmospheric concentration of 0, 0.075, 0.1, 0.25, 0.5, 1, 2.5 and 5 %, both in absence and presence of metabolic activation. | Negative: The test substance was considered not mutagenic under the study conditions. | Registrant: R3 (supporting study) | Unnamed (1980), cited in ECHA (2020a) |

## 8.4 Carcinogenicity

No information on carcinogenicity is available in the EU registration dossier.

## 8.5 Toxicity to reproduction (effects on fertility and developmental toxicity)

**Table 8.4 Summary of mammalian reproductivity toxicity endpoints**

| Method and test substance | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| **Extended One-Generation Reproductive Toxicity Study. OECD TG 443**<br>**GLP** | Rat | Administered via inhalation for 6 hours per day, 7 days a week. Exposure for the parent generation was at 50, 300 and 600 ppm during the 100-week pre-mating period until after weaning. The first-generation offspring were exposed at 50, 100 and 200 ppm from one day after weaning (postnatal day 22) up to sacrifice. | Parental systemic toxicity NOAEC 50 ppm (nominal); based on decreased body weights, decreased food consumption, increased urinary volume, effects on organ weights, macroscopic observations in the kidneys and microscopic effects in the kidneys, heart and thymus.<br>Parental reproductive toxicity NOAEC ≥600 ppm (highest nominal treatment); based on the absence of treatment-related adverse effects on fertility and reproductive performance parameters.<br>Offspring systemic toxicity NOAEC 50 ppm (nominal); based on increased organ weights for the kidney, lung, liver and heart and the histopathological changes in the kidney after macroscopic and microscopic examination. | Registrant: R1 (key study) | Unnamed (2019), cited in ECHA (2020a) |

| Method and test substance | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| | | | Offspring sexual developmental toxicity NOAEC ≥200 ppm (highest nominal treatment); based on the absence of treatment-related effects on sexual development. | | |
| **Screening for reproductive / developmental toxicity, USEPA Fluoroalkenes Final Test Rule**<br>**GLP** | Rat | Administered via inhalation at measured concentrations of 10.1± 0.3, 50.1 ± 1.1 and 150 ± 2.7 ppm for 6 hours per day, 5 days a week over 90 days. | NOAEL 150 ppm (highest nominal treatment); based on no adverse effects on reproductive organs or tissues. | Registrant: R1 (supporting study) | Unnamed (1989), cited in ECHA (2020a) |
| **Prenatal Developmental Toxicity Study, OECD TG 414; equivalent or similar to OECD TG 412, Subacute Toxicity, 28-day study**<br>**GLP** | Rat | Administered via inhalation at 50, 300 and 900 ppm for 6 hours per day from gestation day 6 up to and including day 20. | Maternal toxicity NOAEC 300 ppm (nominal); based on body weight feed intake and kidney weight, supported by macroscopic observations in the 900 ppm group.<br>Developmental toxicity NOAEC 300 ppm (nominal); based on fetus weight and retardation in ossification in the 900 ppm group. | Registrant: R1 (key study) | Unnamed (2018), cited in ECHA (2020a) |

| Method and test substance | Species | Brief study details | Results | Reliability (Klimisch score) | Reference |
|---|---|---|---|---|---|
| **Prenatal Developmental Toxicity Study, OECD TG 414; equivalent or similar to OECD TG 412, Subacute Toxicity, 28-day study**<br>**GLP** | Rabbit | Administered via inhalation at 10, 50 and 300 ppm for 6 hours per day from gestation day 6 up to and including day 28. | Maternal toxicity NOAEC 300 ppm (highest nominal treatment); based on no treatment-related adverse effects in the pregnant females.<br>Developmental toxicity NOAEC 300 ppm (highest nominal treatment); based on no treatment-related adverse effects in the fetuses. | Registrant: R1 (key study) | Unnamed (2019), cited in ECHA (2020a) |

## 8.6 Summary of mammalian toxicology

The EU REACH registration proposes a long-term exposure inhalation Derived No Effect Level (DNEL) for workers of 0.62 mg/m³ air based on the most sensitive repeated dose toxicity endpoint (from a subchronic toxicity study in mice) with an overall assessment factor (AF) of 50. For the general population, a long-term exposure inhalation DNEL of 0.15 mg/m³ air has been proposed, based on the most sensitive repeated dose toxicity endpoint with an overall AF of 100. No oral or dermal route DNELs have been derived because potential worker or general population exposure would likely occur via the inhalation route given HFP is a volatile substance.

