



PFAS in Quantitative Human Health Risk Assessment

Intersoil Barcelona 2026 – Domingo Espinosa Pulido (KEPLER Ingeniería y Ecogestión)



- 01. What are PFAS?
- 02. Main PFAS classes and groups
- 03. What are their singularities? Some physico-chemical properties
- 04. What is the PFAS problem in soil and/or groundwater?
- 05. What is the toxicology of PFAS?

WHAT ARE PFAS?

What does the acronym "PFAS" stand for?

P **Per- and Poly** (refers to the degree of fluorination).

F **Fluoro** (presence of fluorine atoms).

A **Alkyl** (refers to the carbon chain).

S **Substances**

The term is an umbrella covering thousands of distinct compounds.

Full name: Per- and Polyfluoroalkyl Substances (PFAS).

Other ways they are referred to:

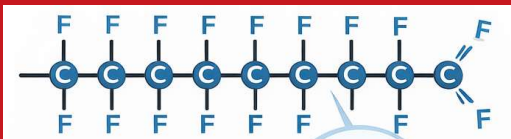
- **Forever Chemicals:** because their structure does not break down under normal environmental conditions.
- **Organofluorine compounds:** due to their carbon-and-fluorine composition.

WHAT GROUPS ARE PFAS CLASSIFIED INTO?

PFAS belong to the group of **synthetic fluorinated organic compounds**.

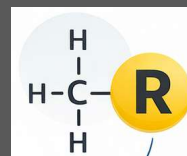
Carbon-Fluorine (C-F) Bond

- One of the strongest, most stable bonds in organic chemistry.
- Gives PFAS their resistance to heat, water and grease.
- Backbone: a chain of carbon atoms fully bonded to fluorine atoms.



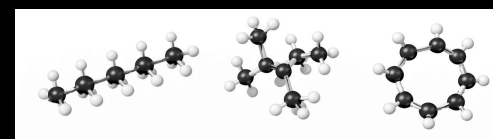
Alkyl Group (R)

- A fragment of a molecule derived from an alkane after losing a hydrogen atom.
- Universally represented by the letter "R".
- Examples: Methyl (CH_3), Ethyl (C_2H_5), C_3H_7 .



Chain Types

- **Linear** (propyl, butyl)
- **Branched** (isopropyl, tert-butyl)
- **Cyclic** (cyclopentyl)



MAIN PFAS CLASSES AND GROUPS

Perfluoroalkyl Acids (PFAAs)

- Includes the two most-studied compounds:
- PFOA: Perfluorooctanoic acid.
- PFOS: Perfluorooctane sulfonate.

Fluorinated Polymers

- E.g. PTFE (polytetrafluoroethylene), commonly known as Teflon.

Fluorotelomers

- Precursors that can degrade into other, more persistent PFAS in the environment.

FASAs

- Perfluoroalkane sulfonamides (S-O₂-N-H₂ group).
- PFOS precursors; neutral charge, volatile (MeFOSA, EtFOSA).

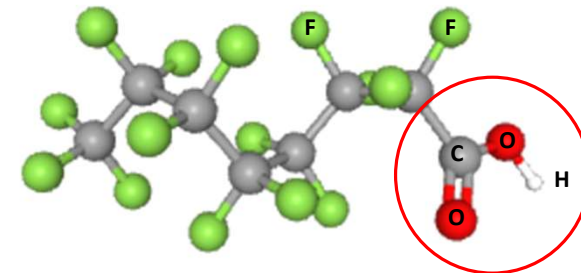
SOME EXAMPLES OF PFAS

PFOA (Perfluorooctanoic acid) — Banned since 2020

- One of the best-known and most-studied PFAS. Considered long-chain.
- **Structure:** a chain of 8 fully fluorine-saturated (perfluorinated) carbons with a carboxyl functional group at the end.

