

FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites



Photo Credit: Bill Gee of WRG Fire Training Simulation Systems Inc

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By

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TABLE OF CONTENTS

Overview	1
1. What are PFASs?	2
2. What is AFFF?	4
3. What are other sources of PFASs?.....	7
4. In what environmental media have PFASs been found?.....	8
5. What is the fate and transport of PFASs in the environment?	9
6. What characterization and remedial tools are available/effective for PFASs?.....	11
7. What are the human and ecological exposure pathways and health effects?	13
8. What is the current regulatory status?.....	16
Acronyms	17
Where can I find more information?	19
References cited	20
Authors	32

Overview

This document was crafted to provide remedial project managers and other stakeholders with a concise summary on the state of knowledge regarding per- and polyfluoroalkyl substances (PFASs) as related to the use and release of aqueous film forming foams (AFFFs) at United States (U.S.) military sites. Eight frequently-asked questions (FAQ) are addressed in this document, which contains citations from the literature that provide more detailed information. The unique structural attributes of PFASs are described along with the use in AFFFs. To place AFFF use into context, other sources of human and environmental exposure to PFASs are provided. The environmental media in which PFASs are found and the factors that control PFASs fate and transport are described. An overview of the characterization and remedial tools that are currently available is provided, in addition to information on the pathways of human and ecological health effects and the current regulatory status of PFASs. A companion is listed, among other resources, at the end of this document that offers more detailed information. This document is not intended for use as a guidance document, as individual branches of the military have issued guidance documents.

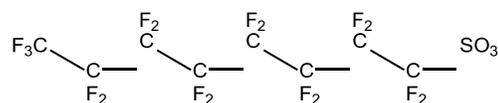
1. What are PFASs?

PFASs are manmade chemicals that are comprised of a carbon background containing many carbon-fluorine (C-F) bonds that impart oil and water repellency.

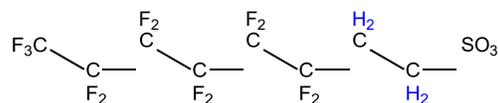
Perfluorinated chemicals (e.g., perfluorooctane sulfonate or PFOS) are not biodegraded in the environment and are not easily broken down by acid, bases, heat, or oxidants due to strong C-F bonds. Perfluorinated chemicals are those in which all the hydrogens on the carbons are replaced by fluorine. The term 'polyfluorinated' applies to chemicals in which not all the hydrogens on the carbons of the molecule are replaced by fluorine. When referring to mixtures of perfluorinated and polyfluorinated chemicals, it is more correct to use the term per- and

Perfluorinated perfluorooctane sulfonate (PFOS) and the 6:2 polyfluorinated fluorotelomer sulfonate (6:2 FTSA)

a) PFOS

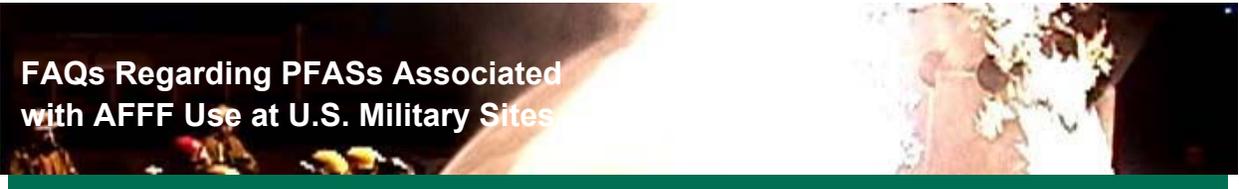


b) 6:2 FTSA



polyfluoroalkyl substances or PFASs.¹ Highly fluorinated perfluorinated and polyfluorinated substances are unique in that they possess many C-F bonds, which are the strongest bonds in nature. Molecules that have many C-F groups together along a carbon backbone have unique oil- and water-repelling properties, which are useful in several applications.¹⁻³ However, other properties of the chemicals are less predictable in terms of their behavior in the environment and in the laboratory. The term 'perfluorinated' is applied to a special subset of chemicals in which all of the hydrogens on all the carbon atoms of the molecule are replaced by fluorine.¹

Many remedial project managers (RPMs) are now familiar with perfluoroalkyl carboxylates (PFCAs), which includes perfluorooctanoate (PFOA), and perfluoroalkyl sulfonates (PFSAs), a class that includes PFOS. In the case of PFCAs and PFSAs, the anionic head groups are negatively charged at environmental pHs (4-9), which render the molecules soluble in water with very low vapor pressures.² The result is that PFCAs and PFSAs are not removed from water by air stripping and are readily transported through porous media.⁴ The PFCAs and PFSAs classes are comprised of homologous series with chain lengths that range from a minimum of C2 up to C10 and higher.⁵⁻⁷ The shorter the chain length, the more water soluble the PFASs and, thus, the more difficult to remove from water by granular activated carbon (GAC).⁸ In addition to anionic PFASs, there are cationic, zwitterionic, and neutral PFASs (e.g., fluorotelomer alcohols and perfluorosulfonamido ethanols).