Self-classification under CLP as STOT-RE 2 (H373) is based on the effects on kidneys observed in the repeated inhalation toxicity studies. Self-classification as Carc. 2 (H351) is based on a weight of evidence, including the toxicokinetic data as the glutathione metabolite may induce kidney tumours by a non-genotoxic mode of action. No classification for mutagenicity is proposed. See Section 9.1 for further details.

# 9 Environmental hazard assessment

## 9.1 Classification and labelling

### 9.1.1 Harmonised classification

There is a current entry for Press. Gas (H280), Acute Tox. 4 (H332) and STOT SE 3 (H335) in Annex VI of the Classification, Labelling and Packaging (CLP) Regulation ((EC) No 1272/2008). This has been carried over in to the GB Mandatory Classification and Labelling (MCL) list (https://www.hse.gov.uk/chemical-classification/classification/harmonised-classification-self-classification.htm).

### 9.1.2 Self-classification

The EU REACH registration dossier for HFP (ECHA, 2020a) includes the following notified hazard warnings:

- Press. Gas (Liq.) (H280)
- Acute Tox. 4 (H332)
- STOT SE 3 (H335) (Respiratory) (inhalation)
- Carc. 2 (H351)
- STOT SE 2 (H371) (Kidneys) (inhalation)
- STOT RE 2 (H373) (Kidneys) (inhalation)

No additional hazard classes are notified in the aggregated self-classifications in the Classification and Labelling (C&L) Inventory (ECHA, 2022).

### 9.1.3 Conclusions for classification and labelling

HFP is not readily biodegradable and there is no evidence that it degrades significantly via abiotic mechanisms (see Section 6.1). It is therefore considered to be “not rapidly degradable” for the purposes of hazard classification.

The estimated range of log $K_{OW}$ <4 indicates that HFP does not meet the bioaccumulation criterion for the purposes of hazard classification.

No experimental acute or chronic aquatic toxicity data are available on HFP itself. Although there are a number of uncertainties, the Environment Agency considers that HFP is unlikely to pose either an acute or chronic hazard to aquatic life, since it is a gas and aqueous exposure is considered minimal.

Based on the currently available information, the Environment Agency agrees that HFP does not currently require classification for aquatic hazards according to the CLP criteria.

## 9.2 Assessment of endocrine disrupting (ED) properties

The ecotoxicity data set does not include any studies that assess ED potential and no additional information was identified during the literature search (Appendix A).

## 9.3 PBT and vPvB assessment

### 9.3.1 Persistence

No environmental half-life data are available for comparison with the definitive criteria in REACH Annex 13.

HFP is not readily biodegradable and there is no evidence that it degrades significantly via hydrolysis (see Section 6.1). Photodegradation in the atmosphere is expected to occur, however the suggested half-life of around 6 to 7 days exceeds the threshold for long-range transport (2 days) and is not sufficiently rapid to rule out P/vP.

HFP meets the screening criterion for being potentially persistent (P) or very persistent (vP).

### 9.3.2 Bioaccumulation

The estimated range of log $K_{OW}$ of HFP (1.5 to 2.5) indicates that it does not screen as being bioaccumulative in aquatic species. There are no measured data for aquatic bioaccumulation of the substance.

The assumption that hydrophobic and lipophilic interactions between compound and substrate (as modelled by the log $K_{OW}$) are the main mechanisms governing bioaccumulation behaviour may not be applicable for this type of substance due to the oleophobic repellency of the perfluorinated alkyl chain.

In terms of bioaccumulation in air breathing organisms, the screening criteria are log $K_{OW}$ >2 and log $K_{OA}$ >5. These criteria are not both met. While there is some evidence from studies in mammals that PFCs may have a long elimination half-life, there are no data available for HFP (see Section 6.3.2). The Environment Agency, however, notes that the predicted log $K_{OA}$ (-0.72) of HFP suggests that air-elimination would be favoured for mammals, rather than bioaccumulation.

Overall, the available data suggest that HFP does not screen as B/vB.