Formula: $\text{CF}_3\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-COOH}$

$(\text{CF}_3\text{-(CF}_2)_6\text{-COOH})$



Carboxyl group: -COOH (right end of the chain)

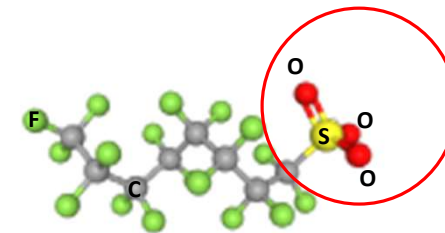
SOME EXAMPLES OF PFAS

PFOS (Perfluorooctane sulfonate) – Banned since 2009

- One of the best-known and most-studied PFAS. Considered long-chain.
- **Structure:** a chain of 8 (octane) fully fluorine-saturated (perfluorinated) carbons with a sulfonate functional group at the end.

Formula: $\text{CF}_3\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-CF}_2\text{-SO}_3\text{H}$

$(\text{CF}_3\text{-(CF}_2)_7\text{-SO}_3\text{H})$



Sulfonate group: $\text{-SO}_3\text{H}$ (right end of the chain)

HOW ARE PFAS PRODUCED OR SYNTHESIZED?

These substances do not occur naturally; they are entirely anthropogenic (man-made). They are synthesized mainly through two industrial processes:

Electrochemical Fluorination (ECF)

- An electric current is passed through a mix of organic compounds in liquid hydrogen fluoride, replacing hydrogen atoms with fluorine.

Telomerization

- A process that "assembles" small molecules to build longer, highly fluorinated carbon chains.

Used in:

Consumer products: cookware, textiles (Gore-Tex), food packaging, dental floss, cosmetics.

Industrial applications: firefighting foams (AFFF), electronics, aerospace and automotive (heat-resistant cables, hydraulic gaskets and seals).

WHAT ARE THEIR SINGULARITIES? SOME PHYSICO-CHEMICAL PROPERTIES

*To understand how PFAS behave, it is essential to understand that their properties are dictated by the **length of the perfluorinated chain** and the **nature of the terminal functional group**.*

- Ease/difficulty of breaking down
- Persistence (highly persistent)
- Solubility
- Volatility
- Henry's constant
- Vapor pressure
- Soil retention capacity: K_{oc}
- Air diffusivity coefficient
- Water diffusivity coefficient
- Acid dissociation constant (pK_a)
- PFAS dynamics in soil and associated groundwater

C-F Bond

C-F

One of the strongest, most stable bonds in organic chemistry – high electronegativity, strong electron pull.

SOME PHYSICO-CHEMICAL PROPERTIES

Property	Description and Behavior
Persistence	Extremely high. Their difficulty breaking down keeps them in the environment for centuries.
Solubility	Many PFAS are highly water-soluble, aiding their spread through rivers and aquifers.
Volatility	Varies by compound. Some precursors are volatile and travel by air; PFAS salts do not.
Vapor pressure	Determines whether the compound tends to evaporate or remain liquid/solid.
Henry's constant	Defines how PFAS distribute between air and water – key to atmospheric transport.

Characteristic	Long Chain (e.g. PFOA, PFOS)	Short Chain (e.g. PFBA, PFBS)
No. of carbons	Generally 8 or more	Generally fewer than 7
Persistence	Extremely high; "forever chemicals"	High; also persistent
Bioaccumulation	Very high in blood and organs	Lower in blood, but highly mobile
Water mobility	Moderate	Very high; travel farther/faster
Filtration difficulty	Removed better with activated carbon	Very hard to remove from drinking water
Regulatory status	Highly restricted or banned	Under evaluation and restriction

The distinction between short chain ($C < 7$) and long chain ($C \geq 8$) PFAS is not merely taxonomic: it **defines behavior in aqueous and organic phases** (solid soil matrix).

