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Fluorocarbons (PFAS)—The Forever Chemicals

Joseph Pizzorno, ND, Editor in Chief

Abstract

Fluorocarbons are fluorinated organic molecules widely used in industry and commerce. Nomenclature has changed over the years, with PFAS becoming the accepted umbrella term. The environment is heavily polluted with these toxins. Worldwide research shows that they contribute to almost every chronic disease. The primary source of human contamination is food packaging. There are significant concerns that the available research has not adequately addressed ultrashort-chain PFAS, which are breakdown products of longer-chain versions and accumulate in the environment at almost 100 times higher concentrations than the longer-chain versions.

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Introduction

Much of the research for the basic science aspects of this editorial came from the *Toxicology Profile for Perfluoroalkyls published by the US Agency for Toxic Substances and Disease Registry in 2021. (*Toxicological Profile for Perfluoroalkyls (cdc.gov)) Those interested in more deeply studying PFAS will find it an excellent resource.

Definition and Terminology

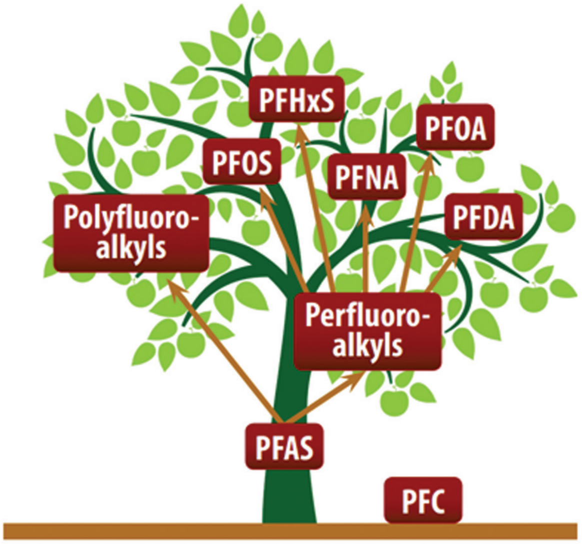
Perfluorocarbons are organofluorine compounds with the formula CxFy.

Reading the research reveals that this class of chemicals has seen diverse names used interchangeably over the years. While perfluorocarbon (PFC) was used most in the past, the research community has settled on PFAS. This editorial uses PFAS as the generic term for all per- and poly-fluorinated compounds. Figure 1 lays out the PFAS tree.

PFAS are fluorinated molecules that are widely used in industry and in diverse products and processes. Examples include water-repelling textiles, grease-resistant paper, nonstick packaging and cooking appliances, medical and laboratory tubing, aqueous film-forming foams, and industrial detergents.

PFAS are highly persistent toxins with half-lives ranging from 2 to 7 years. There are hundreds of unique PFAS, and the rate of detoxification is, in general, inversely proportional to the number of fluorine substitutes.

Figure 1. The PFAS Family Tree[1]



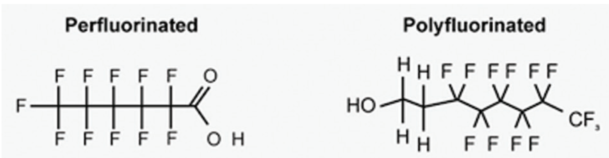
As might be expected with their wide range of use and long persistence, PFAS heavily contaminate the environment.

Classification and Naming

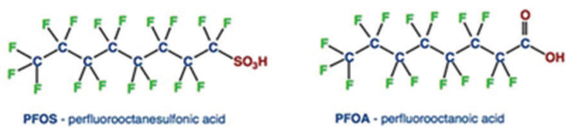
PFAS are a class of over 12 000 compounds, each with a carbon chain of varying length that is either fully or partially saturated with fluorine atoms and has a polar end group.

Key identification criteria for PFAS are

1. Per- or poly-



2. End molecule hydroxyl or sulfate



3. Length (the third letter in the abbreviation usually indicates the carbon-chain length)

Example names are in Table 1.