### 9.3.3 Toxicity

Although there are a number of uncertainties, the Environment Agency considers that HFP is unlikely to meet the REACH Annex 13 criterion for ecotoxicity (T) of a NOEC of < 0.01 mg/L, or the acute screening criterion for being potentially ‘T’ (L/$EC_{50}$ < 0.1 mg/L).

HFP may meet the definitive T criterion based on mammalian toxicity as indicated by the notified self-classifications as STOT RE 2 presented in the EU REACH registration dossier and C&L Inventory.

No avian toxicity data are available.

### 9.3.4 Overall conclusion

HFP screens as P/vP and T (based on a mammalian toxicity self-classification) but does not screen as B/vB based on currently available information.

## 9.4 Groundwater hazard

Draft persistence, mobility and toxicity (PMT) criteria have been developed by the German Federal Environment Agency as intrinsic hazard criteria to identify substances that are difficult to remove during normal wastewater treatment practices and may be a threat to remote aquatic environments and drinking water sources, including groundwater (Arp and Hale, 2019). The criteria for P and vP are consistent with those in REACH Annex 13, whereas the mobile criterion is unique to PMT assessments. The provisional T criteria include those in REACH Annex 13, in addition to considerations for carcinogenicity, effects via lactation, long-term toxicity to the general human population and endocrine disruption potential.

There is currently no legal basis for these criteria under the EU or UK REACH Regulations but for completeness a brief evaluation is included here.

### 9.4.1 Persistence

HFP meets the screening criterion for being P or vP (see Section 9.3).

### 9.4.2 Mobility

An experimental log $K_{OC}$ value is not available. The Environment Agency suggests that a log $K_{OC}$ of 1.72 (range 1.31 to 2.22) can be used as an approximation (see Section 6.2.1). HFP would therefore meet the draft criterion as being mobile (M) (log $K_{OC} \leq 4$) or very mobile (vM) (log $K_{OC} \leq 3$). A definitive log $K_{OC}$ value is not available from a relevant soil study, so there is some uncertainty in this assessment.

### 9.4.3 Toxicity

HFP may meet the T criteria under PMT based on mammalian toxicity, as indicated by the notified self-classifications as STOT RE 2 presented in the EU REACH registration dossier and C&L Inventory.

No information is available on ED potential.

### 9.4.4 Overall conclusion

HFP screens as P/vP and is likely to be extremely persistent in the environment. It is likely to be vM and is also potentially T. However, HFP is a gas with a high HLC. Further discussion is needed to determine whether the proposed PMT/vPvM criteria are relevant for such substances.

## 9.5 Greenhouse gas hazard

Many fluorinated gases have very high GWPs relative to other greenhouse gases, so small atmospheric concentrations can have disproportionately large effects on global temperatures (US EPA, 2020e).

The GWP is defined by the Intergovernmental Panel on Climate Change (IPCC, 2014) as "an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide ($CO_2$). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing."

In 2010, fluorinated gases covered under the Kyoto Protocol (F-gases) accounted for 2% of total anthropogenic greenhouse gas emissions (IPCC, 2014) and PFCs contribute to this.

Greenhouse gas emissions for PFCs are quantified as CO2-equivalent emissions using weightings based on the energy absorbed by a gas over 100 years (the 100-year GWP). PFCs in the homologous series relevant to HFP are listed in Table 9.1. These values are sourced from the Fifth Assessment Report of the IPCC
(IPCC, 2014). HFP is included (in **bold**).

HFP is expected to have a low global warming potential (GWP), with a 100-year GWP in the order of <1.

A qualitative risk characterisation for the atmosphere is included at Section 11.

