Pyrolytic Transformation of PFAS Precursors in AFFF when Applied for Fire Suppression

by
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Abstract

Aqueous Film Forming Foams (AFFF) containing per- and polyfluoroalkyl substance (PFAS) have historically been the standard for extinguishing Class B flammable liquid fires due to superior performance in comparison to Fluorine Free Foams. C8-based fluorosurfactant have most commonly been used in these foams; however, as of the early 2000s there has been a shift away from these foams due the adverse environmental and health effects associated with perfluorinated compounds, such as PFOA and PFOS. As a result, fluorotelomer-based foams and C6-based fluorosurfactant-containing foams have risen in popularity among AFFF manufactures. Currently, our understanding of the fate of these PFAS precursors in AFFF during use in fire suppression is limited. As such, PFAS precursor substances could drive assessment of how harmful these fluorosurfactants are to both humans and the environment.

This study investigated the thermal stability of three pure fluorotelomer PFAS precursors – 10:2, 8:2, and 6:2 fluorotelomer sulfonate (FTS) – along with an AFFF sample known to contain each of these three precursors. Bench scale studies were conducted at high temperatures and pressures using a high pressure reactor vessel, and a simulated hydrocarbon fire scenario with AFFF suppression was conducted using a radiant panel. Post heat treatment samples were analyzed via liquid chromatography tandem mass spectrometry (LC/MS/MS).

Results show that significant thermolysis of all three pure fluorotelomer PFAS precursors was achieved at 400 ºC over a 30 minute duration, and at least one PFAS compound currently regulated in the state of Massachusetts was produced. These results further support the theorized thermal decomposition mechanisms of random- and end-chain scission when analyzing potential transformation pathways. Moreover, a general increase in precursor, short-chain perfluoroalkyl acids (PFAA), and long-chain PFAAs was observed across increasing heat treatment time intervals of the AFFF sample, while a general decrease in precursor, short-chain PFAAs, and long-chain PFAAs was observed across increasing AFFF depths/volumes. Ultimately, these results indicate that PFAS

precursors have the potential to transform into other types of polyfluoroalkyl substances as well as perfluoroalkyl substances under relatively moderate pyrolytic conditions that simulate AFFF use during fire events.

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List of PFAS Compounds

Compound Name	Acronym	CAS Number
PERFLUOROALKYL CARBOXYLIC ACIDS (PFCAs)		
Perfluorooctadecanoic Acid	PFODA	16517-11-6
Perfluorohexadecanoic Acid	PFHxDA	67905-19-5
Perfluorotetradecanoic Acid	PFTA	376-06-7
Perfluorotridecanoic Acid	PFTrDA	72629-94-8
Perfluorododecanoic Acid	PFDoA	307-55-1
Perfluoroundecanoic Acid	PFUnA	2058-94-8
Perfluorodecanoic Acid	PFDA	335-76-2
Perfluorononanoic Acid	PFNA	375-95-1
Perfluorooctanoic Acid	PFOA	335-67-1
Perfluoroheptanoic Acid	PFHpA	375-85-9
Perfluorohexanoic Acid	PFHxA	307-24-4
Perfluoropentanoic Acid	PFPeA	2706-90-3
Perfluorobutanoic Acid	PFBA	375-22-4
PERFLUOROALKYL SULFONIC ACIDS (PSFAs)		
Perfluorobutanesulfonic Acid	PFBS	375-73-5
Perfluorohexanesulfonic Acid	PFHxS	355-46-4
Perfluorooctanesulfonic Acid	PFOS	1763-23-1
FLUOROTELOMERS		
1H,1H,2H,2H-Perfluorododecanesulfonic Acid	10:2FTS	120226-60-0
1H,1H,2H,2H-Perfluorodecanesulfonic Acid	8:2FTS	39108-34-4
1H,1H,2H,2H-Perfluorooctanesulfonic Acid	6:2FTS	27619-97-2
1H,1H,2H,2H-Perfluorohexanesulfonic Acid	4:2FTS	757124-72-4
PERFLUOROALKANE SULFONAMIDES (FASAs)		
Perfluorooctanesulfonamide	FOSA	754-91-6
N-Ethyl Perfluorooctane Sulfonamide	NEtFOSA	4151-50-2
N-Methyl Perfluorooctane Sulfonamide	NMeFOSA	31506-32-8
PERFLUOROALKANE SULFONYL SUBSTANCES		
N-Ethyl Perfluorooctanesulfonamido Ethanol	NEtFOSE	1691-99-2
N-Methyl Perfluorooctanesulfonamido Ethanol	NMeFOSE	24448-09-7
N-Ethyl Perfluorooctanesulfonamidoacetic Acid	NEtFOSAA	2991-50-6
N-Methyl Perfluorooctanesulfonamidoacetic Acid	NMeFOSAA	2355-31-9
PER- and POLYFLUOROALKYL ETHER CARBOXYLIC ACIDS		
2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid	HFPO-DA	13252-13-6
4,8-Dioxa-3h-Perfluorononanoic Acid	ADONA	919005-14-4
CHLORO-PERFLUOROALKYL SULFONIC ACIDS		
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid	11Cl-PF3OUdS	763051-92-9
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid	9Cl-PF3ONS	756426-58-1
PERFLUOROETHER SULFONIC ACIDS (PFESAs)		
Perfluoro(2-Ethoxyethane) Sulfonic Acid	PFEESA	113507-82-7
PERFLUOROETHER/POLYETHER CARBOXYLIC ACIDS (PFPCAs)		
Perfluoro-3-Methoxypropanoic Acid	PFMPA	377-73-1
Perfluoro-4-Methoxybutanoic Acid	PFMBA	863090-89-5
Nonafluoro-3,6-Dioxaheptanoic Acid	NFDHA	151772-58-6

Chapter 1: Background

1.1 Introduction

Per- and polyfluoroalkyl substances (PFAS) comprise a complex family of synthetic organofluorine chemicals that have been mass produced for over half a century (Crownover et al., 2019). These anthropogenic chemicals are commonly used in a variety of products ranging from nonstick cookware, personal care products, high-temperature resistant products, and aqueous film-forming foams (AFFFs) (Alinezhad et al., 2022). Firefighters have historically utilized AFFFs to extinguish hydrocarbon-based fuel fires or what they are conventionally referred to – Class B fires (e.g., vehicle fires) – due to the high thermal and chemical stability of PFAS in AFFF, which can be attributed to the electronegativity and bond strength of the carbon-fluorine bond (Appendix A.1). As shown in Figure 1, the typical composition of 3% AFFF concentrate consists of a mixture of more than 60% water/diluent, <20% is solvents, and as much as 18% is surfactants of which less than 2% is fluorosurfactants (PFAS) (Maga et al., 2021).

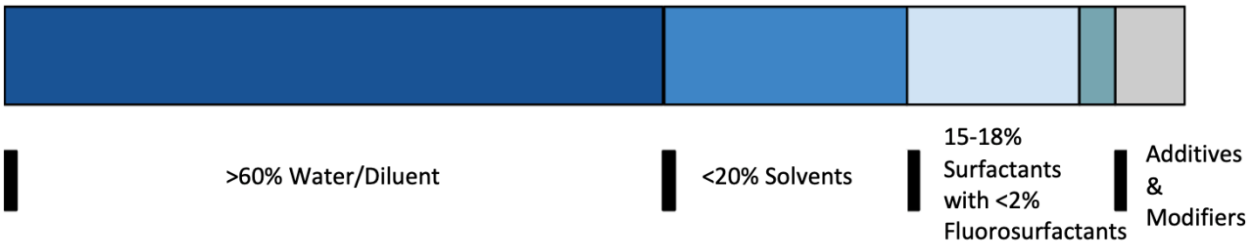


Figure 1. Typical Composition of AFFF – 3% AFFF Concentrate (Adapted from Kempisty et al., 2016).

PFAS are classified as perfluorinated or polyfluorinated depending on the number of H-atoms attached to C-atoms in nonfluorinated analogues that have been replaced by F-atoms. Perfluoroalkyl substances comprises compounds where all H-atoms attached to C-atoms have been replaced by F-atoms, and polyfluoroalkyl substances comprises compounds where the majority, but not all, H-atoms attached to C-atoms have been replaced by F-atoms (Buck et al., 2011). Perfluoroalkyl chains are often found to be

attached to polyfluoroalkyl substances at one or more of the compounds nonfluorinated moieties (Xiao et al., 2021). Previous studies of polyfluorinated compounds from AFFF utilized between 1970s and 90s to extinguish fires on U.S. Air Force Bases have provided evidence that the nonfluorinated part of the molecule attached to the perfluorinated chain is amenable to microbial or chemical transformation – with the potential to produce perfluorinated carboxylates and perfluorinated sulfonates (Houtz et al., 2013). Therefore, as polyfluorinated compounds in AFFF have the potential to produce perfluoroalkyl substances through polyfluorinated intermediates they are referred to as PFAS precursors.

It is estimated that more than 3000 PFAS have been manufactured with more than 750 PFAS compounds having been detected in environmental and biological samples. Additionally, more than 400 sites having been identified in the United States with known or suspected releases of PFAS due to the use of AFFFs for fire training. Moreover, long-chain PFAS bioaccumulate in food chains, posing human and ecological human health risks. As such, there has been increased research and attention towards PFAS and PFAS containing products among firefighting professionals, scientist, engineers, policymakers, and the general public. Smaller communities have even begun introducing PFAS advisory committees into their frameworks (Alinezhad et al., 2022).

1.2 Human Exposure and Health Effects

With a high prevalence in the environment humans can be exposed to PFAS through several pathways, with the main human pathway of exposure being ingestion. Food such as milk, butter, meats, fish, and vegetables have previously tested positive for PFAS in selected samples. Moreover, plants harvested for human or livestock consumption that have accumulated PFAS from contaminated soils or fertilized with contaminated biosolids can uptake PFAS, creating further human exposure pathway from the terrestrial environment (Dauchy, 2019).

Exposure through contaminated drinking water is one of the largest threats with estimates of drinking water containing 10 ng/L PFAS contributing to 20% of total human PFAS exposure (Marquez and Hoye, 2018). Repeated exposure to PFAS through drinking

water has been estimated to increase serum levels 100 to 130-fold the drinking water concentration (Post et al., 2012). Once PFAS enters the body, end transformation products (perfluoroalkyl substances) are not metabolized and remain chemically inert. After ingestion, PFAS are completely absorbed and distribute primarily in the serum, liver, and kidneys. With the half-life of PFAS ranging from 5-10 years in humans depending on composition (PFOS – 8.5 years and PFOA – 5.4 years) (USEPA, 2009).

In a 2011 study by the United States National Center for Environmental Health, Centers for Disease Control and Prevention, PFOS, PFOA, PFNA, and PFHxS were detected in more than 95% of the blood serum of all US residents tested (Kato et al., 2011).

Adverse health effects in humans have also been linked to exposure to PFAS. Chronic exposure to relatively low concentrations of PFAS – namely PFOA and PFOS – have been correlated to increased health risks. Health risks associated with serum PFOA and PFOS levels include: elevated cholesterol, kidney and liver dysfunction, elevated immune responses, thyroid disease, osteoarthritis, delayed puberty, early menopause, decreased fertility, increased risk of preeclampsia, reduced antibody response, and increased body mass index. Moreover, studies in occupational exposure have correlated bladder, kidney, and prostate cancer with elevated PFAS serum levels (USEPA, 2018).

1.3 United States PFAS Regulatory History

Currently, the United States Environmental Protection Agency (USEPA) is proposing the first ever national drinking water standard to limit six PFAS compounds: PFOA, PFOS, PFNA, PFHxS, PFBS, and GenX. If finalized, PFOA and PFOS would be regulated individually at 4 ppt, while PFNA, PFHxS, PFBS, and GenX would be regulated as a mixture (EPA, 2023). The proposal has been part of ongoing research, manufacturing restrictions, and health advisory limits in finished drinking water by the U.S. and international regulators since the early 2000s. This has included reduced production of specific PFAAs in 2002, a phase out of PFOS production by 3M in 2003 (which has resulted in increased production of shorter chain PFAA with shorter half-lives in humans, but are more mobile and more widespread in

the environment (Houtz, et al., 2016)), and restricted production and use of PFOS by the Stockholm Convention in 2009 (PFOA followed suit in 2019). Additionally, in 2009, the USEPA released a provisional health advisory of 200 ng/L for PFOS and 400 ng/L for PFOA in drinking water – listing PFOA as a likely carcinogen (USEPA, 2013). This was later reduced in 2018 when the EPA set a recommended safety guideline of a maximum 70 ng/L of PFAS in drinking water (for daily consumption throughout a person's life). Which was the same year the USEPA held the PFAS National Leadership Summit (NLS). The summit was held to discuss and share information to identify and develop both near-term actions and risk communication strategies for PFAS. The following four major action items were determined from the PFAS NLS for the USEPA: (1) Evaluate the need for a maximum contaminant level (MCL) for PFOS and PFOA; (2) Develop groundwater cleanup recommendations for PFOS and PFOA; (3) Start the process to consider establishing liability under CERCLA Section 107 or 102; and (4) Develop toxicity values for PFBS and Gen-X compounds (USEPA, 2018).

Since 2018, the USEPA has updated it PFAS drinking water lifetime health advisory, as of June 15th, 2022 – which now includes four PFAS compound health advisories: (1) Interim updated Health Advisory for PFOA = 0.004 nanograms per liter (ng/L), or parts per trillion (ppt), (2) Interim updated Health Advisory for PFOS = 0.02 ng/L, (3) Final Health Advisory for GenX chemicals = 10 ng/L, and (4) Final Health Advisory for PFBS = 2,000 ng/L. This update has followed ongoing studies by the EPA since 2016 to determine the health effects of several PFAS compounds (MassDEP, 2022).

As no federal MCL currently exist for PFAS in finished drinking water, individual states have taken the lead. Many states have adopted rules for both protecting groundwater, surface water, and to provide guidance values for drinking water, however the number of states that have MCLs for PFAS is limited. Seven states have since approved strict limits to PFAS contamination in drinking water: New Hampshire, New Jersey, New York, Vermont, California, Michigan, and Massachusetts. While Alaska, California, Colorado, Connecticut, Illinois, Maryland, Minnesota, North Carolina, New Mexico, Ohio, Oregon, and

Washington have all adopted guidance levels, notification levels, and/or health advisories for PFAS in drinking water (SaferStates, 2022) (Figure 2).

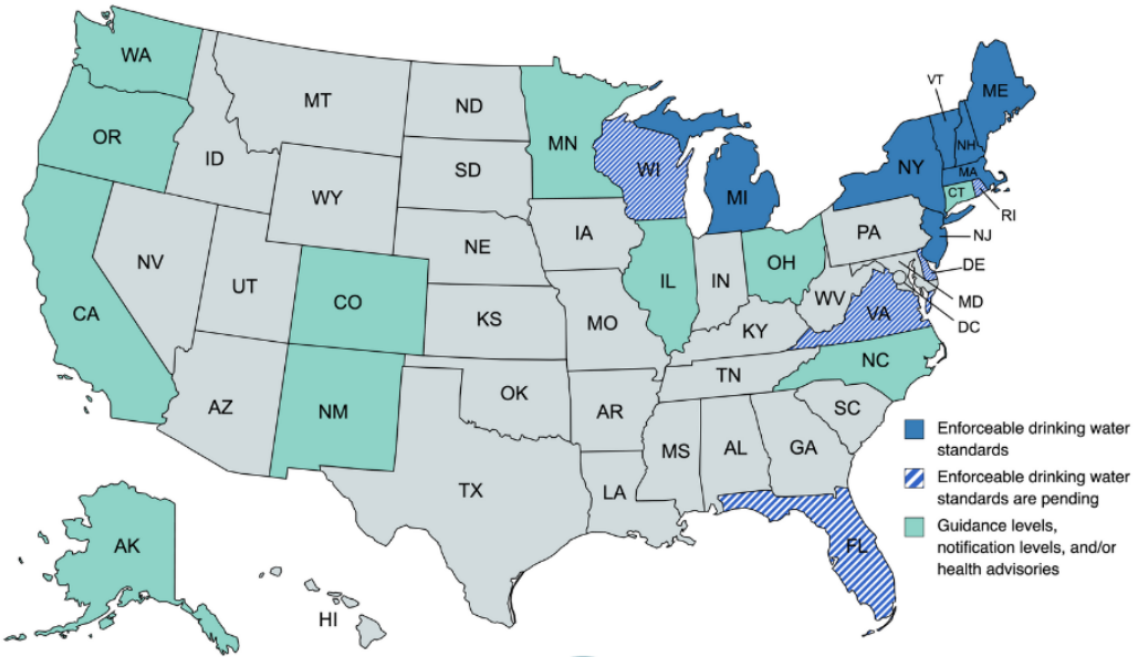
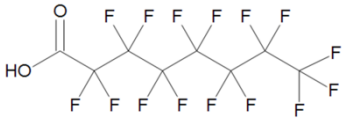
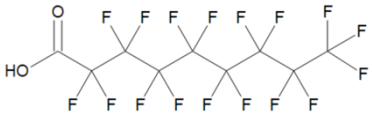
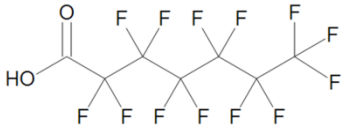
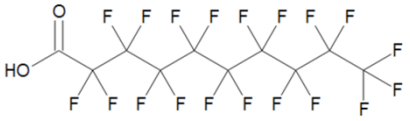


Figure 2. Current state of PFAS regulations in the United States (Image Source: SaferStates, 2022).

As this study was conducted in Massachusetts, an emphasis has been given towards the current guidelines and controlled PFAS compounds in Massachusetts, which are set by the Massachusetts Department of Environmental Protection (MassDEP). Most recently in October 2020, MassDEP published a Massachusetts Maximum Contaminant Level (MMCL) of 20 ng/L "applicable to community (COM) and non-transient non-community (NTNC) systems for the sum of the concentrations of perfluorooctane sulfonic acid (PFOS); perfluorooctanoic acid (PFOA); perfluorohexane sulfonic acid (PFHxS); perfluorononanoic acid (PFNA); perfluoroheptanoic acid (PFHpA); and perfluorodecanoic acid (PFDA)." These six PFAS are collectively referred to as the 'PFAS6' by MassDEP (MassDEP, 2022), see Table 1 for chemical structures. This standard has been established to be protective against any potential health affects related to PFAS ingestion through drinking water and is 50 ng/L less than the current EPA recommended limit for PFAS in drinking water of 70 ng/L for

daily consumption throughout a person's life (EPA, 2018). Polyfluorinated precursors to regulated PFAS compounds have been detected in all fluorinated firefighting foams characterized to date (FDSA, 2022).

Table 1. Massachusetts Department of Environmental Protection PFAS6

Chemical Name	Abbreviation	Chemical Structure
perfluorooctane sulfonic acid	PFOS	
perfluorooctanoic acid	PFOA	
perfluorohexane sulfonic acid	PFHxS	
perfluorononanoic acid	PFNA	
perfluoroheptanoic acid	PFHpA	
perfluorodecanoic acid	PFDA	

1.5 End of Life Handling and Remediation

As for end-of-life treatment processes for the handling of PFAS in AFFF containing spent fire-extinguishing waters and contaminated waters, there are currently no processes that both technologically efficient and cost-effective (Maga et al., 2021). Nevertheless, the EPA has published four strategies to reduce or eliminate PFAS contamination in water

– granular activated charcoal (GAC), powdered activated charcoal (PAC), ion exchange, and high-pressure membranes (EPA, 2018). It should be noted, each of these strategies is effective at removing only certain types of PFAS compounds.

Both GAC and PAC strategies share the same similar removal principle by adsorption using activated carbon. By taking advantage of activated carbon's high porosity and large surface area to volume ratio and the affinity of PFAS compounds to bind to interfaces – PFAS compound are driven to readily adsorb activated charcoal particles. However, GAC and PAC differ through the size of the activated charcoal particles – with GAC utilizing larger particle and PAC using finer particles. The larger particle size of the GAC process makes it effective removing contamination from longer chain PFAS compounds (e.g., PFOA and PFOS) and less effective at removing and capturing shorter chain compounds (e.g. PFBS and PFBA). PAC is more effective at capturing a wider variety of chain lengths than GAC but requires more treatment steps and is less cost effective (EPA, 2018). Moreover, in practice adsorption of fluorosurfactants on activated carbon tend to range from 0.01 to a maximum 1% (0.1 to 1.0 g) of AFFF/kg activated carbon, resulting in the accumulation of untreated residues from water treatment – especially when short-chained AFFF formulations are introduced into the treatment process (Xiao et al., 2017).

The strategy of ion exchange separates PFAS from water through small scale positively charged anion exchange resin (AER), comprised of tiny beads made from hydrocarbons. As the perfluorinated section of PFAS compounds are negatively charged they are attached to the positively charged anion resin. One advantage of this strategy is that it can be performed during water passthrough or mobilization, as the beads are large enough to remain in place in a fixed bed as water passes over them. Other advantages include eliminating contamination from PFAS compounds for a set period as it is not limited to chain length. However, treatment of large quantities of fire-extinguishing water and contaminated water is a relatively expensive procedure (EPA, 2018).

Finally, high pressure membrane operations removal strategies, such as nanofiltration or reverse osmosis, operate through the application of pressure to water in

order to mobilize it through a membrane that can accept or reject species or particles based on molecular size – ideally only allowing water to pass through the membrane. This process can remove up to 90% of all PFAS compounds from water (EPA, 2018). However, this method produces higher concentration wastewater as a byproduct (retained high-strength concentrated waste that does not pass through the membrane), meaning a secondary PFAS treatment process must follow (Ahrens and Bundschuh 2014). As such, this method has shown to be effective at the small scale through personal filtration units for homes, where PFAS contaminated wastewater can be diluted by other sources of wastewater, but less so on the industrial side of water treatment for PFAS (EPA, 2018).

Remediation through incineration of PFAS containing substances such as AFFF, and oxidative methods using both physical (ultraviolet) and chemical processes (ozone) have also been tested and considered. However, because these methods require extensive energy (with temperatures of 900 ºC -1,100 ºC required for PFAS incineration), large quantities of water to treat a diluted fraction of AFFF, and are all relatively uneconomical they are rarely utilized (EPA, 2018).

There has also recently been an interest in thermal treatment remediation techniques by the USEPA to degrade or manage PFAS migration in contaminated materials, as noted within their Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances, 2020 report (USEPA, 2020). While preliminary studies have reported thermal treatment as being a highly effective method for decontaminating PFAS-containing materials, including soil, activated carbon, and sludge (Crownover et al., 2019, Duchesne et al., 2020, Hao et al., 2021, and Wu et al., 2019) an understanding of both PFAS and precursor decomposition pathways and the potential resultant byproducts are still limited (Alinezhad et al., 2022).

1.4 Thermal Decomposition and Intermediate Pathways to Date

As previously stated, PFAS compounds have a high thermal stability and are highly resistant to chemical decomposition – this is due to the presence of the strong carbon-fluorine bond present in all PFAS compounds. Temperatures greater than or equal to 400 ºC are required for most PFAS compounds to begin thermal degradation, with complete decomposition and defluorination taking place between 900 ºC -1,100 ºC (EPA, 2018). Previous studies have shown polyfluorinated compounds to be less thermally stable than their perfluoroalkyl counterparts. With thermal decomposition taking place between 200 ºC – 300 ºC for polyfluorinated compounds and 200 ºC – 400 ºC for perfluoroalkyl compounds (Xiao et al., 2021, Deng et al., 2021, and Alinezhad et al., 2022). Decomposition of PFAS is influenced by the bond dissociation energies (see Appendix A-2 for Fluorine energy of dissociation comparison) and underlying decomposition mechanisms of which two have been theorized in recent thermal decomposition studies of the per- and polyfluoroalkyl substances – PFOA, PFOS, 8:2 flurotelomer sulfonate, and N-Methyl Perfluorooctanesulfonamido acetic Acid (Figure 3).

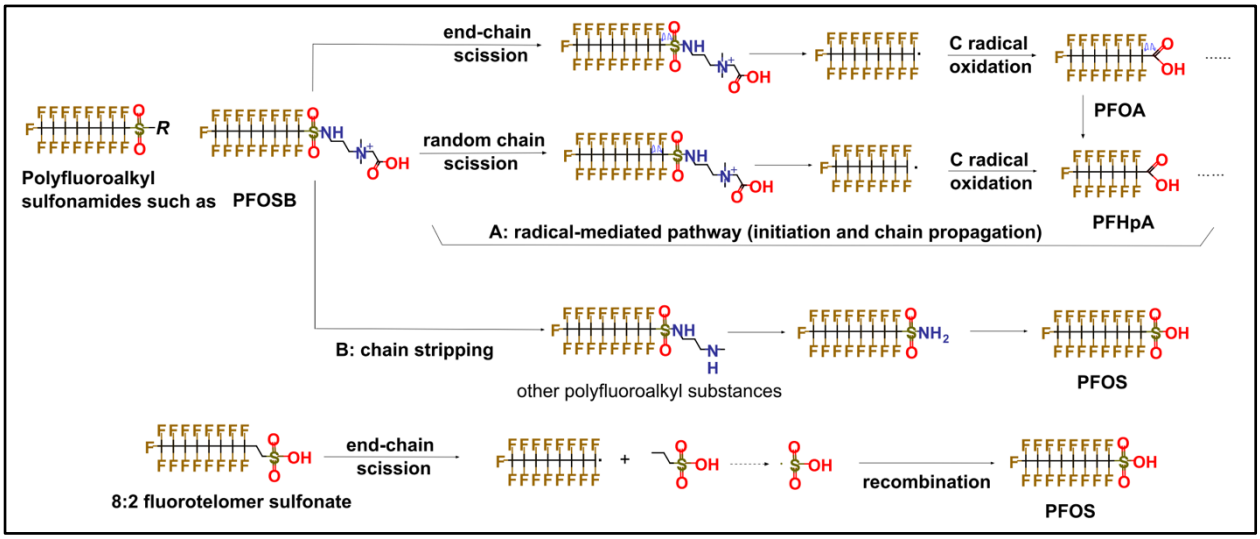


Figure 3. Pathways for decomposition of polyfluoroalkyl sulfonamides and 8:2 FTS (Image Source: Xiao et al., 2021).

The first decomposition mechanisms identified with polyfluorinated compounds is a radical-mediated mechanism involving initiation, chain propagation, and termination.

Within the initiation phase two pathways were identified: (1) End-chain scission: the nonfluorinated side chain and perfluoroalkyl chain are broken up within the PFAS compound, and (2) Random-chain scission: a C–C bond breaks off at a random location on the perfluoroalkyl chain. Resultant perfluoroalkyl radicals undergo C radical oxidation generates perfluoroalkyl carboxylic acids of different chain lengths, PFOA and PFHpA for instance, and Perfluoroalkyl Sulfonic Acids (such as PFOS). The second thermal decomposition mechanisms identified in the study involved chain stripping or the degradation and elimination of the nonfluorinated moiety of polyfluoroalkyl sulfonamides which can ultimately produce PFOS (Xiao et al., 2021).

1.6 Fluorine Free Foams

Besides remediation processes, there has also been a shift toward Fluorine free foams (FFFs) in recent years, to reduce the spread of PFAS into the environment and humans. While AFFF formulations have a mixture of hydrocarbon and fluorocarbon surfactants, fluorine free foams such as RF6-ICAO (RF6) do not, only containing hydrocarbon surfactants.

During a hydrocarbon firefighting scenario, foam is applied to a fuel pool by a nozzle forming a foam blanket. As the foam accumulates it creates a barrier between the fuel pool and fire above. Eventually, extinguishment is achieved as the foam layer builds up and vapors from the fuel pool traveling upwards to the fire are suppressed. During this process, AFFFs have two separate mechanisms that combine to aid in the extinguishment of a flammable liquid fire – a water and surfactant film that forms on the fuel surface and a foam blanket of bubbles – while FFFs have only the foam blanket to seal in the vapors. As such, the capabilities of FFFs are highly dependent on the characteristics of the foam blanket, which is dependent on both the discharge devices and foam composition (NFPA, 2021).

During extinguishment foam is exposed to heat and fuel – resulting in the degradation and performance of a foam and reducing the foam's ability to block fuel

vapors. Previous studies and test have shown that fluorine-free foams degrade faster than AFFF, with one study showing that RF6 and SDS fluorine-free foams degraded 3-times faster at room temperature and 12-times faster at elevated temperatures over fuel than AFFF (Hinnant, 2017). Moreover, in studies performed by the fire research organization LASTFIRE in partnership with the National Fire Protection Association (NFPA), an international nonprofit organization seeking to "reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education" (NFPA, 2022), when comparing the capabilities of the FFFs to AFFF at the same foam quality and aspiration – FFFs required between 1.5 to 3 times the application rates to facilitate a comparable performance for selected fuels. As a result, further insight into the degradation mechanisms in FFF is required to further increase its application over AFFFs (NFPA, 2021). This further incentivizes foam manufacturers to continue to develop products with fluorosurfactant levels beyond EPA guidelines – with an emphasis towards reduction of fluorine content and not a complete phase out (Cortina, 2010).

Post-EPA stewardship program C6-based fluorosurfactant-containing foams have been developed to reduce the use of C8-based materials and minimize contamination levels of C8 fluorosurfactants in C6-based formulations (NFPA, 2021). These foams operate on the same film forming principles of older C8 formulations; however, they have not been subject to similar levels of large-scale testing or actual incident application as FFFs and AFFFs. However, early evidence has shown that 'C6' firefighting foams can contain PFAS undetectable conventional commercial analysis, and similar to older formulations can convert to regulated PFAS (FDSA, 2022). Moreover, due to formulation's proprietary nature, the identities of surfactants in firefighting foams are not typically disclosed (meaning they could or could not still contain C8 or above formulations). This further increases the challenge of identifying potential environmental and physiological impacts of specific PFAS compounds of interest. It should also be noted, in terms of polyfluoroalkyl substance replacement of PFOS, PFOA, and other long-chain perfluorinated compounds in AFFF, fluorotelomers have been the primary replacement precursor compound (Cortina, 2010).

Currently, our understanding of the precursors in aqueous film-forming foam is limited and incomplete. Previous studies have focused on perfluoroalkyl substances and potential chemical and biotransformation pathways of PFAS compounds (Harding-Marjanovic et al., 2015 and Alinezhad et al., 2022), with limited information available for the thermal stability and pyrolytic transformation byproducts/intermediates of polyfluoroalkyl substances (Crownover et al., 2019, Xiao et al., 2020, Xiao et al., 2021, and Duchesne et al., 2020). As such, PFAS precursor substances could drive assessment of how harmful these fluorosurfactants are to both humans and the environment.

The objective of this study was to explore PFAS precursors in spent AFFF under pyrolytic conditions to better understand the thermal stability of these precursors and potential decomposition intermediates and byproducts – an emphasis will be given toward analysis of the six MassDEP PFAS compounds that are currently regulated as of October 2020, as this study is being conducted in Massachusetts. Hypotheses that informed this study are as follows:

1. As fluorotelomer PFAS precursors are known to degrade, transform, and incinerate under high temperature conditions in engineered systems, similar degradation processes likely occur in AFFF containing fluorotelomer precursors located in close proximity to fire events.

2. As fluorotelomer PFAS precursors have previously been documented as transforming into the six MassDEP regulated PFAS compounds – specifically PFOA and PFOS – under certain biological and chemical processes, similar intermediates are expected to be produced under simulated Class B fire conditions.

3. Transformations of fluorotelomer PFAS precursors are expected to support chain stripping and random- and end-chain scission thermal degradation mechanisms, pathways, and patterns, theorized in previous studies (Xiao et al., 2021, Deng et al., 2021, and Alinezhad et al., 2022).

4. Moderate temperatures in the range of 300-400 ºC and a heat flux of 40 KW/m^2 will likely begin to degrade the studied polyfluoroalkyl substances –10:2, 8:2, and 6:2 FTS – under simulated Class B pyrolytic conditions.

Chapter 2: Methods

2.1 Materials

Three PFAS precursor compounds were obtained and evaluated in their pure form, 1H,1H,2H,2H Perfluorooctanesulfonic Acid (6:2 FTS), 1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2 FTS), and 1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2 FTS), due to their prevalence and concentrations detected in all inventoried MassDEP Massachusetts Fire Department AFFF samples manufactured post 2002[1].

Each PFAS precursor compound was purchased from Wellington Laboratories at a minimum 98% purity, 1.2 mL volume, and 50 µg/mL concentration in methanol (See Table 2). Additionally, an AFFF sample was obtained from a local Fire Department and stored in 1000 mL Fisher Scientific Pyrex glass bottles. Purified water was produced in the lab with a Barnstead Labtower Reverse Osmosis water purifier from Thermo Fisher Scientific. The chemical structures of all PFAS compounds used are displayed below in Table 2, as well as manufacturing and composition information for the AFFF sample used in Table 3. Appendix B.1 provides a breakdown of each PFAS precursor compound detected in the pure AFFF sample analyzed according to the MassDEP AFFF library. Corresponding initial concentrations of each PFAS precursor compound is also provided along with known potential intermediates. Appendix B.2 shows corresponding MassDEP PFAS6 compounds and concentration found in the pure AFFF sample used throughout this study, and Appendix B.3 shows long- and short-chain PFAAs detected in the pure AFFF sample.

[1] In 2018 MassDEP started the Legacy Firefighting Foam Take-Back Program, which targeted all foams manufactured before 2003. These Foams contained 2%-5% PFAS by volume and contain PFAS compounds, which have previously contaminated groundwater and drinking water sources across the country (MassDEP, 2022).

Table 2. Pure PFAS precursor substances used in thermal treatment experiments throughout this study with chemical structures.