Table 1. Common PFAS Compound Names[2]

X	Y	Acronym	Name	Formula
B = buta (4 carbon)	A = Carboxulate or carboxlic acid	PFBA	Perfluorobutanoate	$C_3F_7CO_2^-$
			Perfluorobutanoate acid	C_3F_7COOH
	S = sulfonate or sulfonic acid	PFBS	Perfluorobutane sulfonate	$C_4F_9SO_3^-$
			Perfluorobutane sulfonic acid	$C_4F_7SO_3H$
O = octa (8 carbon)	A = Carboxylate or carboxylic acid	PFOA	Perfluorooctanoate	$C_7F_{15}CO_2^-$
			Perfluorooctanoic acid	$C_7F_{15}COOH$
	S = sulfonate or sulfonic acid	PFOS	Perfluoroocatane sulfonate	$C_8F_{17}SO_3^-$
			Perfluoroctane sulfonic acid	$C_8F_{17}SO_3H$

Chain Length

PFAS are classified according to chain length:

- **Long-chain:** 7 or more perfluorocarbons for perfluorocarboxylates (PFCAs), and 6 or more perfluorocarbons for perfluorosulfonates (PFSAs)
- **Short-chain:** 3 to 7 perfluorocarbons for PFCAs, and 4 to 5 perfluorocarbons for PFSAs
- **Ultrashort-chain:** 2 or fewer perfluorocarbons for PFCAs, and 3 or fewer perfluorocarbons for PFSAs and other PFAS

Challenges

This has been a challenging editorial to write. Normally, when I study an environmental metal or chemical toxicant, the patterns of exposure and disease causations and associations quickly become clear. For PFAS, a number of problems showed up immediately:

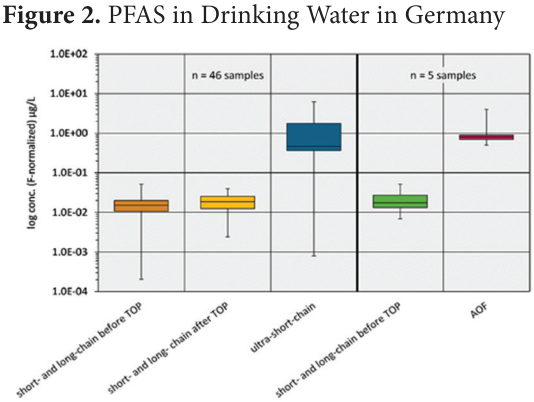
1. The mechanisms of damage are poorly understood.
2. Most of the safety research is with animals. However, rodents detoxify PFAS 10 to 1000 times faster than humans do.
3. The PFAS that have been measured and studied may not be the worst fluorocarbons. Specifically, virtually all the research is on short-, medium-, and long-length perfluorinated compounds, but emerging research suggests that the ultrashort perfluorinated compounds are the worst for human health AND that their concentrations in water are typically 100 times higher.
4. The actual exposure has shifted a lot in the past decade as we transitioned from the now banned perfluorooctanoic acid (PFOA) to supposedly safer perfluorooctane sulfonic acid (PFOS) and other perfluorinated compounds. Unfortunately, like so many other substitutions of toxic chemicals we often don't have much long term safety data.
5. Exposure is so widespread and persistent that there is virtually no human control population.
6. Further complicating our understanding is that several PFAS have nonlinear health damaging effects.
7. There are many disease associations, but they are of marginal statistical significance—probably because of the issues in this list.

The Problem of Under-Recognized Ultrashort-Chain PFAS

The ultrashort-chain PFAS are degradation products of longer-chain PFAS. Commercial laboratories do not currently measure most ultrashort-chain PFAS. Ultrashort-chain PFAS commonly contaminate drinking water and are found in high concentrations in the body. Worse, these molecules are water soluble, and there are no current environmental regulations.[3]

Figure 2, from a recent study of drinking water in Germany, illustrates the problem well. Note that the vertical axis is a log scale.

Figure 2. PFAS in Drinking Water in Germany



Abbreviations: AOF, adsorbable organic fluorine; TOP, total oxidizable precursor.