Long-Chain Compounds (Highly Lipophilic)

Substances such as PFODA (C18), PFTetDA (C14), PFDoDA (C12), PFUDA (C11), PFNA (C9) and PFOS (C8) show:

- **Low Aqueous Solubility:** as the number of $-CF_2-$ groups increases, the molecule becomes more hydrophobic.
- **High K_{oc} (adsorption coefficient):** **strong affinity for soil organic matter – limits mobility** but **increases local persistence**.
- **Bioaccumulation:** structural similarity to fatty acids makes them bind strongly to serum proteins (e.g., albumin), hindering excretion.

Short-Chain Compounds (Highly Hydrophilic)

Substances such as PFHxS (C6), PFHxA (C6) and PFPrA (C3) show different behavior:

- **High Solubility:** the hydrophilic functional group (sulfonate or carboxylate) dominates over the short fluorinated chain.
- **Low Vapor Pressure:** facilitates **long-distance transport through the water cycle**.
- **Diffusivity:** much **higher water diffusivity coefficients** than long chains, allowing rapid penetration into deep aquifers.

SOLUBILITY AND VAPOR PRESSURE

These properties are **inversely related** to the length of the perfluorinated chain.

- **Solubility:** follows a decreasing logarithmic trend. PFHxA (C6) and **PFPrA** (C3) are highly hydrophilic because the carboxylate group dominates the molecule; **PFDoDA** (C12) and higher are extremely hydrophobic.
- **Vapor Pressure:** perfluorinated **acids** (neutral forms) are volatile, but at environmental pH they mostly exist as anions (**salts**) with negligible vapor pressure, tending to stay in the aqueous phase or adsorbed to particles.

Acronym	Type	Chain Length	Water Solubility	Volatility / Henry's Constant
PFODA	Carboxylate	C18 (very long)	Negligible	Very low (tends to adsorb)
PFTetDA	Carboxylate	C14 (long)	Very low	Solid / particulate phase
PFUDA	Carboxylate	C11 (long)	Low	Low
PFOS	Sulfonate	C8 (long)	Moderate (as salt)	Non-volatile
PFHxS	Sulfonate	C6 (short/medium)	High	Low
PFHxA	Carboxylate	C6 (short)	Very high	Moderate (volatile precursors)
PFPrA	Carboxylate	C3 (very short)	Extreme	High aqueous mobility



HENRY'S LAW CONSTANT (H): VOLATILITY

- For ionic PFAS (such as PFOS or PFOA), the **H value is very low**. They do not evaporate easily from water bodies.
- However, precursors (such as **fluorotelomer alcohols, FTOH**) have high constants, allowing global atmospheric transport (FTOH, FOSE, FOSA).

US EPA criterion to be considered volatile:

- Vapor pressure > 1 mm Hg
- Dimensionless Henry's constant > 4.1×10^{-4}

- Reported Henry's law coefficients can span several orders of magnitude for a single PFAS (ITRC 2026a), making it hard to determine which values best represent real-world behavior.
- Vapor-phase presence is currently understood to be associated mainly with neutral PFAS – FTOH, FOSE, perfluorooctane sulfonamide (FOSA) – and ultra-short-chain PFAS (≤ 3 carbon atoms).

PFAS MEETING THE EPA CRITERION FOR VOLATILITY – 1/2

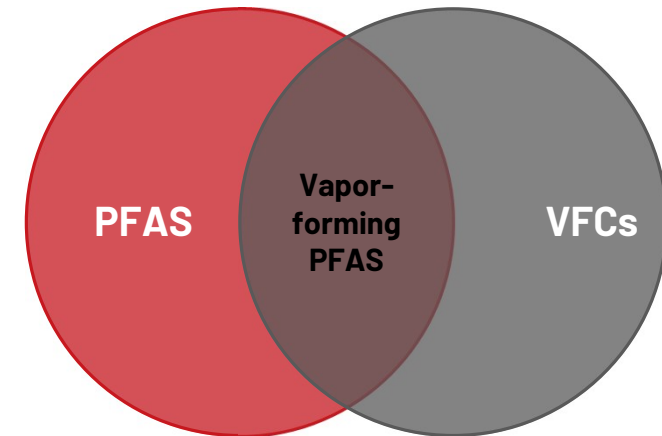
Acronym	Name	CAS No.	C	Group	Max Vapor Pres. (mmHg)	Max Henry (atm·m ³ /mol)
PFP	Perfluoropropane	76-19-7	3	Perfluoroalkane	7500	8.91
PFB	Perfluorobutane	355-25-9	4	Perfluoroalkane	2003	1.17
PFPe	Perfluoropentane	678-26-2	5	Perfluoroalkane	647	0.985
PFHx	Perfluorohexane	355-42-0	6	Perfluoroalkane	232	0.845
PFHp	Perfluoroheptane	335-57-9	7	Perfluoroalkane	82.5	0.729
PFO	Perfluorooctane	307-34-6	8	Perfluoroalkane	32.3	0.626
PFN	Perfluorononane	375-96-2	9	Perfluoroalkane	10.1	0.538