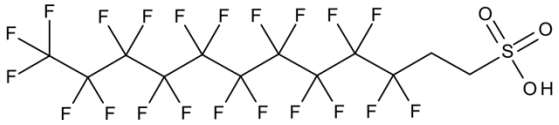
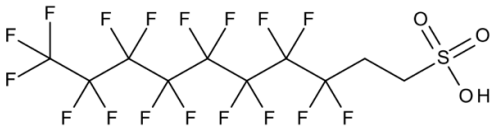
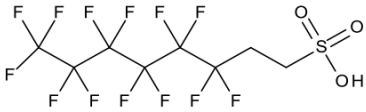
Chemical Name	Abbreviation	Chemical Structure
1H,1H,2H,2H-Perfluorododecanesulfonic Acid	10:2 FTS	
1H,1H,2H,2H-Perfluorodecanesulfonic Acid	8:2 FTS	
1H,1H,2H,2H-Perfluorooctanesulfonic Acid	6:2 FTS	

Table 3. AFFF sample used in thermal treatment experiments throughout this study.

Manufacturer	**Manufacturing Date**	**Recommended Dilution**
NF Universal Gold®	2004	1%/3%

2.2 Precursor Solution Preparation

As low quantities of PFAS are required to achieve relevant concentrations above the 20 nanograms per liter (ng/L) Massachusetts Maximum Contaminant Level (MMCL) for public drinking water, samples were prepared through serial dilutions – until desired volumes for auto and micropipetting were achieved along with a concentration of 100 ng/L – well above the 20 ng/L PFAS MMCL and EPA 70 ng/L Health Advisory Standard. Using a PFAS concentration larger than the PFAS drinking water standard also ensured a greater chance of not falling below potential PFAS compound intermediate calibration curve concentrations during sample analysis. Liquid volumetric measurements and transfer were performed with Fisherbrand Finnpipette II 100-1000 µL automatic pipettes. To sufficiently fill the thermal treatment vessel a 100 mL volumetric flask was used when preparing precursor stock solutions. Precursor samples solutions were prepared via the following procedure:

1. 100 µL of isolated and pure precursors listed in Table 2 were transfer to a 100 mL volumetric flask in the first dilution of each sample, allowing for minimum dilutions and repeated tests if necessary. Purified water was then added to the 100 mL meniscus – creating 100 mL volume of high concentration (50,000 ng/L) PFAS precursor sample (when solving for C_2 within the following equation: $C_1V_1 = C_2V_2$).
2. To calculate the volume of the high concentration solution in step one to reach the next target concentration (100 ng/L) the equation $C_1V_1 = C_2V_2$ was used again to solve for the unknown volume (V_1); which was calculated as 200,0000 nL (0.2 mL) for each precursor sample, where; C_1= 50,000 ng/L (from step 1), C_2= 100 ng/L, and V_2= $100 \bullet 10^6$ nL.
3. 45 mL of the 100 mL precursor stock solution was then transferred to the Parr Instrument Company Series 4740 HP/HT Pressure Vessel.
4. Steps 1-3 were repeated for all three precursors in Table 2, with the final dilution resulting in a 100 ng/L stock solution of each PFAS compound listed.

2.3 Pressure Vessel Thermal Experiments

Thermal degradation of both pure PFAS precursors and AFFF samples were performed in a Parr Instrument Company Series 4740 HP/HT Pressure Vessel (Figure 4). This method was selected to maintain a constant pressure above the water saturation

pressure for any given temperature. This ensured that samples would not evaporate under an intense heat flux from the vessel's Ceramic Fiber Heater. The vessel's volume was selected based on the range of AFFF foam typically used within NFPA 412 protocols for testing firefighting foam expansion, wherein volumes between 40-60 mL of AFFF are used to produce a sample of foam that is typical of that applied to a burning fuel surface under anticipated fire conditions (NFPA, 2020). As such, a vessel with a 1 in diameter and 75 mL volume was selected for thermal degradation testing of all experimental samples. This volume range coincided with the recommend sample volume of 45 mL, recommend by Parr through the Maximum Allowable Water Loading Equation (Equation 1), to prevent damaging this pressure vessel model (see Appendix D for Volume Multiplier ranges).

$$MAWL = \frac{(0.9)(Vessel\ Volume)}{(Volume\ Multiplier\ at\ Maximum\ Temperture)} \qquad (Equation\ 1)$$

As for the temperature and pressure component of the vessel, previous studies testing the thermal degradation properties of each of the MassDEP and PFAS6 chemicals have shown fluoride yields at temperatures greater than or equal to 400 ºC (Xiao et al., 2021, Alinezhad et al., 2022, and Yao et al. 2022). To perform tests at high temperatures between 100 - 500 ºC, a pressure range of 1 - 500 bar (15 - 7250 psi) is required to prevent evaporation of samples. This was achieved with the Series 4740 HP/HT Pressure Vessel's Flexible Graphite Flat Gasket attachment, which allowed for a maximum operating temperature between 400 ºC - 538 ºC and maximum operating pressure of 586 bar (8500 psi).

Prior to elevated temperature treatments, the open pressure vessel chamber was loaded onto a vice and sample was applied via a glass pipette. Next, the Flexible Graphite Flat Gasket was placed into the pressure gauge mount and placed on top of the bottom half of the vessel chamber, still in the vice. This was followed by placing a stainless steel gasket over the pressure gauge mount, and then screwing the top half of the vessel chamber on to the bottom half, until a closed seal was formed. All screws on the top half of the vessel chamber were tightened using a torque wrench first at 10 and then at 15 foot-pounds in an

alternating pattern around the top half of the vessel chamber. Additionally, all screws were coated with nickel alloy lubricant for a better seal and to decrease the risk of damage during treatment intervals. Afterwards, the pressure gauge and thermocouple attachment were fastened on to the top half of the vessel chamber, prior to being coated with nickel alloy lubricant, and tightened with an appropriate wrench. Lastly, after mounting the vessel chamber and pressure gauge onto the stand shown in Figure 4, wiring the thermocouple to the control panel, adjusting the height of the Ceramic Fiber Heater so it surrounds the entire bottom section of the vessel chamber, and tightening the pressure seal to the chamber, the temperature control panel was set to a desired steady state temperature and sample testing commenced.

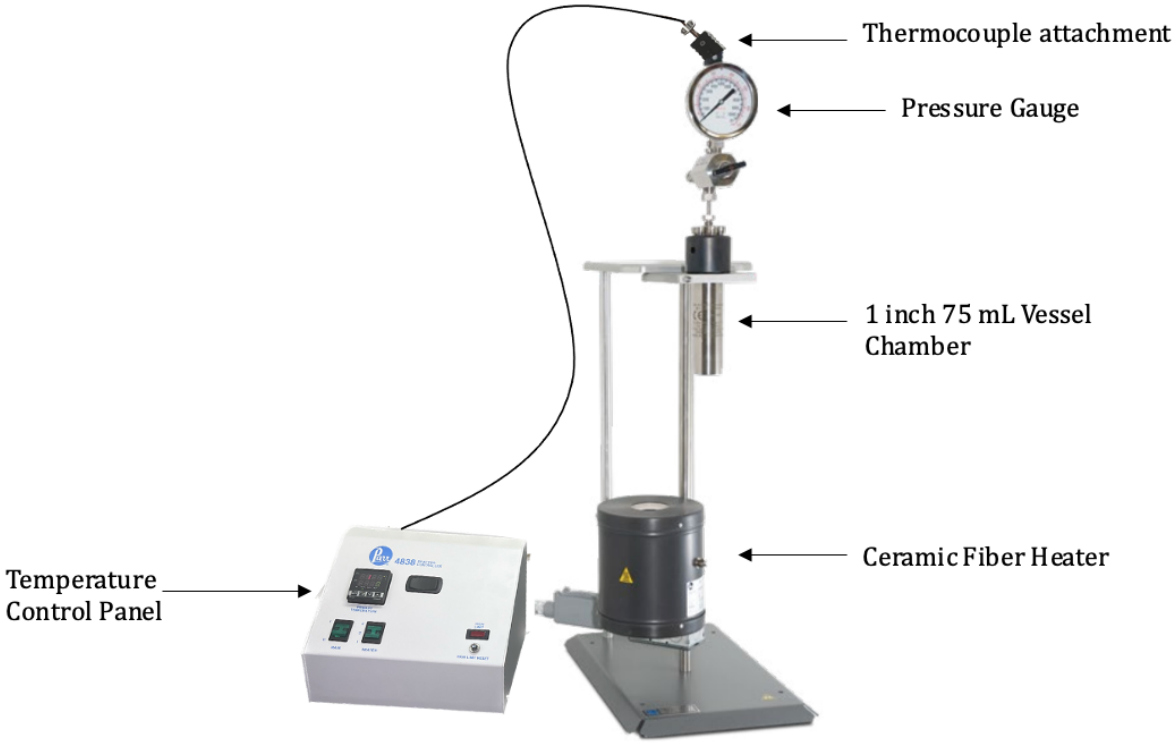


Figure 4. Parr Instrument Company Series 4740 HP/HT Pressure Vessel

2.4 PFAS Precursor Degradation in Pressure Vessel Testing

Following dilution, PFAS precursor samples were transferred to the Parr Instrument Company Series 4740 HP/HT Pressure Vessel. Xiao et al. has previously demonstrated that

polyfluoroalkyl substances tend to begin degrading between 200−400 °C after 10-30 minutes of constant heat exposure, with near-complete decomposition occurring at ≥400 °C after 5-10 minutes of constant heat exposure (Xiao et al., 2021, Alinezhad et al., 2022, and Yao et al. 2022). However, to account for any variability that may occur due to difference in parameters and lab materials, preliminary tests were performed through defluorination of pure PFAS precursors solutions over several distinct time intervals – 5, 10, 15, 20, 25, and 30 minutes – at 400 ºC, and fluoride ion concentrations monitored.

Defluorination of the pure fluorotelomer sulphonate groups heated in the reactor were measured using a Thermo Scientific Dionex ICS -2100 ion chromatography system equipped with a Dionex AS-15 4X150 mm analytical column and Dionex AG-15 4X50 mm guard column. A calibration curve of fluoride standards purchased from Dionex was developed using 4000, 2000, 1200, 800, 400, and 200 ppb calibrated standards. Fluoride elution time was approximately 4.2 minutes, and sample run time was 32 minutes to ensure all ions were eluted. Moreover, to measure potential background fluoride levels in samples, blanks were run during each ICS test.

The total fluoride ion concentrations detected from the fluorotelomer sulfonate compounds tested within the ICS were then compared to the estimated total fluorine ion content developed from pure precursor manufacturer data and basic stoichiometry calculations of each pure precursor for 100 ng/L stock solutions. The ICS detected approximately 4-8% defluorination at a temperature of 400 ºC and 30 minute treatment interval, with approximately 3-6% percent defluorination occurring at the 20 minute treatment interval, and approximately 2-5% defluorination occurring at the 10 minute treatment interval across all precursors. When further comparing these findings to the degradation patterns produced in Xiao et al., 2021 and Alinezhad et al., 2022, the intervals and temperature ranges documented during the degradation of the polyfluoroalkyl substances tested, which includes 8:2 FTS, follow a similar pattern. Each of these three samples once extracted, were labeled and stored in a dark fridge below 10 °C as required by EPA Method 537.1, before analysis for potential PFAS intermediates. Figure 5 shows

defluorination percentages across 10 minute intervals at 300 and 400 ºC for pure 8:2 FTS following successful C-F bond breakage.

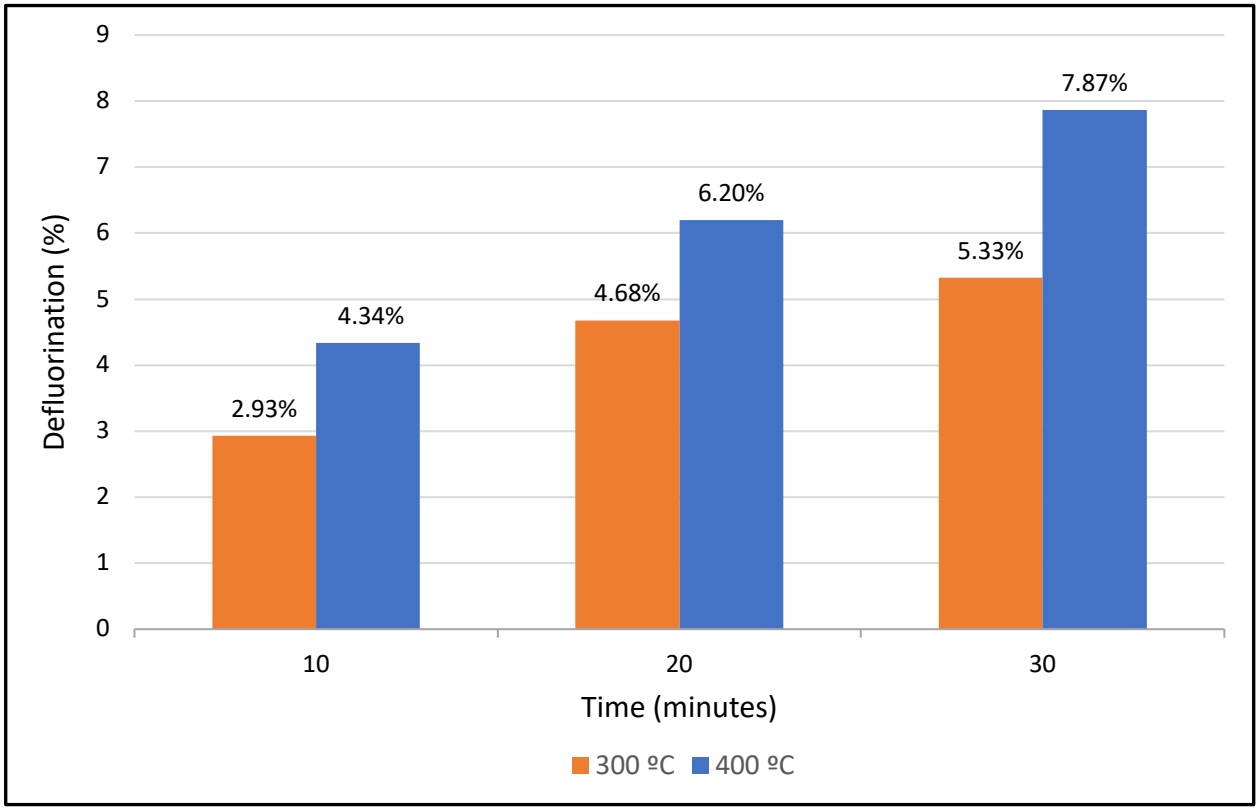


Figure 5. 8:2 FTS defluorination percentages across 10-minute intervals at 300 and 400 ºC.

2.5 AFFF Solution Preparation and Pressure Vessel Degradation

AFFF samples were prepared in accordance with percent concentrate manufacture instructions. NF Universal Gold® AFFF samples were prepared in 1% solutions (10 mL of AFFF in 1000 mL solution) as typically applied for fire suppression. As complete degradation of AFFF samples was not an objective of this study, a temperature of 300 ºC was selected when evaluating AFFF transformation over 10, 20, and 30 minute intervals. This was based on both empirical polyfluoroalkyl substance degradation data (Xiao et al., 2021 and Alinezhad et al., 2022), ICS fluoride ion concentration at 300 ºC over increasing time intervals (10, 20, and 30 minutes) for each PFAS precursor tested, as well as persistent failure to sustain pressure in the reactor at temperatures greater than 300 ºC.

As the properties of AFFF result in bubbling and expansion when exposed to elevated temperatures, only 15 mL of diluted AFFF was pipetted into the pressure vessel across each run – in comparison to the 45 mL of sample that was used during precursor runs. Other than the reduction in the sample volume placed into the pressure vessel chamber and the selected degradation temperature, reactor operations remained unchanged across pure precursor and AFFF solution samples.

2.5 Simulated Burn Procedure

To more accurately simulate the potential pyrolytic transformations effects of AFFF during a typical hydrocarbon fire scenario a simulated burn procedure was developed. Throughout the process of suppressing a hydrocarbon fire, AFFF is thoroughly spread across the area containing the fire. As such, a percentage of the applied AFFF does not directly blanket a fuel source, and is instead subjected to the radiant heat flux of the hydrocarbon fire while in close proximity to a fuel source. If subject to pyrolytic transformation AFFF containing PFAS precursor could potentially leach and mobilize regulated PFAS compounds into groundwater and drinking water sources leading to contamination. The following procedure describes provides a model of such an event, where AFFF containing PFAS precursors are subjected to expected heat fluxes from a vehicle hydrocarbon fire, via a radiative heat flux from a radiant panel rated for maximum heat flux of 93 kW/m^2. PFAS chemical analysis was followed to determine and quantify any pyrolytic transformation effect on known precursors and precursor concentrations within the AFFF samples.

2.5.1 Simulated Foam Heating Apparatus

A 30 by 30 cm square-shaped Infra-Red radiant panel (Omega Engineering, QC series, 4000 W-240 V) calibrated to a heat flux of approximately 40 KW/m^2, was used to supply a relatively uniform heat flux to an AFFF target located below the panel bottom surface. The radiant panel was positioned 30 cm directly above a 20 cm x 20 cm stainless steel pan with a depth of 4.5 cm. Within the pan a 0.80 cm thick slab of oak wood covered the bottom of the pan to create an adiabatic surface, while the translucent AFFF samples

underwent thermal treatment. Prior to thermal treatment, heat flux calibration was performed using a Thin Skin Calorimeter (TSC). The TSC was placed at the same distance from the IR radiant panel as the AFFF substance contained within the pan, approximately 33 cm away. Figure 6 provides a side view of the components which made up the apparatus.

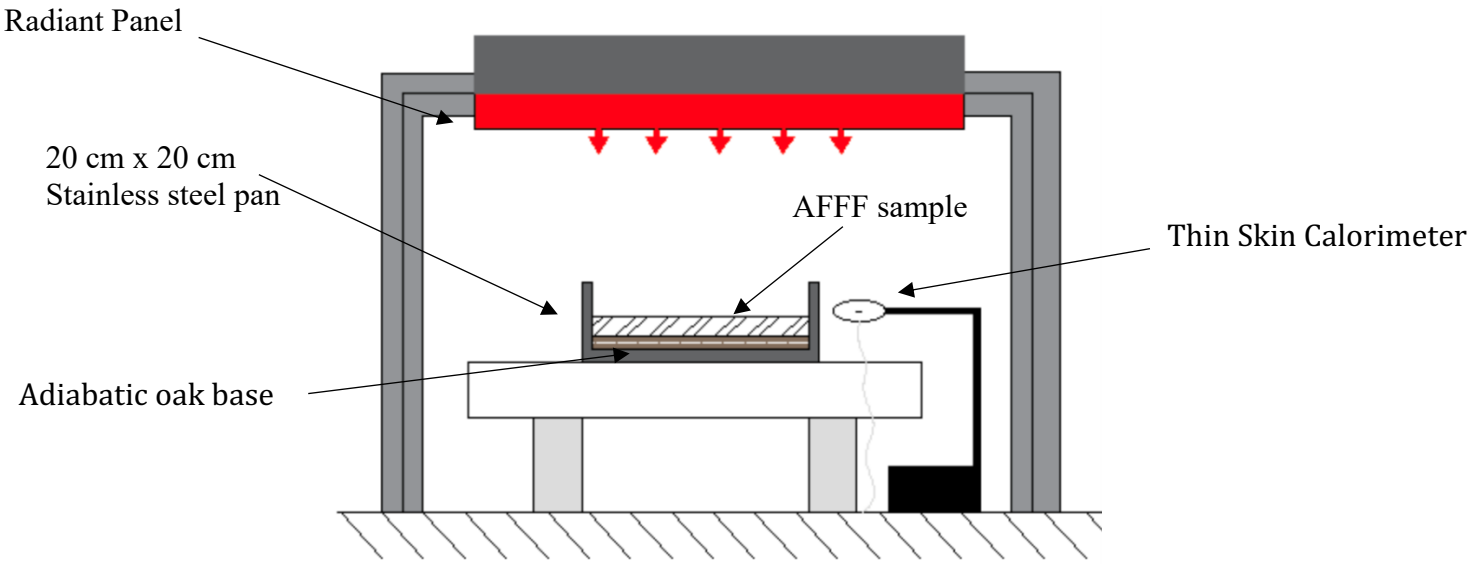


Figure 6. Schematic of simulated AFFF heating apparatus used to apply a 40 kW/m^2 heat flux onto AFFF samples.

2.5.2 Simulated Vehicle Fire Procedure

The Omega Engineering, QC series, 4000 W-240 V Infra-Red radiant panel was calibrated with the TSC to a heat flux of 40 kW/m^2, to simulate a typical maximum heat flux expected during a gasoline vehicle hydrocarbon event – based on data from several previous studies (Hu et., 2020, Terziev et al., 2019, and Watanabe et al., 2012). Next the 400 cm^2 pan containing an adiabatic oak base was filled with three varying levels of AFFF sample: 5 mm, 6 mm, and 7 mm. These depths were based on AFFF foam application densities for hydrocarbon-based fuel fires, which typically range from 4.1 to 6.5 mm/min (L/min•m^2) for tank, fueling, and spill area systems (NFPA, 2021). As such, individual tests were performed at thicknesses approximate or within the range of typical AFFF delivery

rates for the selected heat flux, to simulate varying AFFF application volumes during a fire scenario.

Before the heat input from the radiant panel was supplied the pan containing AFFF sample was adjusted and aligned with the near center of the radiant panel. Test were performed for 20 minute intervals to simulate the duration of the maximum heat flux recorded within past vehicle fire studies (Hu et al., 2020, Terziev et al., 2019, and Watanabe et al., 2012). During the 20 minute thermal treatment period, recordings of the foam's behavior were taken to note any differences in the characteristics of AFFF samples at varying depths. At 20 minutes the heat input from the radiant panel ceased, and treated samples were extracted from the pan via glass pipette, labeled, and stored in a dark fridge below 10 °C, as required by EPA Method 537.1.

2.5.2 Thin Skin Calorimeter Calibration

The TSC used throughout this procedure was constructed using 9 cm disc of low thermal conductivity insulation core, a 1 cm stainless steel disc, and a length of 24 Gauge Type-K insulated thermocouple wire. The stainless-steel disc was mounted flush to the surface of the insulation core and the thermocouple wire was welded on the opposite side of the disk. The thermocouple's wires were run through the insulation core and covered by a protective mesh, where they eventually led to the data acquisition hardware, and temperature reading were stored and processed in LabVIEW (see Figure 7).

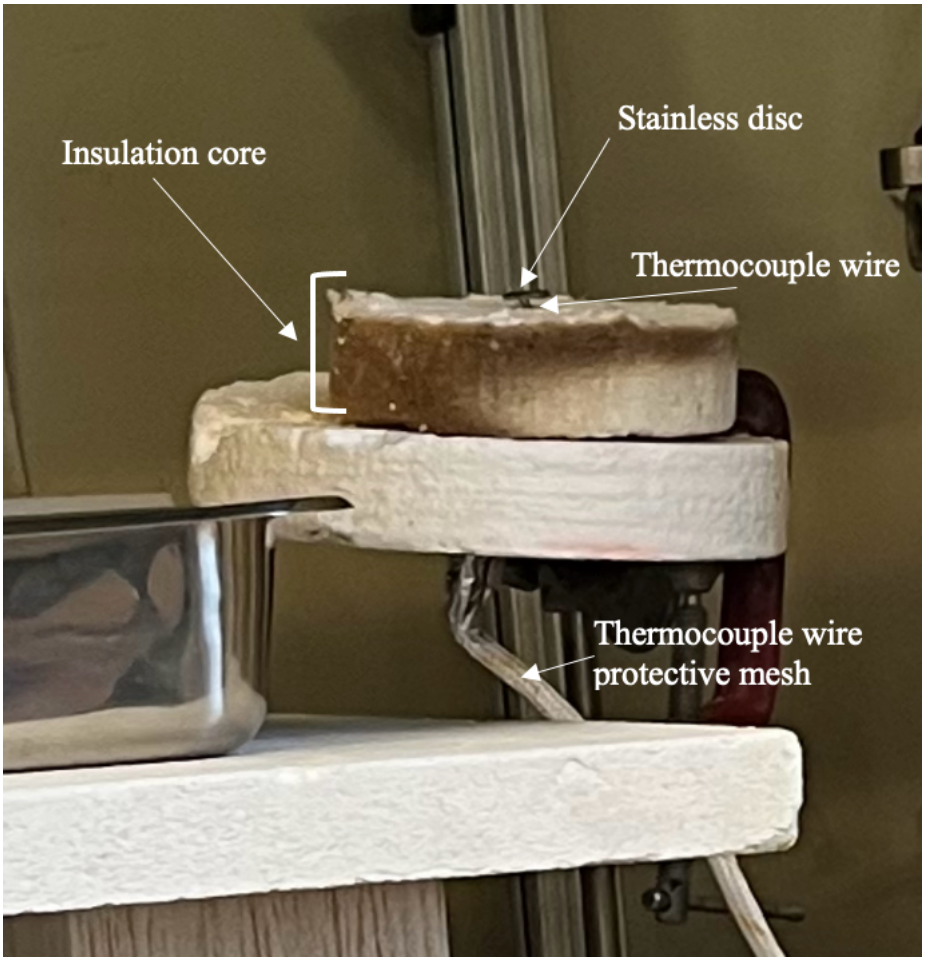


Figure 7. Side view of thin skin calorimeter assembled for simulated burn procedure, with thermocouple wire pulled slightly away from insulation core to show connection.

To create the TSC calibration curve shown in Figure 7, nine test were carried out across three incident heat flux settings on a laboratory cone calorimeter, utilizing ASTM E459-22: Standard Test Method for Measuring Heat Transfer Rate Using a Thin-Skin Calorimeter (ASTM, 2022). During each test the TSC used was placed at a uniform distance from the Cone and flame, and temperature reading were recorded in LabVIEW, until steady state was achieved. Prior to the start of each test room temperature steady state was achieved at a heat flux of 0 kW/m^2 and recorded. Table 4 shows steady state temperature readings recorded for applied cone calorimeter heat fluxes of 0, 20, 30, and 50 kW/m^2.

Table 4. Steady state temperature recordings for applied cone calorimeter heat fluxes.

Heat Flux (kW/m^2)	Steady State Temperature (ºC)	Average SS Temperature (ºC)	Standard Deviation
0	20	20	0
	20		
	20		
	20		
	20		
	20		
	20		
	20		
	20		
20	338.93	331.19	6.78
	326.30		
	328.34		
30	371.75	376.50	4.27
	377.77		
	380		
50	525.03	516.01	7.95
	513		
	510		

The average steady state temperatures across the eighteen cone calorimeter tests were then plotted against their corresponding heat fluxes, as shown in Figure 8. The end result was a calibration curve with a linear fit that approximates heat flux as a function of temperature, according to the linear fit equation shown in Figure 8. The horizontal error bars shown in Figure 8 represent standard deviations for each temperature set.

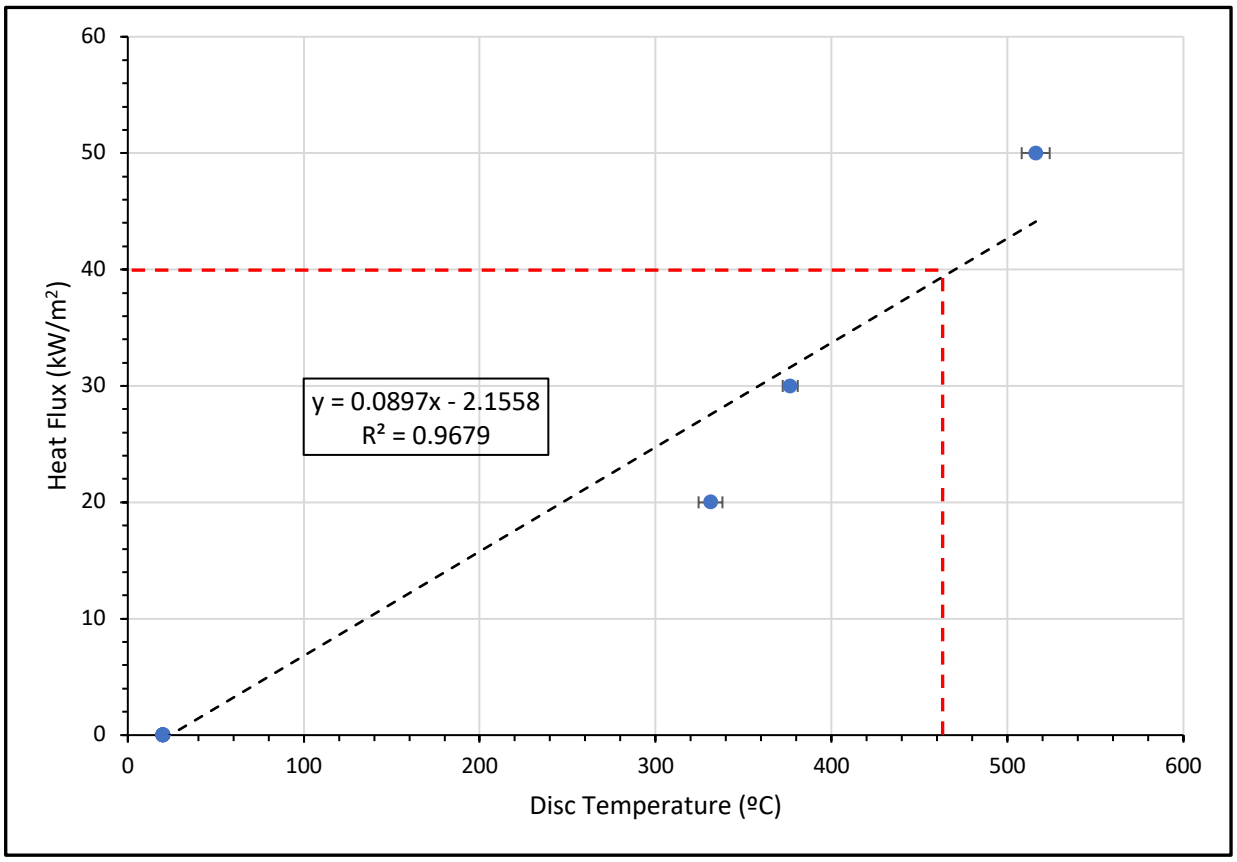


Figure 8. Thin Skin Calorimeter Calibration Curve

Using the cone calorimeter heat flux calibration curve in Figure 8, several trials were run at varying radiant panel setting to achieve a steady state temperature of 460 ºC corresponding to a heat flux of approximately 40 kW/m^2 (see dashed red line in Figure 8). During these tests the TSC was placed 33 cm directly underneath the radiant panel in the same location used during experimental tests. 40 kW/m^2 was eventually achieved at a setting approximately 90% the panel's maximum capacity. Figure 9 shows LabVIEW steady temperature data recorded during one of three AFFF radiant panel tests, with the panel set at 90% capacity (460 ºC, 40 kW/m^2). It should be noted, at 100% capacity the radiant panel is expected to output a heat flux of 93 kW/m^2, as such, the reduced heat flux output at 90% the panels capacity is likely due to the distance the TSC was placed aways from the panel during temperature recordings, property changes in the TSC's disc and insulation core as heat flux increased (temperature was recorded on bottom side of TSC), and energy

loss experienced within the panel itself as it worked to achieve a 90% capacity heat flux output.

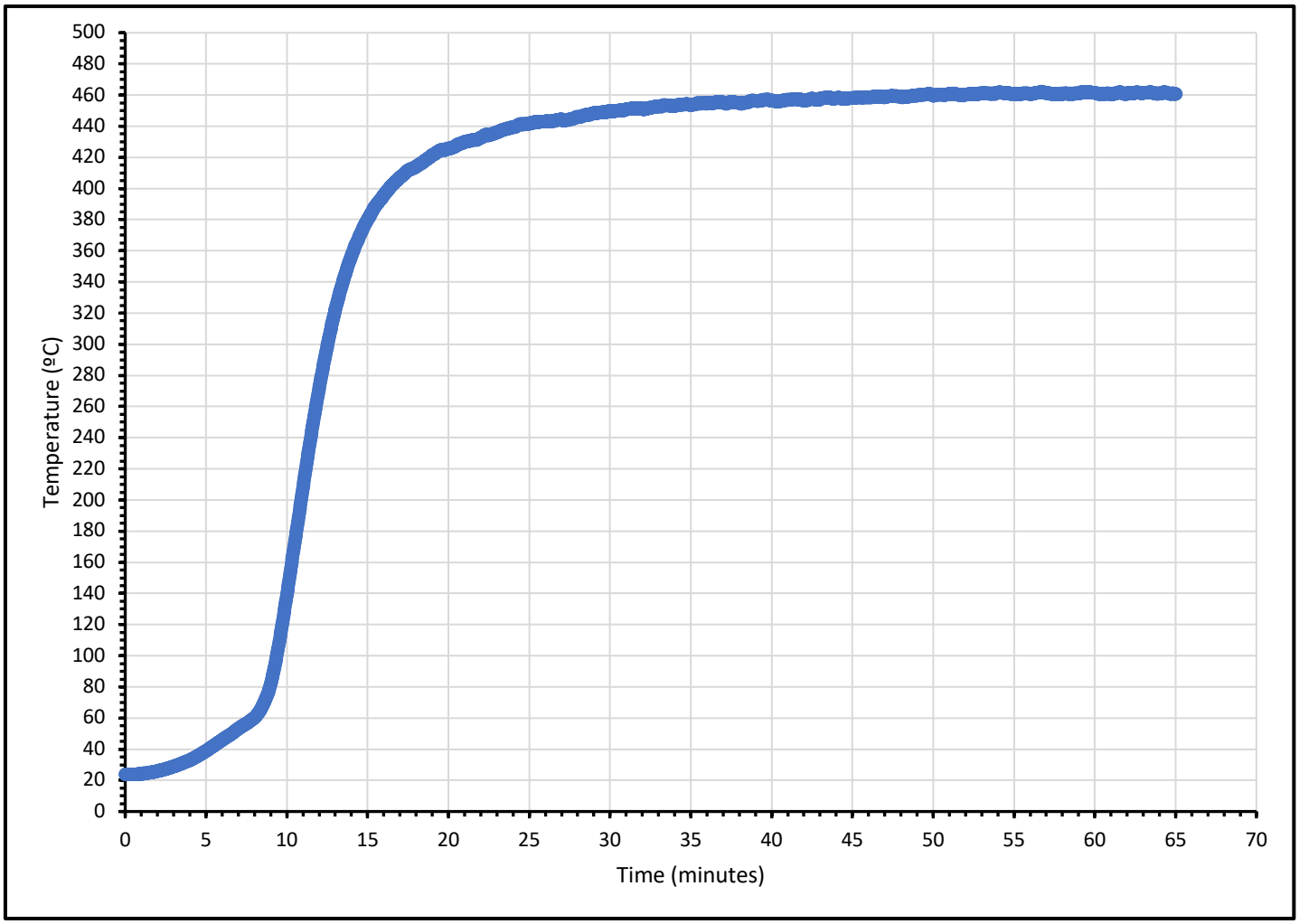


Figure 9. Steady state temperature recording during simulated burn procedure.