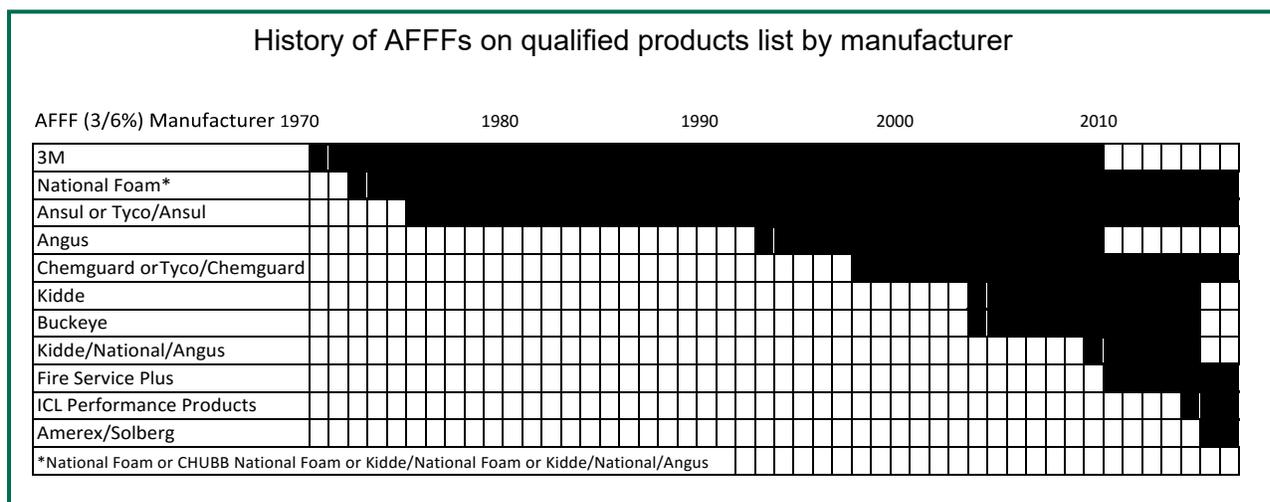


FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

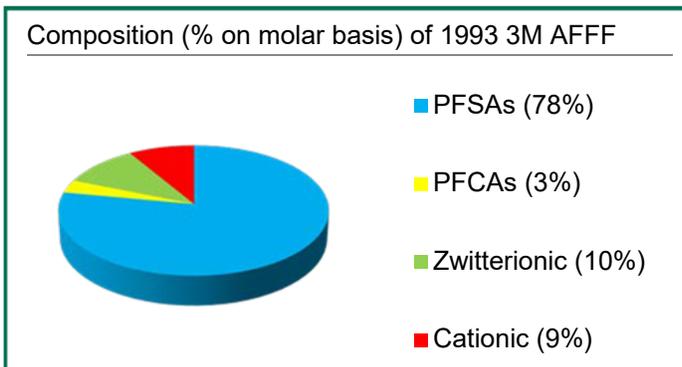
Because ionic PFASs (e.g., PFOS) are not volatile, they cannot be detected by conventional gas chromatography mass spectrometry (GC-MS). Therefore, anionic PFASs were not detected by GC-MS when groundwater at military sites was initially screened for priority pollutants, such as fuels and chlorinated solvents. It was not until the development of liquid chromatography-tandem mass spectrometry (LC-MS/MS) that chemists had the analytical capability to detect and quantify PFASs. Furthermore, it is only within the last 10 years that high quality analytical standards have become available.

2. What is AFFF?

AFFFs are proprietary mixtures that are used to extinguish fuel-based fires. Of the U.S. AFFF market, the military uses 75%, while municipal airports, refineries, fuel tank farms, and other industries use the remaining 25%.^{9,10} Non-military sectors that use AFFF are often "fence line" neighbors to military sites because military and civilian airports are often co-located with oil refineries and fuel storage tank farms. The first AFFFs were created in the 1960s by 3M, and 3M was the sole supplier from the mid-1960s until 1973.^{11,12} From 1973 onward, fluorotelomer-based AFFF manufacturers created AFFFs that met the U.S. Military Specification criteria and were placed on the U.S. military qualified products list.⁷ As a result, most entities probably received one or more types of AFFF from the 1960s through the early 1990s. 3M AFFF was removed from the qualified products list in 2010.