Table 9.1 Global warming potential of PFCs

| **Perfluoroalkane** | **Trade name** | **Atmospheric lifetime years** | **Atmospheric lifetime days** | **GWP (100 years) as $CO_2$ equivalent** |
|---|---|---|---|---|
| **Tetrafluoromethane** | PFC14 | 50 000 | - | 6 630 |
| **Perfluoroethane** | PFC116 | 10 000 | - | 11 100 |
| **-** | PFC-c216 | 3 000 | - | 9 200 |
| **Perfluoropropane** | PFC-218 | 2 600 | - | 8 900 |
| **Perfluorocyclobutane** | PFC-318 | 3 200 | - | 9 540 |
| **Perfluorobutane** | PFC-31-10 | 2 600 | - | 9 200 |
| **Perfluoropentane** | PFC-41-12 | 4 100 | - | 8 550 |
| **Perfluorohexane** | PFC-51-14 | 3 100 | - | 7 910 |
| **Perfluoroheptane** | PFC-61-16 | 3 000 | - | 7 820 |
| **Perfluorooctane** | PFC-71-18 | 3 000 | - | 7 620 |
| **Perfluorodecalin** | PFC-91-18 | 2 000 | - | 7 190 |
| **Perfluorodecalin (cis)** | - | 2 000 | - | 7 240 |
| **Perfluorodecalin trans)** | - | 2 000 | - | 6 290 |
| **Perfluoroethene** | PFC-1114 | - | 1.1 | <1 |
| **Perfluoropropene** | **PFC-1216** | **-** | **4.9** | ***<1*** |
| **Perfluorobuta-1,3-diene** | - | - | 1.1 | <1 |
| **Perfluorobut-1-ene** | - | - | 6 | <1 |
| **Perfluorobut-2-ene** | - | - | 31 | 2 |
| **Perfluorocyclo-pentene** | - | - | 31 | 2 |

## 9.6 Limit values

### 9.6.1 Predicted No Effect Concentration (PNEC) derivation

A PNEC is an indication of an acceptable environmental concentration based on evidence from (eco)toxicity studies.

The available hazard information is discussed in Sections 7, 8 and 9. As HFP is a gas and aquatic and soil exposure are considered minimal, the EU REACH registration claims that experimental ecotoxicity testing is not scientifically warranted. The Environment Agency agrees that HFP is likely to pose a low hazard to aquatic wildlife and soil-dwelling organisms.

Nevertheless, the EU REACH registration has calculated PNECs based on predicted endpoints, as presented in Table 9.2. The Environment Agency has not derived any PNECs because they give a misleading impression of toxicity for this substance.

**Table 9.2 PNECs derived for HFP by the EU REACH registration (ECHA, 2020a)**

| Protection goal | PNEC | Notes |
|---|---|---|
| **Fresh surface water** | 0.033 mg/L | |
| **Freshwater sediment** | 0.279 mg/kg sediment dw | |
| **Sewage treatment micro-organisms** | - | No data: aquatic toxicity unlikely |
| **Marine surface water** | 0.003 mg/L | |
| **Marine sediment** | 0.028 mg/kg sediment dw | |
| **Soil** | 0.264 mg/kg soil dw | |
| **Secondary poisoning** | - | No potential for bioaccumulation |

### 9.6.2 Qualitative/semi-quantitative descriptors for other critical hazards

HFP potentially meets the draft PMT/vPvM criteria, although it is a gas. The risk management approach for PMT/vPvM substances has not yet been established in the UK.

# 10 Exposure assessment

## 10.1 Environmental releases

The substance is registered for use as a raw material in the UK by F2 Chemicals Ltd. An assessment of environmental exposure is not available in the UK REACH registration information. The Environment Agency has therefore prepared a qualitative environmental exposure assessment based on publicly available information from the EU REACH registration dossier, the environmental permit and the F2 Chemicals Ltd website. This has been done to help decide on the priority for further work – it does not affect the company's responsibilities to demonstrate safe use for their substance under UK REACH.

HFP is used at a single site in the production of perfluoroalkanes. It should therefore be mostly consumed in these reactions. From information within the Environmental Permit, environmental releases can be expected to be primarily to the air compartment. Releases of PFCs (total) are in the region of 6 tonnes/year although the composition (i.e. exact type and quantity of each PFC) is unknown.

There are no direct releases to surface water, soil or groundwater based on the environmental permit information and use pattern. There is no on-site treatment, and the effluent is discharged off-site to a municipal sewage treatment plant at Clifton Marsh.

Further refinement would be required to improve the reliability of this exposure assessment. This could include specific information on UK tonnages, uses and releases, monitoring data and/or more reliable experimental data on physico-chemical properties to use in exposure modelling.