2.6 PFAS Detection

Following thermal degradation in the pressure vessel and radiant panel, pure precursor and AFFF samples were transferred to 250 mL polypropylene bottles fitted with polypropylene screw caps and stored in an ice filled cooler before undergoing chemical analysis. It should be noted that pure precursor pressure vessel samples all fell below 250 mL, while AFFF and pressure vessel radiant panel samples were repeated to satisfy the laboratory 250 mL sample volume requirement; volumes from identical experiments were combined to achieve the typically required 250 mL sample size. Analysis was performed by Alpha Analytical Laboratories. Samples collected were analyzed for PFAS via Environmental Protection Agency Method 537.1. Method 537.1 was published by the EPA in November 2018, in a procedure titled, "Determination of selected per- and polyfluorinated alkyl substances in drinking water by solid phase extraction and LC/MS/MS" (Shoemaker et al., 2018). The method combines solid-phase extraction (SPE) and liquid chromatography tandem mass spectrometry (LC-MS/MS) to extract, enhance, and quantify PFAS concentrations in water samples.

During solid phase extraction, samples were passed through a solid sorption media (polystyrene divinylbenzene) designed to capture the target analytes. Target analytes were then eluted from the solid phase with a methanol solvent. Extract was then subjected to applied nitrogen in a heated water bath and concentrated to dryness, and then set to a 1 mL volume methanol: water ratio of with 96:4% (vol/vol) with the addition of the internal standards. A 10 µL injection was then made into a liquid chromatograph, equipped with a C_{18} column, and directly connected to a tandem mass spectrometer. Analytes were then separated, identified, and quantified through comparison of actual mass spectra and retention times to reference spectra and retention times during uniform LC/MS/MS conditions – calibration standards. Using this internal standard technique, and the measured mass to charge ratio of ions within a sample, the concentrations of target compounds were determined. Tables 5 summarizes all analytes tested and their corresponding Method Detection Limits (MDL).

Table 5. PFAS compounds scanned during LC/MS/MS analysis and corresponding typical AFFF and water/effluent MDL's.

Matrix	AFFF	Water/Effluent
Analyte	**MDL (ppt)**	**MDL (ppt)**
Perfluorobutanoate (PFBA)	8	0.33
Perfluoropentanoate (PFPeA)	5	0.20
Perfluorohexanoate (PFHxA)	8	0.32
Perfluoroheptanoate (PFHpA)	6	0.22
Perfluorooctanoate (PFOA)	8	0.30
Perfluorononanoate (PFNA)	6	0.22
Perfluorodecanoate (PFDA)	8	0.33
Perfluoroundecanoate (PFUnA)	7	0.26
Perfluorododecanoate (PFDoA)	9	0.38
Perfluorotridecanoate (PFTrDA)	6	0.24
Perfluorobutanesulfonate (PFBS)	6	0.25
Perfluoropentanesulfonate (PFPeS)	5	0.20
Perfluorohexanesulfonate (PFHxS)	5	0.22
Perfluoroheptanesulfonate (PFHpS)	3	0.14
Perfluorooctanesulfonate (PFOS)	8	0.33
Perfluorononanesulfonate (PFNS)	8	0.30
Perfluorodecanesulfonate (PFDS)	8	0.33
Perfluorododecanesulfonate (PFDoS)	4	0.18
4:2 fluorotelomersulfonate (4:2 FTS)	57	2.28
6:2 fluorotelomersulfonate (6:2 FTS)	99	3.97
8:2 fluorotelomersulfonate (8:2 FTS)	39	1.57
N-Methylperfluorooctanesulfonamidoacetic acid (N-MeFOSAA)	6	0.59
N-Ethylperfluorooctanesulfonamidoacetic acid (N-EtFOSAA)	5	0.32
Perfluorooctanesulfonamide (PFOSA), a.k.a FOSA	15	0.23

2.7 Glassware Cleaning Procedure

All flasks, containers, and measuring devices were washed thoroughly with purified water and methanol after every experiment. Previous studies citing this method have randomly selected cleaned containers and added 25 mL of purified water and measured PFAS in the water – with no measurable concentrations of target PFAS compounds being detected (Xiao et al., 2021 and Alinezhad et al., 2022). Similarly, throughout this study, multiple purified water samples, blanks, were added to the pressure vessel chamber and heated at 300 ºC and 400 ºC, as well as to the 400 cm^2 stainless steel pan following pure PFAS precursor and AFFF radiant panel tests and cleaning. Collected samples were then run through the ICS to detect the presence of fluoride ions as a result of PFAS degradation – and hence an artifact of improper or unthorough cleaning of lab instruments. In all blank samples tested the ICS detected no measurable concentration of fluoride ions.

Chapter 3: Results and Discussion

The following chapter summarizes the LC/MS/MS analysis results of pure polyfluorinated precursors and AFFF following pressure vessel thermal treatment, and LC/MS/MS results of AFFF degraded in simulated vehicle fire heat flux conditions through the radiant panel test. A discussion of the potential intermediate pathways of decomposition, and the impact of formed intermediates follows.

3.1 Pure Fluorotelomer Precursor Results

3.1.1 Pure Precursor Resultant Concentration Post Heat Treatment Experiments

Three pure precursor samples subject to heat treatment at 400 ºC for 30 minutes were selected for LC/MS/MS analysis. Each sample originally contained 100 ng/L of 10:2, 8:2, and 6:2 FTS at purities greater than or equal to 98% according to Wellington Laboratories (Appendix D). It was found that each sample gave quantitative yields of at least one of the following: smaller chain PFAS precursors, long-chain PFAAs, and short-chain PFAAs. Additionally, the initial PFAS precursor subject to treatment was not detected in LC/MS/MS results across all three samples tested. Raw data of LC/MS/MS results are provided in Appendix E for all three precursors. It should be noted that PFAS concentration marked by a 'J-flag' indicate that the sample is an estimated value as the detected concentration fell below the analytical Reporting Limit (RL) but was above the analytical MDL.

Figure 10 shows the resultant compounds detected during LC/MS/MS following significant thermolysis of 10:2 FTS. Analytical results indicated that two shorter chain precursors, 8:2 and 6:2 FTS, were detected above the analytical RL at concentrations of 32 ng/L and 45 ng/L, respectively. Additionally, concentrations of a short-chain PFAA, PFHxA, and a long-chain PFAA, PFOA, were detected below the analytical RL, estimated at concentrations of 8.56 ng/L and 15 ng/L, respectively. PFOA is a PFAS compound regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies.

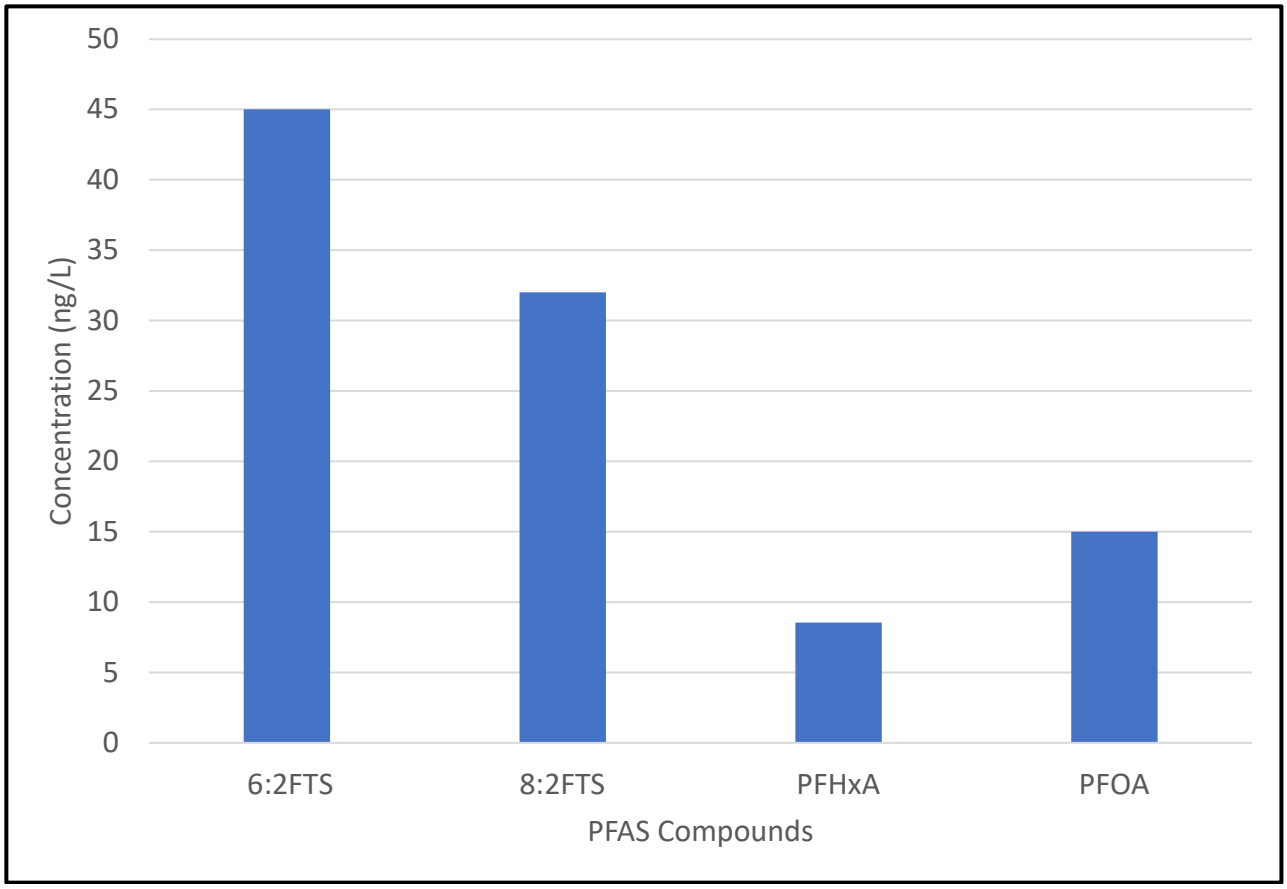


Figure 10. 10:2 FTS thermal transformation intermediate compounds and corresponding concentrations after heat treatment at 400 ºC for 30 minutes.

Figure 11 shows the resultant compounds detected during LC/MS/MS following significant thermolysis of 8:2 FTS. Analytical results indicated that one smaller chain precursor, 6:2 FTS, was detected above the analytical MDL at a concentration of 18.5 ng/L. Concentrations of two short-chain PFAAs, PFBA and PFHxA, were also detected above the analytical MDL at concentrations of 4.79 ng/L and 11.8 ng/L, respectively. Finally, concentrations of two long-chain PFAAs, PFOA and PFOS, were estimated at 23 ng/L and 29 ng/L, respectively. PFOA and PFOS are PFAS compounds regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies.

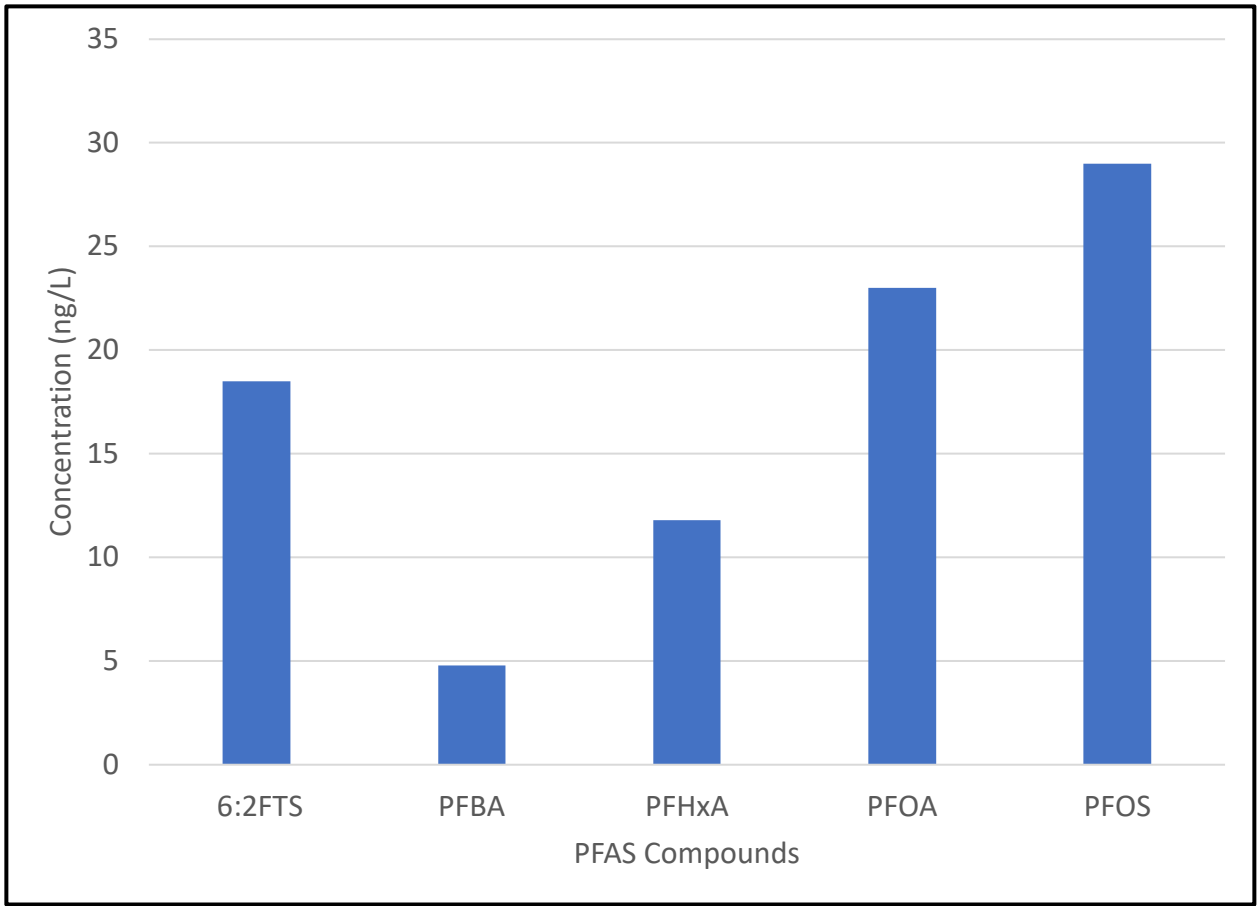


Figure 11. 8:2 FTS thermal transformation intermediate compounds and corresponding concentrations after heat treatment at 400 ºC for 30 minutes.

Finally, Figure 12 shows the resultant compounds detected by LC/MS/MS analysis following significant thermolysis of 6:2 FTS. Analytical results indicated that one small-chain PFAA, PFBS, was detected below the analytical RL at an estimated concentration of 6.60 ng/L. Additionally, the concentration of one long-chain PFAAs, PFOA, was detected below the analytical RL, and estimated at a concentration of 32 ng/L. Finally, the long-chain PFAA, PFOS, was detected above the analytical RL at a concentration of 41.9 ng/L. As previously noted, PFOA and PFOS are PFAS compound regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies – with a Massachusetts Maximum Contaminant Level of 20 ng/L for the sum of PFAS6 compounds.

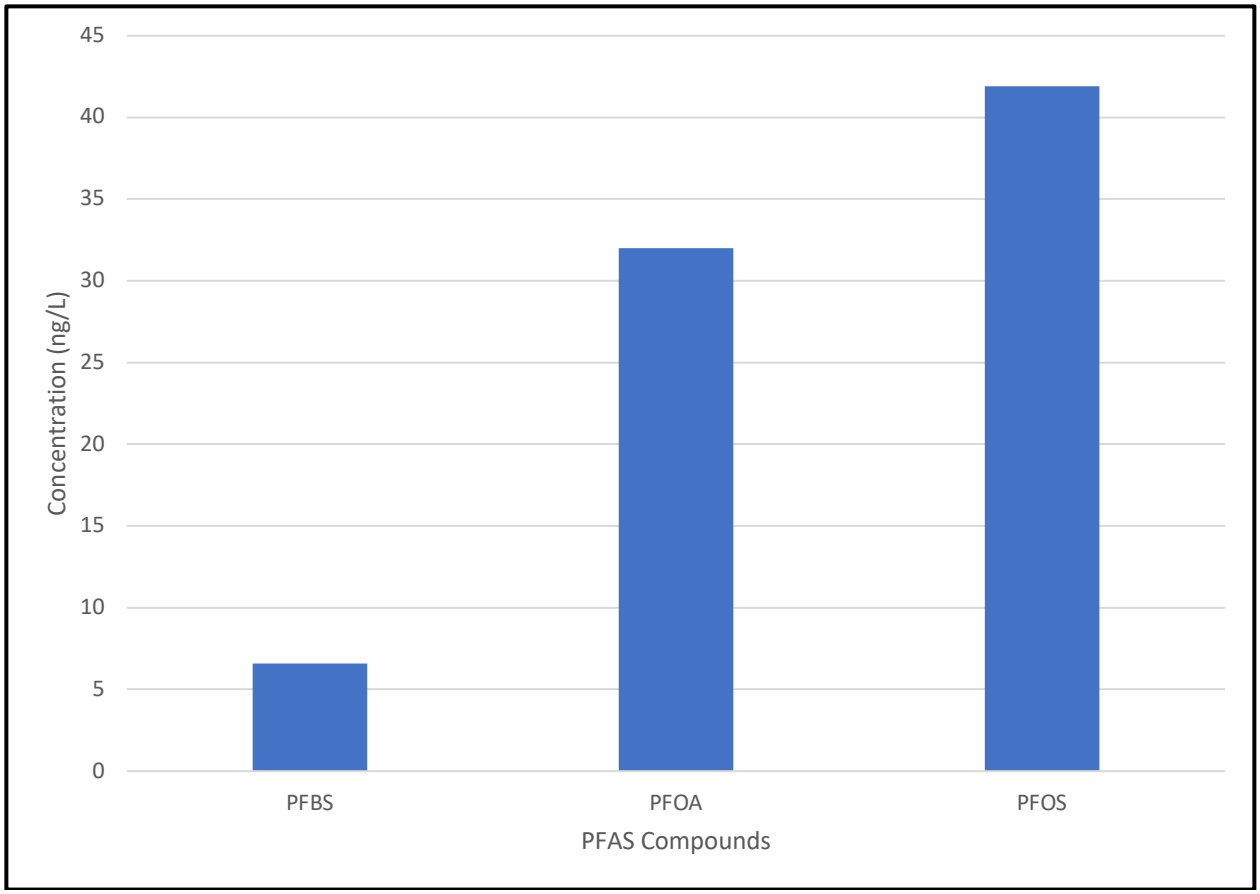


Figure 12. 6:2 FTS thermal transformation intermediate compounds and corresponding concentrations after heat treatment at 400 ºC for 30 minutes.

A total fluorine mass balance was also conducted for each pure precursor sample pre- and post-thermal treatment as shown in Figure 13. Solid bars represent pre-treatment total fluorine concentrations, which are 100% for each of the three precursors tests, and the composite bars represent post-treatment total fluorine concentrations. Post-thermal treatment results indicated a fluorine recovery of 97.10% for 10:2 FTS, 94.28% for 8:2 FTS, and 96.24% for 6:2 FTS. The remaining fluorine not recovered was likely in the form of ionic fluorine or smaller fluorinated-organic compound not detected through the LC/MS/MS procedure, unless an additional MS Total Organoflurine analysis is performed. These results coincide with the prior studies of Xiao et al., and Alinezhad et al., who each indicated high thermal decomposition rates of polyfluoroalkyl substances between 300 ºC - 400 ºC, as well as ICS defluorination analysis described in section 2.4.

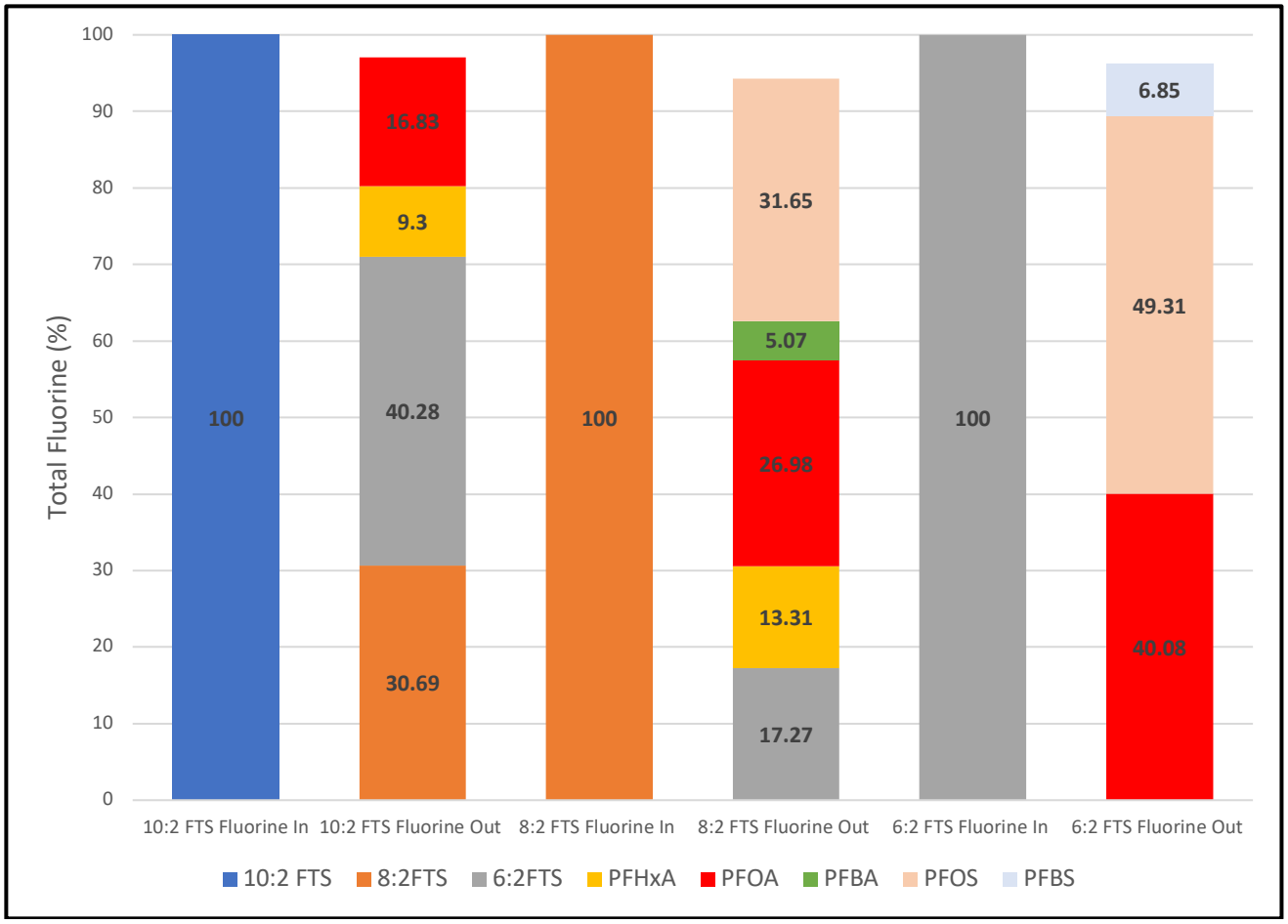


Figure 13. PFAS pure precursor fluorine mass balance pre- and post-thermal treatment.

The results presented in Figures 10-13 and Appendix E further support the potential thermal transformation mechanisms of random- and end-chain scission highlight in section 1.4. Figure 14 provides sample thermal transformation pathways for 10:2 FTS into PFOA, 8:2 FTS into PFHxA, and 6:2 FTS into PFOS.

The transformation of 10:2 FTS into PFOA and 8:2 FTS into PFHxA are each examples of random-chain scission, wherein a C-C bond along the polyfluoroalkyl chain breaks off at a seemingly random location (Xiao et al., 2021, Deng et al., 2021, and Alinezhad et al., 2022). Then C radical oxidation takes place along the resultant perfluoroalkyl radicals, generating PFAAs of different chain lengths. In the case of 10:2 FTS random-chain scission took place at C7, ultimately leading to C8 PFOA once C radical oxidation with a carboxyl group takes place. Similarly, in the case of 8:2 FTS, random-chain

scission took place at C5, ultimately leading to C6 PFHxA once C radical oxidation with a carboxyl group takes place.

The transformation of 6:2 FTS into PFOS is a potential example of end-chain scission, wherein the bond between the polyfluoroalkyl chain and carboxyl group or sulfonate group on the nonfluorinated side is broken, and similar to random-chain scission, resultant perfluoroalkyl radicals undergo C radical oxidation. In the case of 6:2 FTS into PFOS, following complete fluorination of the ethyl moiety, the sulfonate head undergoes recombination with the perfluoroalkyl radical. Potential pathways for each transformation products of the pure precursors subjected to thermal degradation through either random- or end-chain scission are shown in Appendix F.

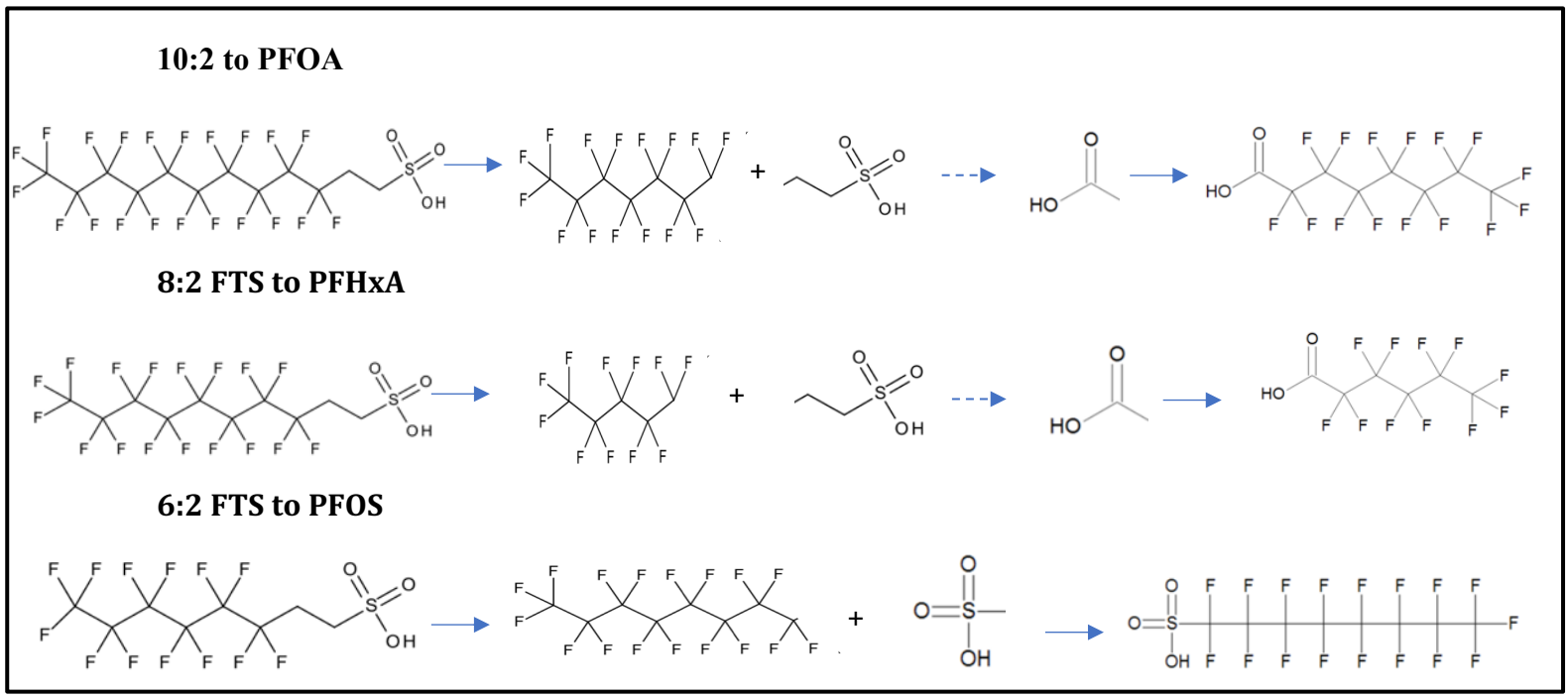


Figure 14. Potential thermal transformation pathways for 10:2, 8:2, and 6:2 precursor samples tested.

3.2 Aqueous Film Forming Foam Thermal Treatment Results

3.2.1 AFFF PFAS Concentrations at Increasing Treatment Durations

Three AFFF samples subject to heat treatment a 300 ºC at 10, 20, and 30 minute intervals within the pressure vessel were selected for LC/MS/MS analysis. Each sample contained 250 mL of a 1% solution of NF Universal Gold® AFFF. It was found that across increasing time intervals some PFAS compounds within the AFFF formulation experienced an increase in concentration while others decreased. Each PFAS compound concentration detected in LC/MS/MS results was compared to its corresponding 1% AFFF compound concentration from pure NF Universal Gold® results recorded within the MassDEP AFFF Library (see pure AFFF concentration data in Appendix B). Any deviations between MassDEP AFFF Library PFAS compound concentrations and those detected could potentially be the result of varying volumes in PFAS samples provided for LC/MS/MS analysis or evidence of thermal transformation.

Figure 15 shows the resultant precursor compounds detected during LC/MS/MS following 10, 20, and 30 minute heat treatment intervals durations, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF precursor results were reported above the analytical reporting limit. 4:2 FTS was reported as a non-detect (ND) within the pure AFFF sample tested throughout this study according the MassDEP AFFF LC/MS/MS library. However, across increasing heat treatment intervals an increase in 4:2 FTS was observed reaching 6020 ng/L after 30 minutes of thermal treatment. Conversely, 6:2 FTS and 8:2 FTS showed decreases in concentration across increasing heat treatment intervals, declining from 990000 ng/L to 960000 ng/L in the case of 6:2 FTS and from 284000 ng/L to 250000 ng/L in the case of 8:2 FTS. It should also be noted that while the MassDEP AFFF Library indicated a 1% solution of NF Universal Gold® should contain a quantifiable concentration of 10:2 FTS, no concentration was reported in LC/MS/MS data across all three time intervals.

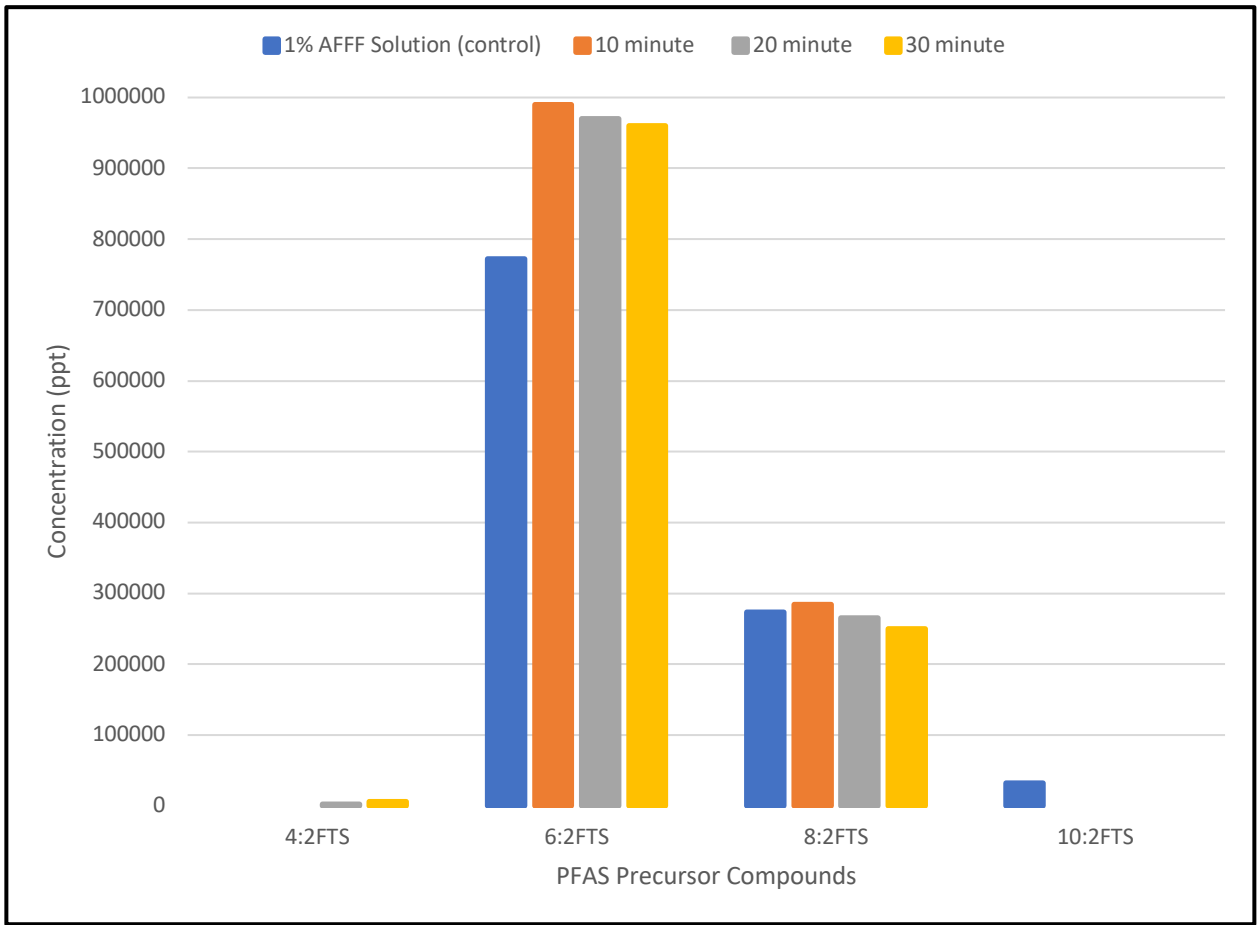


Figure 15. AFFF sample PFAS precursor concentrations detected at 10, 20, and 30 minute treatment durations at 300 ºC within pressure vessel.