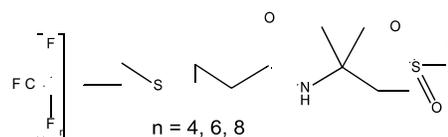
At present, only AFFFs made by manufacturers that historically incorporated polyfluoroalkyl substances into their formulations are on the qualified products list and are purchased and stockpiled for use on U.S. military bases. AFFFs are complex proprietary mixtures that contain hydrocarbon surfactants, solvents, and PFASs. The PFAS compositions of AFFFs made after 1989 by 3M and other manufacturers using fluorotelomer-chemistry based AFFFs are known⁵⁻⁷ and characterized by grams per liter (g/L) levels of PFASs. The commercial AFFFs are diluted to either 3% or 6% prior to their application. The composition of AFFFs prior to 1989 is not known because older AFFFs are no longer available. PFOS comprised the largest fraction of PFASs while PFCAs



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

comprise approximately 3% of the PFASs in 3M AFFF.⁵ The PFOA concentrations in 3M AFFF made on or after 1989 are approximately 1/100th of that of PFOS. Concentrations in groundwater that are equivalent to or that exceed those of PFOS cannot yet be explained by 3M AFFF compositions dating back to 1989. The PFAS composition of AFFFs made by 3M prior to 1989 may be different from those made on or after 1989.⁵ Fluorotelomer-based AFFFs have been on the qualified products list since 1973.^{11,12} The polyfluorinated forms possess two carbons located between the fully fluorinated portion of the carbon chain and the polar head group, which is characteristic of fluorotelomer-derived chemicals.² Many of the polyfluorinated precursors in fluorotelomer-based AFFFs possess a sulfur atom.^{7,13-15} Polyfluorinated fluorotelomer thioamido sulfonate (FtTAoS) precursors in Ansul AFFF are aerobically biodegraded to fluorotelomer sulfonates (FTSAs) and persistent PFCAs.^{16,17} FTSAs biotransform under aerobic conditions to PFCAs,¹⁸ but do not biotransform under anaerobic conditions.¹⁹ To date, there are no reported anaerobic transformation pathways for FtTAoS or FTSAs. Other than for the FtTAoS precursors in Ansul AFFF, little is known about the transformation of the polyfluorinated forms in fluorotelomer-based AFFFs. Moreover, fluorotelomer-based chemicals in some AFFFs are chemically oxidized to FTSAs.²⁰ For example, Houtz et al. (2013) found additional unidentified polyfluorinated precursors in groundwater, soil, and sediment using the total oxidizable precursor (TOP) assay.²¹ The TOP assay quantifies precursors in environmental media by quantifying the net increase in dead-end PFCAs after the sample is exposed to hydroxyl radicals.²²

Polyfluoroalkyl thioamido sulfonate (FtTAoS) precursor in Ansul AFFF.



More recently, more than 40 classes of PFASs were identified in AFFF and AFFF-impacted groundwater, and many of them appear to be 3M-derived.¹⁵ At present, the analytical capacity developed in academic laboratories to quantify these anionic, zwitterionic, and cationic newly-identified PFASs in groundwater, sediment, and soil is not available among commercial laboratories. In addition, the abiotic and biologically-mediated transformation pathways, transport characteristics, and toxicities of the newly-identified PFASs have not yet been determined. There is only a single report of the semi-volatile fluorotelomer alcohols (FTOHs) in AFFF formulations.²³ The FTOHs are likely present as by-products along with FTSAs and PFCAs formed during the synthesis of the telomer-based precursors.

The U.S. military uses AFFF during firefighter training and during emergencies (e.g., aircraft crashes)²⁴ and it is also deployed in automated fire suppression systems in hangars. In the case of equipment testing, various practices were used by the U.S. Navy



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

and the U.S. Air Force. For example, capacity tests and time-and-distance calibrations were conducted routinely, and in the past, resulted in the discharge of relatively large volumes of AFFF. In the case of personnel training, relatively smaller volumes of AFFF were discharged in any single event, but typically occurred at the same location over a period of many years. While fire-training activities occurred with actual fuel-based fires in unlined areas up until the mid-1990s, modern firefighter training areas are engineered facilities that typically use natural gas as a fuel source, thereby eliminating the need to train with AFFF. Importantly, the Department of Defense has recently instituted numerous policies designed to limit or eliminate all incidental discharge of AFFF.