Routes of Exposure

The routes of exposure to PFAS are diverse and common. In general, they come from food, water, clothing, dust, industrial processes—basically they come from everywhere. Table 2 provides an example of their use in industry.

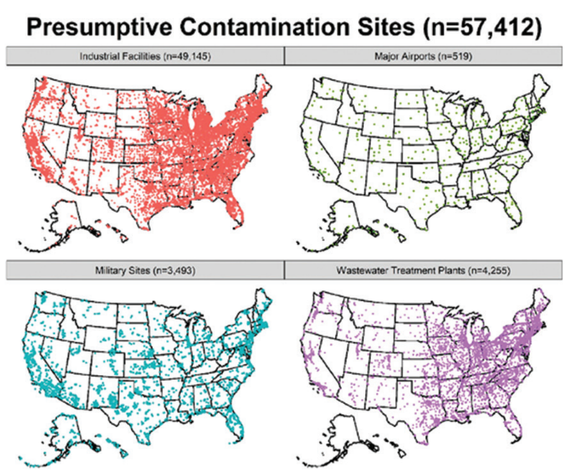
Table 2. Industrial Uses of PFAS[4]

Point Source Category	Description	Uses or Sources of PFAS [a]
Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF)	Industrial facilities that manufacture organic chemicals, plastics, synthetic fibers or resin products, including those that manufacture PFAS or process PFAS in production of such products. Subject to ELGs in 40 CFR Part 414.	- Manufacture PFAS through electrochemical fluorination, telomerization, or other processes. - Polymerization processing aids. - Production of plastic, rubber, and resin. - Present in manufacture of commercial chemical products (e.g., carpet cleaning sprays, cleaning agents, protective coatings).
Metal Finishing	Industrial facilities that change the surface of an object to improve its appearance or durability. Includes six primary operations: electroplating, electroless plating, anodizing, coating, printed circuit board manufacturing, and chemical etching and milling. Subject to ELGs in 40 CFR Part 433.	- PFAS-containing chemicals used as wetting agents, mist and fume suppressants to prevent air emissions of toxic metal fumes, agents to reduce mechanical wear, and surface coatings to impart certain characteristics (e.g., reduced corrosion, enhanced appearance).
Pulp, Paper, and Paperboard	Mills that convert wood into pulp, paper, paperboard, and other cellulose-based products. Subject to ELGs in 40 CFR Part 430.	- PFAS-containing chemicals used to impart products with water and grease repellency (e.g., food packaging, coated papers). - Recycling of paper and paperboard products treated with PFAS.
Textile Mills	Mills that receive and prepare fibers; transform materials into yarn, thread, or webbing; convert yarn and webbing into fabric or related products; or finish these materials to produce consumer products (e.g., thread, yarn, bolt fabric, hosiery, towels, sheets, carpet). Subject to ELGs in 40 CFR Part 410.	- PFAS-containing chemicals used to impart outdoor gear, clothing, household, and other textile products with water, oil, soil, and heat resistance.
Commercial Airports	Commercial facilities associated with commercial air transport or aircraft flight operations. Excludes facilities operated by the United States Department of Defense (DOD). Subject to ELGs in 40 CFR Part 449.	- PFAS are a component of aqueous film-forming foam (AFFF), used for exterminating hydrocarbon fuel fires and firefighting training.

a – In general, PFAS may be used as coatings or surfactants for mechanical components (e.g., semiconductors, wiring, tubing, piping, seals, gaskets, etc.) used at many types of industrial facilities.

This widespread use has resulted in extensive contamination of the environment, as can be seen in Figure 3.