Figure 16 shows the resultant short-chain PFAA compounds detected during LC/MS/MS following 10, 20, and 30 minute heat treatment intervals durations, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF short-chain PFAA results were reported above the analytical reporting limit. LC/MS/MS results showed that PFBA, PFBS, PFHxA, PFHxS, and PFHpS all increased in concentration with increasing treatment times, while PFPeA and PFPeS experienced decreases in concentration across increasing treatment times. It is also worth noting, concentrations of PFHpS were reported as a non-detect within the pure NF Universal Gold® sample in MassDEP AFFF Library samples. PFHxS is a PFAS compound

regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies.

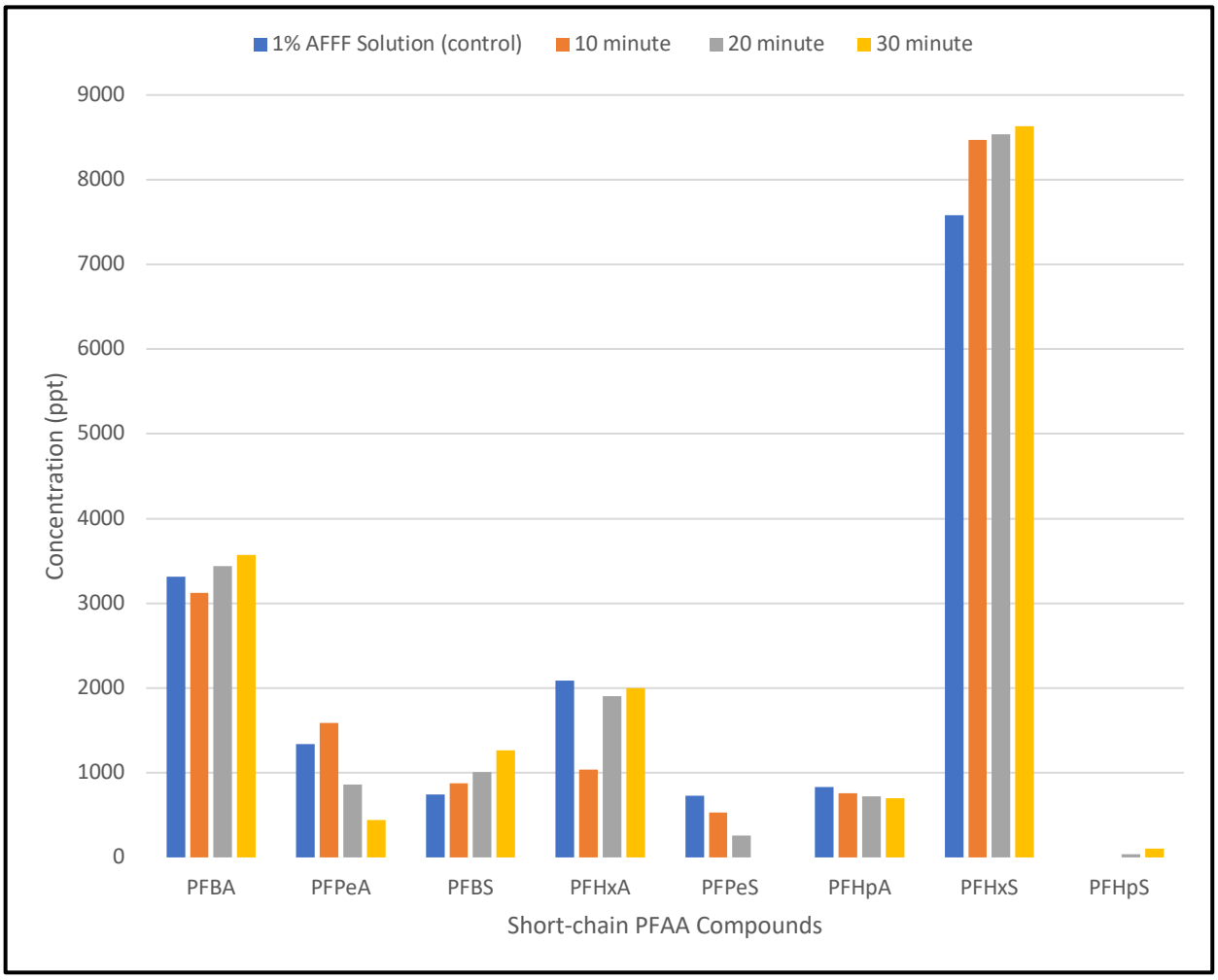


Figure 16. AFFF sample short-chain PFAA compound concentrations detected at 10, 20, and 30 minute treatment durations at 300 ºC within pressure vessel.

Finally, Figure 17 shows the resultant long-chain PFAA compounds detected during LC/MS/MS following 10, 20, and 30 minute heat treatment intervals durations, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF long-chain PFAA results were reported above the analytical reporting limit. LC/MS/MS results showed that PFOA, PFOS, PFNA, PFDA, and PFTA all increased in concentration with increasing treatment times, while PFUnA and PFDoA experienced fluctuations in concentration over increasing intervals. PFOA, PFOS,

PFNA, and PFDA are all PFAS compound regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies. It should also be noted, concentrations of PFTA and PFUnA were initially reported as a non-detects within the pure NF Universal Gold® sample in MassDEP AFFF Library samples.

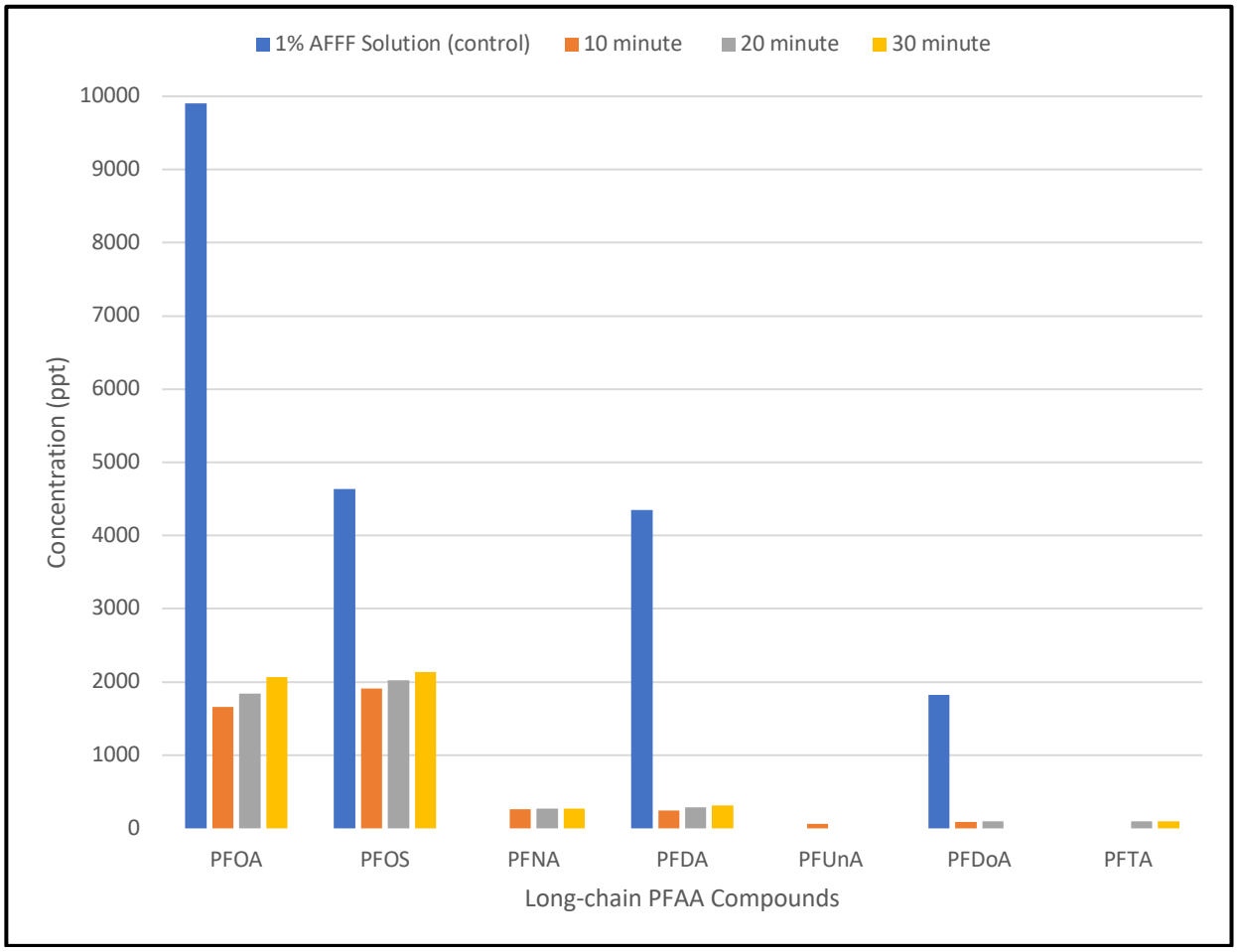


Figure 17. AFFF sample long-chain PFAA compound concentrations detected at 10, 20, and 30 minute treatment durations at 300 ºC within pressure vessel.

The decrease in longer-chain PFAS precursor compound in the AFFF tested in Figure 15 and increase in short- and long-chain PFAA compounds further support the theory that PFAS precursor have the potential to transform into other types of PFAS compounds under pyrolytic conditions. When comparing LC/MS/MS data of pure precursors alongside the LC/MS/MS for the AFFF sample tested in this data set, all short- and long-chain PFAAs detected in pure precursor samples post-heat treatment showed

increases in concentrations within the AFFF sample across increasing heat treatment times. These compounds include the short-chain PFAAs, PFHxA, PFBS, and PFBA, and long-chain PFAAs, PFOS and PFOA.

Furthermore, evidence of potential precursor transformation can also be linked to short and long chain PFAAs detected in LC/MS/MS data that were initially non-detects within the pure AFFF sample tested. When considering that AFFF samples provided for analysis were diluted to a 1% solution in comparison pure AFFF sample concentration provided in the MassDEP Library, this argument is further strengthened. As previously stated, the short-chain PFAA, PFHpS, and the long-chain PFAAs, PFUnA and PFTA, were all detected in the 1% AFFF solution samples subjected to elevated temperatures, but not detected within the pure AFFF sample.

Finally, when comparing the PFAS compounds that experienced increases in concentration to chromatogram data in Xiao et al., 2021, peaks of PFBS, PFHxS, PFHpS, and PFOS all occurred within the AFFF sample tested at 300 ºC. Although the manufacturer of the AFFF was not disclosed in this study, as well as whether 10:2, 8:2, and 6:2 FTS were precursors present in the AFFF, it is worth noting the similarities between these data sets.

3.2.2 Simulated Burn Procedure AFFF Results

Three AFFF samples subject to a calibrated 40 kW/m^2 heat flux at depths of 5 mm, 6 mm, and 7 mm were selected for LC/MS/MS analysis to simulate varying application volumes. Each sample contained a 1% solution of NF Universal Gold® AFFF. In general, it was found that as the depth increased PFAS compounds tended to decrease. Each PFAS compound concentration detected in LC/MS/MS results was compared to its corresponding 1% AFFF compound concentration from pure NF Universal Gold® results recorded within the MassDEP AFFF Library (see pure AFFF concentration data in Appendix B). Any deviations between MassDEP AFFF Library PFAS compound concentrations and those detected could potentially be the result of varying volumes in PFAS samples provided

for LC/MS/MS analysis or evidence of thermal transformation. Raw data of LC/MS/MS Alpha Labs Analytical results are provided in Appendix G for all three treatment intervals.

Raw data of LC/MS/MS Alpha Labs Analytical results are provided in Appendix G for all three treatment intervals. As previously stated, PFAS concentration marked by a 'J-flag' indicate that the sample is an estimated value as the detected concentration fell below the analytical RL but was above the analytical MDL. Additionally, PFAS concentration marked by a 'F-flag' indicate that the concentration of an analyte exceeds the range of the calibration cure and/or range of the LC/MS/MS instrument and should therefore be considered an estimated maximum concentration.

Figure 18 shows the resultant precursor compounds detected during LC/MS/MS analysis following 40 kW/m^2 heat flux treatments at depths of 5 mm, 6 mm, and 7 mm, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF precursor results were reported above the analytical reporting limit, except for PFHxS and PFOA within the 5 mm AFFF sample, which are represented by estimated values. 4:2 FTS was reported as a non-detect (ND) within the pure AFFF sample tested throughout this study according the MassDEP AFFF LC/MS/MS library. However, across increasing depths/volumes a decrease in 4:2 FTS was observed – attaining a concentration of 2650 ng/L at a 5 mm depth and 1170 ng/L at a 7 mm depth. Conversely, 6:2 FTS and 8:2 FTS showed an increase in concentration across increasing depths, starting at 789000 ng/L at a 5 mm depth and ending at 800200 ng/L at a 7 mm depth in the case of 6:2 FTS and from 287850 ng/L to 298900 ng/L in the case of 8:2 FTS. It should also be noted that while the MassDEP AFFF Library indicated a 1% solution of NF Universal Gold® should contain a quantifiable concentration of 10:2 FTS, no concentration was reported in LC/MS/MS data across all three time intervals.

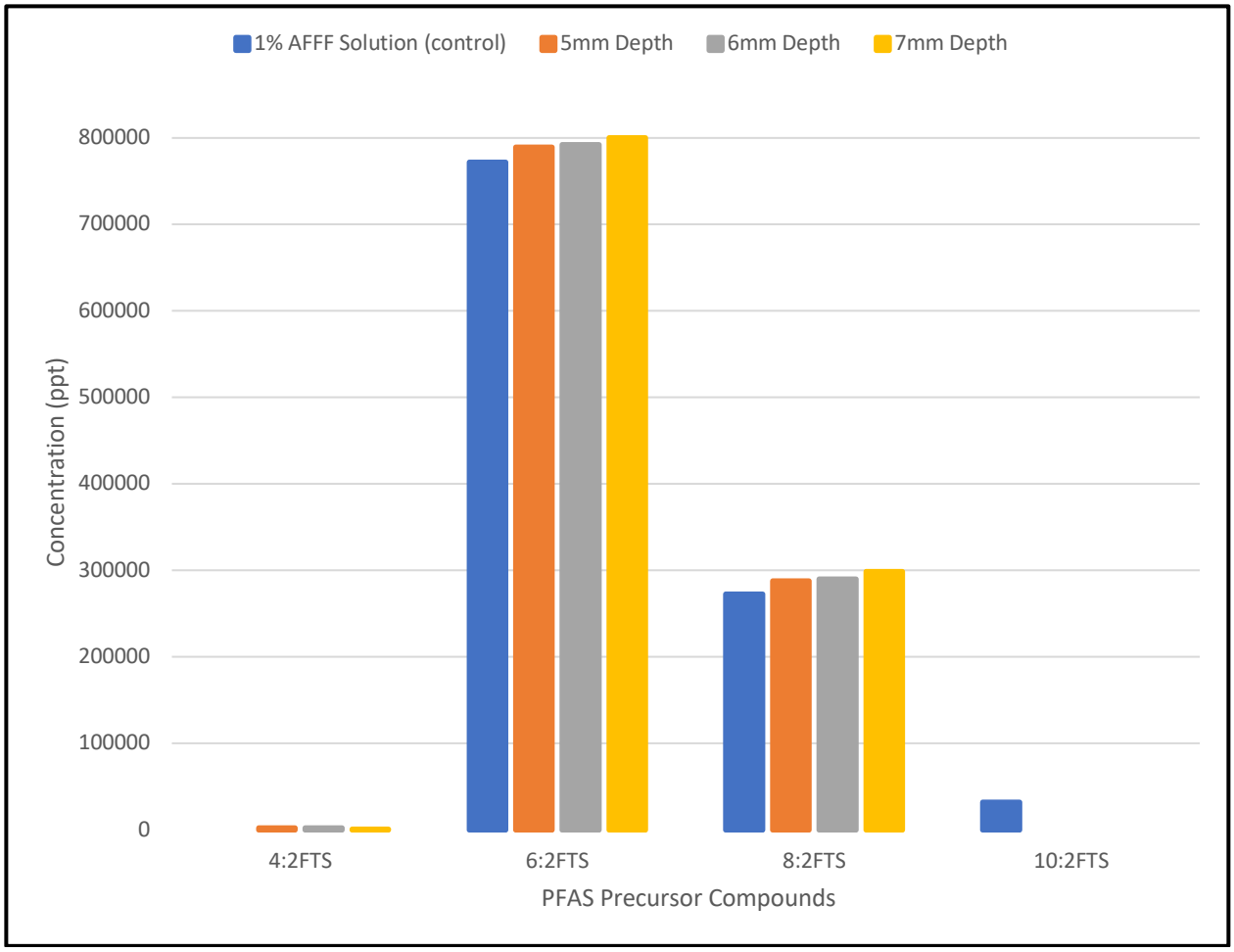


Figure 18. AFFF sample PFAS precursor concentrations detected at 5, 6, and 7 mm depths post radiant panel simulated burn procedure at 40 kW/m^2.

Figure 19 shows the resultant short-chain PFAAs compounds detected during LC/MS/MS analysis following 40 kW/m^2 heat flux treatments at depths of 5 mm, 6 mm, and 7 mm, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF short-chain PFAAs results were reported above the analytical reporting limit. LC/MS/MS results showed that PFBA, PFPeA, PFBS, PFHxA, PFHxS, and PFHpA all decreased in concentration with increasing AFFF depth/volume. PFHxS and PFHpA are both PFAS compound regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies.

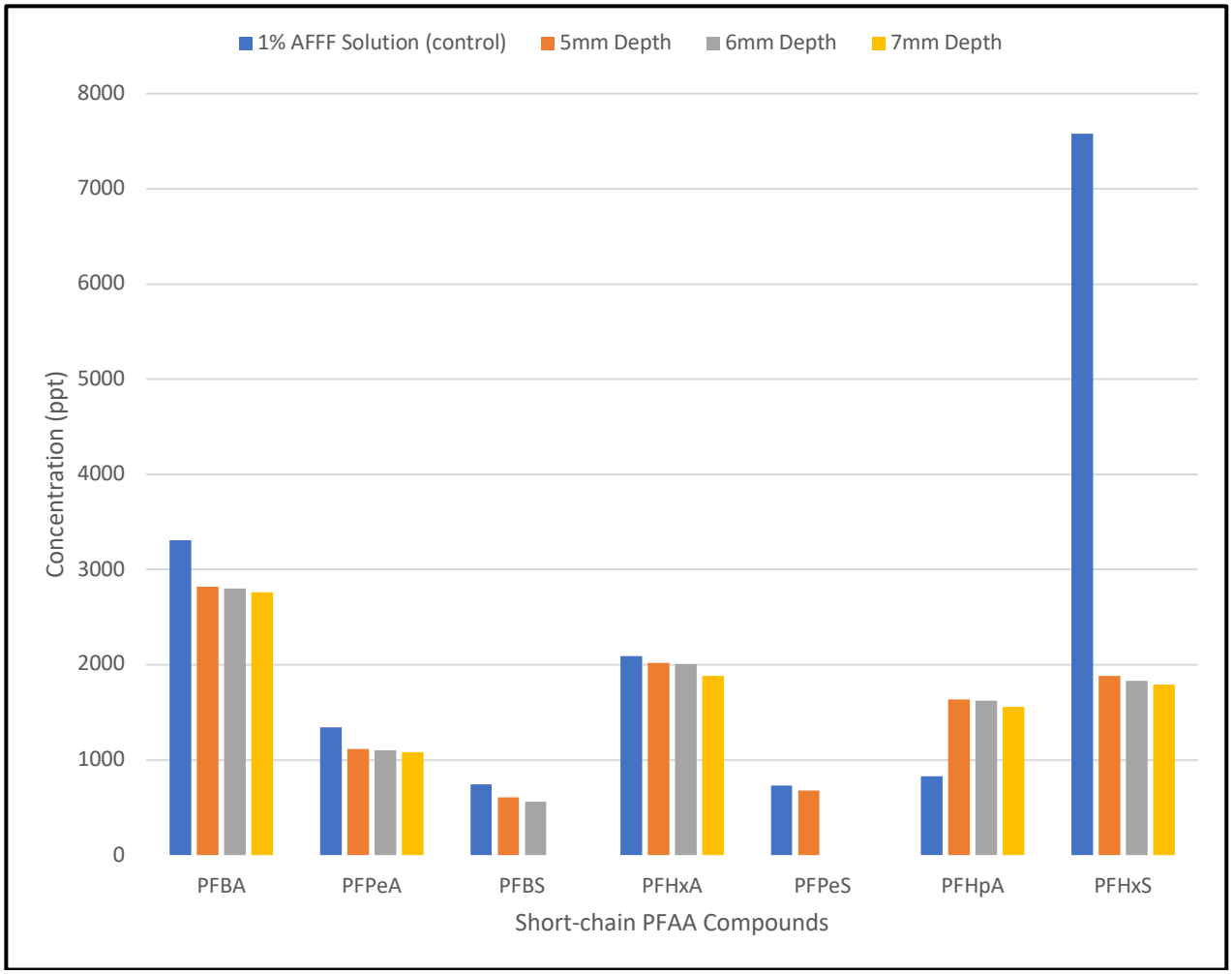


Figure 19. AFFF sample short-chain PFAA concentrations detected at 5, 6, and 7 mm depths post radiant panel simulated burn procedure at 40 kW/m^2.

Finally, Figure 20 shows the resultant long-chain PFAAs compounds detected during LC/MS/MS analysis following 40 kW/m^2 heat flux treatments at depths of 5 mm, 6 mm, and 7 mm, denoted by the orange, grey, and yellow bars, respectively. Blue bars correspond to a 1% AFFF compound concentration from pure NF Universal Gold® results according to the MassDEP AFFF library. Concentrations of all AFFF long-chain PFAAs results were reported above the analytical reporting limit. LC/MS/MS results showed that PFOS and PFDA followed a similar pattern to the short-chain PFAA compound, decreasing in concentration with increasing AFFF depth/volume. While it is not possible to confirm, PFOA, PFNA, and PFUnA likely decreased in concentration with increasing AFFF depth/volume as well, however due to concentrations levels for 6 mm and 7 mm depths falling below analytical

MDL's, these concentrations were reported as ND in LC/MS/MS results (Appendix G). Deviations in the concentration patterns across the short- and long-chain PFAA group occurred in PFDoA and PFTA concentrations. PFDoA increased in concentration with increasing AFFF depth/volume, and PFTA fluctuated in concentration with increasing AFFF depth/volume (with the minimum concentration occurring at 6 mm and the largest concentration occurring at 7 mm). PFOA, PFOS, PFNA, and PFDA are all PFAS compound regulated in the State of Massachusetts, under the Massachusetts PFAS Standards for Public Drinking Water Supplies.

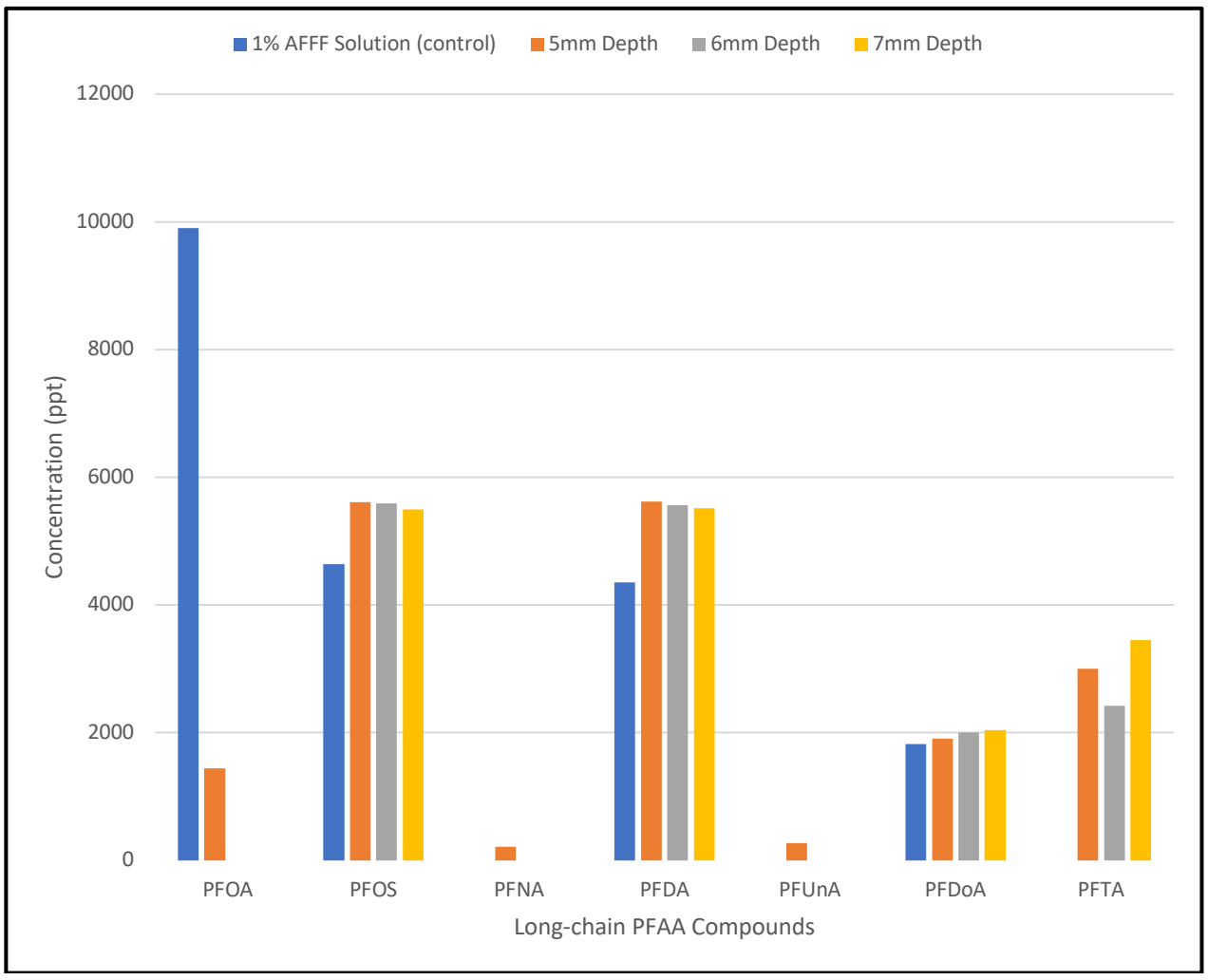


Figure 20. AFFF sample long-chain PFAA concentrations detected at 5, 6, and 7 mm depths post simulated burn procedure at 40 kW/m^2.

Similar to the pressure vessel AFFF results, PFAS compounds detected in the AFFF simulated burn procedure LC/MS/MS results further support the theory that PFAS precursor have the potential to transform into other types of PFAS compounds under pyrolytic conditions, as well as the likelihood for a temperature gradient across increasing AFFF application volumes.

The general trend in LC/MS/MS results for precursor results in the simulated burn procedure followed increasing concentrations across increasing depths/volumes, while PFAA results followed the opposite pattern decreasing in concentration across increasing depths/volumes. As such, these results support the theory that degradation of AFFF PFAS precursors occurred more rapidly at lower depths/volumes, resulting in elevated production and concentrations of short- and long-chain PFAA transformation products. Furthermore, a reason for this precursor, PFAA, and potential transformation byproduct pattern could result from the cooling effects of a more diverse temperature gradients at higher depths/volumes, due to the downward flow of heat flux from the radiant panel onto AFFF volumes. In turn, AFFF samples at 5 mm depths would be elevated to higher temperatures during exposure to 40 kW/m^2 heat flux treatments, in comparison to AFFF samples at 6 mm and 7mm depths.

In terms of observed thermal response across each radiant panel test, more turbulent levels of foam expansion and bubbling within the steel pan were observed during the 20 minute thermal treatment period for the 5 mm AFFF solution in comparison to the 6 mm and 7 mm tests. Bubbles were observed at a height of approximately 2 cm and endured for 1-2 minutes before new bubbles formed. During 6 mm and 7 mm tests bubbles remained in the pan for 5-10 minutes and were smaller and more clustered. Noticeable expansion occurred at 5 minutes for the 5 mm test, 7 minutes for the 6 mm test, and 11 minutes for 7 mm test. Evaporation of the AFFF solution was observed across each test, with noticeable evaporation occurring at 6 minutes for the 5 mm test, 9 minutes for the 6 mm test, and 13 minutes for the 7 mm test. In terms of other physical changes to the AFFF solution under radiative heat flux, there was no observable color change or a notable difference in viscosity across all tests. Table 6 provides a summary of the results recorded

during each trial of the simulated procedure, including the percentage loss of AFFF due to evaporation and notable observations.

Table 6. Simulated burn procedure experimental matrix

Trial	Depth (mm)	Initial Volume (cm^3)	Final Volume (cm^3)	Percentage Loss (%)	Observations
1	5	200	109.50	45.25	Turbulent bubbling and foam expansion, noticeable evaporation at 6 minutes, and no apparent changes in color or viscosity
2	6	240	165	31.25	Smaller bubble formation with increased expansion, noticeable evaporation at 9 minutes, and no apparent changes in color or viscosity
3	7	280	210.50	24.82	Longer duration for expansion and bubbling to occur – beginning at 10 minutes. Similar bubble shape and expansion characteristics to Trial 2. Noticeable evaporation at 13 minutes, and no apparent changes in color or viscosity.

3.3 Implications of Precursor and AFFF Results

Trends in post-thermal treatment results for pure PFAS precursor samples, AFFF samples subject to increasing heat treatment intervals, and AFFF subjected to a simulated hydrocarbon fire scenario all provide further evidence that PFAS precursors have the potential to transform under pyrolytic conditions of during a real Class B fire scenario. As a result, the data in this study has implications for human and environmental health as well as thermal treatment methods.

In terms of human and environmental health, exposure and mobilization of the precursor transformation products in the current study such as PFOS and PFOA, could occur as a result of spent AFFF degrading in close proximity to a fire event. If leached into sources of drinking water sources these compounds could lead to a greater degree of treatment necessary to for drinking water treatment plant – especially when considering

that the studied precursors resulted in the potential formation of all six Massachusetts regulated PFAS compounds PFOA, PFOS, PFHxS, PFDA, PFNA and PFHpA in drinking water. Moreover, these results potentially provide further evidence that PFAS compounds detected in groundwater and soils of sites known to have historically been contaminated with AFFF (e.g., airport fire training grounds) may have previously been PFAS precursors, such as 10:2, 8:2, and 6:2 FTS, and transformed via thermolysis.

Finally, as previously noted in section 1.5, thermal treatment methods, such as the those provided in the USEPA's 2020 Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances report, have proven to be effective strategies to destruct PFAS because this approach is cable of breaking down the strong halogen-carbon bonds, such as C–F bonds. Therefore, these finding suggest that varying level of thermal treatment of PFAS and AFFF-imparted sites may result in unintentional formation of certain PFAS compounds. As a result, LC/MS/MS data from this study could be used to justify alternative thermal remediation techniques, as well as bolster support for the use of fluorine free foams, to limit the potential for production of unwanted perfluoroalkyl substances from precursor compounds.

Chapter 4: Conclusions

4.1 Conclusions from PFAS Precursor and AFFF Bench-Scale Testing

Results of this PFAS study indicate that 10:2, 8:2, and 6:2 FTS polyfluoroalkyl substances can transform into shorter chain polyfluoroalkyl substances as well as perfluoroalkyl substances regulated in the state of Massachusetts. Pressure vessel heat treatment of all three precursors gave quantitative yields of PFOA and PFOS, with 8:2 and 6:2 FTS producing both perfluoroalkyl compounds following thermolysis. Additional fluorine mass balance data for each precursor post-thermal treatment showed greater than 94% recovery of for all transformation byproducts produced, demonstrating a high degradation and transformation efficiency for each precursor. Moreover, PFAS precursor transformation products produced provide further support for random- and end-chain scission thermal transformation pathways.

A similar narrative was observed for experimental PFAS precursor thermolysis performed within AFFF subjected to elevated temperatures and heat fluxes. General trends in AFFF sample pressure vessel data at increasing time intervals showed decreases in polyfluoroalkyl substances and increases in perfluoroalkyl substances – indicating increased transformation over longer exposure. Increases in five of the six Massachusetts regulated PFAS compounds (PFHxS PFOA, PFOS, PFNA, and PFDA) across 10, 20, and 30 minute thermal treatment times. General trends in AFFF simulated burn results showed increases in polyfluoroalkyl substances and decreases in perfluoroalkyl substances over increasing AFFF depths/volumes – potentially indicating increased precursor intermediate production at lower depth/volumes and decreased precursor intermediate production at higher depth/volume. This may have been a result of the temperature gradient created through the AFFF sample under the radiant panel heat flux. Ultimately, these results indicate that PFAS precursor have the potential to transform into other types of polyfluoroalkyl substances as well as perfluoroalkyl substances under relatively moderate pyrolytic conditions that simulate AFFF use during fire events.