# 11 Risk characterisation

HFP is used as a raw material in the manufacture of other PFAS and is a gas at standard pressure and temperature. The substance does not meet the PBT/vPvB criteria but does screen as potentially meeting the draft PMT/vPvM criteria. No information is available about endocrine disruption. A conclusion cannot be drawn about risks arising from the vPvM properties of the substance until a UK Government policy position on use of these criteria is available. However, aquatic emissions are likely to be negligible. The influence of volatility is also not considered under the criteria. There are no data on effects of this gas on plants via aerial exposure.

Annual environmental releases from the UK manufacturing site are unknown. There is no information about whether specific measures are taken to recover or destroy this substance following use. It can be assumed that any unreacted HFP will be present in the total PFC emission to air (in the region of 6 tonnes/year), although it is likely to comprise a relatively small proportion of this release.

On this basis, the Environment Agency considers that the direct risk to the aquatic and terrestrial environment from HFP is likely to be low. Risks via atmospheric exposure cannot be assessed due to lack of information.

# 12 Conclusion and recommendations

## 12.1 Conclusion

HFP is a linear perfluoroalkene, containing only carbon and fluorine atoms. It is a gas at standard pressure and temperature, and is used at a single site as a raw material in the production of other substances. The emission pathway is likely to be to air, and the amounts are likely to be relatively low.

HFP is not readily biodegradable and there is no evidence that it significantly degrades via abiotic mechanisms such as hydrolysis. HFP therefore screens as P or vP. However, there is evidence to show that HFP photolytically degrades in the atmosphere. There are no valid experimental log $K_{OW}$ and aquatic bioconcentration data for HFP itself. In the absence of better information and based on QSAR approaches, the likely log $K_{OW}$ for HFP of around 2 (Section 5.4) suggests that it does not screen as potentially B in aquatic organisms. HFP is a gas and so this might not be a relevant trigger. There are some indications of retention in mammalian tissues (which is possibly non-lipid mediated) but also of elimination by exhalation of high vapour pressure PFCs in mammalian studies.

There are no ecotoxicity data on HFP itself to determine whether it meets the ‘T’ criteria for ecotoxicity. As HFP is a gas with a high HLC, testing would be difficult. Whilst there are some uncertainties with the assumptions made, and further scientific justification for waiving of (eco)toxicological testing in REACH registrations could be provided, the information considered in Section 7 indicates that HFP is unlikely to exhibit toxicity to aquatic or soil-dwelling organisms.

Draft PMT/vPvM criteria have been proposed in the EU to identify chemicals that may pose a risk to groundwater. HFP screens as P/vP and vM and human health self-classifications indicate it might be T. However, HFP is a gas and the influence of volatility is not currently considered under these criteria. The uncertainty regarding its log $K_{OW}$ also feeds through to the calculation of a log $K_{OC}$ and the environmental distribution modelling for HFP (Section 6.2).

Available information suggests that HFP also has the potential for long-range transport. It is not identified in the Ozone-Depleting Substances (ODS) and Fluorinated Greenhouse Gases (F-gas) regulations and is expected to have a low global warming potential (GWP), with a 100-year GWP in the order of <1 (see Section 9.5). No information is available about potential effects on plants following aerial exposure.

On this basis, the Environment Agency considers that the direct risk to the aquatic and terrestrial environment from HFP is likely to be low. Risks via atmospheric exposure cannot be assessed due to lack of information.

## 12.2 Recommendations

### 12.2.1 Recommendations to the UK supplier

Although this assessment is not a formal evaluation under UK REACH, the Environment Agency proposes several ways to improve the data package to allow a more robust assessment of the hazards, exposure and risks posed by HFP:

- Details of an appropriate analytical methodology for measuring HFP (and related PFCs) emissions to air (see Section 2.1).
- Updated study summary for surface tension (Section 5.2).
- Water solubility should be measured using an appropriate standard method, taking care to minimise colloid formation (Section 5.3). The HLC should then be recalculated, unless directly measured (Section 6.2.2).
- A log $K_{OW}$ value should be determined using measured data (for example, the ratio of solubility in water and in n-octanol). Any experimental method should take care to avoid colloid formation and minimise the losses due to volatility (Section 5.4). Any change to the log $K_{OW}$ should be reflected in related partition coefficients like log $K_{OC}$ (Section 6.2).
- Given the lack of experimental ecotoxicity data it is recommended that the data waivers are updated to reflect additional information on the exposure assessment and distribution modelling. This should focus in particular on adaptation of standard long-term aquatic, sediment and soil toxicity testing requirements (Section 7).
- To allow better quantitative estimates of emissions to environmental compartments, specific information could be provided on UK tonnages, uses, releases and more reliable experimental data on physico-chemical properties (to improve exposure modelling) (Section 10). Direct measurement of emissions could also be considered using monitoring data.