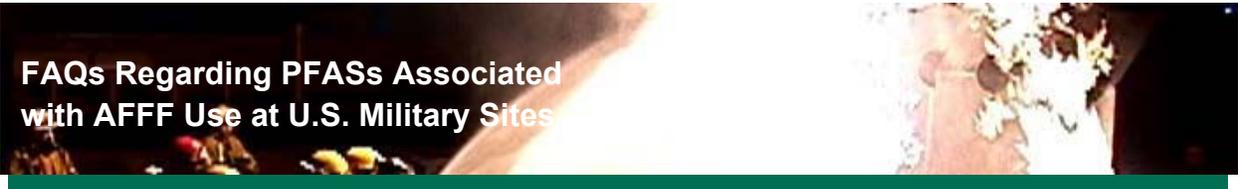
3. What are other sources of PFASs?

There is extensive literature documenting the occurrence of PFASs in environmental media and biota, including humans. Many reviews on the general topic of PFAS sources and occurrences exist.^{4,25-31} Recent work indicates that for adults *not* near a point source, food is the primary route exposure, followed by drinking water, and then indoor dust.^{31,32} PFASs are found in cereals, fish, juice, milk, olive oil, and meat³³ as well as in prepared foods.³⁴ For fetuses and infants, primary exposure routes include transmission by cord blood and breast milk, respectively.^{32,35,36} For humans near a point source, drinking water is an important route of exposure,^{31,37} including for short chain PFASs.³⁸⁻⁴⁰ Humans are exposed to gas-phase PFASs through the inhalation of volatile FTOHs and perfluoroalkyl sulfonamidoethanols that are then transformed to PFCAs.⁴¹⁻⁴³ Papers and textiles associated with consumer goods also serve as sources of human exposure to PFASs.⁴⁴ Non-volatile PFASs associated with papers and textiles on consumer goods can be ingested in the form of particles, such as dust.⁴⁵⁻⁴⁹ The association of PFASs with food packaging,⁵⁰⁻⁵² carpets,^{53,54} and carpet treatments⁵⁵ is now well documented. Occupational exposure at chemical manufacturing sites that produce PFOA,^{56,57} PFASs,⁵⁸ and precursors of PFOS (such as perfluorooctane sulfonyl fluoride)⁵⁹ is well-documented. Professional ski waxers⁴¹ and firefighters are also occupationally exposed to PFASs.⁶⁰⁻⁶³

Environmental emissions include those from manufacturing sites such as air (stack) emissions⁶⁴⁻⁶⁶ and effluents that impact drinking water.^{64,67-70} Industrial waste-impacted sites are sources of PFASs-contaminated drinking water.^{31,71} Additional examples of manufacturing include perfluorononanoic acid (PFNA) and PFOA-contaminated sites associated with the manufacture of plastics/polymers.^{2,3} Chromium electroplating wastes were also identified by the U.S. Environmental Protection Agency (USEPA) as sources of PFASs.⁷² Landfill leachates are second only to AFFF-impacted groundwater in the number and concentration of PFASs detected.⁷³⁻⁷⁷ Landfills are sources of volatile FTOHs to the atmosphere⁷⁸ and refugee emissions from landfills can impact groundwater.⁴ Effluents from lined landfills are exported to municipal wastewater treatment plants,⁷⁴ but municipal wastewater effluent and biosolids are sources of PFASs that impact water supplies and enter the food supply due to uptake by crops.⁷⁹⁻⁸⁷

4. In what environmental media have PFASs been found?

Within the context of AFFF-impacted sites, most concerns about PFASs arise due to the contamination of groundwater that may be used as drinking water. Though many site investigations are ongoing, many classes of PFASs are observed in groundwater at essentially every AFFF-impacted site investigated to date.^{5,88,89} Importantly, while PFCAs and PFASs are always present, with PFOA and PFOS often at levels up to 1,000-10,000 times above the health advisory levels, these classes of PFASs are not always the most abundant.⁹⁰ Soils and sediments at AFFF-impacted sites can also have considerable levels (up to 10,000 to 100,000 micrograms per kilogram [$\mu\text{g}/\text{kg}$] of PFOS), and this is not restricted to fire training areas.^{24,89} Ongoing research is evaluating the relative mass of PFASs associated with soils and sediments. Evidence to date indicates considerable PFASs may remain in soils and sediments near source zones. While some PFASs can be found in soils at even remote locations, presumably due to atmospheric deposition, the levels in these soils are generally less than 1 to 2 $\mu\text{g}/\text{kg}$,^{91,92} well below the levels observed at AFFF-impacted sites.⁸⁹ Finally, in addition to soil, sediment, and groundwater, if an AFFF-impacted site drains to adjacent surface water bodies, sampling of surface waters, aquatic sediments, and even biota (e.g., fish) at these sites may be appropriate due to the bioaccumulative nature of some PFASs such as PFOS. For example, levels of PFOS in fish prompted Michigan to issue a fish consumption advisory.⁹³