4.2 Recommendations for Further Study

It is recommended that additional experimentation be completed for 10:2, 8:2, and 6:2 FTS precursors as well as the AFFF sample used to replicate thermal treatment results and provide further validity of assumptions described in Chapter 3. Additional precursors that were detected in the AFFF samples in MassDEP Library but were less prevalent across the majority of samples included Perfluorooctanesulfonamide (FOSA) and 1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2 FTS). Conducting similar experimental procedures on these precursors could potentially provide further evidence of PFAS precursor stability in presence of pyrolytic conditions.

If results and experimental methods are replicated, it is also recommended that a higher concentration of pure precursor be subjected to thermal treatment to decrease the likelihood of potential intermediates falling below the analytical Method Detection Limits and estimated intermediates falling between the analytical Minimum Detection Limits and Reporting Limit. Additionally, analysis of total organofluorine species produced during post pressure vessel thermal treatment test would aid in creating a more complete fluorine mass balance of PFAS intermediates post-treatment, as well as the identification of further potential transformation pathways.

Finally, as this study was conducted using bench-scale testing methods and laboratory prepared water and AFFF samples, it recommended that further experimentation be performed larger scale. This could occur using a methodology centered around an actual controlled burn scenario, or through collecting actual samples of spent AFFF from suppressed Class B fire events followed by LC/MS/MS analysis of these samples. Both methods would likely provide more accurate concentrations expectations of the effects pyrolytic conditions have on polyfluoroalkyl precursors, perfluoroalkyl substances, and potential PFAS intermediates.

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Appendix A: Fluorine Properties

A.1) Bond strengths (Kildahl, 1995)

Bond	E, kcal/mole
C-F	115
C-Cl	81
C-Br	68
C-I	57
C-H	98
H-F	135
H-Cl	103
H-Br	86
N-F	67

A.2) Dissociation energies ($X_2 \rightarrow 2X$) (Kildahl, 1995)[2]

Molecule	Dissociation Energy, kcal/mole
F_2	38
Cl_2	58
Br_2	46
I_2	36
H_2	109
O_2	118
N_2	225

[2] Fluorine's low energy of dissociation allows for significant yields of fluorine atoms to be available for bond formation at room temperature (Kildahl, 1995).

Appendix B: Pure AFFF Data

B.1) NF Universal Gold® AFFF sample PFAS precursors, initial concentrations, and corresponding intermediates following biotic and/or abiotic degradation (Harding-Marjanovic et al., 2015 and Alinezhad et al., 2022).

Manufacturer	PFAS Precursor	Concentration (ng/L)	PFAS Intermediates
NF Universal Gold®	10:2 FTS	3230000	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFOS
	8:2FTS	27300000	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFOS
	6:2FTS	77200000	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFOS
	4:2FTS	ND	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFOS
	FOSA	ND	PFOS and PFOA
	NEtFOSA	ND	PFOS and PFOA
	NMeFOSA	ND	PFOS and PFOA
	NEtFOSE	ND	PFOS and PFOA
	NMeFOSE	ND	PFOS and PFOA
	NEtFOSAA	ND	PFOS and PFOA
	NMeFOSAA	ND	PFOS and PFOA

B.2) Pure AFFF sample MassDEP PFAS6 concentrations prior to thermal degradation.

Manufacturer	MassDEP PFAS6	MassDEP PFAS6 Concentrations detected in samples (ng/L)
NF Universal Gold®	perfluorooctane sulfonic acid (PFOS)	464000
	perfluorooctanoic acid (PFOA)	990000
	perfluorohexane sulfonic acid (PFHxS)	758000
	perfluorononanoic acid (PFNA)	ND
	perfluoroheptanoic acid (PFHpA)	83000
	perfluorodecanoic acid (PFDA)	435000

B.3) Pure AFFF sample MassDEP library concentration for remaining long- and short-chain PFAAs prior to degradation.

Manufacturer	MassDEP PFAS6	MassDEP PFAS6 Concentrations detected in samples (ng/L)
NF Universal Gold®	(PFBA)	331000
	(PFPeA)	134000
	(PFBS)	74000
	(PFHxA)	209000
	(PFPeS)	73000
	(PFUnA)	ND
	(PFDoA)	182000
	(PFTA)	ND
	(PFHpS)	ND

Appendix C: Pressure Vessel Reactor Volume Limits at Elevated Temperatures

C.1) Liquid volumes and vapor pressures for water in a closed vessel at elevated temperatures (Keenan & Keyes, 1961).

Temperature ºC	Specific Volume of the Liquid, cu. ft. /lb.	Vapor Pressure psig	Volume Multiplier, $Sp.V_T/Sp.V_{77ºF}$	% Volume Increase
25	0.01607	---	1.00	0
100	0.0162	0	1.04	4
200	0.0183	211	1.15	15
250	0.0201	562	1.25	25
282	0.0215	948	1.34	34
300	0.0225	1230	1.40	40
321	0.0241	1650	1.50	50
349	0.0278	2350	1.73	73
363	0.0315	2780	1.96	96
371	0.0369	3070	2.30	130
372	0.0385	3120	2.40	140
373	0.0410	3160	2.55	155
374	0.0503	3190	3.13	213
(Critical Point)				

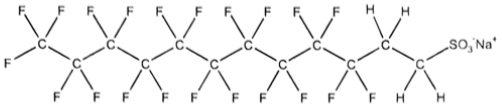
Appendix D: 10:2, 8:2, and 6:2 FTS Purity Certificates

Appendix D.1) 10:2 FTS pure precursor Wellington Laboratory manufacture purity certificate.

WELLINGTON LABORATORIES

CERTIFICATE OF ANALYSIS
DOCUMENTATION

PRODUCT CODE:	10:2FTS	**LOT NUMBER:**	102FTS0122
COMPOUND:	Sodium 1H,1H,2H,2H-perfluorododecanesulfonate		
STRUCTURE:		**CAS #:**	108026-35-3



MOLECULAR FORMULA:	$C_{12}H_4F_{21}SO_3Na$	**MOLECULAR WEIGHT:**	650.18
CONCENTRATION:	50.0 ± 2.5 µg/mL (Na salt)	**SOLVENT(S):**	Methanol
	48.3 ± 2.4 µg/mL (10:2FTS acid)		
	48.2 ± 2.4 µg/mL (10:2FTS anion)		
CHEMICAL PURITY:	>98%		
LAST TESTED: (mm/dd/yyyy)	01/27/2022		
EXPIRY DATE: (mm/dd/yyyy)	01/27/2027		
RECOMMENDED STORAGE:	Refrigerate ampoule		

DOCUMENTATION/ DATA ATTACHED:

Figure 1: LC/MS Data (Full Scan and Mass Spectrum)
Figure 2: LC/MS/MS Data (Selected MRM Transitions)

ADDITIONAL INFORMATION:

- See page 2 for further details.

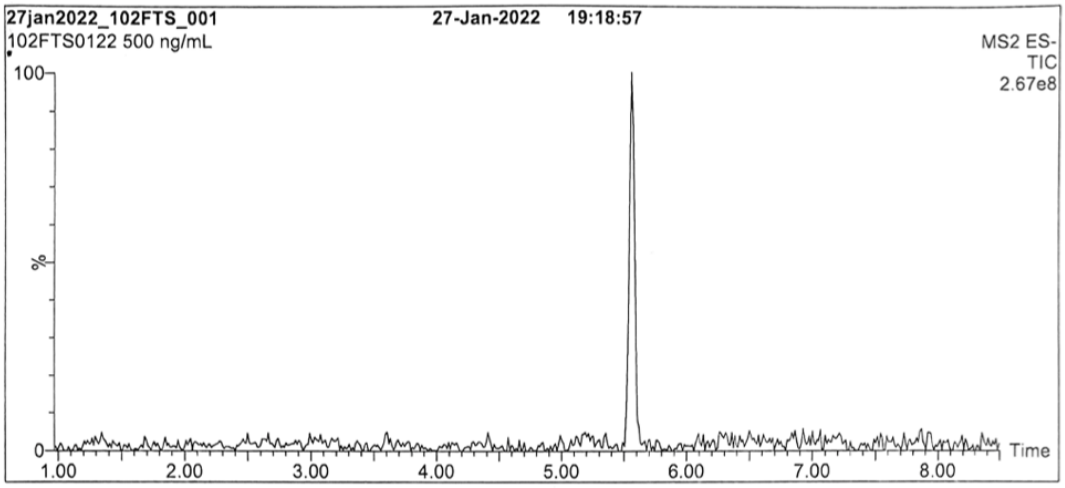
FOR LABORATORY USE ONLY: NOT FOR HUMAN OR DRUG USE

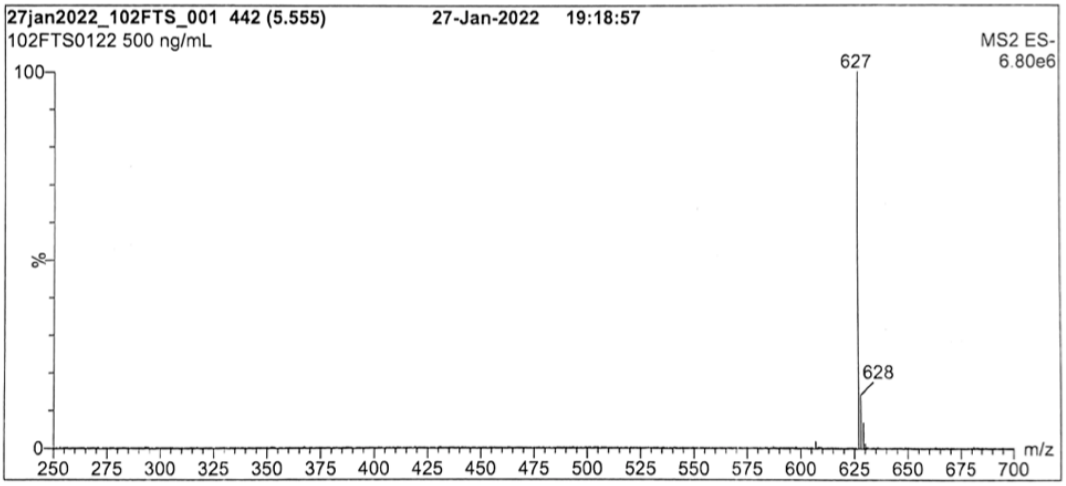
Certified By: _____ **Date:** 02/04/2022 (mm/dd/yyyy)
B.G. Chittim, General Manager

Wellington Laboratories Inc., 345 Southgate Dr. Guelph ON N1G 3M5 CANADA
519-822-2436 • Fax: 519-822-2849 • info@well-labs.com

Form#:27, Issued 2004-11-10
Revision#:9, Revised 2020-12-23

Figure 1: **10:2FTS; LC/MS Data (Full Scan and Mass Spectrum)**





Conditions for Figure 1:

Waters Acquity Ultra Performance LC
Waters Xevo TQ-S micro MS

Chromatographic Conditions:

Column: Acquity UPLC BEH Shield RP_{18}
1.7 µm, 2.1 x 100 mm

Mobile phase: Gradient
Start: 40% H_2O / 60% (80:20 MeOH:ACN)
(both with 10 mM NH_4OAc buffer)
Ramp to 90% organic over 8 min and hold for 2 min
before returning to initial conditions in 0.75 min.
Time: 12 min

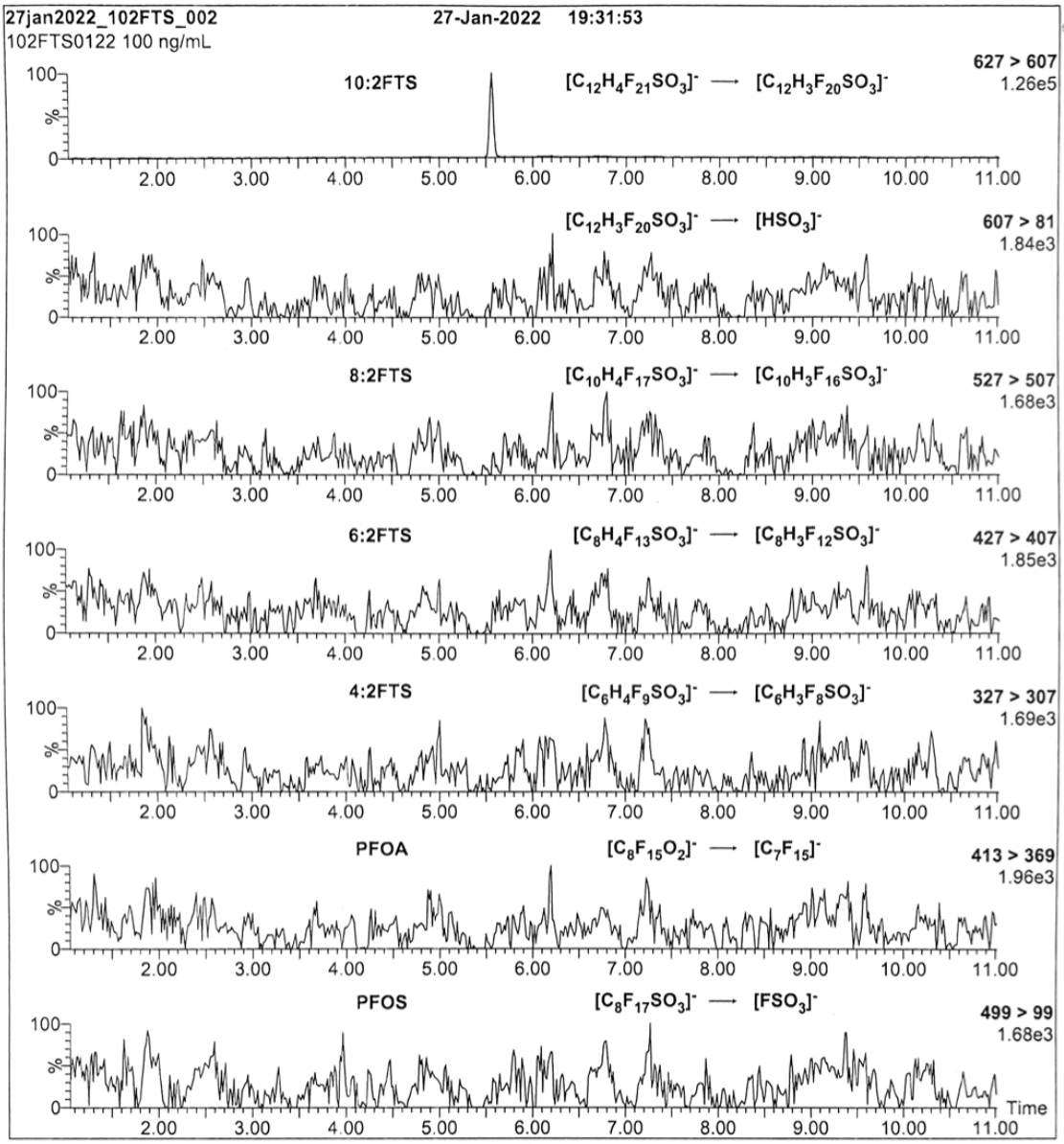
Flow: 300 µL/min

MS Parameters:

Experiment: Full Scan (250 - 850 amu)

Source: Electrospray (negative)
Capillary Voltage (kV) = 2.00
Cone Voltage (V) = 25.00
Desolvation Temperature (°C) = 500
Desolvation Gas Flow (L/hr) = 1000

Figure 2: **10:2FTS; LC/MS/MS Data (Selected MRM Transitions)**



Conditions for Figure 2:

Injection: On-column (10:2FTS)

Mobile phase: Same as Figure 1

Flow: 300 µL/min

MS Parameters:

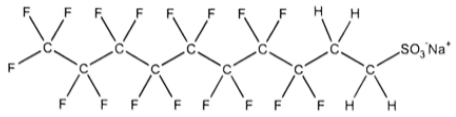
Collision Gas (mbar) = 3.29e-3
Collision Energy (eV) = 25

Appendix D.2) 8:2 FTS pure precursor Wellington Laboratory manufacture purity certificate.

WELLINGTON LABORATORIES

CERTIFICATE OF ANALYSIS
DOCUMENTATION

PRODUCT CODE:	8:2FTS	**LOT NUMBER:**	82FTS0122
COMPOUND:	Sodium 1H,1H,2H,2H-perfluorodecanesulfonate		
STRUCTURE:		**CAS #:**	27619-96-1



MOLECULAR FORMULA:	$C_{10}H_4F_{17}SO_3Na$	**MOLECULAR WEIGHT:**	550.16
CONCENTRATION:	50.0 ± 2.5 µg/mL (Na salt) 48.0 ± 2.4 µg/mL (8:2FTS acid) 47.9 ± 2.4 µg/mL (8:2FTS anion)	**SOLVENT(S):**	Methanol
CHEMICAL PURITY:	>98%		
LAST TESTED: (mm/dd/yyyy)	02/08/2022		
EXPIRY DATE: (mm/dd/yyyy)	02/08/2027		
RECOMMENDED STORAGE:	Refrigerate ampoule		

DOCUMENTATION/ DATA ATTACHED:

Figure 1: LC/MS Data (Full Scan and Mass Spectrum)
Figure 2: LC/MS/MS Data (Selected MRM Transitions)

ADDITIONAL INFORMATION:

- See page 2 for further details.

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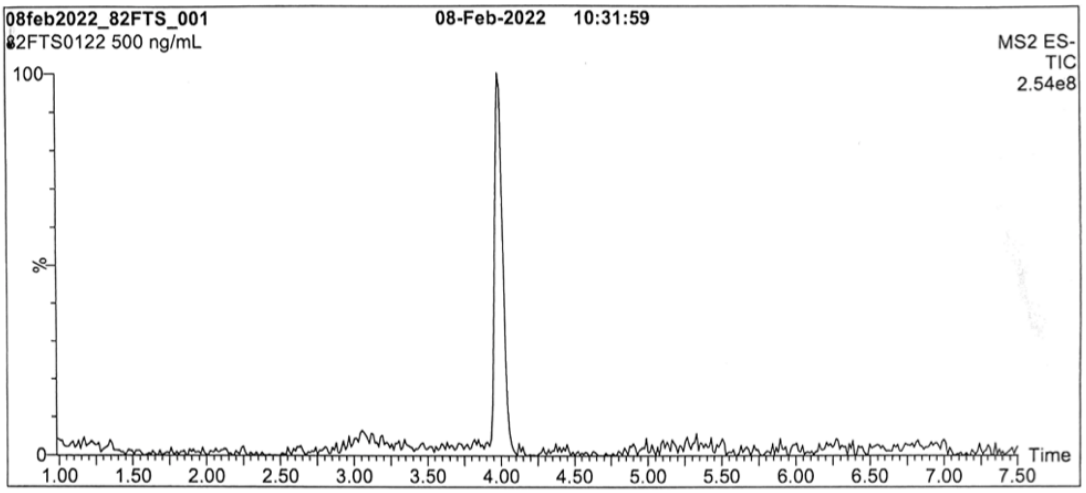
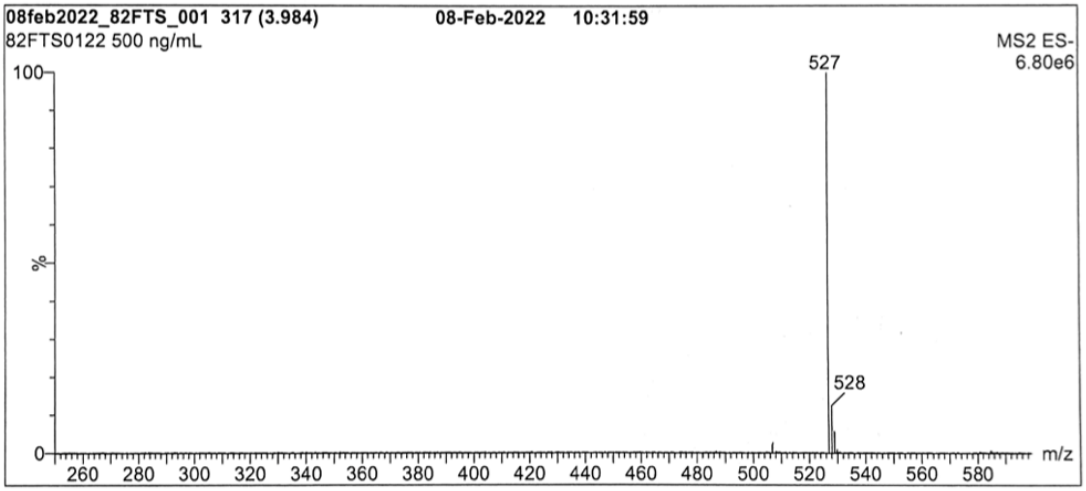
Certified By: _____ **Date:** 02/11/2022 (mm/dd/yyyy)
B.G. Chittim, General Manager

Wellington Laboratories Inc., 345 Southgate Dr. Guelph ON N1G 3M5 CANADA
519-822-2436 • Fax: 519-822-2849 • info@well-labs.com

Figure 1: **8:2FTS; LC/MS Data (Full Scan and Mass Spectrum)**





Conditions for Figure 1:

Waters Acquity Ultra Performance LC
Waters Xevo TQ-S micro MS

Chromatographic Conditions:

Column: Acquity UPLC BEH Shield RP_{18}
1.7 µm, 2.1 x 100 mm

Mobile phase: Gradient
Start: 40% H_2O / 60% (80:20 MeOH:ACN)
(both with 10 mM NH_4OAc buffer)
Ramp to 90% organic over 9 min and hold for 1 min
before returning to initial conditions in 0.75 min.
Time: 12 min

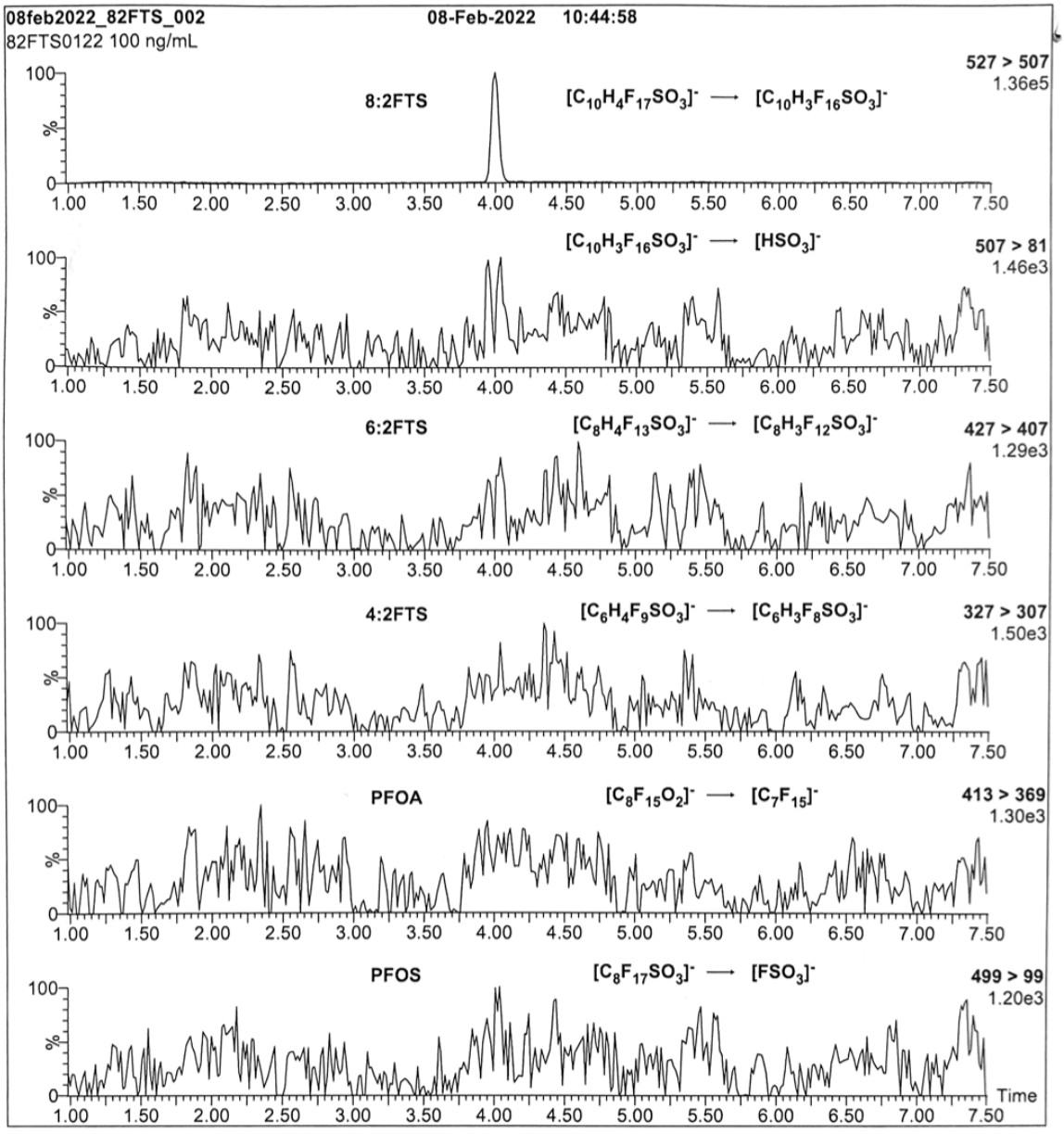
Flow: 300 µL/min

MS Parameters:

Experiment: Full Scan (250 - 850 amu)

Source: Electrospray (negative)
Capillary Voltage (kV) = 2.00
Cone Voltage (V) = 25.00
Desolvation Temperature (°C)= 500
Desolvation Gas Flow (L/hr) = 1000

Figure 2: **8:2FTS; LC/MS/MS Data (Selected MRM Transitions)**



Conditions for Figure 2:

Injection: On-column (8:2FTS)

Mobile phase: Same as Figure 1

Flow: 300 µL/min

MS Parameters:

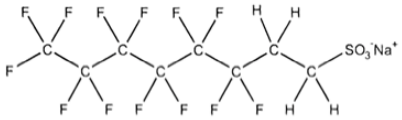
Collision Gas (mbar) = 3.35e-3
Collision Energy (eV) = 26

Appendix D.3) 6:2 FTS pure precursor Wellington Laboratory manufacture purity certificate.

WELLINGTON LABORATORIES

CERTIFICATE OF ANALYSIS
DOCUMENTATION

PRODUCT CODE:	6:2FTS	**LOT NUMBER:**	62FTS0722
COMPOUND:	Sodium 1H,1H,2H,2H-perfluorooctanesulfonate		
STRUCTURE:		**CAS #:**	27619-94-9



MOLECULAR FORMULA:	$C_8H_4F_{13}SO_3Na$	**MOLECULAR WEIGHT:**	450.15
CONCENTRATION:	50.0 ± 2.5 µg/mL (Na salt) 47.6 ± 2.4 µg/mL (6:2FTS acid) 47.4 ± 2.4 µg/mL (6:2FTS anion)	**SOLVENT(S):**	Methanol
CHEMICAL PURITY:	>98%		
LAST TESTED: (mm/dd/yyyy)	08/05/2022		
EXPIRY DATE: (mm/dd/yyyy)	08/05/2027		
RECOMMENDED STORAGE:	Refrigerate ampoule		

DOCUMENTATION/ DATA ATTACHED:

Figure 1: LC/MS Data (Full Scan and Mass Spectrum)
Figure 2: LC/MS/MS Data (Selected MRM Transitions)

ADDITIONAL INFORMATION:

- See page 2 for further details.

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Certified By: _____ **Date:** 08/18/2022 (mm/dd/yyyy)
B.G. Chittim, General Manager

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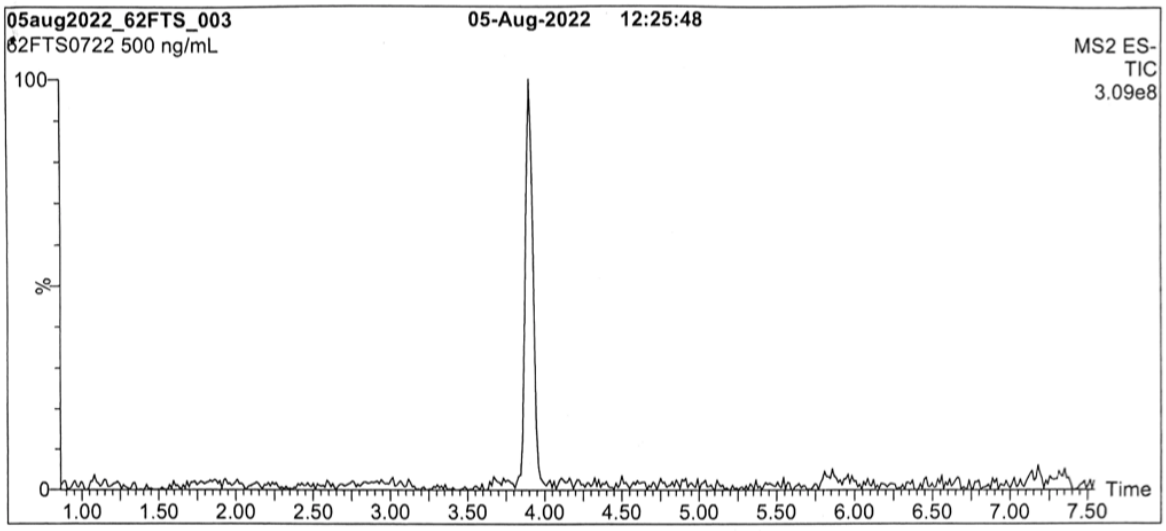
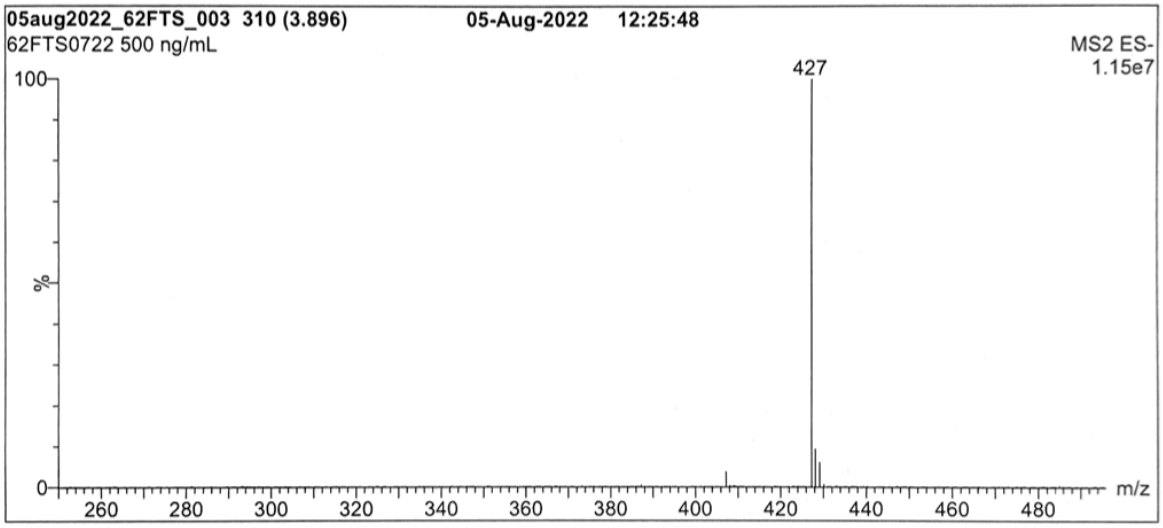
Form#:27, Issued 2004-11-10
Revision#:9, Revised 2020-12-23

Figure 1: **6:2FTS; LC/MS Data (Full Scan and Mass Spectrum)**





Conditions for Figure 1:

Waters Acquity Ultra Performance LC
Waters Xevo TQ-S micro MS

Chromatographic Conditions:

Column: Acquity UPLC BEH Shield RP_{18}
1.7 µm, 2.1 x 100 mm

Mobile phase: Gradient
Start: 50% H_2O / 50% (80:20 MeOH:ACN)
(both with 10 mM NH_4OAc buffer)
Ramp to 90% organic over 9 min and hold for
1 min before returning to initial conditions in 0.75 min.
Time: 12 min

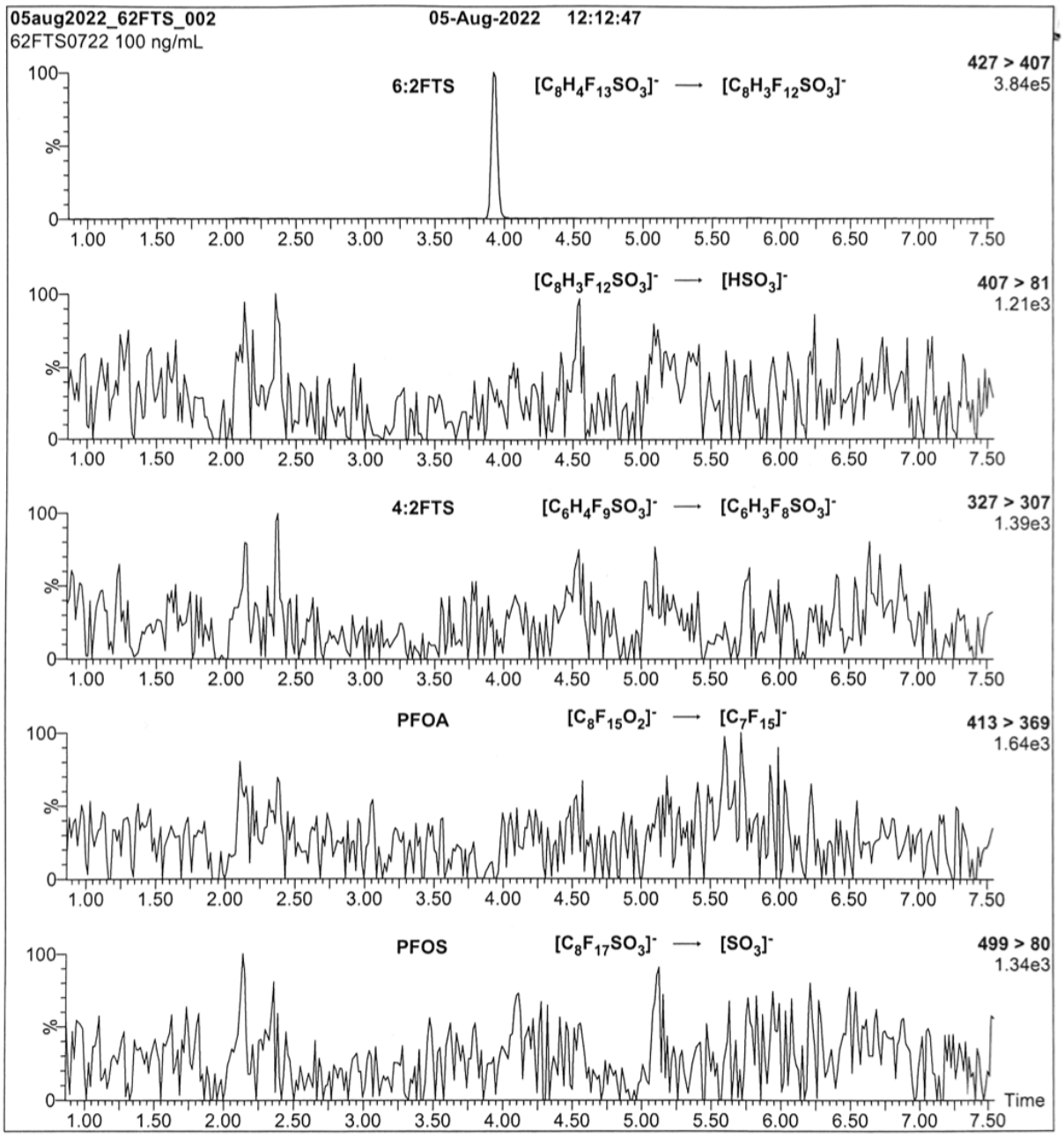
Flow: 300 µL/min

MS Parameters:

Experiment: Full Scan (250 - 850 amu)

Source: Electrospray (negative)
Capillary Voltage (kV) = 2.00
Cone Voltage (V) = 25.00
Desolvation Temperature (°C) = 500
Desolvation Gas Flow (L/hr) = 1000

Figure 2: **6:2FTS; LC/MS/MS Data (Selected MRM Transitions)**



Conditions for Figure 2:

Injection: On-column (6:2FTS)

Mobile phase: Same as Figure 1

Flow: 300 µL/min

MS Parameters:

Collision Gas (mbar) = 3.29e-3
Collision Energy (eV) = 20

Appendix E: Pure PFAS Precursor Raw LC/MS/MS Data

ANALYTICAL REPORT

Lab Number:	L2271017
Client:	New England Disposal Technologies, Inc. 83 Gilmore Drive Sutton, MA 01590
ATTN:	Mike Robertson
Phone:	(508) 234-4440
Project Name:	102027
Project Number:	Not Specified
Report Date:	01/20/23

Certifications & Approvals: MA (M-MA030), NH NELAP (2062), CT (PH-0141), DoD (L2474), FL (E87814), IL (200081), LA (85084),

ME (MA00030), MD (350), NJ (MA015), NY (11627), NC (685), OH (CL106), PA (68-02089), RI (LAO00299), TX (T104704419), VT (VT-0015), VA (460194), WA (C954), US Army Corps of Engineers, USDA (Permit #P330-17-00150), USFWS (Permit #206964).