### 12.2.2 General regulatory recommendations for consideration by relevant UK authorities

The proposed PMT/vPvM criteria are not an official hazard category under UK REACH. Development of a Government policy on the risk management implications for PMT/vPvM substances could be considered. The relevance of these criteria to highly volatile liquids and gases could also be determined.

The Environment Agency along with HSE have been undertaking a Regulatory Management Options Analysis (RMOA) for PFAS, and the information summarised in this evaluation has fed into that analysis to identify the most appropriate risk management measures for PFAS in a UK context.

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# 14 List of abbreviations

| | |
|---|---|
| % | Percentage |
| B | Bioaccumulative |
| BCF | Bioconcentration factor |
| BMF | Biomagnification factor |
| CAS | Chemical Abstracts Service |
| CLP | Classification, labelling and packaging (of substances and mixtures) |
| cm | Centimetre |
| CoRAP | Community Rolling Action Plan |
| CSR | Chemical Safety Report |
| CTD | Characteristic travel distance |
| d | Day |
| $DegT_{50}$ | Degradation half-life or transformation half-life (days) |
| DMEL | Derived Minimal Effect Level |
| DNEL | Derived No Effect Level |
| DSD | Dangerous Substances Directive |
| $DT_{50}$ | Dissipation half-life (days) |
| dw | Dry weight |
| $EC_{10}$ | 10% effect concentration |
| $EC_{50}$ | 50% effect concentration |
| ECETOC TRA | European Centre for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment |
| ECHA | European Chemicals Agency |
| EPA | Environmental Protection Agency |
| EPM | Equilibrium Partitioning Method |

| | |
|---|---|
| EQS | Environmental Quality Standard |
| ERC | Environmental release category |
| ES | Exposure Scenario |
| EU | European Union |
| EUSES | European Union System for the Evaluation of Substances |
| FSDT | Fish Sexual Development Test |
| g | Gramme |
| GC | Gas chromatography |
| GC/FID | Gas chromatography – Flame Ionisation Detection |
| GC/MS | Gas chromatography – mass spectrometry |
| GLP | Good laboratory practice |
| H | Hours |
| HFP | HexafluoropropeneHLC Henry's Law Constant |
| hPa | Hectopascal |
| HPLC | High performance liquid chromatography |
| ISO | International Organisation for Standardisation |
| IUCLID | International Uniform Chemical Information Database |
| IUPAC | International Union of Pure and Applied Chemistry |
| Kg | Kilogram |
| kJ | Kilojoule |
| km | Kilometre |
| $K_{AW}$ | Air-water partition coefficient |
| $K_{OA}$ | Octanol-air partition coefficient |
| $K_{OC}$ | Organic carbon-water partition coefficient |
| $K_{OW}$ | Octanol-water partition coefficient |

| | |
|---|---|
| kPa | Kilopascal |
| $K_{SUSP-WATER}$ | Suspended matter–water partitioning coefficient |
| $k_x$ | Rate constants (days-1) |
| L | Litre |
| $LC_{50}$ | 50% lethal effect concentration |
| LEV | Local Exhaust Ventilation |
| LOD | Limit of detection |
| Log | Logarithmic value |
| LOQ | Limit of quantitation |
| M | Molar |
| m/z | Mass to charge ratio |
| mg | Milligram |
| min | Minute |
| mL | Millilitre |
| mol | Mole |
| MS | Mass spectrometry |
| NICNAS | National Industrial Chemicals Notification and Assessment Scheme |
| nm | Nanometre |
| NOAEL | No observed adverse effect level |
| NOEC | No-observed effect concentration |
| NOEL | No observed effect level |
| NONS | Notification of New Substances Regulations 1993 |
| OC | Operational condition |
| OECD | Organisation for Economic Co-operation and Development |
| OSPAR | Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic |