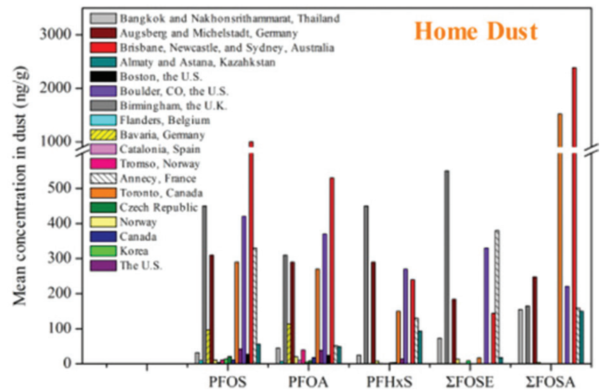
Figure 3. Industrial Contamination of the Environment with PFAS[5]



This widespread contamination of the environment shows up in household dust all over the world, as shown in Figure 4. Clearly, a clean home is important for health.

Prepared and packaged foods are the major source of PFAS. The amount leached into food is increased by higher fat, lower pH, increased salt, alcohol, time, heat, and surface area of the food in contact with the packaging.[7]

Figure 4. PFAS in House Dust[6]



While fast food is a significant source of PFAS, prepared popcorn is much worse—by a factor of 5.[8] Even straws are a significant source.[9]

Several professions have unusually high levels of PFAS exposure. Those professions most exposed are firefighters, construction workers, furniture makers, and ski technicians (professional ski waxers have up to 25 times as many PFAS in their blood as the general population).[10] Basically everyone who uses nonstick or stain-guard products is exposed. We even have to consider newly installed carpet. Those interested will find Dr Steven Genuis' case report illuminating.[11]

Worldwide research to quantify the primary sources of PFAS exposure in the general population found that more than 90% of the average body load comes from diet.[12] However, these studies did not include the ultrashort-chain PFAS. If these had been included, it is quite possible that water is also a primary source of exposure.

Body Load

All these exposures add up to a significant body burden[13]:

Industrial workers: 1000 ng/mL
Highly exposed residents (without occupational exposure): 423 ng/mL
US population: 4.9 ng/mL

There is good news and bad. The good news is that the body load of PFOA has decreased 90% since these compounds were banned 10 years ago.[14] The bad news is that they have been replaced with other PFAS.

Excretion and Detoxification

PFAS are difficult for humans to detoxify and have half-lives measured in years. They are excreted through urine, menstrual blood, breast milk, and stool but not through sweat. Most of the detoxification is through the liver, though mechanisms are unclear.

In general, the longer the chain and the more saturation with fluorine the slower the detoxification.

Table 3 shows the rates of detoxification of the most common PFAS. Note especially the dramatic differences in detoxification rates between the rodents typically used for toxicology research and humans and nonhuman primates. Also of interest is that female rats are much more effective at this detoxification than male rats.

Table 3. Half-Lives of Common PFAS[15]

	Humans	Nonhuman primates	Rats	Mice
PFOA	2.1–10.1 years	20.1–32.6 days	Males: 44–322 hours Females: 1.9–16.2 hours	
PFOS	3.3–27 years	110–170 days	179–1,968 hours	731–1,027 hours
PFHxS	4.7–35 years	87–141 days	Males: 382–688 hours Females: 1.03–41.28 hours	597–643 hours
PFNA	2.5–4.3 years		Males: 710–1,128 hours Females: 33.6–58.6 hours	619.2–1,653 hours
PFBS	665 hours	8.0–95.2 hours	2.1–7.42 hours	
PFBA	72–81 hours	40.3–41.0 hours	1.03–9.22 hours	2.79–13.34 hours

Disease Associations

This is where the research is so frustrating. While PFAS body load correlates with many diseases, the actual increase is apparently relatively modest. Figure 5 provides a clear graphical presentation of how pervasively PFAS damage human tissues.

Figure 5. PFAS Damage Many Tissues[16]

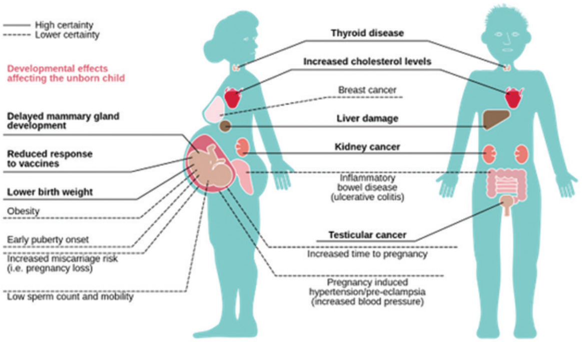


Table 4 lists the diseases that have research-documented correlations with the body load of PFAS.