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

faster than their longer-chain counterparts (PFOS and PFOA, respectively). The PFASs also tend to sorb more strongly than the PFCAs of equal chain length (e.g., $K_d(\text{PFOS}) > K_d(\text{PFNA})$).⁹⁶ In addition, linear PFOS gave greater K_{oc} values than did branched PFOS.⁹⁸ Based on their relative retention on analytical columns during chemical analysis, one might also expect branched isomers of PFASs to sorb less strongly to environmental solids than their linear counterparts. Finally, some PFCAs/PFSAs may associate with non-aqueous phase liquids (NAPLs),^{97,99} and any alterations in subsurface conditions, such as those brought about by remedial activities, has the potential to impact PFCAs/PFSAs transport.¹⁰⁰ Unfortunately, the transport of other anionic, cationic, and zwitterionic PFASs in AFFF is less studied. The transport of cationic PFASs will be retarded by negatively-charged soils and aquifer matrix constituents, potentially resulting in significantly elevated soil concentrations in or near source zones. In contrast, the behavior of zwitterionic PFASs may be more difficult to predict.^{89,101}

6. What characterization and remedial tools are available/effective for PFASs?

The industry has begun to develop tools to better characterize PFASs. Analytical results from commercial laboratories provide a partial picture of PFAS contamination. Commercial laboratories typically use LC-MS/MS to quantify a suite of approximately 12 to 16 different PFASs. The TOP assay^{21,22} provides a practical way to quantify precursors without needing to identify and quantify each type of precursor using LC-MS/MS or other advanced mass spectrometric methods such as quadrupole time of flight (QTOF MS). Precursors quantified by the TOP assay indicate the magnitude of the potential “hidden” long-term source of PFCAs and PFASs at a site. A high dose of hydrogen peroxide or other hydroxyl radical-based oxidant is added to a sample under basic (high pH) conditions. After sufficient time for precursors to react, dead-end PFCAs are quantified using LC-MS/MS.²² A few commercial laboratories have also developed specialized analytical methods to directly measure precursors, such as FTSA. Fingerprinting PFASs contamination by LC-MS/MS and QTOF-MS is likely to provide input into conceptual site models (e.g., differentiate between multiple potential sources of PFASs, evaluate precursor biodegradation and persistence).

Field screening tools for PFASs may provide cost and schedule advantages. Current laboratory analytical methods are priced per sample and the cost depends on type of service with a standard turnaround time of one to two weeks. Given the need for more information when drilling at field sites, a mobile field screening unit is under development that is capable of measuring PFOS and PFOA at micrograms per liter ($\mu\text{g/L}$) levels. Sensor-based technologies are also under development,¹⁰² as well as inexpensive high-throughput screening tools such as particle-induced gamma emission (PIGE), which quantifies total fluorine on surfaces^{52,103} and is being modified for quantifying total fluorine in groundwater. A method for non-targeted analysis of PFASs using nuclear magnetic resonance is also under development and is expected to be field-portable.

Because many AFFF-impacted sites have little or no existing monitoring wells and the extent of contamination is largely unknown, PFAS-impacted sites also provide an opportunity to apply lessons learned from decades of site characterization at chlorinated solvent sites, using techniques such as vertical aquifer sampling, hydraulic profiling, and other high-resolution methods to pinpoint (rather than average) contaminant concentrations in different subsurface lithological units.

Treatment of PFASs is challenging and costly due to the stability of PFOS and the complexity of PFASs. Current remediation for PFASs typically relies on a combination of