| | |
|---|---|
| p | Statistical probability |
| Pa | Pascal |
| PACT | Public Activities Co-ordination Tool |
| PBT | Persistent, Bioaccumulative and Toxic |
| PC | Product category |
| PEC | Predicted environmental concentration |
| pg | Picogramme |
| PFAS | Per- and polyfluorinated alkyl substances |
| PFC | Perfluorocarbon |
| PFCA | Perfluoroalkyl carboxylic acids |
| PFOS | Perfluorooctanesulfonate |
| PFOA | Perfluorooctanoic acid |
| pKa | Acid dissociation constant |
| PNEC | Predicted no effect concentration |
| POP | Persistent organic pollutant |
| Pov | Overall persistence |
| ppb | Parts per billion |
| PPE | Personal Protective Equipment |
| ppm | Parts per million |
| PROC | Process Category |
| QSAR | Quantitative structure-activity relationship |
| OPERA | OPEn structure–activity/property Relationship App |
| $r^2$ | Correlation coefficient |
| RCR | Risk characterisation ratio |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemicals (EU Regulation No. 1907/2006) |

| | |
|---|---|
| RMM | Risk Management Measures |
| RPE | Respiratory protective equipment |
| rpm | Revolutions per minute |
| SMILES | Simplified Molecular Input Line Entry System |
| SVHC | Substance of Very High Concern |
| t | Tonne |
| TE | Transfer Efficiency |
| T.E.S.T | Toxicity Estimation Software Tool |
| TG | Test Guideline |
| TSCA | Toxic Substances Control Act |
| UK | United Kingdom |
| US EPA | United Stated Environmental Protection Agency |
| UV | Ultraviolet |
| vB | Very bioaccumulative |
| vP | Very persistent |
| VP | Vapour pressure |
| vPvB | Very persistent and very bioaccumulative |
| WAF | Water Accommodated Fraction |
| WSF | Water Soluble Fraction |
| wt | Weight |
| wwt | Wet weight |
| WWTP | Wastewater Treatment Plant |
| µg | Microgram |

# 15 Appendix A: Literature search

A literature search was undertaken by the Environment Agency on 20th April 2020 to identify published information relevant to the assessment of HFP. The keywords listed in Table A.1 were searched for in PubMed (https://pubmed.ncbi.nlm.nih.gov/) and Science Direct (https://www.sciencedirect.com/). To maximise the number of records identified, keywords were based on the substance name only, and not on the endpoints of interest or year of publication.

**Table A.1 Literature search terms and number of hits**

| Search terms | Pub Med | Science Direct |
|---|---|---|
| **116-15-4** | 9 | 101 |
| **Hexafluoropropene** | 57 | 1194 |
| **Total unique records** | 59 | 1283 |

The identified records were screened manually for relevance to this assessment based on the title and abstract. Articles identified as of potential interest were obtained and reviewed for relevance. Those that were found to be relevant are discussed in the appropriate sections of this report.

# 16 Appendix B: QSAR Models

Two main databases were used to source *in silico* data for this evaluation when required. These were the United States Environmental Protection Agency (US EPA) CompTox Dashboard (US EPA, 2020a) and the Royal Society of Chemistry (RSC) ChemSpider portal (RSC, 2020a). Both integrate diverse types of relevant domain data through a cheminformatics platform and are built upon a database of curated substance properties linked to chemical structures (Williams *et al*., 2017).

The QSAR models available from these two platforms are presented in Table B.1 (data from other open access models are available in the CompTox dashboard, but for the sake of brevity, these have not been used for the purposes of this evaluation).