PFAS MEETING THE EPA CRITERION FOR VOLATILITY – 2/2

Acronym	Name	CAS No.	C	Group	Max Vapor Pres. (mmHg)	Max Henry (atm·m ³ /mol)
PFD	Perfluorodecane	307-45-9	10	Perfluoroalkane	3.11	0.462
PFUn	Perfluoroundecane	306-94-5	11	Perfluoroalkane	1.18	0.397
4:2 FTOH	4:2 Fluorotelomer alcohol	2043-47-2	6	Fluorotelomer alcohol	11.5	2.80E-03
6:2 FTOH	6:2 Fluorotelomer alcohol	647-42-7	8	Fluorotelomer alcohol	1.13	1.55E-03
MeFOSA	N-Methyl perfluorooctane sulfonamide	31506-32-8	9	Perfluoroalkyl sulfonamide	0.0021	1.04E-04
EtFOSA	N-Ethyl perfluorooctane sulfonamide	4151-50-2	10	Perfluoroalkyl sulfonamide	0.0025	1.02E-04

VAPOR-FORMING PFAS AND VOLATILIZATION PATHWAYS

- Certain PFAS have **vapor pressures high enough to be designated vapor-forming chemicals**, raising vapor-intrusion concerns for indoor air above contaminated soils or groundwater (USEPA 2023).
 - Little consensus exists on **what subsurface or indoor-air concentrations should trigger a vapor-intrusion assessment**. Inhalation toxicity values for **vapor-forming PFAS are currently lacking**.
-
- FTOH, FOSE, FOSA – theoretically meet the volatility criterion.
 - Practical experience is less conclusive.
 - Absence of inhalation toxicity values.



Conceptual relationship between PFAS and vapor-forming PFAS (VFCs) - not meant to be quantitative (adapted from C. Regan, Haley and Aldrich).

PFAS BEHAVIOR BY CHAIN TYPE AND OCTANOL-WATER COEFFICIENT (KOW)

Compound	Chain (C)	Log Kow (approx.)	Predominant Behavior
PFPrA	3	Low	Extreme aqueous mobility; impossible to filter with activated carbon.
PFHxA / PFHxS	6	Moderate	High solubility; rapid transport in groundwater.
PFOS / PFNA	8/9	High	Bioaccumulative; high affinity for proteins and sediments.
PFDoDA / PFUDA	12/11	Very high	Immobile in soil; high persistence in deep sediments.
PFODA	18	Extreme	Wax-like behavior; low mobility, high adsorption.

pKa measures a molecule's tendency to release a proton (H^+) and become a negatively-charged anion.

Influence of the Functional Group on pKa and Mobilization

Sulfonates (PFSA)

- PFOS or PFHxS have an extremely low pKa — generally negative or near zero.
- This makes them stronger acids than carboxylates.

Carboxylates (PFCA)

- PFHxA, PFNA or PFODA have a slightly higher pKa, typically 0.5–3.0.
- Still strong acids, remaining deprotonated in almost any natural environmental scenario.