Table 4. Diseases Correlated with Body Load of PFAS[16-22]

Cancer
Cardiovascular disease
COVID-19
Diabetes
Gout
Infertility (male and female)
Inflammatory bowel disease
Impaired fetal development
Kidney disease
Lipid abnormalities
Liver damage
Mitochondrial dysfunction
Nonalcoholic fatty liver disease
Obesity
Osteoporosis
Thyroid dysfunction

Assessment

Assessment of body load of PFAS is currently very difficult. Some commercial laboratories are starting to implement the technology needed to measure these molecules in human fluids. However, the scientists have many challenges, including the use of equipment that contains Teflon tubing or other PFAS.

At this time, indirect measures to detect significant PFAS exposure may be clinically more useful, and certainly much less expensive. Alanine transaminase (ALT), bilirubin, γ-glutamyltransferase, (GGTP) and uric acid all increase **within the "normal range"** after PFAS exposure.[24-26] Once again, the normal range includes a lot of sickness and is NOT the healthy range.

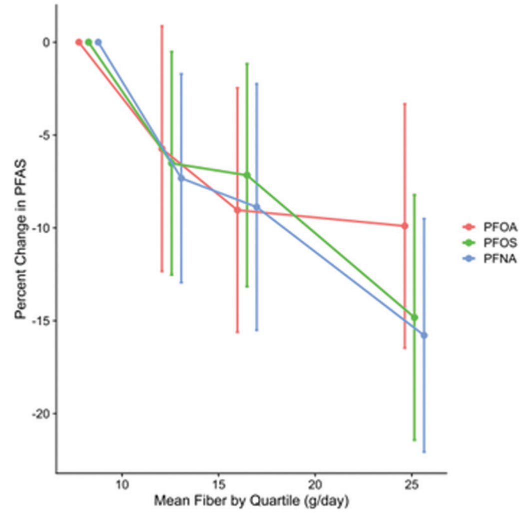
My recommendation is to directly measure PFAS to establish a baseline. Then use the inexpensive indirect measures to monitor intervention efficacy.

Treatment

As is usual with toxins, avoidance is the key. Since the main source of PFAS, by far, is food (but may also be water, if the ultrashort-chain PFAS are shown to be significant), addressing the food-packaging problem will be hugely successful. The best way to accomplish this is to not eat out, NEVER eat microwave popcorn, and replace all kitchen storage and cookware with those made from glass, stainless steel, or ceramics. Carbon block filters are effective at removing PFAS from water.

Of great importance is recognizing that enterohepatic recirculation is a significant factor impairing PFAS excretion from the body. As would be expected, increasing dietary fiber definitely increases the rate of excretion in the stool. Figure 6 presents this very clearly. However, note that the top dosage was only 25 grams per day—far less than the amount in human evolutionary diet. The rate of excretion can also be increased through the use of bile sequestrants, such as cholestyramine.[27]

Figure 6. Dietary Fiber Increases PFAS Excretion[28]



Finally, several herbs and nutrients can help prevent the damage caused by PFAS. Curcumin has been shown in cell cultures to decrease DNA damage.[29] Vitamin C blunts insulin resistance in humans.[30] Blueberries were shown in an animal study to decrease PFAS neurotoxicity.[31]

Conclusion

Exposure to PFAS is ubiquitous but is primarily from food. The entire population has a body load of PFAS that increases their risk of the most common chronic diseases. The very long half-lives of PFAS mean that, while avoidance is important, intervention is required to decrease body load.

I do not think the research is clear enough yet to determine exactly how much disease is caused by PFAS. I suspect we will find it significant as the ultrashort-chain PFAS are researched.

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