**Table B.1 QSAR model outline**

| Name | Brief description |
|---|---|
| **ACD/Labs** | Predicts physicochemical properties via the Percepta Platform (http://www.acdlabs.com/products/percepta/) |
| **EPISuite™ Estimation Programs Interface Suite™ for Microsoft® Windows** | A Windows®-based suite of physical/chemical, environmental fate and ecotoxicity property estimation programs developed by the US EPA and Syracuse Research Corp. It uses a single input (typically a SMILES string) to run the following estimation programs: AOPWIN™, AEROWIN™, BCFBAF™, BioHCwin, BIOWIN™, ECOSAR™, HENRYWIN™, HYDROWIN™, KOAWIN™, KOCWIN™, KOWWIN™, LEV3EPI™, MPBPWIN™, STPWIN™, WATERNT™, WSKOWWIN™ and WVOLWIN™. |
| **OPEn structure–activity/property Relationship App (OPERA)** | Open source suite of QSAR models providing predictions and additional information including applicability domain and accuracy assessment, as described in Williams *et al*. (2017). All models were built on curated data and standardized chemical structures as described in Mansouri *et al*. (2016). All OPERA properties are predicted under ambient conditions of 760 mmHg (103 kPa) at 25 °C. |
| **T.E.S.T. Toxicity Estimation Software Tool** | US EPA software application for estimating the toxicity of chemicals using QSAR methods. EPISuite™ is the model used to generate some physico-chemical data, although TEST does not report $K_{OW}$ values and uses a different database for surface tension. (US EPA, 2016). |

**EPISuite™**

Table B.2 summarises the PFCs identified in the training / validation sets for EPISuite™. Applicability domain (US EPA, 2020c).

**Table B.2 EPISuite™ PFCs included in training and validation sets**

| EPISuite model | Training set | Validation set |
|---|---|---|
| **MPBPVP v 1.42** | Tetrafluoromethane; hexafluoroethane; Tetrafluoroethylene; octafluoropropane; Hexafluoropropene; decafluorobutane; Perfluorocyclobutane; perfluoro-n-hexane; perfluorocyclohexane; perfluoroheptane; perfluoromethylcyclohexane | Not available |
| **WSKOWWIN v 1.41** | None identified | Octafluoropropane; octafluorocyclobutane |
| **Water solubility estimate from fragments (v 1.01 est)** | trifluoromethane | Tetrafluoromethane; hexafluoroethane; octafluoropropane; perfluorocyclobutane; tetrafluoroethylene |
| **KOAWIN v 1.1** | Uses KOWWIN and HENRYWIN databases | Uses KOWWIN and HENRYWIN databases |
| **KOCWIN v 1.66** | None identified | None identified |
| **KOWWIN v 1.67** | Tetrafluoromethane; hexafluoroethane | perfluorocyclohexane |
| **HENRYWIN v 3.1** | Tetrafluoromethane; hexafluoroethane; tetrafluoroethene | Octafluoropropane; perfluorocyclobutane |

**Open Structure-activity/property Relationship App (OPERA)**

OPERA is a free and open-source/open-data suite of QSAR models providing predictions for physicochemical properties, environmental fate parameters, and toxicity endpoints. Applicability domain (AD) (Williams *et al.,* 2017):

- If a chemical is considered outside the global AD and has a low local AD index (< 0.4), the prediction can be unreliable.
- If a chemical is considered outside the global AD but the local AD index is average (0.4–0.6), the query chemical is on the boundary of the training set but has quite

similar neighbours (average reliability). If the local AD index is high (> 0.6), the prediction can be trusted.
- If a chemical is considered inside the global AD but the local AD index is average (0.4–0.6), the query chemical falls in a “gap” of the chemical space of the model but still falls within the boundaries of the training set and is surrounded with training chemicals. The prediction therefore should be considered with caution.
- If a chemical is considered inside the global AD and has a high local AD index (> 0.6), the prediction can be considered reliable.

**T.E.S.T. (Toxicity Estimation Software Tool)** [26]

Data sets used in T.E.S.T. (US EPA, 2016) for parameters reported at 25°C:

- Surface tension: Dataset for 1 416 chemicals obtained from the data compilation of Jasper 1972;
- Water solubility: Dataset of 5 020 chemicals was compiled from the database in EPI Suite$^{TM}$. Chemicals with water solubilities exceeding 1,000,000 mg/L were omitted from the overall dataset
- Vapour pressure: Dataset of 2 511 chemicals was compiled from the database in EPI Suite$^{TM}$

T.E.S.T. displays structures for substances from the test and training sets that are closest to the substance where a predicted value is required. A comparison between the experimental and predicted value for the substances in the test and training sets provides a similarity coefficient. If the predicted values match the experimental values for similar chemicals in the test and training set (and the similar chemicals were predicted well), there is greater confidence in the predicted value for the substance under evaluation.

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