320 Forbes Boulevard, Mansfield, MA 02048-1806

508-822-9300 (Fax) 508-822-3288 800-624-9220 - www.alphalab.com

Project Name:	102027	**Lab Number:**	L2271017
Project Number:	Not Specified	**Report Date:**	01/20/23

Alpha Sample ID	Client ID	Matrix	Sample Location	Collection Date/Time	Receive Date
L2271017-01	10:2 FTS 400*C (1)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271017-02	8:2 FTS 400*C (2)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271017-03	6:2 FTS 400*C (3)	WATER	WPI WORCESTER	12/15/22 12:10	12/16/22

Project Name:	102027	**Lab Number:**	L2271017
Project Number:	Not Specified	**Report Date:**	01/20/23

Case Narrative

The samples were received in accordance with the Chain of Custody and no significant deviations were encountered during the preparation or analysis unless otherwise noted. Sample Receipt, Container Information, and the Chain of Custody are located at the back of the report.

Results contained within this report relate only to the samples submitted under this Alpha Lab Number and meet NELAP requirements for all NELAP accredited parameters unless otherwise noted in the following narrative. The data presented in this report is organized by parameter (i.e. VOC, SVOC, etc.). Sample specific Quality Control data (i.e. Surrogate Spike Recovery) is reported at the end of the target analyte list for each individual sample, followed by the Laboratory Batch Quality Control at the end of each parameter. Tentatively Identified Compounds (TICs), if requested, are reported for compounds identified to be present and are not part of the method/program Target Compound List, even if only a subset of the TCL are being reported. If a sample was re-analyzed or re-extracted due to a required quality control corrective action and if both sets of data are reported, the Laboratory ID of the re-analysis or re-extraction is designated with an "R" or "RE", respectively.

When multiple Batch Quality Control elements are reported (e.g. more than one LCS), the associated samples for each element are noted in the grey shaded header line of each data table. Any Laboratory Batch, Sample Specific % recovery or RPD value that is outside the listed Acceptance Criteria is bolded in the report. In reference to questions H (CAM) or 4 (RCP) when "NO" is checked, the performance criteria for CAM and RCP methods allow for some quality control failures to occur and still be within method compliance. In these instances, the specific failure is not narrated but noted in the associated QC Outlier Summary Report, located directly after the Case Narrative. QC information is also incorporated in the Data Usability Assessment table (Format 11) of our Data Merger tool, where it can be reviewed in conjunction with the sample result, associated regulatory criteria and any associated data usability implications.

Soil/sediments, solids and tissues are reported on a dry weight basis unless otherwise noted. Definitions of all data qualifiers and acronyms used in this report are provided in the Glossary located at the back of the report.

HOLD POLICY - For samples submitted on hold, Alpha's policy is to hold samples (with the exception of Air canisters) free of charge for 21 calendar days from the date the project is completed. After 21 calendar days, we will dispose of all samples submitted including those put on hold unless you have contacted your Alpha Project Manager and made arrangements for Alpha to continue to hold the samples. Air canisters will be disposed after 3 business days from the date the project is completed.

Please contact Project Management at 800-624-9220 with any questions.

Case Narrative (continued)

Perfluorinated Alkyl Acids by Isotope Dilution

L2271017-01R and -02R: The samples were re-analyzed due to QC failures in the original analysis. The results of the re-analysis are reported.

L2271017-03R: The sample was re-analyzed due to QC failures in the original analysis. The results of the re-analysis are reported for 6:2FTS.

ORGANICS

SEMIVOLATILES

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

SAMPLE RESULTS

Lab ID: L2271017-01 R
Client ID: 10:2 FTS 400*C (1)
Sample Location: WPI WORCESTER

Date Collected: 12/15/22 12:00
Date Received: 12/16/22
Field Prep: Not Specified

Sample Depth:
Matrix: Water
Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/18/23 00:56
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	ND		ng/l	31.2	6.38	1
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	31.2	6.19	1
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	31.2	3.72	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	31.2	7.06	1
Perfluorohexanoic Acid (PFHxA)	8.56	JF	ng/l	31.2	5.12	1
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	31.2	3.83	1
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	31.2	3.52	1
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	31.2	5.88	1
Perfluorooctanoic Acid (PFOA)	15.0	J	ng/l	31.2	3.69	1
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	45		ng/l	31.2	20.8	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	31.2	10.8	1
Perfluorononanoic Acid (PFNA)	ND		ng/l	31.2	4.88	1
Perfluorooctanesulfonic Acid (PFOS)	ND		ng/l	31.2	7.88	1
Perfluorodecanoic Acid (PFDA)	ND		ng/l	31.2	4.75	1
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	32		ng/l	31.2	18.9	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	31.2	17.5	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	31.2	10.1	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	31.2	4.06	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	31.2	15.3	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	31.2	9.06	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	31.2	12.6	1
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	31.2	5.81	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	31.2	5.11	1
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	31.2	3.88	1

Project Name:	102027	**Lab Number:**	L2271017
Project Number:	Not Specified	**Report Date:**	01/20/23

SAMPLE RESULTS

Lab ID:	L2271017-01 R	Date Collected:	12/15/22 12:00
Client ID:	10:2 FTS 400*C (1)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	97		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	101		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	101		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	83		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	93		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	93		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	101		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	93		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	93		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	94		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	95		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	92		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	87		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	65		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	88		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	30		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	68		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	77		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	90		22-136

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

SAMPLE RESULTS

Lab ID: L2271017-02 R
Client ID: 8:2 FTS 400*C (2)
Sample Location: WPI WORCESTER

Date Collected: 12/15/22 12:00
Date Received: 12/16/22
Field Prep: Not Specified

Sample Depth:
Matrix: Water
Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/18/23 01:12
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	4.79	J	ng/l	47.1	9.60	1
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	47.1	9.32	1
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	47.1	5.60	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	47.1	10.6	1
Perfluorohexanoic Acid (PFHxA)	11.8	J	ng/l	47.1	7.72	1
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	47.1	5.77	1
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	47.1	5.30	1
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	47.1	8.85	1
Perfluorooctanoic Acid (PFOA)	23	J	ng/l	47.1	5.56	1
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	18.50	J	ng/l	47.1	31.4	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	47.1	16.2	1
Perfluorononanoic Acid (PFNA)	ND		ng/l	47.1	7.34	1
Perfluorooctanesulfonic Acid (PFOS)	29	J	ng/l	47.1	11.9	1
Perfluorodecanoic Acid (PFDA)	ND		ng/l	47.1	7.16	1
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND		ng/l	47.1	28.5	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	47.1	26.4	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	47.1	15.2	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	47.1	6.12	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	47.1	23.1	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	47.1	13.6	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	47.1	18.9	1
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	47.1	8.76	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	47.1	7.70	1
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	47.1	5.84	1

Project Name:	102027	**Lab Number:**	L2271017
Project Number:	Not Specified	**Report Date:**	01/20/23

SAMPLE RESULTS

Lab ID:	L2271017-02 R	Date Collected:	12/15/22 12:00
Client ID:	8:2 FTS 400*C (2)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	96		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	100		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	100		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	89		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	99		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	98		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	100		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	98		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	91		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	93		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	88		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	85		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	87		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	66		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	80		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	23		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	66		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	75		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	80		22-136

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

SAMPLE RESULTS

Lab ID: L2271017-03 Date Collected: 12/15/22 12:10

Client ID: 6:2 FTS 400*C (3) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 09:37

Analytical Date: 01/16/23 04:59

Analyst: SG

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	ND		ng/l	40.7	8.31	1
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	40.7	8.07	1
Perfluorobutanesulfonic Acid (PFBS)	6.60	J	ng/l	40.7	4.85	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	40.7	9.21	1
Perfluorohexanoic Acid (PFHxA)	ND		ng/l	40.7	6.68	1
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	40.7	5.00	1
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	40.7	4.59	1
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	40.7	7.66	1
Perfluorooctanoic Acid (PFOA)	32.0	J	ng/l	40.7	4.81	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	40.7	14.0	1
Perfluorononanoic Acid (PFNA)	ND		ng/l	40.7	6.36	1
Perfluorooctanesulfonic Acid (PFOS)	41.9		ng/l	40.7	10.3	1
Perfluorodecanoic Acid (PFDA)	ND		ng/l	40.7	6.19	1
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND		ng/l	40.7	24.7	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	40.7	22.8	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	40.7	13.2	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	40.7	5.30	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	40.7	20.0	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	40.7	11.8	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	40.7	16.4	1
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	40.7	7.58	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	40.7	6.67	1
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	40.7	5.05	1

Project Name:	102027	**Lab Number:**	L2271017
Project Number:	Not Specified	**Report Date:**	01/20/23

SAMPLE RESULTS

Lab ID:	L2271017-03	Date Collected:	12/15/22 12:10
Client ID:	6:2 FTS 400*C (3)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	95		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	114		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	90		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	81		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	86		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	90		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	95		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	95		62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	106		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	93		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	83		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	95		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	75		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	97		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	11		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	77		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	82		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	74		22-136

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 23:44
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 01-03 Batch: WG1732534-1					
Perfluorobutanoic Acid (PFBA)	ND		ng/l	2.00	0.408
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	2.00	0.396
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	2.00	0.238
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	2.00	0.452
Perfluorohexanoic Acid (PFHxA)	ND		ng/l	2.00	0.328
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	2.00	0.245
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	2.00	0.225
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	2.00	0.376
Perfluorooctanoic Acid (PFOA)	ND		ng/l	2.00	0.236
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ND		ng/l	2.00	1.33
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	2.00	0.688
Perfluorononanoic Acid (PFNA)	ND		ng/l	2.00	0.312
Perfluorooctanesulfonic Acid (PFOS)	ND		ng/l	2.00	0.504
Perfluorodecanoic Acid (PFDA)	ND		ng/l	2.00	0.304
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND		ng/l	2.00	1.21
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	2.00	1.12
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	2.00	0.648
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	2.00	0.260
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	2.00	0.980
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	2.00	0.580
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	2.00	0.804
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	2.00	0.372
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	2.00	0.327
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	2.00	0.248

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 23:44
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 01-03 Batch: WG1732534-1					

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	103		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	124		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	95		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	82		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	94		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	96		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	99		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	99		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	91		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	93		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	98		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	102		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	96		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	89		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	116		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	19		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	88		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	112		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	105		22-136

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab	Associated sample(s): 01-03 Batch: WG1732534-2							
Perfluorobutanoic Acid (PFBA)	107		-		67-148	-		30
Perfluoropentanoic Acid (PFPeA)	106		-		63-161	-		30
Perfluorobutanesulfonic Acid (PFBS)	105		-		65-157	-		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	120		-		37-219	-		30
Perfluorohexanoic Acid (PFHxA)	101		-		69-168	-		30
Perfluoropentanesulfonic Acid (PFPeS)	110		-		52-156	-		30
Perfluoroheptanoic Acid (PFHpA)	105		-		58-159	-		30
Perfluorohexanesulfonic Acid (PFHxS)	110		-		69-177	-		30
Perfluorooctanoic Acid (PFOA)	103		-		63-159	-		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	150		-		49-187	-		30
Perfluoroheptanesulfonic Acid (PFHpS)	100		-		61-179	-		30
Perfluorononanoic Acid (PFNA)	95		-		68-171	-		30
Perfluorooctanesulfonic Acid (PFOS)	105		-		52-151	-		30
Perfluorodecanoic Acid (PFDA)	101		-		63-171	-		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	112		-		56-173	-		30
Perfluorononanesulfonic Acid (PFNS)	113		-		48-150	-		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	117		-		60-166	-		30
Perfluoroundecanoic Acid (PFUnA)	101		-		60-153	-		30
Perfluorodecanesulfonic Acid (PFDS)	113		-		38-156	-		30
Perfluorooctanesulfonamide (FOSA)	109		-		46-170	-		30
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	105		-		45-170	-		30
Perfluorododecanoic Acid (PFDoA)	120		-		67-153	-		30

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab	Associated sample(s): 01-03 Batch: WG1732534-2							
Perfluorotridecanoic Acid (PFTrDA)	116		-		48-158	-		30
Perfluorotetradecanoic Acid (PFTA)	93		-		59-182	-		30

Surrogate (Extracted Internal Standard)	LCS %Recovery	Qual	LCSD %Recovery	Qual	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	98				58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	116				62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	92				70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	83				12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	95				57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	95				60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	94				71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	102				62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	96				14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	106				59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	97				69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	99				62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	110				10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	83				24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	97				55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	21				5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	83				27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	96				48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	107				22-136

Matrix Spike Analysis

Batch Quality Control

Project Name: 102027 ***Lab Number:*** L2271017

Project Number: Not Specified ***Report Date:*** 01/20/23

Parameter	*Native Sample*	*MS Added*	*MS Found*	*MS %Recovery*	*Qual*	*MSD Found*	*MSD %Recovery*	*Qual*	*Recovery Limits*	*RPD*	*Qual*	*RPD Limits*
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-03 QC Batch ID: WG1732534-3 QC Sample: L2270787-01 Client ID: MS Sample												
Perfluorobutanoic Acid (PFBA)	0.774J	37.9	38.0	98		-	-		67-148	-		30
Perfluoropentanoic Acid (PFPeA)	0.733J	37.9	39.7	103		-	-		63-161	-		30
Perfluorobutanesulfonic Acid (PFBS)	1.09J	33.7	35.8	103		-	-		65-157	-		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND	35.6	44.6	125		-	-		37-219	-		30
Perfluorohexanoic Acid (PFHxA)	0.965J	37.9	38.4	99		-	-		69-168	-		30
Perfluoropentanesulfonic Acid (PFPeS)	ND	35.7	39.9	112		-	-		52-156	-		30
Perfluoroheptanoic Acid (PFHpA)	0.400J	37.9	38.4	100		-	-		58-159	-		30
Perfluorohexanesulfonic Acid (PFHxS)	0.505J	34.6	43.5	124		-	-		69-177	-		30
Perfluorooctanoic Acid (PFOA)	1.14J	37.9	41.0	105		-	-		63-159	-		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	3.70	36.1	49.6	127		-	-		49-187	-		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	36.2	39.7	110		-	-		61-179	-		30
Perfluorononanoic Acid (PFNA)	ND	37.9	39.1	103		-	-		68-171	-		30
Perfluorooctanesulfonic Acid (PFOS)	1.52J	35.2	45.9	126		-	-		52-151	-		30
Perfluorodecanoic Acid (PFDA)	ND	37.9	39.9	105		-	-		63-171	-		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND	36.4	46.7	128		-	-		56-173	-		30
Perfluorononanesulfonic Acid (PFNS)	ND	36.5	39.4	108		-	-		48-150	-		30
N- Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	37.9	43.6	115		-	-		60-166	-		30
Perfluoroundecanoic Acid (PFUnA)	ND	37.9	38.7	102		-	-		60-153	-		30
Perfluorodecanesulfonic Acid (PFDS)	ND	36.6	39.2	107		-	-		38-156	-		30
Perfluorooctanesulfonamide (FOSA)	ND	37.9	36.9	97		-	-		46-170	-		30
N- Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	37.9	43.8	116		-	-		45-170	-		30
Perfluorododecanoic Acid (PFDoA)	ND	37.9	38.9	103		-	-		67-153	-		30

Matrix Spike Analysis

Batch Quality Control

Project Name: 102027 ***Lab Number:*** L2271017

Project Number: Not Specified ***Report Date:*** 01/20/23

Parameter	*Native Sample*	*MS Added*	*MS Found*	*MS %Recovery*	*Qual*	*MSD Found*	*MSD %Recovery*	*Qual*	*Recovery Limits*	*RPD*	*Qual*	*RPD Limits*
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-03 QC Batch ID: WG1732534-3 QC Sample: L2270787-01 Client ID: MS Sample												
Perfluorotridecanoic Acid (PFTrDA)	ND	37.9	45.9	121		-	-		48-158	-		30
Perfluorotetradecanoic Acid (PFTA)	ND	37.9	43.5	115		-	-		59-182	-		30

Surrogate (Extracted Internal Standard)	*MS % Recovery*	*MS Qualifier*	*MSD % Recovery*	*MSD Qualifier*	*Acceptance Criteria*
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	98				10-162
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	100				12-142
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	92				14-147
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	43				27-126
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	46				24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	74				55-137
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	63				62-124
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**50**	Q			57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**53**	Q			60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	98				71-134
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	67				48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	75				22-136
Perfluoro[13C4]Butanoic Acid (MPFBA)	**51**	Q			58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	**54**	Q			62-163
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	15				5-112
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	90				69-131
Perfluoro[13C8]Octanoic Acid (M8PFOA)	**54**	Q			62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	64				59-139
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	97				70-131

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-03 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						
Perfluorobutanoic Acid (PFBA)	2.02	1.98	ng/l	2		30
Perfluoropentanoic Acid (PFPeA)	3.01	3.00	ng/l	0		30
Perfluorobutanesulfonic Acid (PFBS)	2.64	2.63	ng/l	0		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND	ND	ng/l	NC		30
Perfluorohexanoic Acid (PFHxA)	3.05	2.89	ng/l	5		30
Perfluoropentanesulfonic Acid (PFPeS)	0.338J	0.380J	ng/l	NC		30
Perfluoroheptanoic Acid (PFHpA)	1.64J	1.73J	ng/l	NC		30
Perfluorohexanesulfonic Acid (PFHxS)	1.90	1.74J	ng/l	NC		30
Perfluorooctanoic Acid (PFOA)	4.73	4.23	ng/l	11		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	1.54J	ND	ng/l	NC		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	ND	ng/l	NC		30
Perfluorononanoic Acid (PFNA)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonic Acid (PFOS)	3.92	3.56	ng/l	10		30
Perfluorodecanoic Acid (PFDA)	ND	ND	ng/l	NC		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND	ND	ng/l	NC		30
Perfluorononanesulfonic Acid (PFNS)	ND	ND	ng/l	NC		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	ND	ng/l	NC		30
Perfluoroundecanoic Acid (PFUnA)	ND	ND	ng/l	NC		30
Perfluorodecanesulfonic Acid (PFDS)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonamide (FOSA)	ND	ND	ng/l	NC		30

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-03 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	ND	ng/l	NC		30
Perfluorododecanoic Acid (PFDoA)	ND	ND	ng/l	NC		30
Perfluorotridecanoic Acid (PFTrDA)	ND	ND	ng/l	NC		30
Perfluorotetradecanoic Acid (PFTA)	ND	ND	ng/l	NC		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	68		61		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		76		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	84		85		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	74		73		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**55**	Q	**51**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	61		**54**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	90		90		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	67		**57**	Q	62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	75		73		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	76		61		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	88		91		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	75		**54**	Q	62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	65		76		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	56		39		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	100		70		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	6		6		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	45		37		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	91		72		48-131

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271017

Project Number: Not Specified **Report Date:** 01/20/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-03 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	69		65		22-136

Project Name: 102027

Project Number: Not Specified

Lab Number: L2271017

Report Date: 01/20/23

Sample Receipt and Container Information

Were project specific reporting limits specified? YES

Cooler Information

Cooler	*Custody Seal*
A	Absent

Container Information

Container ID	*Container Type*	*Cooler*	*Initial pH*	*Final pH*	*Temp deg C*	*Pres*	*Seal*	*Frozen Date/Time*	*Analysis(*)*
L2271017-01A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271017-02A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271017-03A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)

*Values in parentheses indicate holding time in days

Project Name: 102027 **Lab Number:** L2271017

Project Number: **Report Date:** 01/20/23

PFAS PARAMETER SUMMARY

Parameter	Acronym	CAS Number
PERFLUOROALKYL CARBOXYLIC ACIDS (PFCAs)		
Perfluorooctadecanoic Acid	PFODA	16517-11-6
Perfluorohexadecanoic Acid	PFHxDA	67905-19-5
Perfluorotetradecanoic Acid	PFTA/PFTeDA	376-06-7
Perfluorotridecanoic Acid	PFTrDA	72629-94-8
Perfluorododecanoic Acid	PFDoA	307-55-1
Perfluoroundecanoic Acid	PFUnA	2058-94-8
Perfluorodecanoic Acid	PFDA	335-76-2
Perfluorononanoic Acid	PFNA	375-95-1
Perfluorooctanoic Acid	PFOA	335-67-1
Perfluoroheptanoic Acid	PFHpA	375-85-9
Perfluorohexanoic Acid	PFHxA	307-24-4
Perfluoropentanoic Acid	PFPeA	2706-90-3
Perfluorobutanoic Acid	PFBA	375-22-4
PERFLUOROALKYL SULFONIC ACIDS (PFSAs)		
Perfluorododecanesulfonic Acid	PFDoDS/PFDoS	79780-39-5
Perfluorodecanesulfonic Acid	PFDS	335-77-3
Perfluorononanesulfonic Acid	PFNS	68259-12-1
Perfluorooctanesulfonic Acid	PFOS	1763-23-1
Perfluoroheptanesulfonic Acid	PFHpS	375-92-8
Perfluorohexanesulfonic Acid	PFHxS	355-46-4
Perfluoropentanesulfonic Acid	PFPeS	2706-91-4
Perfluorobutanesulfonic Acid	PFBS	375-73-5
Perfluoropropanesulfonic Acid	PFPrS	423-41-6
FLUOROTELOMERS		
1H,1H,2H,2H-Perfluorododecanesulfonic Acid	10:2FTS	120226-60-0
1H,1H,2H,2H-Perfluorodecanesulfonic Acid	8:2FTS	39108-34-4
1H,1H,2H,2H-Perfluorooctanesulfonic Acid	6:2FTS	27619-97-2
1H,1H,2H,2H-Perfluorohexanesulfonic Acid	4:2FTS	757124-72-4
PERFLUOROALKANE SULFONAMIDES (FASAs)		
Perfluorooctanesulfonamide	FOSA/PFOSA	754-91-6
N-Ethyl Perfluorooctane Sulfonamide	NEtFOSA	4151-50-2
N-Methyl Perfluorooctane Sulfonamide	NMeFOSA	31506-32-8
PERFLUOROALKANE SULFONYL SUBSTANCES		
N-Ethyl Perfluorooctanesulfonamido Ethanol	NEtFOSE	1691-99-2
N-Methyl Perfluorooctanesulfonamido Ethanol	NMeFOSE	24448-09-7
N-Ethyl Perfluorooctanesulfonamidoacetic Acid	NEtFOSAA	2991-50-6
N-Methyl Perfluorooctanesulfonamidoacetic Acid	NMeFOSAA	2355-31-9
PER- and POLYFLUOROALKYL ETHER CARBOXYLIC ACIDS		
2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid	HFPO-DA	13252-13-6
4,8-Dioxa-3h-Perfluorononanoic Acid	ADONA	919005-14-4
CHLORO-PERFLUOROALKYL SULFONIC ACIDS		
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid	11Cl-PF3OUdS	763051-92-9
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid	9Cl-PF3ONS	756426-58-1
PERFLUOROETHER SULFONIC ACIDS (PFESAs)		
Perfluoro(2-Ethoxyethane)Sulfonic Acid	PFEESA	113507-82-7
PERFLUOROETHER/POLYETHER CARBOXYLIC ACIDS (PFPCAs)		
Perfluoro-3-Methoxypropanoic Acid	PFMPA	377-73-1
Perfluoro-4-Methoxybutanoic Acid	PFMBA	863090-89-5
Nonafluoro-3,6-Dioxaheptanoic Acid	NFDHA	151772-58-6

Project Name: 102027 **Lab Number:** L2271017

Project Number: **Report Date:** 01/20/23

PFAS PARAMETER SUMMARY

Parameter	Acronym	CAS Number
FLUOROTELOMER CARBOXYLIC ACIDS (FTCAs)		
3-Perfluoroheptyl Propanoic Acid	7:3FTCA	812-70-4
2H,2H,3H,3H-Perfluorooctanoic Acid	5:3FTCA	914637-49-3
3-Perfluoropropyl Propanoic Acid	3:3FTCA	356-02-5

GLOSSARY

Acronyms

DL - Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the limit of quantitation (LOQ). The DL includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

EDL - Estimated Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the reporting limit (RL). The EDL includes any adjustments from dilutions, concentrations or moisture content, where applicable. The use of EDLs is specific to the analysis of PAHs using Solid-Phase Microextraction (SPME).

EMPC - Estimated Maximum Possible Concentration: The concentration that results from the signal present at the retention time of an analyte when the ions meet all of the identification criteria except the ion abundance ratio criteria. An EMPC is a worst-case estimate of the concentration.

EPA - Environmental Protection Agency.

LCS - Laboratory Control Sample: A sample matrix, free from the analytes of interest, spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes.

LCSD - Laboratory Control Sample Duplicate: Refer to LCS.

LFB - Laboratory Fortified Blank: A sample matrix, free from the analytes of interest, spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes.

LOD - Limit of Detection: This value represents the level to which a target analyte can reliably be detected for a specific analyte in a specific matrix by a specific method. The LOD includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

LOQ - Limit of Quantitation: The value at which an instrument can accurately measure an analyte at a specific concentration. The LOQ includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

Limit of Quantitation: The value at which an instrument can accurately measure an analyte at a specific concentration. The LOQ includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

MDL - Method Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the reporting limit (RL). The MDL includes any adjustments from dilutions, concentrations or moisture content, where applicable.

MS - Matrix Spike Sample: A sample prepared by adding a known mass of target analyte to a specified amount of matrix sample for which an independent estimate of target analyte concentration is available. For Method 332.0, the spike recovery is calculated using the native concentration, including estimated values.

MSD - Matrix Spike Sample Duplicate: Refer to MS.

NA - Not Applicable.

NC - Not Calculated: Term is utilized when one or more of the results utilized in the calculation are non-detect at the parameter's reporting unit.

NDPA/DPA - N-Nitrosodiphenylamine/Diphenylamine.

NI - Not Ignitable.

NP - Non-Plastic: Term is utilized for the analysis of Atterberg Limits in soil.

NR - No Results: Term is utilized when 'No Target Compounds Requested' is reported for the analysis of Volatile or Semivolatile Organic TIC only requests.

RL - Reporting Limit: The value at which an instrument can accurately measure an analyte at a specific concentration. The RL includes any adjustments from dilutions, concentrations or moisture content, where applicable.

RPD - Relative Percent Difference: The results from matrix and/or matrix spike duplicates are primarily designed to assess the precision of analytical results in a given matrix and are expressed as relative percent difference (RPD). Values which are less than five times the reporting limit for any individual parameter are evaluated by utilizing the absolute difference between the values; although the RPD value will be provided in the report.

SRM - Standard Reference Material: A reference sample of a known or certified value that is of the same or similar matrix as the associated field samples.

STLP - Semi-dynamic Tank Leaching Procedure per EPA Method 1315.

TEF - Toxic Equivalency Factors: The values assigned to each dioxin and furan to evaluate their toxicity relative to 2,3,7,8-TCDD.

TEQ - Toxic Equivalent: The measure of a sample's toxicity derived by multiplying each dioxin and furan by its corresponding TEF and then summing the resulting values.

TIC - Tentatively Identified Compound: A compound that has been identified to be present and is not part of the target compound list (TCL) for the method and/or program. All TICs are qualitatively identified and reported as estimated concentrations.

Report Format: DU Report with 'J' Qualifiers

Footnotes

1 - The reference for this analyte should be considered modified since this analyte is absent from the target analyte list of the original method.

Terms

Analytical Method: Both the document from which the method originates and the analytical reference method. (Example: EPA 8260B is shown as 1,8260B.) The codes for the reference method documents are provided in the References section of the Addendum.
Chlordane: The target compound Chlordane (CAS No. 57-74-9) is reported for GC ECD analyses. Per EPA,this compound "refers to a mixture of chlordane isomers, other chlorinated hydrocarbons and numerous other components." (Reference: USEPA Toxicological Review of Chlordane, In Support of Summary Information on the Integrated Risk Information System (IRIS), December 1997.)
Difference: With respect to Total Oxidizable Precursor (TOP) Assay analysis, the difference is defined as the Post-Treatment value minus the Pre-Treatment value.
Final pH: As it pertains to Sample Receipt & Container Information section of the report, Final pH reflects pH of container determined after adjustment at the laboratory, if applicable. If no adjustment required, value reflects Initial pH.
Frozen Date/Time: With respect to Volatile Organics in soil, Frozen Date/Time reflects the date/time at which associated Reagent Water-preserved vials were initially frozen. Note: If frozen date/time is beyond 48 hours from sample collection, value will be reflected in 'bold'.
Gasoline Range Organics (GRO): Gasoline Range Organics (GRO) results include all chromatographic peaks eluting from Methyl tert butyl ether through Naphthalene, with the exception of GRO analysis in support of State of Ohio programs, which includes all chromatographic peaks eluting from Hexane through Dodecane.
Initial pH: As it pertains to Sample Receipt & Container Information section of the report, Initial pH reflects pH of container determined upon receipt, if applicable.
PAH Total: With respect to Alkylated PAH analyses, the 'PAHs, Total' result is defined as the summation of results for all or a subset of the following compounds: Naphthalene, C1-C4 Naphthalenes, 2-Methylnaphthalene, 1-Methylnaphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Fluorene, C1-C3 Fluorenes, Phenanthrene, C1-C4 Phenanthrenes/Anthracenes, Anthracene, Fluoranthene, Pyrene, C1-C4 Fluoranthenes/Pyrenes, Benz(a)anthracene, Chrysene, C1-C4 Chrysenes, Benzo(b)fluoranthene, Benzo(j)+(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Perylene, Indeno(1,2,3-cd)pyrene, Dibenz(ah)+(ac)anthracene, Benzo(g,h,i)perylene. If a 'Total' result is requested, the results of its individual components will also be reported.
PFAS Total: With respect to PFAS analyses, the 'PFAS, Total (5)' result is defined as the summation of results for: PFHpA, PFHxS, PFOA, PFNA and PFOS. In addition, the 'PFAS, Total (6)' result is defined as the summation of results for: PFHpA, PFHxS, PFOA, PFNA, PFDA and PFOS. For MassDEP DW compliance analysis only, the 'PFAS, Total (6)' result is defined as the summation of results at or above the RL. Note: If a 'Total' result is requested, the results of its individual components will also be reported.
Total: With respect to Organic analyses, a 'Total' result is defined as the summation of results for individual isomers or Aroclors. If a 'Total' result is requested, the results of its individual components will also be reported. This is applicable to 'Total' results for methods 8260, 8081 and 8082.