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

different management approaches. Soils and sediments can be excavated and treated if needed, followed by off-site disposal or reuse. Several commercial products (e.g., RemBind+™, MatCARE™) mix clay and activated carbon with other reagents to stabilize soils and reduce short-term leaching of PFOA and PFOS. The performance of these technologies has not been characterized for other PFASs, such as fluorotelomer sulfonates. Treatment technologies include soil washing and incineration. For groundwater and surface water, ex situ technologies are typically employed. Most full-scale PFAS treatment systems use GAC or ion exchange. Bed life can be limited by the presence of shorter-chained PFASs that break through sooner than longer-chained heavier PFASs.⁸ Perfluorobutanoate (PFBA) and PFOA are among the PFASs that been observed to break through GAC most rapidly during column studies. Research into alternative sorbents is ongoing. Membrane treatment (e.g., reverse osmosis) is also effective for PFAS removal but can be more expensive.⁸ Experimental methods such as sonochemical degradation, sub- or super-critical treatment, microwave-hydrothermal treatment, and non-thermal plasma treatment have also been proven effective in the laboratory.¹⁰⁴ Research is ongoing to develop and test effective in situ groundwater remediation technologies. In situ chemical oxidation is partially effective in degrading some PFASs.¹⁰⁵ Proof-of-concept studies have demonstrated that enzymes can degrade some PFCAs under aerobic conditions.⁹⁵

7. What are the human and ecological exposure pathways and health effects?

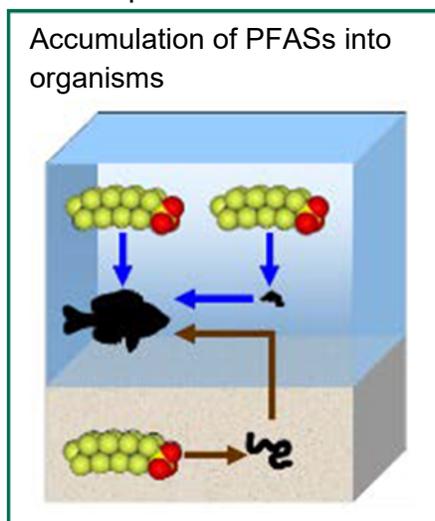
Human and ecological exposures to PFASs can include any of the basic exposure pathways for chemicals in the environment. Exposure pathways that originate with PFASs in water, sediment, soil, dust, and gas (e.g., atmosphere, soil vapor) can include direct absorption across the skin or dermis, inhalation of volatile PFASs or PFASs bound to particulates, and direct ingestion.^{106,107} Because PFASs can accumulate in biological tissue and lead to biomagnification of PFASs within food webs,¹⁰⁸ consumption of animals and plants can also be an important exposure pathway.^{4,109}

In terms of investigating sites contaminated with PFASs, risks associated with the following key exposure routes are usually the focus of most quantitative evaluations of human exposures:

- Direct ingestion of drinking water that is contaminated due to PFASs present in surface water or groundwater resources. This can be an important exposure pathway for both on-site and off-site receptors, as many PFASs are water soluble and can impact water resources several miles from the point of initial release.
- Incidental dietary ingestion of soil, dust, or sediment due to interaction with these media.
- Ingestion of food contaminated with PFASs. This can occur due to the accumulation of PFASs in plants (produce) grown on PFAS-contaminated soil or irrigated with PFAS-contaminated water. Some PFASs can also bioaccumulate in aquatic food webs and reach concentrations of concern in aquatic animals such as fish or mussels that are consumed by humans. Because of their environmental mobility, this process can occur in aquatic ecosystems both on- and off-site.

The following key exposure routes are the focus of most quantitative evaluations of ecological exposures:

- Direct ingestion of surface water by terrestrial vertebrate wildlife, and absorption of PFASs from surface water by aquatic animals such as fish, are important exposure pathways. Exposures can





FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

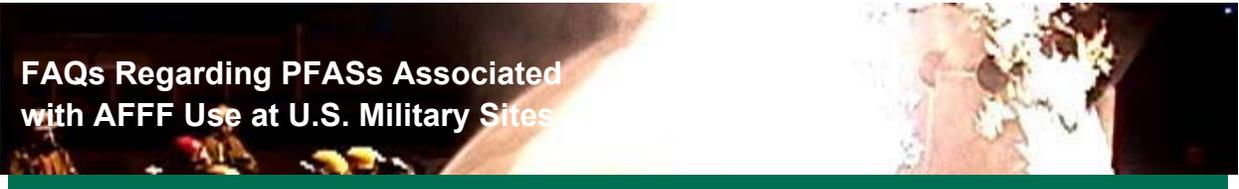
occur in surface waters on-site or off-site (downgradient surface water or groundwater emergence to surface water), as many PFASs are water-soluble and can impact water resources several miles from the point of initial release.

- Incidental dietary ingestion of soil and sediment is an exposure route for both terrestrial and aquatic vertebrate wildlife.
- Ingestion of food contaminated with PFASs is an exposure route for both terrestrial and aquatic vertebrate wildlife and fish that may consume lower trophic level organisms (e.g., plants, earthworms, aquatic invertebrates, etc.) living in PFAS-contaminated soil, sediment, or water.