Short-Chain PFAS (High Mobility)

- Compounds such as PFPrA (C3) and PFHxA (C6) have high solubility and a low adsorption coefficient (K_{oc}).
- Because their pK_a is low, they are negatively charged at neutral pH – generating electrostatic repulsion with negatively-charged soil clays and favoring massive leaching toward aquifers.

Long-Chain PFAS (Low Mobility)

- Compounds such as PFDoDA (C12) and PFODA (C18) are extremely hydrophobic.
- Although ionized (low pK_a), the van der Waals forces along their long carbon chain are strong enough that the molecule prefers to "stick" to soil organic matter rather than dissolve – movement through the subsurface is very slow (retarded transport).

PFAS: THE FOREVER CHEMICALS AND YOUR HEALTH

HOW THEY ACT IN YOUR BODY



Bind to proteins, not fat. Accumulate in blood, liver and kidneys – unlike other organic pollutants.



Remain in the body for years. Human half-life can range from 2 to 35 years.



The body doesn't break them down. Excreted in their original form, mainly via urine and feces.

MAIN HEALTH RISKS



Alter the liver, raise cholesterol. Increase total and LDL ("bad") cholesterol levels in the blood.



Exposure transfers from mother to child. Cross the placenta and are excreted in breast milk.



Potential carcinogen. PFOA is considered a possible carcinogen, linked to testicular and kidney cancer.

Some effects of PFOA and/or PFOS on health

WHAT IS THE TOXICOLOGY OF PFAS?

- **Organ-specific distribution:** unlike other organic pollutants that accumulate in fat, PFAS have an affinity for proteins and distribute mainly to the liver, kidneys and blood. In blood, they bind strongly to serum albumin.
- **Persistence in the body:** long-chain PFAS are eliminated very slowly, with human half-lives measured in years (2–35, depending on the substance). Short-chain PFAS are excreted much faster – half-lives from hours or days up to a month (e.g. PFBA, PFBS).
- **Large biological differences in elimination:** excretion rates vary dramatically between species – e.g. PFOA's half-life is several years in humans but only hours in female rats – complicating direct dose extrapolation from animals to humans.
- **Developmental toxicity:** prenatal exposure is associated with reduced birth weight in humans.

WHAT IS THE TOXICOLOGY OF PFAS?

- **Hepatic and lipid effects:** in animals, PFAS increase liver weight and cause hypertrophy; in humans, they are associated with higher total and LDL cholesterol, as PFAS exposure alters how the liver processes and clears fats.
- **Mother-to-infant transfer:** PFAS cross the placenta and are excreted in breast milk, exposing fetuses and infants during critical periods; infant levels can be substantially higher than in mothers.
- **Absence of chemical metabolism:** PFAS do not break down or react chemically in the body, so they are excreted mainly through urine and feces in their original form.
- **Carcinogenic potential:** PFOA has been concluded to be a possible human carcinogen (Group 2B), linked to increased testicular and kidney cancer in highly exposed populations.
- **Toxic potency and dose:** in animal studies, long-chain compounds tend to show toxicity at lower doses than short-chain ones, since slow excretion means the same dose yields a much higher, more persistent internal (blood) concentration.

PFAS VALUES VS. TOXICOLOGICAL CONSTANTS – RAIS DATABASE (JAN. 2026) – 1/3



DWSHA: Drinking Water System Health Advisory | HHTV: Human Health Toxicity Values | WI: Wisconsin