Data Qualifiers

A - Spectra identified as "Aldol Condensates" are byproducts of the extraction/concentration procedures when acetone is introduced in the process.

B - The analyte was detected above the reporting limit in the associated method blank. Flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank. For MCP-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank. For DOD-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank AND the analyte was detected above one-half the reporting limit (or above the reporting limit for common lab contaminants) in the associated method blank. For NJ-Air-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte above the reporting limit. For NJ-related projects (excluding Air), flag only applies to associated field samples that have detectable concentrations of the analyte, which was detected above the reporting limit in the associated method blank or above five times the reporting limit for common lab contaminants (Phthalates, Acetone, Methylene Chloride, 2-Butanone).

C - Co-elution: The target analyte co-elutes with a known lab standard (i.e. surrogate, internal standards, etc.) for co-extracted analyses.

D - Concentration of analyte was quantified from diluted analysis. Flag only applies to field samples that have detectable concentrations of the analyte.

E - Concentration of analyte exceeds the range of the calibration curve and/or linear range of the instrument.

F - The ratio of quantifier ion response to qualifier ion response falls outside of the laboratory criteria. Results are considered to be an estimated maximum concentration.

G - The concentration may be biased high due to matrix interferences (i.e, co-elution) with non-target compound(s). The result should be considered estimated.

H - The analysis of pH was performed beyond the regulatory-required holding time of 15 minutes from the time of sample collection.

I - The lower value for the two columns has been reported due to obvious interference.

J - Estimated value. The Target analyte concentration is below the quantitation limit (RL), but above the Method Detection Limit (MDL) or Estimated Detection Limit (EDL) for SPME-related analyses. This represents an estimated concentration for Tentatively

Report Format: DU Report with 'J' Qualifiers

Data Qualifiers

M - Reporting Limit (RL) exceeds the MCP CAM Reporting Limit for this analyte.

ND - Not detected at the method detection limit (MDL) for the sample, or estimated detection limit (EDL) for SPME-related analyses.

NJ - Presumptive evidence of compound. This represents an estimated concentration for Tentatively Identified Compounds (TICs), where the identification is based on a mass spectral library search.

P - The RPD between the results for the two columns exceeds the method-specified criteria.

Q - The quality control sample exceeds the associated acceptance criteria. For DOD-related projects, LCS and/or Continuing Calibration Standard exceedences are also qualified on all associated sample results. Note: This flag is not applicable for matrix spike recoveries when the sample concentration is greater than 4x the spike added or for batch duplicate RPD when the sample concentrations are less than 5x the RL. (Metals only.)

R - Analytical results are from sample re-analysis.

RE - Analytical results are from sample re-extraction.

S - Analytical results are from modified screening analysis.

V - The surrogate associated with this target analyte has a recovery outside the QC acceptance limits. (Applicable to MassDEP DW Compliance samples only.)

Z - The batch matrix spike and/or duplicate associated with this target analyte has a recovery/RPD outside the QC acceptance limits. (Applicable to MassDEP DW Compliance samples only.)

Report Format: DU Report with 'J' Qualifiers

REFERENCES

134 Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) using Isotope Dilution. Alpha SOP 23528.

LIMITATION OF LIABILITIES

Alpha Analytical performs services with reasonable care and diligence normal to the analytical testing laboratory industry. In the event of an error, the sole and exclusive responsibility of Alpha Analytical shall be to re-perform the work at it's own expense. In no event shall Alpha Analytical be held liable for any incidental, consequential or special damages, including but not limited to, damages in any way connected with the use of, interpretation of, information or analysis provided by Alpha Analytical.

We strongly urge our clients to comply with EPA protocol regarding sample volume, preservation, cooling, containers, sampling procedures, holding time and splitting of samples in the field.

Certification Information

The following analytes are not included in our Primary NELAP Scope of Accreditation:

Westborough Facility
EPA 624/624.1: m/p-xylene, o-xylene, Naphthalene
EPA 625/625.1: alpha-Terpineol
EPA 8260C/8260D: NPW: 1,2,4,5-Tetramethylbenzene; 4-Ethyltoluene, Azobenzene; SCM: Iodomethane (methyl iodide), 1,2,4,5-Tetramethylbenzene; 4-Ethyltoluene.
EPA 8270D/8270E: NPW: Dimethylnaphthalene,1,4-Diphenylhydrazine, alpha-Terpineol; SCM: Dimethylnaphthalene,1,4-Diphenylhydrazine.
SM4500: NPW: Amenable Cyanide; SCM: Total Phosphorus, TKN, NO2, NO3.

Mansfield Facility
SM 2540D: TSS
EPA 8082A: NPW: PCB: 1, 5, 31, 87,101, 110, 141, 151, 153, 180, 183, 187.
EPA TO-15: Halothane, 2,4,4-Trimethyl-2-pentene, 2,4,4-Trimethyl-1-pentene, Thiophene, 2-Methylthiophene, 3-Methylthiophene, 2-Ethylthiophene, 1,2,3-Trimethylbenzene, Indan, Indene, 1,2,4,5-Tetramethylbenzene, Benzothiophene, 1-Methylnaphthalene. **Biological Tissue Matrix:** EPA 3050B

The following analytes are included in our Massachusetts DEP

Scope of Accreditation Westborough Facility:

Drinking Water
EPA 300.0: Chloride, Nitrate-N, Fluoride, Sulfate; **EPA 353.2**: Nitrate-N, Nitrite-N; **SM4500NO3-F**: Nitrate-N, Nitrite-N; **SM4500F-C, SM4500CN-CE,**
EPA 180.1, SM2130B, SM4500Cl-D, SM2320B, SM2540C,
SM4500H-B, SM4500NO2-B EPA 332: Perchlorate; **EPA 524.2:**
THMs and VOCs; **EPA 504.1:** EDB, DBCP. **Microbiology**:
SM9215B; SM9223-P/A, SM9223B-Colilert-QT,SM9222D.

Non-Potable Water
SM4500H,B, EPA 120.1, SM2510B, SM2540C, SM2320B, SM4500CL-E, SM4500F-BC, SM4500NH3-BH: Ammonia-N and Kjeldahl-N, **EPA 350.1**:
Ammonia-N, **LACHAT 10-107-06-1-B**: Ammonia-N, **EPA 351.1, SM4500NO3-F, EPA 353.2**: Nitrate-N**, SM4500P-E,SM4500P-B, E, SM4500SO4-E,**
SM5220D, EPA 410.4, SM5210B, SM5310C, SM4500CL-D, EPA 1664, EPA 420.1, SM4500-CN-CE, SM2540D, EPA 300: Chloride, Sulfate, Nitrate.
EPA 624.1: Volatile Halocarbons & Aromatics,
EPA 608.3: Chlordane, Toxaphene, Aldrin, alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, Dieldrin, DDD, DDE, DDT, Endosulfan I, Endosulfan II, Endosulfan sulfate, Endrin, Endrin Aldehyde, Heptachlor, Heptachlor Epoxide, PCBs **EPA 625.1**: SVOC (Acid/Base/Neutral Extractables), **EPA 600/4-81-045**: PCB-Oil.
Microbiology: **SM9223B-Colilert-QT; Enterolert-QT, SM9221E, EPA 1600, EPA 1603, SM9222D.**

Mansfield Facility:

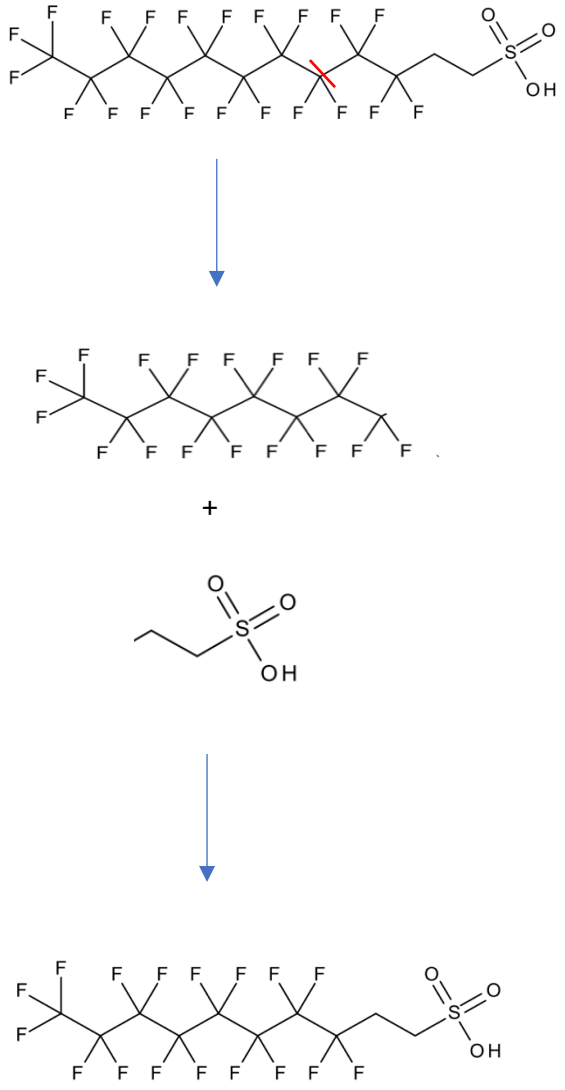
Drinking Water
EPA 200.7: Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Na, Ag, Ca, Zn. **EPA 200.8:** Al, Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Mn, Ni, Se, Ag, TL, Zn.
EPA 245.1 Hg.
EPA 522, EPA 537.1.

Non-Potable Water
EPA 200.7: Al, Sb, As, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Se, Ag, Na, Sr, TL, Ti, V, Zn.
EPA 200.8: Al, Sb**,** As, Be, Cd, Cr, Cu, Fe, Pb, Mn, Ni, K, Se, Ag, Na, TL, Zn.
EPA 245.1 Hg.
SM2340B

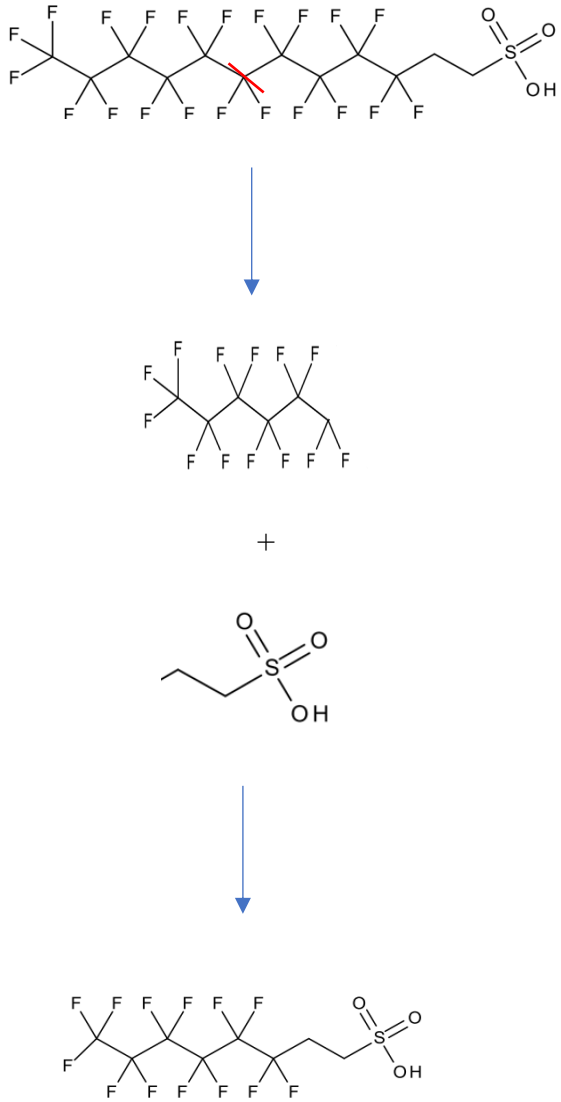
For a complete listing of analytes and methods, please contact your Alpha Project Manager

Appendix F: Pure PFAS Precursor Thermal Transformation Pathways

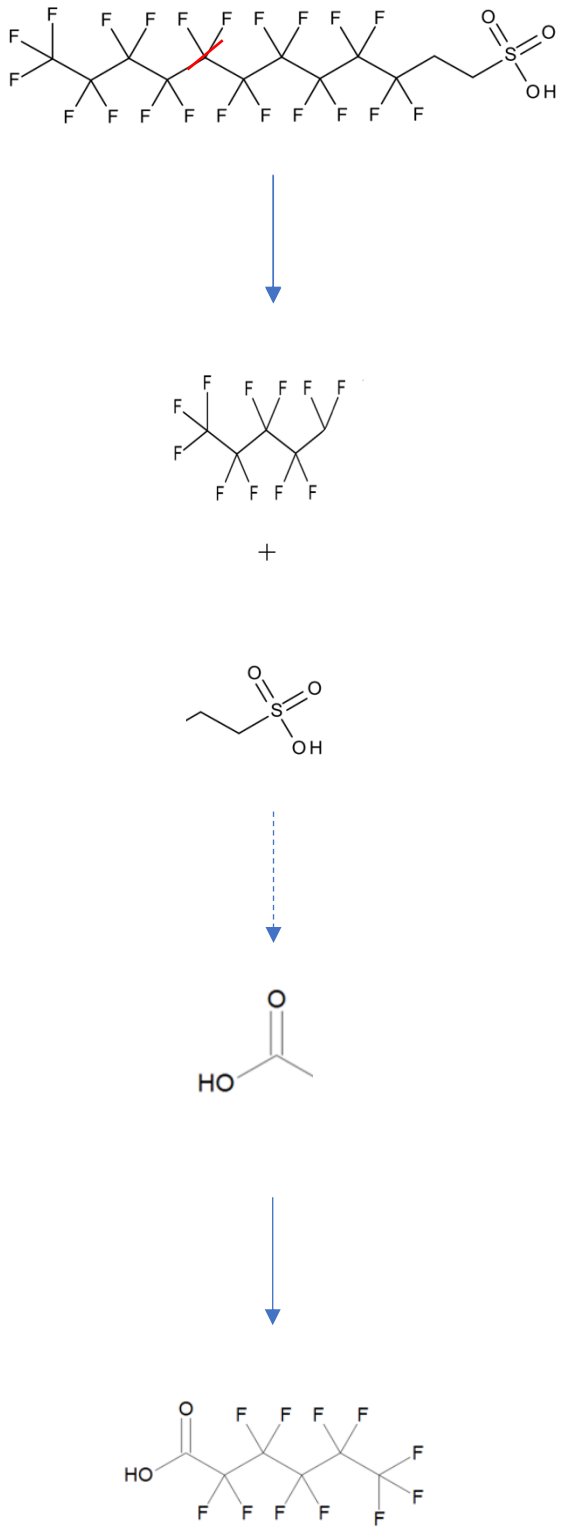
F.1) 10:2 FTS to 8:2 FTS (Note, red lines indicate scission locations)



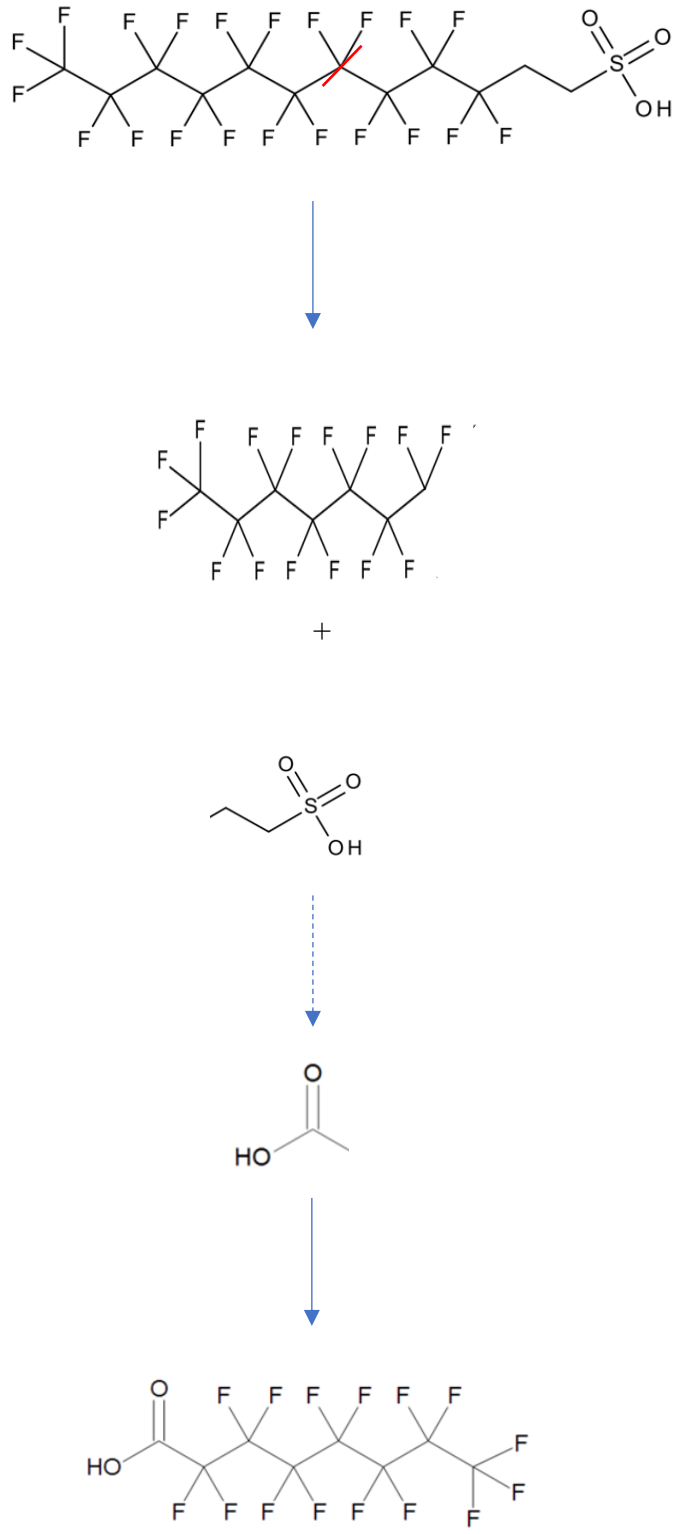
F.2) 10:2 to 6:2 FTS



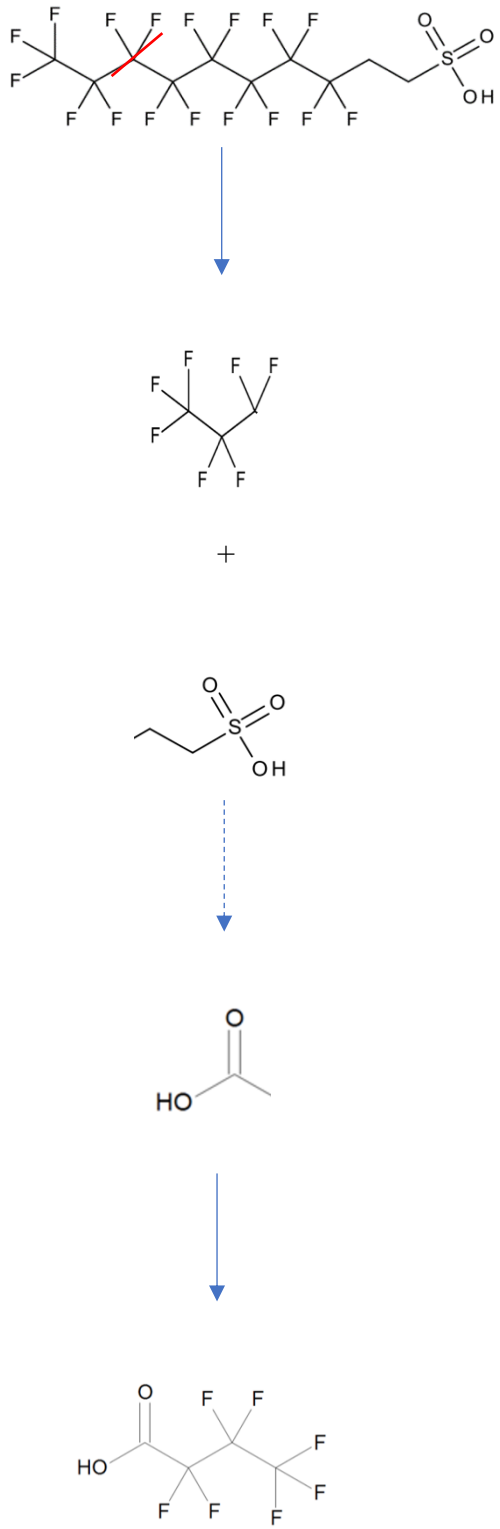
F.3) 10:2 to PFHxA



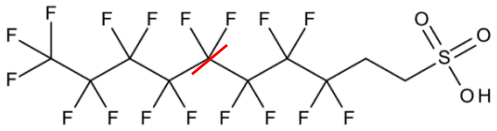
F.4) 10:2 to PFOA

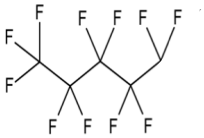


F.5) 8:2 FTS to PFBA



F.6) 8:2 FTS to PFHxA





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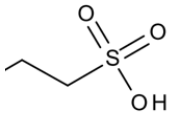
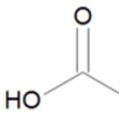
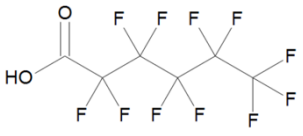
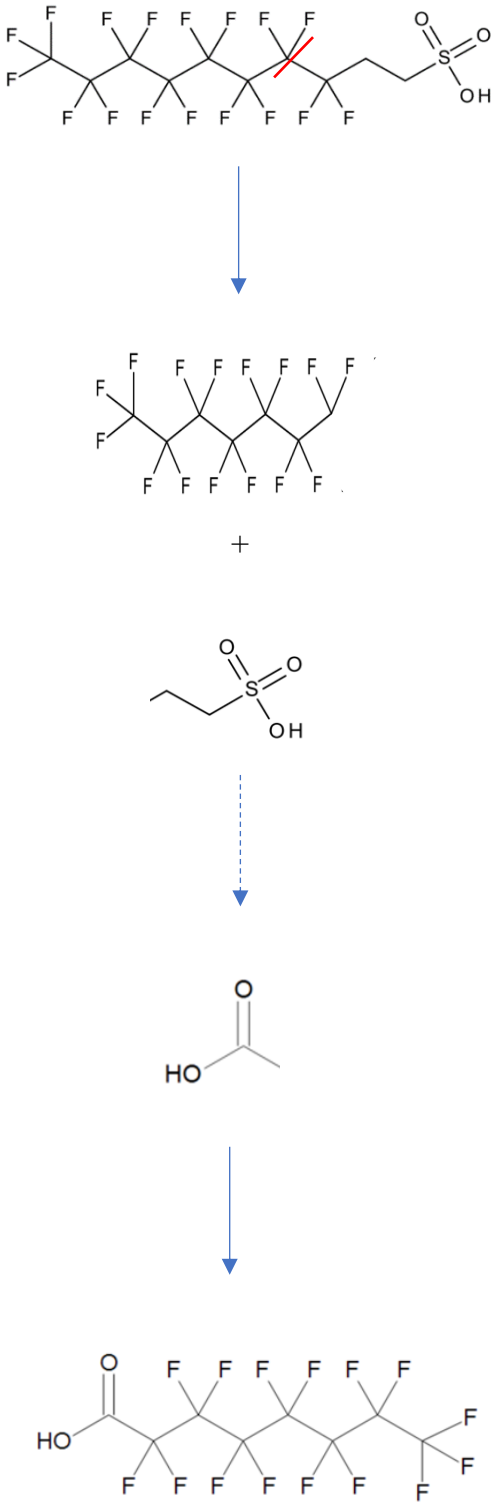


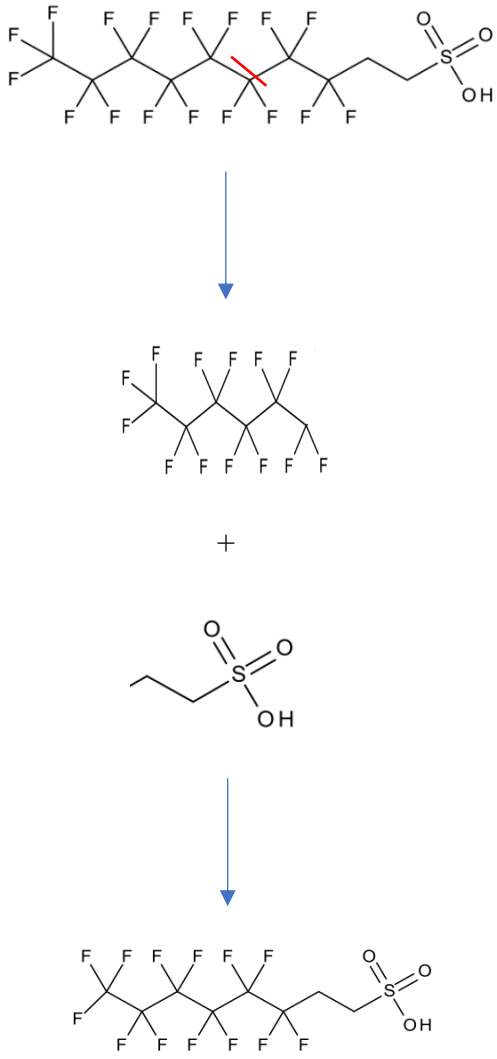




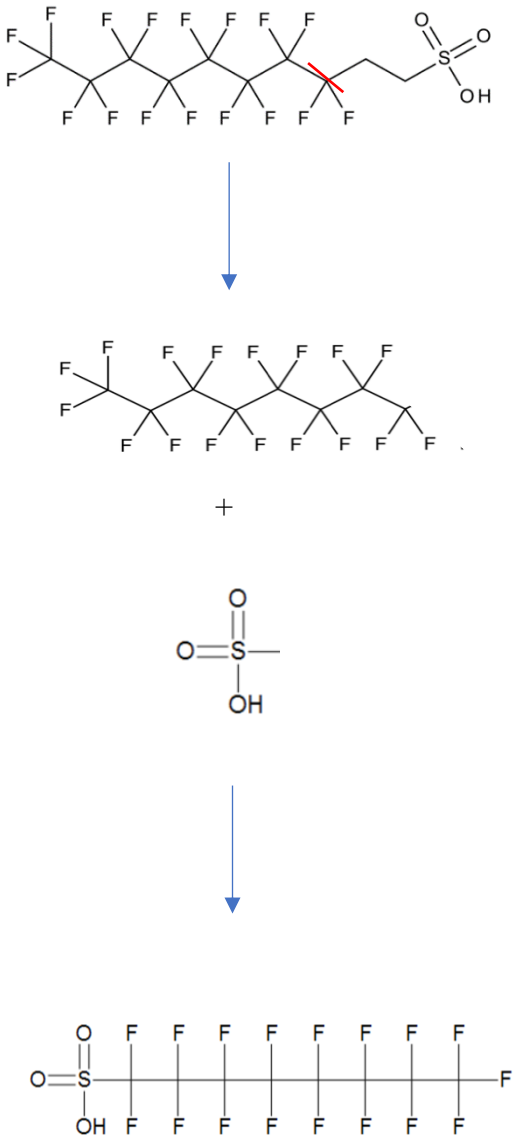
F.7) 8:2 FTS to PFOA



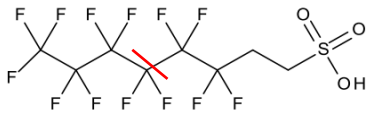
F.8) 8:2 FTS to 6:2 FTS

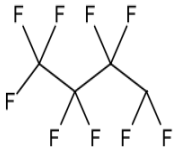


F.9) 8:2 FTS to PFOS



F.10) 6:2 FTS to PFBS





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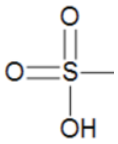
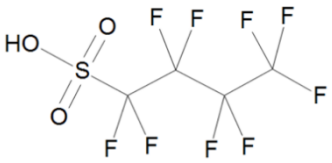
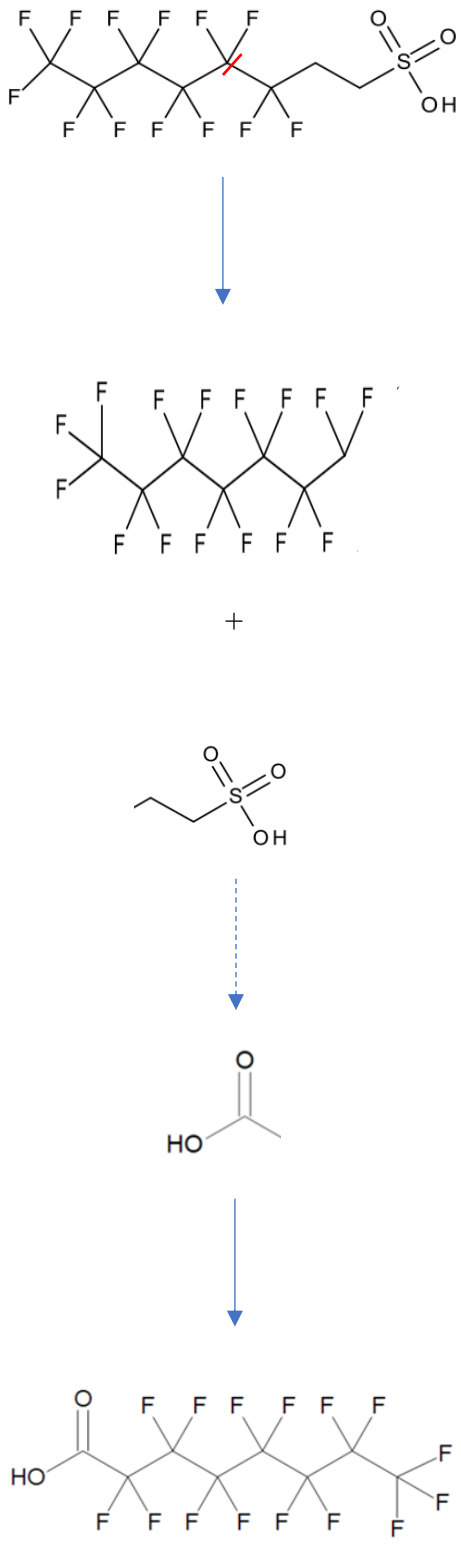
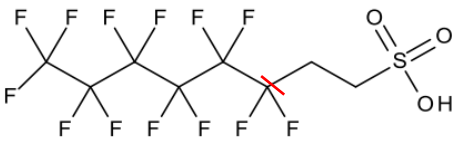


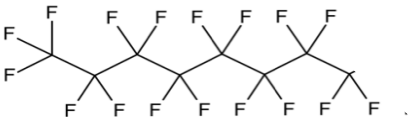


F.11) 6:2 FTS to PFOA



F.12) 6:2 FTS to PFOS





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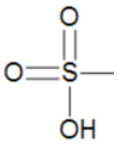

Appendix G: AFFF Raw LC/MS/MS Data

ANALYTICAL REPORT

Lab Number:	L2271012
Client:	New England Disposal Technologies, Inc. 83 Gilmore Drive Sutton, MA 01590
ATTN:	Mike Robertson
Phone:	(508) 234-4440
Project Name:	102027
Project Number:	Not Specified
Report Date:	02/01/23

Certifications & Approvals: MA (M-MA030), NH NELAP (2062), CT (PH-0141), DoD (L2474), FL (E87814), IL (200081), LA (85084),
ME (MA00030), MD (350), NJ (MA015), NY (11627), NC (685), OH (CL106), PA (68-02089), RI (LAO00299), TX (T104704419), VT (VT-0015), VA (460194), WA (C954), US Army Corps of Engineers, USDA (Permit #P330-17-00150), USFWS (Permit #206964).

320 Forbes Boulevard, Mansfield, MA 02048-1806
508-822-9300 (Fax) 508-822-3288 800-624-9220 - www.alphalab.com

Project Name: 102027
Project Number: Not Specified

Lab Number: L2271012
Report Date: 02/01/23

Alpha Sample ID	Client ID	Matrix	Sample Location	Collection Date/Time	Receive Date
L2271012-01	NF GOLD PU 10M (4)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271012-02	NF GOLD PU 20M (5)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271012-03	NF GOLD PU 30M (6)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271012-04	NF GOLD PU 5MM (7)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271012-05	NF GOLD PU 6MM (8)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22
L2271012-06	NF GOLD PU 7MM (9)	WATER	WPI WORCESTER	12/15/22 12:00	12/16/22

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

Case Narrative

The samples were received in accordance with the Chain of Custody and no significant deviations were encountered during the preparation or analysis unless otherwise noted. Sample Receipt, Container Information, and the Chain of Custody are located at the back of the report.

Results contained within this report relate only to the samples submitted under this Alpha Lab Number and meet NELAP requirements for all NELAP accredited parameters unless otherwise noted in the following narrative. The data presented in this report is organized by parameter (i.e. VOC, SVOC, etc.). Sample specific Quality Control data (i.e. Surrogate Spike Recovery) is reported at the end of the target analyte list for each individual sample, followed by the Laboratory Batch Quality Control at the end of each parameter. Tentatively Identified Compounds (TICs), if requested, are reported for compounds identified to be present and are not part of the method/program Target Compound List, even if only a subset of the TCL are being reported. If a sample was re-analyzed or re-extracted due to a required quality control corrective action and if both sets of data are reported, the Laboratory ID of the re-analysis or re-extraction is designated with an "R" or "RE", respectively.