The health effects of PFASs are currently under study, with the most information available for PFOA and PFOS. PFOA and PFOS exhibit adverse effects in laboratory toxicity evaluations with mammals and birds, with developmental and reproductive effects being particularly sensitive endpoints.¹⁰⁹⁻¹¹¹ PFOS and PFOA may exhibit immunotoxic potential,¹¹² and carcinogenicity potential is considered as “suggestive” for both PFOA and PFOS by the USEPA and “possibly” for PFOA by the International Agency for Research on Cancer.^{110,111} Based on the USEPA’s analysis of PFOA, current information indicate non-cancer effects occur at lower exposures than cancer effects. Non-cancer human health reference toxicity values for PFOA and PFOS are available,^{110,111,113,114} and these values are being used in risk assessments to evaluate human health risks from PFOS and PFOA due to drinking water consumptions and other exposures. Additionally, at sufficient levels, ecotoxicological effects of PFOA and PFOS on aquatic and terrestrial animals (including fish and invertebrates) as well as plants have been documented.^{109,115}

There are few risk-based environmental criteria or standards for evaluating the potential health risks to human and ecological receptors. Several state agencies in the U.S. and the USEPA have calculated risk-based criteria for PFOA, PFOS, and a few other perfluoroalkyl acids. These criteria focus on direct human health exposures to soil or drinking water. Risk-based criteria associated with human exposures via other potentially-important exposures, such as levels of PFASs in water used to irrigate food crops or levels of PFASs in surface water or aquatic sediment that may result in unacceptable bioaccumulation in fish (e.g., recreational or subsistence fishers) are not available. Additionally, there are no US or state screening criteria for ecological exposures to aquatic life or wildlife.

Exceedance of human health drinking water or soil criteria, and/or the presence of other complete exposure pathways to human or ecological receptors may potentially justify a formal quantitative site-specific risk assessment to determine if a response is warranted



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

for active management of exposures to PFASs. Although there are dozens of PFASs that may be detected in environmental media at PFAS-impacted sites, the availability of toxicity information limits risk assessments to PFOA, PFOS, and/or the few other perfluoroalkyl acids that are characterized toxicologically. Although USEPA's drinking water advisories for PFOA and PFOS indicate that the risks of PFOA and PFOS should be evaluated additively (i.e., summing the exposures of PFOA and PFOS to evaluate risk), there is currently no scientific or regulatory consensus on how to evaluate PFAS mixtures for risk-based decision making.¹¹⁶ Until additional information and guidance becomes available, it is likely that risk assessment and management decisions will continue to focus primarily on PFOS and/or PFOA.

8. What is the current regulatory status?

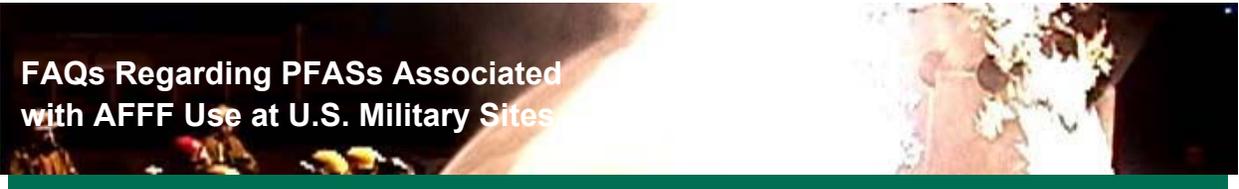
Regulatory approaches and drivers to assess and manage PFASs continue to evolve, and it is highly recommended to confer with legal counsel on the latest regulatory and policy developments prior to major strategic management decisions or interactions with regulators and stakeholders. Although PFASs are still referred to as emerging compounds and may lack the full force of policy and regulation as other regulated chemicals, a variety of U.S. federal and state approaches are driving the investigation and management of PFASs.

On the U.S. federal level, several regulations may influence decision making at sites impacted with PFASs. USEPA has finalized Health Advisory levels for PFOA and PFOS in drinking water (81 FR 33289, May 25, 2016).^{110,111,117} Although these levels are not regulations and should not be construed as legally enforceable federal standards, regulatory and public concern and litigation pressure may prompt action at some sites that exceed these levels. Human health toxicity reference values published by USEPA as a part of the Health Advisory levels and other ecological toxicity information have the capability to be applied in a risk assessment context, and risk assessments may be a potential chemical-specific line of evidence that may prompt Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions. However, PFASs are not yet classified under CERCLA as hazardous substances, so cost recovery under Superfund may not be allowable (although PFASs are considered a CERCLA pollutant or contaminant and can prompt investigation). Additionally, the Clean Water Act is being used to prompt regulatory action for PFOS at the state level¹¹⁸ based on risk assessment and policy lines of evidence. PFOS, perfluorobutanesulfonic acid (PFBS), PFHxS, PFNA, PFOA, and perfluoroheptanoic acid (PFHpA) are listed under the Safe Drinking Water Act (SDWA) third Unregulated Contaminant Monitoring Rule (UCMR 3) program. Under UCMR 3, public water systems monitor for these PFASs (and other constituents) to provide data that serve as a primary source of occurrence and exposure information that USEPA uses to develop regulatory decisions.