Group	Name	Acronym	CAS	Oral RfD (mg/kg-d)	RfD Src	SFo (mg/kg-d) ⁻¹	SFo Src	Chain	Cancer
Carboxyl	Perfluorobutanoic acid	PFBA	375-22-4	1.00E-03	IRIS	-	-	Short (C4)	Not classif.
Carboxyl	Perfluorodecanoic acid	PFDA	335-76-2	2.07E-09	IRIS	-	-	Long (C10)	Not classif.
Carboxyl	Perfluorohexanoic acid	PFHxA	307-24-4	5.00E-04	IRIS	-	-	Short (C6)	No evidence
Carboxyl	Perfluorononanoic acid	PFNA	375-95-1	3.00E-06	DWSHA	-	-	Long (C9)	Not classif.
Carboxyl	Perfluorooctanoic acid	PFOA	335-67-1	3.00E-08	DWSHA	29300	DWSHA	Long (C8)	Grp 1 / Carcin.
Carboxyl	Perfluoropropanoic acid	PFPrA	422-64-0	5.00E-04	HHTV	-	-	Short (C3)	Not classif.
Carboxyl	Perfluorotetradecanoic acid	PFTetDA	0376-06-07	1.00E-03	WI	-	-	Long (C14)	Not classif.
Carboxyl	Perfluoroundecanoic acid	PFUnDA	2058-94-8	3.00E-04	WI	-	-	Long (C11)	Not classif.

PFAS VALUES VS. TOXICOLOGICAL CONSTANTS – RAIS DATABASE (JAN. 2026) – 2/3

Group	Name	Acronym	CAS	Oral RfD (mg/kg-d)	RfD Src	SFo (mg/kg-d) ⁻¹	SFo Src	Chain	Cancer
Carboxyl	Perfluorododecanoic acid	PFDODA	307-55-1	5.00E-05	WI Current	-	-	Long (C12)	Not classif.
Ether	4,8-dioxa-3H-perfluoro...	ADONA	958445-44-8	3.00E-06	DWSHA	-	-	Short (C7)	Not classif.
Ether	GenX acid	GenX	13252-13-6	3.00E-06	IRIS	-	-	Short (C6)	Suggestive
Other	Bis(perfluoromethylsulf...) anion	PFSI	98837-98-0	3.00E-04	HHTV	-	-	-	Not classif.
Other	Bis(trifluoromethylsulfonyl)amine	TFSI	82113-65-3	3.00E-04	HHTV	-	-	-	Not classif.
Sulfonamide	N-Ethyl-perfluorooctanesulf.	EtFOSA	4151-50-2	1.00E-07	DWSHA	-	-	Long (C10)	Not classif.
Sulfonamide	2-(N-Ethylperfluorooctanesulf...)	EtFOSE	1691-99-2	1.00E-07	DWSHA	-	-	Long (C10)	Not classif.
Sulfonamide	N-Methylperfluorooctanesulf.	MeFOSA	31506-32-8	1.00E-07	DWSHA	-	-	Long (C9)	Not classif.

PFAS VALUES VS. TOXICOLOGICAL CONSTANTS – RAIS DATABASE (JAN. 2026) – 3/3



Group	Name	Acronym	CAS	Oral RfD (mg/kg-d)	RfD Src	SFo (mg/kg-d) ⁻¹	SFo Src	Chain	Cancer
Sulfonamide	2-(N-Methylperfluorooctanesulf...)	MeFOSE	24448-09-07	1.00E-07	DWSHA	-	-	Long (C9)	Not classif.
Sulfonamide	Perfluorooctanesulfon... acid	FOSAA	2806-24-8	1.00E-07	DWSHA	-	-	Long (C10)	Not classif.
Sulfonamide	N-Ethyl-perfluorooctanesulf... acid	EtFOSAA	2991-50-6	1.00E-07	DWSHA	-	-	Long (C12)	Not classif.
Sulfonamide	N-Methyl-perfluorooctanesulf... acid	MeFOSAA	2355-31-9	1.00E-07	DWSHA	-	-	Long (C11)	Not classif.
Sulfonic	Perfluorobutanesulfonic acid	PFBS	375-73-5	3.00E-04	IRIS	-	-	Short (C4)	No evidence
Sulfonic	Perfluorohexanesulfonic acid	PFHxS	355-46-4	4.20E-10	IRIS	-	-	Long (C6)	No evidence
Sulfonic	Perfluorooctanesulfonic acid	PFOS	1763-23-1	1.00E-07	DWSHA	39.5	DWSHA	Long (C8)	Grp 2B / Suggest.

DERMAL AND GASTROINTESTINAL ABSORPTION FACTORS

Substance	CAS No.	RAGS Part E Dermal Factor	RAGS Part E ABS Ref.	RAGS Part E GI Factor	RAGS Part E GIABS Ref.
Perfluorohexanesulfonic acid (PFHxS)	355-46-4	0.1	RAGSE	1	RAGSE
Perfluorooctanesulfonic acid (PFOS)	1763-23-1	0.1	RAGSE	1	RAGSE
Perfluorooctanoic acid (PFOA)	335-67-1	0.1	RAGSE	1	RAGSE

COMPARISON WITH TOXICOLOGICAL CONSTANTS OF OTHER SOIL CONTAMINANTS

- PFOA and PFOS have oral reference doses far more restrictive than vinyl chloride or trichloroethylene, and oral cancer slope factors far more restrictive than these compounds.
- For oral RfD, the smaller the value the more restrictive; for SFo, the larger the value the more restrictive the toxicological constant.

Substance	Oral RfD (mg/kg-d)	RfD Source	SFo (mg/kg-d) ⁻¹	SFo Source
PFOA	3.00E-08	DWSHA	29300	DWSHA
PFHxS	4.20E-10	IRIS	-	-
PFOS	1.00E-07	DWSHA	39.5	DWSHA
PFDA	2.00E-09	IRIS Current	-	-
Vinyl chloride	3.00E-03	IRIS Current	7.20E-01	IRIS Current
Tetrachloroethylene	6.00E-03	IRIS Current	2.10E-03	IRIS Current
Trichloroethylene	5.00E-04	IRIS Current	4.60E-02	IRIS Current

PFAS ANALYZED BY THE LABORATORY WITH TOXICOLOGICAL CONSTANT VALUES



Group	Name	Acronym	CAS	Oral RfD (mg/kg-d)	RfD Src	SFo (mg/kg-d) ⁻¹	SFo Src	Chain
Carboxyl	Perfluorobutanoic acid	PFBA	375-22-4	1.00E-03	IRIS	-	-	Short (C4)
Carboxyl	Perfluorodecanoic acid	PFDA	335-76-2	2.00E-09	IRIS	-	-	Long (C10)
Carboxyl	Perfluorohexanoic acid	PFHxA	307-24-4	5.00E-04	IRIS	-	-	Short (C6)
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Carboxyl	Perfluorododecanoic acid	PFDoDA	307-55-1	5.00E-05	WI Current	-	-	Long (C12)
Sulfonic	Perfluorobutanesulfonic acid	PFBS	375-73-5	3.00E-04	IRIS	-	-	Short (C4)
Sulfonic	Perfluorohexanesulfonic acid	PFHxS	355-46-4	4.20E-10	IRIS	-	-	Long (C6)
Sulfonic	Perfluorooctanesulfonic acid	PFOS	1763-23-1	1.00E-07	DWSHA	39.5	DWSHA	Long (C8)

KEY TAKEAWAYS ON PFAS

-  **Importance of alkyl chain type (R):** short chains vs. long chains.
 -  **Importance of the chemical group:** carboxyls vs. sulfonates and sulfonamide.
 -  **Strength of the Carbon-Fluorine bond** hinders degradation — high stability against fire, grease and water.
 -  **Polarity and environmental dynamics vary** depending on whether PFAS are present as an acid (PFAA) or as a salt.
 -  **Environmental dynamics depend on properties** such as solubility, Henry's constant, vapor pressure, Koc, and diffusivity in air and water.
 -  **Internal polarity differences** within the PFAS molecule itself determine its mobility and dynamics in soil.
 -  **Toxicity differs greatly between animals (mice) and humans**, complicating extrapolation.
- Effects on humans:**
-  **Binds to blood proteins (albumin)** and distributes to the kidneys and liver.
 -  **Crosses the placenta and breast milk** to newborns (bioaccumulation).
 -  **Some PFAS compounds are carcinogenic in humans** (testicular, renal).

Not all PFAS with toxicological constant values are analyzed by commercial laboratories.

Thank you!

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