At the state level, several states (e.g., New Jersey, Minnesota, Alaska, Texas) have published their own screening levels and human health reference toxicity values for PFASs (primarily PFOA and PFOS) that may be different than the latest values published by USEPA. A variety of state policies and regulations are being used to prompt action, including litigation. For example, in 2016, the Governor of New York signed a statute of limitations law¹¹⁹ to allow resident affected by a PFOA releases at the Hoosick Falls site to file personal injury claims. Careful navigation of U.S. federal and state policies and regulations is needed on PFASs as they continue to evolve.

Acronyms

$\mu\text{g}/\text{kg}$	micrograms per kilogram
$\mu\text{g}/\text{L}$	micrograms per liter
AFFF	aqueous film forming foam
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
C-F	carbon-fluorine
ECF	electrochemical fluorination
FTOHs	fluorotelomer alcohols
FTSA	fluorotelomer sulfonate
FtTAoS	fluorotelomer thioamido sulfonates
g/L	grams per liter
GAC	granular activated carbon
GC-MS	gas chromatography-mass spectrometry
ITRC	Interstate Technology and Regulatory Council
K_d	soil-water partition coefficient
K_{oc}	octanol-water partition coefficient
LC-MS/MS	liquid chromatography-tandem mass spectrometry
NAPL	non-aqueous phase liquid
PFASs	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoate
PFBS	perfluorobutanesulfonic acid
PFCA	perfluorinated carboxylates
PFHxA	perfluorohexanoate
PFHxS	perfluorohexane sulfonate
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoate
PFOS	perfluorooctane sulfonate



FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

PFASs	perfluoroalkyl sulfonates
PIGE	particle induced gamma emission
QTOF	quadrupole time of flight
SDWA	Safe Drinking Water Act
TOP	total oxidizable precursor
UCMR3	Unregulated Contamination Monitoring Rule 3
U.S.	United States
USEPA	United States Environmental Protection Agency

Where can I find more information?

The Interstate Technology and Regulatory Council (ITRC) created fact sheets to summarize the science and emerging technologies for PFASs. The fact sheets include: (1) History and Use; (2) Nomenclature Overview and Physical and Chemical Properties; (3) Regulatory Summary; (4) Environmental Fate and Transport; (5) Site Characterization Tools, Sampling Techniques, and Laboratory Analytical Methods; and (6) Remediation Technologies and Methods.

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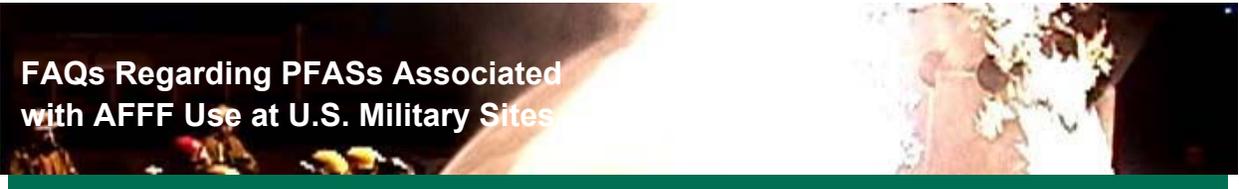
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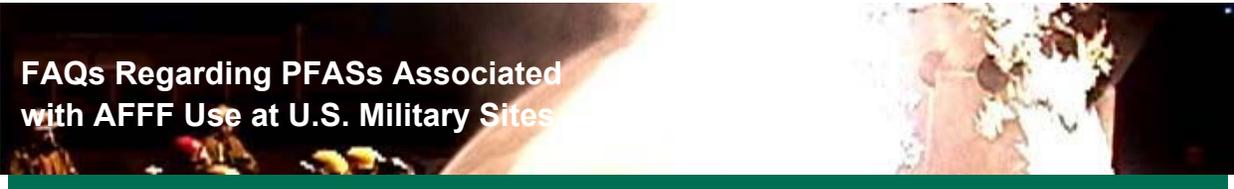
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FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

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FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites

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