When multiple Batch Quality Control elements are reported (e.g. more than one LCS), the associated samples for each element are noted in the grey shaded header line of each data table. Any Laboratory Batch, Sample Specific % recovery or RPD value that is outside the listed Acceptance Criteria is bolded in the report. In reference to questions H (CAM) or 4 (RCP) when "NO" is checked, the performance criteria for CAM and RCP methods allow for some quality control failures to occur and still be within method compliance. In these instances, the specific failure is not narrated but noted in the associated QC Outlier Summary Report, located directly after the Case Narrative. QC information is also incorporated in the Data Usability Assessment table (Format 11) of our Data Merger tool, where it can be reviewed in conjunction with the sample result, associated regulatory criteria and any associated data usability implications.

Soil/sediments, solids and tissues are reported on a dry weight basis unless otherwise noted. Definitions of all data qualifiers and acronyms used in this report are provided in the Glossary located at the back of the report.

HOLD POLICY - For samples submitted on hold, Alpha's policy is to hold samples (with the exception of Air canisters) free of charge for 21 calendar days from the date the project is completed. After 21 calendar days, we will dispose of all samples submitted including those put on hold unless you have contacted your Alpha Project Manager and made arrangements for Alpha to continue to hold the samples. Air canisters will be disposed after 3 business days from the date the project is completed.

Please contact Project Management at 800-624-9220 with any questions.

Case Narrative (continued)

Report Revision

February 01, 2023: The Project Location was amended.

Perfluorinated Alkyl Acids by Isotope Dilution

L2271012-01: The 4:2FTS, 6:2FTS and 8:2FTS result is not reported because the quadratic fit of the curve does not allow for an estimated "E" flagged value. The sample was re-analyzed on dilution and the result within the calibration curve is reported for this compound.

L2271012-01 through -06, WG1732772-1, WG1732772-4, and WG1732772-5 : Extracted Internal Standard recoveries were outside the acceptance criteria for individual analytes. Please refer to the surrogate section of the report for details.

L2271012-02 through -06: The 6:2FTS and 8:2FTS result is not reported because the quadratic fit of the curve does not allow for an estimated "E" flagged value. The sample was re-analyzed on dilution and the result within the calibration curve is reported for these compounds.

L2271012-04D, -05D, and -06D: The sample was re-analyzed on dilution due to matrix interference in the original analysis. The results of the re-analysis are reported for PFOA.

WG1732772-2R: The LCS was re-analyzed due to QC failures in the original analysis. The results of the re-analysis are reported.

WG1732772-3R: The LCSD was re-analyzed due to QC failures in the original analysis. The results of the re-analysis are reported.

ORGANICS

SEMIVOLATILES

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-01 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 10M (4) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 09:37

Analytical Date: 01/16/23 03:19

Analyst: SG

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	3120		ng/l	33.3	--	1
Perfluoropentanoic Acid (PFPeA)	1590		ng/l	33.3	--	1
Perfluorobutanesulfonic Acid (PFBS)	877		ng/l	33.3	--	1
Perfluorohexanoic Acid (PFHxA)	1040		ng/l	33.3	--	1
Perfluoropentanesulfonic Acid (PFPeS)	531		ng/l	33.3	--	1
Perfluoroheptanoic Acid (PFHpA)	756		ng/l	33.3	--	1
Perfluorohexanesulfonic Acid (PFHxS)	8467		ng/l	33.3	--	1
Perfluorooctanoic Acid (PFOA)	1658		ng/l	33.3	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	33.3	--	1
Perfluorononanoic Acid (PFNA)	264		ng/l	33.3	--	1
Perfluorooctanesulfonic Acid (PFOS)	1910		ng/l	33.3	--	1
Perfluorodecanoic Acid (PFDA)	240		ng/l	33.3	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	33.3	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	33.3	--	1
Perfluoroundecanoic Acid (PFUnA)	61.2		ng/l	33.3	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	33.3	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	33.3	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	33.3	--	1
Perfluorododecanoic Acid (PFDoA)	90.7		ng/l	33.3	--	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	33.3	--	1
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	33.3	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-01	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 10M (4)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	93		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	110		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	100		70-131
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**337**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**383**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	97		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	95		62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**432**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	101		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	89		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**145**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	**200**	Q	55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	58		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	**155**	Q	27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	82		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	136		22-136

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-01 D2	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 10M (4)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified
Sample Depth:			
Matrix:	Water	Extraction Method:	ALPHA 23528
Analytical Method:	134,LCMSMS-ID	Extraction Date:	01/12/23 09:37
Analytical Date:	01/19/23 11:08		
Analyst:	JW		

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	990000		ng/l	66700	--	2000
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	284000		ng/l	66700	--	2000

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	78		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	80		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-01 D
Client ID: NF GOLD PU 10M (4)
Sample Location: WPI WORCESTER

Date Collected: 12/15/22 12:00
Date Received: 12/16/22
Field Prep: Not Specified

Sample Depth:
Matrix: Water
Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/17/23 16:06
Analyst: PS

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	18400		ng/l	3330	--	100

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	90		12-142

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-02 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 20M (5) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 09:37

Analytical Date: 01/16/23 03:36

Analyst: SG

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	3440		ng/l	33.3	--	1
Perfluoropentanoic Acid (PFPeA)	862		ng/l	33.3	--	1
Perfluorobutanesulfonic Acid (PFBS)	1008		ng/l	33.3	--	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	2370		ng/l	33.3	--	1
Perfluorohexanoic Acid (PFHxA)	1900		ng/l	33.3	--	1
Perfluoropentanesulfonic Acid (PFPeS)	258		ng/l	33.3	--	1
Perfluoroheptanoic Acid (PFHpA)	722		ng/l	33.3	--	1
Perfluorohexanesulfonic Acid (PFHxS)	8537		ng/l	33.3	--	1
Perfluorooctanoic Acid (PFOA)	1840		ng/l	33.3	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	41.2		ng/l	33.3	--	1
Perfluorononanoic Acid (PFNA)	266		ng/l	33.3	--	1
Perfluorooctanesulfonic Acid (PFOS)	2020		ng/l	33.3	--	1
Perfluorodecanoic Acid (PFDA)	288		ng/l	33.3	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	33.3	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	33.3	--	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	33.3	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	33.3	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	33.3	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	33.3	--	1
Perfluorododecanoic Acid (PFDoA)	92.7		ng/l	33.3	--	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	33.3	--	1
Perfluorotetradecanoic Acid (PFTA)	95.4		ng/l	33.3	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-02	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 20M (5)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	88		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	106		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	95		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	**237**	Q	12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**202**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**220**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	101		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	93		62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**256**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	100		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	101		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	104		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	**169**	Q	55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	24		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	115		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	113		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	116		22-136

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-02 D	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 20M (5)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified
Sample Depth:			
Matrix:	Water	Extraction Method:	ALPHA 23528
Analytical Method:	134,LCMSMS-ID	Extraction Date:	01/12/23 09:37
Analytical Date:	01/18/23 16:52		
Analyst:	JW		

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	970000		ng/l	33300	--	1000
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	265000		ng/l	33300	--	1000

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	101		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	99		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-03 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 30M (6) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 09:37

Analytical Date: 01/16/23 03:53

Analyst: SG

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	3570		ng/l	33.3	--	1
Perfluoropentanoic Acid (PFPeA)	442		ng/l	33.3	--	1
Perfluorobutanesulfonic Acid (PFBS)	1261		ng/l	33.3	--	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	6020		ng/l	33.3	--	1
Perfluorohexanoic Acid (PFHxA)	2000		ng/l	33.3	--	1
Perfluoropentanesulfonic Acid (PFPeS)	0		ng/l	33.3	--	1
Perfluoroheptanoic Acid (PFHpA)	698		ng/l	33.3	--	1
Perfluorohexanesulfonic Acid (PFHxS)	8630		ng/l	33.3	--	1
Perfluorooctanoic Acid (PFOA)	2070		ng/l	33.3	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	105		ng/l	33.3	--	1
Perfluorononanoic Acid (PFNA)	271		ng/l	33.3	--	1
Perfluorooctanesulfonic Acid (PFOS)	2140		ng/l	33.3	--	1
Perfluorodecanoic Acid (PFDA)	310		ng/l	33.3	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	33.3	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	33.3	--	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	33.3	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	33.3	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	33.3	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	33.3	--	1
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	33.3	--	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	33.3	--	1
Perfluorotetradecanoic Acid (PFTA)	97.2		ng/l	33.3	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-03	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 30M (6)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	98		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	123		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	93		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	111		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**148**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**150**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	97		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	101		62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**174**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	99		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	87		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	112		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	**149**	Q	55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	49		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	**145**	Q	27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	93		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	130		22-136

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-03 D
Client ID: NF GOLD PU 30M (6)
Sample Location: WPI WORCESTER

Date Collected: 12/15/22 12:00
Date Received: 12/16/22
Field Prep: Not Specified

Sample Depth:
Matrix: Water
Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/18/23 02:02
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	960000		ng/l	3330	--	1000
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	250000		ng/l	3330	--	1000

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	91		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	88		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-04 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 5MM (7) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 09:37

Analytical Date: 01/16/23 04:09

Analyst: SG

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	2820		ng/l	200	--	1
Perfluoropentanoic Acid (PFPeA)	1111		ng/l	200	--	1
Perfluorobutanesulfonic Acid (PFBS)	604		ng/l	200	--	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	2650		ng/l	200	--	1
Perfluorohexanoic Acid (PFHxA)	2017		ng/l	200	--	1
Perfluoropentanesulfonic Acid (PFPeS)	681		ng/l	200	--	1
Perfluoroheptanoic Acid (PFHpA)	1634		ng/l	200	--	1
Perfluorohexanesulfonic Acid (PFHxS)	1880	F	ng/l	200	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	200	--	1
Perfluorononanoic Acid (PFNA)	213		ng/l	200	--	1
Perfluorooctanesulfonic Acid (PFOS)	5610		ng/l	200	--	1
Perfluorodecanoic Acid (PFDA)	5620		ng/l	200	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	200	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	200	--	1
Perfluoroundecanoic Acid (PFUnA)	268		ng/l	200	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	200	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	200	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	200	--	1
Perfluorododecanoic Acid (PFDoA)	1910		ng/l	200	--	1
Perfluorotridecanoic Acid (PFTrDA)	333	F	ng/l	200	--	1
Perfluorotetradecanoic Acid (PFTA)	3000		ng/l	200	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-04	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 5MM (7)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	93		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	109		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	111		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	111		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**904**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**1080**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	101		71-134
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**970**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	90		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	88		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**210**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	**265**	Q	55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	107		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	**248**	Q	27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	**192**	Q	48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	**153**	Q	22-136

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-04 D
Client ID: NF GOLD PU 5MM (7)
Sample Location: WPI WORCESTER

Date Collected: 12/15/22 12:00
Date Received: 12/16/22
Field Prep: Not Specified

Sample Depth:
Matrix: Water
Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/19/23 11:24
Analyst: JW

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorooctanoic Acid (PFOA)	1440	J	ng/l	20000	--	100
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	789000		ng/l	20000	--	100
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	287850		ng/l	20000	--	100

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C8]Octanoic Acid (M8PFOA)	101		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	111		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	147		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-05 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 6MM (8) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 13:45

Analytical Date: 01/15/23 19:36

Analyst: RS

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	2800		ng/l	500	--	1
Perfluoropentanoic Acid (PFPeA)	1100		ng/l	500	--	1
Perfluorobutanesulfonic Acid (PFBS)	560		ng/l	500	--	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	2090		ng/l	500	--	1
Perfluorohexanoic Acid (PFHxA)	2005		ng/l	500	--	1
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	500	--	1
Perfluoroheptanoic Acid (PFHpA)	1620		ng/l	500	--	1
Perfluorohexanesulfonic Acid (PFHxS)	1830		ng/l	500	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	500	--	1
Perfluorononanoic Acid (PFNA)	ND		ng/l	500	--	1
Perfluorooctanesulfonic Acid (PFOS)	5590		ng/l	500	--	1
Perfluorodecanoic Acid (PFDA)	5560		ng/l	500	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	500	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	500	--	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	500	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	500	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	500	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	500	--	1
Perfluorododecanoic Acid (PFDoA)	2000		ng/l	500	--	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	500	--	1
Perfluorotetradecanoic Acid (PFTA)	2420		ng/l	500	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-05	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 6MM (8)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	105		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	74		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	88		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	104		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**290**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	88		71-134
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**308**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	105		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	108		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**145**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	123		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	**143**	Q	5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	98		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	99		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	84		22-136

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-05 D	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 6MM (8)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified
Sample Depth:			
Matrix:	Water	Extraction Method:	ALPHA 23528
Analytical Method:	134,LCMSMS-ID	Extraction Date:	01/12/23 13:45
Analytical Date:	01/19/23 11:57		
Analyst:	JW		

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorooctanoic Acid (PFOA)	ND		ng/l	10000	--	20
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	7920000		ng/l	10000	--	20
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	290000		ng/l	10000	--	20

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C8]Octanoic Acid (M8PFOA)	104		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	117		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	114		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

SAMPLE RESULTS

Lab ID: L2271012-06 Date Collected: 12/15/22 12:00

Client ID: NF GOLD PU 7MM (9) Date Received: 12/16/22

Sample Location: WPI WORCESTER Field Prep: Not Specified

Sample Depth:

Matrix: Water Extraction Method: ALPHA 23528

Analytical Method: 134,LCMSMS-ID Extraction Date: 01/12/23 13:45

Analytical Date: 01/15/23 20:09

Analyst: RS

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorobutanoic Acid (PFBA)	2760		ng/l	500	--	1
Perfluoropentanoic Acid (PFPeA)	1080		ng/l	500	--	1
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	500	--	1
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	1170		ng/l	500	--	1
Perfluorohexanoic Acid (PFHxA)	1880		ng/l	500	--	1
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	500	--	1
Perfluoroheptanoic Acid (PFHpA)	1560		ng/l	500	--	1
Perfluorohexanesulfonic Acid (PFHxS)	1790		ng/l	500	--	1
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	500	--	1
Perfluorononanoic Acid (PFNA)	ND		ng/l	500	--	1
Perfluorooctanesulfonic Acid (PFOS)	5500		ng/l	500	--	1
Perfluorodecanoic Acid (PFDA)	5520		ng/l	500	--	1
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	500	--	1
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	500	--	1
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	500	--	1
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	500	--	1
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	500	--	1
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	500	--	1
Perfluorododecanoic Acid (PFDoA)	2040		ng/l	500	--	1
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	500	--	1
Perfluorotetradecanoic Acid (PFTA)	3450		ng/l	500	--	1

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-06	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 7MM (9)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified

Sample Depth:

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor

Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	103		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	78		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	91		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	96		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**228**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	82		71-134
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**262**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	104		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	106		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**141**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	116		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	**136**	Q	5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	100		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	94		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	83		22-136

Project Name:	102027	**Lab Number:**	L2271012
Project Number:	Not Specified	**Report Date:**	02/01/23

SAMPLE RESULTS

Lab ID:	L2271012-06 D	Date Collected:	12/15/22 12:00
Client ID:	NF GOLD PU 7MM (9)	Date Received:	12/16/22
Sample Location:	WPI WORCESTER	Field Prep:	Not Specified
Sample Depth:			
Matrix:	Water	Extraction Method:	ALPHA 23528
Analytical Method:	134,LCMSMS-ID	Extraction Date:	01/12/23 13:45
Analytical Date:	01/19/23 02:23		
Analyst:	AC		

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab						
Perfluorooctanoic Acid (PFOA)	ND		ng/l	10000	--	20
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	800200		ng/l	10000	--	20
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	298900		ng/l	10000	--	20

Surrogate (Extracted Internal Standard)	% Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C8]Octanoic Acid (M8PFOA)	100		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	113		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	100		10-162

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 23:44
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 01-04 Batch: WG1732534-1					
Perfluorobutanoic Acid (PFBA)	ND		ng/l	2.00	--
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	2.00	--
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	2.00	--
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	2.00	--
Perfluorohexanoic Acid (PFHxA)	ND		ng/l	2.00	--
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	2.00	--
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	2.00	--
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	2.00	--
Perfluorooctanoic Acid (PFOA)	ND		ng/l	2.00	--
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ND		ng/l	2.00	--
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	2.00	--
Perfluorononanoic Acid (PFNA)	ND		ng/l	2.00	--
Perfluorooctanesulfonic Acid (PFOS)	ND		ng/l	2.00	--
Perfluorodecanoic Acid (PFDA)	ND		ng/l	2.00	--
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND		ng/l	2.00	--
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	2.00	--
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	2.00	--
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	2.00	--
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	2.00	--
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	2.00	--
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	2.00	--
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	2.00	--
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	2.00	--
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	2.00	--

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 23:44
Analyst: SG

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 09:37

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 01-04 Batch: WG1732534-1					

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	103		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	124		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	95		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	82		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	94		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	96		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	99		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	99		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	91		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	93		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	98		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	102		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	96		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	89		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	116		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	19		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	88		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	112		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	105		22-136

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 18:47
Analyst: RS

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 13:45

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 05-06 Batch: WG1732772-1					
Perfluorobutanoic Acid (PFBA)	ND		ng/l	500	--
Perfluoropentanoic Acid (PFPeA)	ND		ng/l	500	--
Perfluorobutanesulfonic Acid (PFBS)	ND		ng/l	500	--
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND		ng/l	500	--
Perfluorohexanoic Acid (PFHxA)	ND		ng/l	500	--
Perfluoropentanesulfonic Acid (PFPeS)	ND		ng/l	500	--
Perfluoroheptanoic Acid (PFHpA)	ND		ng/l	500	--
Perfluorohexanesulfonic Acid (PFHxS)	ND		ng/l	500	--
Perfluorooctanoic Acid (PFOA)	ND		ng/l	500	--
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ND		ng/l	500	--
Perfluoroheptanesulfonic Acid (PFHpS)	ND		ng/l	500	--
Perfluorononanoic Acid (PFNA)	ND		ng/l	500	--
Perfluorooctanesulfonic Acid (PFOS)	ND		ng/l	500	--
Perfluorodecanoic Acid (PFDA)	ND		ng/l	500	--
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND		ng/l	500	--
Perfluorononanesulfonic Acid (PFNS)	ND		ng/l	500	--
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND		ng/l	500	--
Perfluoroundecanoic Acid (PFUnA)	ND		ng/l	500	--
Perfluorodecanesulfonic Acid (PFDS)	ND		ng/l	500	--
Perfluorooctanesulfonamide (FOSA)	ND		ng/l	500	--
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND		ng/l	500	--
Perfluorododecanoic Acid (PFDoA)	ND		ng/l	500	--
Perfluorotridecanoic Acid (PFTrDA)	ND		ng/l	500	--
Perfluorotetradecanoic Acid (PFTA)	ND		ng/l	500	--

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Method Blank Analysis

Batch Quality Control

Analytical Method: 134,LCMSMS-ID
Analytical Date: 01/15/23 18:47
Analyst: RS

Extraction Method: ALPHA 23528
Extraction Date: 01/12/23 13:45

Parameter	Result	Qualifier	Units	RL	MDL
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab for sample(s): 05-06 Batch: WG1732772-1					

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	105		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	81		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	87		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	85		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	95		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	120		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	101		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	121		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	79		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	117		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	109		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	108		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	91		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	109		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	116		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	**137**	Q	5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	86		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	89		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	76		22-136

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab	Associated sample(s): 01-04 Batch: WG1732534-2							
Perfluorobutanoic Acid (PFBA)	107		-		67-148	-		30
Perfluoropentanoic Acid (PFPeA)	106		-		63-161	-		30
Perfluorobutanesulfonic Acid (PFBS)	105		-		65-157	-		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	120		-		37-219	-		30
Perfluorohexanoic Acid (PFHxA)	101		-		69-168	-		30
Perfluoropentanesulfonic Acid (PFPeS)	110		-		52-156	-		30
Perfluoroheptanoic Acid (PFHpA)	105		-		58-159	-		30
Perfluorohexanesulfonic Acid (PFHxS)	110		-		69-177	-		30
Perfluorooctanoic Acid (PFOA)	103		-		63-159	-		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	150		-		49-187	-		30
Perfluoroheptanesulfonic Acid (PFHpS)	100		-		61-179	-		30
Perfluorononanoic Acid (PFNA)	95		-		68-171	-		30
Perfluorooctanesulfonic Acid (PFOS)	105		-		52-151	-		30
Perfluorodecanoic Acid (PFDA)	101		-		63-171	-		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	112		-		56-173	-		30
Perfluorononanesulfonic Acid (PFNS)	113		-		48-150	-		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	117		-		60-166	-		30
Perfluoroundecanoic Acid (PFUnA)	101		-		60-153	-		30
Perfluorodecanesulfonic Acid (PFDS)	113		-		38-156	-		30
Perfluorooctanesulfonamide (FOSA)	109		-		46-170	-		30
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	105		-		45-170	-		30
Perfluorododecanoic Acid (PFDoA)	120		-		67-153	-		30

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab	Associated sample(s): 01-04		Batch: WG1732534-2					
Perfluorotridecanoic Acid (PFTrDA)	116		-		48-158	-		30
Perfluorotetradecanoic Acid (PFTA)	93		-		59-182	-		30

Surrogate (Extracted Internal Standard)	LCS %Recovery	Qual	LCSD %Recovery	Qual	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	98				58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	116				62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	92				70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	83				12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	95				57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	95				60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	94				71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	102				62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	96				14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	106				59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	97				69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	99				62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	110				10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	83				24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	97				55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	21				5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	83				27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	96				48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	107				22-136

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 Batch: WG1732772-2 WG1732772-3								
Perfluorobutanoic Acid (PFBA)	104		104		67-148	0		30
Perfluoropentanoic Acid (PFPeA)	104		104		63-161	0		30
Perfluorobutanesulfonic Acid (PFBS)	101		103		65-157	2		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	115		116		37-219	1		30
Perfluorohexanoic Acid (PFHxA)	102		104		69-168	2		30
Perfluoropentanesulfonic Acid (PFPeS)	102		101		52-156	1		30
Perfluoroheptanoic Acid (PFHpA)	103		106		58-159	3		30
Perfluorohexanesulfonic Acid (PFHxS)	104		102		69-177	2		30
Perfluorooctanoic Acid (PFOA)	105		111		63-159	6		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	116		116		49-187	0		30
Perfluoroheptanesulfonic Acid (PFHpS)	98		97		61-179	1		30
Perfluorononanoic Acid (PFNA)	104		108		68-171	4		30
Perfluorooctanesulfonic Acid (PFOS)	101		97		52-151	4		30
Perfluorodecanoic Acid (PFDA)	106		99		63-171	7		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	117		131		56-173	11		30
Perfluorononanesulfonic Acid (PFNS)	114		113		48-150	1		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	106		111		60-166	5		30
Perfluoroundecanoic Acid (PFUnA)	99		100		60-153	1		30
Perfluorodecanesulfonic Acid (PFDS)	118		113		38-156	4		30
Perfluorooctanesulfonamide (FOSA)	108		110		46-170	2		30
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	102		106		45-170	4		30
Perfluorododecanoic Acid (PFDoA)	106		133		67-153	23		30

Lab Control Sample Analysis

Batch Quality Control

Project Name: 102027 **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	LCS %Recovery	Qual	LCSD %Recovery	Qual	%Recovery Limits	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 Batch: WG1732772-2 WG1732772-3								
Perfluorotridecanoic Acid (PFTrDA)	116		128		48-158	10		30
Perfluorotetradecanoic Acid (PFTA)	129		131		59-182	2		30

Surrogate (Extracted Internal Standard)	LCS %Recovery	Qual	LCSD %Recovery	Qual	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	103		107		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	114		118		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	91		95		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	83		89		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	88		95		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	96		102		60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	99		107		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	102		106		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	100		106		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	96		99		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	96		105		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	97		100		62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	106		99		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	91		89		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	115		113		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	91		91		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	82		86		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	102		92		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	90		89		22-136

Matrix Spike Analysis

Batch Quality Control

Project Name: 102027 ***Lab Number:*** L2271012

Project Number: Not Specified ***Report Date:*** 02/01/23

Parameter	*Native Sample*	*MS Added*	*MS Found*	*MS %Recovery*	*Qual*	*MSD Found*	*MSD %Recovery*	*Qual*	*Recovery Limits*	*RPD*	*Qual*	*RPD Limits*
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-04 QC Batch ID: WG1732534-3 QC Sample: L2270787-01 Client ID: MS Sample												
Perfluorobutanoic Acid (PFBA)	ND	37.9	38.0	98		-	-		67-148	-		30
Perfluoropentanoic Acid (PFPeA)	ND	37.9	39.7	103		-	-		63-161	-		30
Perfluorobutanesulfonic Acid (PFBS)	ND	33.7	35.8	103		-	-		65-157	-		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND	35.6	44.6	125		-	-		37-219	-		30
Perfluorohexanoic Acid (PFHxA)	ND	37.9	38.4	99		-	-		69-168	-		30
Perfluoropentanesulfonic Acid (PFPeS)	ND	35.7	39.9	112		-	-		52-156	-		30
Perfluoroheptanoic Acid (PFHpA)	ND	37.9	38.4	100		-	-		58-159	-		30
Perfluorohexanesulfonic Acid (PFHxS)	ND	34.6	43.5	124		-	-		69-177	-		30
Perfluorooctanoic Acid (PFOA)	ND	37.9	41.0	105		-	-		63-159	-		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	3.70	36.1	49.6	127		-	-		49-187	-		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	36.2	39.7	110		-	-		61-179	-		30
Perfluorononanoic Acid (PFNA)	ND	37.9	39.1	103		-	-		68-171	-		30
Perfluorooctanesulfonic Acid (PFOS)	ND	35.2	45.9	126		-	-		52-151	-		30
Perfluorodecanoic Acid (PFDA)	ND	37.9	39.9	105		-	-		63-171	-		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND	36.4	46.7	128		-	-		56-173	-		30
Perfluorononanesulfonic Acid (PFNS)	ND	36.5	39.4	108		-	-		48-150	-		30
N- Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	37.9	43.6	115		-	-		60-166	-		30
Perfluoroundecanoic Acid (PFUnA)	ND	37.9	38.7	102		-	-		60-153	-		30
Perfluorodecanesulfonic Acid (PFDS)	ND	36.6	39.2	107		-	-		38-156	-		30
Perfluorooctanesulfonamide (FOSA)	ND	37.9	36.9	97		-	-		46-170	-		30
N- Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	37.9	43.8	116		-	-		45-170	-		30
Perfluorododecanoic Acid (PFDoA)	ND	37.9	38.9	103		-	-		67-153	-		30

Matrix Spike Analysis

Batch Quality Control

Project Name: 102027 ***Lab Number:*** L2271012

Project Number: Not Specified ***Report Date:*** 02/01/23

Parameter	*Native Sample*	*MS Added*	*MS Found*	*MS %Recovery*	*Qual*	*MSD Found*	*MSD %Recovery*	*Qual*	*Recovery Limits*	*RPD*	*Qual*	*RPD Limits*
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-04 QC Batch ID: WG1732534-3 QC Sample: L2270787-01 Client ID: MS Sample												
Perfluorotridecanoic Acid (PFTrDA)	ND	37.9	45.9	121		-	-		48-158	-		30
Perfluorotetradecanoic Acid (PFTA)	ND	37.9	43.5	115		-	-		59-182	-		30

Surrogate (Extracted Internal Standard)	*MS % Recovery*	*MS Qualifier*	*MSD % Recovery*	*MSD Qualifier*	*Acceptance Criteria*
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	98				10-162
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	100				12-142
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	92				14-147
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	43				27-126
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	46				24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	74				55-137
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	63				62-124
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**50**	Q			57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**53**	Q			60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	98				71-134
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	67				48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	75				22-136
Perfluoro[13C4]Butanoic Acid (MPFBA)	**51**	Q			58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	**54**	Q			62-163
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	15				5-112
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	90				69-131
Perfluoro[13C8]Octanoic Acid (M8PFOA)	**54**	Q			62-129
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	64				59-139
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	97				70-131

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-04 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						
Perfluorobutanoic Acid (PFBA)	2.02	1.98	ng/l	2		30
Perfluoropentanoic Acid (PFPeA)	3.01	3.00	ng/l	0		30
Perfluorobutanesulfonic Acid (PFBS)	2.64	2.63	ng/l	0		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	ND	ND	ng/l	NC		30
Perfluorohexanoic Acid (PFHxA)	3.05	2.89	ng/l	5		30
Perfluoropentanesulfonic Acid (PFPeS)	ND	ND	ng/l	NC		30
Perfluoroheptanoic Acid (PFHpA)	ND	ND	ng/l	NC		30
Perfluorohexanesulfonic Acid (PFHxS)	1.90	ND	ng/l	NC		30
Perfluorooctanoic Acid (PFOA)	4.73	4.23	ng/l	11		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ND	ND	ng/l	NC		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	ND	ng/l	NC		30
Perfluorononanoic Acid (PFNA)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonic Acid (PFOS)	3.92	3.56	ng/l	10		30
Perfluorodecanoic Acid (PFDA)	ND	ND	ng/l	NC		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	ND	ND	ng/l	NC		30
Perfluorononanesulfonic Acid (PFNS)	ND	ND	ng/l	NC		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	ND	ng/l	NC		30
Perfluoroundecanoic Acid (PFUnA)	ND	ND	ng/l	NC		30
Perfluorodecanesulfonic Acid (PFDS)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonamide (FOSA)	ND	ND	ng/l	NC		30

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-04 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	ND	ng/l	NC		30
Perfluorododecanoic Acid (PFDoA)	ND	ND	ng/l	NC		30
Perfluorotridecanoic Acid (PFTrDA)	ND	ND	ng/l	NC		30
Perfluorotetradecanoic Acid (PFTA)	ND	ND	ng/l	NC		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	68		61		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		76		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	84		85		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	74		73		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	**55**	Q	**51**	Q	57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	61		**54**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	90		90		71-134
Perfluoro[13C8]Octanoic Acid (M8PFOA)	67		**57**	Q	62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	75		73		14-147
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	76		61		59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	88		91		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	75		**54**	Q	62-124
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	65		76		10-162
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	56		39		24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	100		70		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	6		6		5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	45		37		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	91		72		48-131

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 01-04 QC Batch ID: WG1732534-4 QC Sample: L2270787-02 Client ID: DUP Sample						

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	69		65		22-136

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-4 QC Sample: L2271012-05 Client ID: NF GOLD PU 6MM (8)						
Perfluorobutanoic Acid (PFBA)	2800	3000	ng/l	4		30
Perfluoropentanoic Acid (PFPeA)	1100	1150	ng/l	2		30
Perfluorobutanesulfonic Acid (PFBS)	560	590	ng/l	5		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	2090	2260	ng/l	8		30
Perfluorohexanoic Acid (PFHxA)	2005	2205	ng/l	1		30
Perfluoropentanesulfonic Acid (PFPeS)	ND	530	ng/l	NC		30
Perfluoroheptanoic Acid (PFHpA)	1620	1630	ng/l	1		30
Perfluorohexanesulfonic Acid (PFHxS)	1830	1960	ng/l	7		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	ND	ng/l	NC		30
Perfluorononanoic Acid (PFNA)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonic Acid (PFOS)	5590	5800	ng/l	4		30
Perfluorodecanoic Acid (PFDA)	5560	5880	ng/l	6		30
Perfluorononanesulfonic Acid (PFNS)	ND	ND	ng/l	NC		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	ND	ng/l	NC		30
Perfluoroundecanoic Acid (PFUnA)	ND	ND	ng/l	NC		30
Perfluorodecanesulfonic Acid (PFDS)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonamide (FOSA)	ND	ND	ng/l	NC		30
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	ND	ng/l	NC		30
Perfluorododecanoic Acid (PFDoA)	2000	2300	ng/l	10		30
Perfluorotridecanoic Acid (PFTrDA)	ND	ND	ng/l	NC		30

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-4 QC Sample: L2271012-05 Client ID: NF GOLD PU 6MM (8)						
Perfluorotetradecanoic Acid (PFTA)	2420	2570	ng/l	6		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	105		103		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		81		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	74		72		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	88		90		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	104		98		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**290**	Q	**274**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	88		79		71-134
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**308**	Q	**330**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	105		106		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	108		101		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**145**	Q	**136**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	123		126		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	**143**	Q	**139**	Q	5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	98		100		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	99		95		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	84		83		22-136

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-4 QC Sample: L2271012-05 Client ID: NF GOLD PU 6MM (8)						
Perfluorooctanoic Acid (PFOA)	ND	ND	ng/l	NC		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	7920000	8010000	ng/l	7		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	290000	392000	ng/l	25		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C8]Octanoic Acid (M8PFOA)	104		100		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	117		113		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	114		98		10-162

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-5 QC Sample: L2271012-06 Client ID: NF GOLD PU 7MM (9)						
Perfluorobutanoic Acid (PFBA)	2760	2830	ng/l	3		30
Perfluoropentanoic Acid (PFPeA)	1080	1120	ng/l	4		30
Perfluorobutanesulfonic Acid (PFBS)	ND	ND	ng/l	NC		30
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	1170	1190	ng/l	2		30
Perfluorohexanoic Acid (PFHxA)	18800	19800	ng/l	5		30
Perfluoropentanesulfonic Acid (PFPeS)	ND	ND	ng/l	NC		30
Perfluoroheptanoic Acid (PFHpA)	820	870	ng/l	6		30
Perfluorohexanesulfonic Acid (PFHxS)	980	1010	ng/l	3		30
Perfluoroheptanesulfonic Acid (PFHpS)	ND	ND	ng/l	NC		30
Perfluorononanoic Acid (PFNA)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonic Acid (PFOS)	3170	2890	ng/l	9		30
Perfluorodecanoic Acid (PFDA)	3210	3050	ng/l	5		30
Perfluorononanesulfonic Acid (PFNS)	ND	ND	ng/l	NC		30
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	ND	ND	ng/l	NC		30
Perfluoroundecanoic Acid (PFUnA)	ND	ND	ng/l	NC		30
Perfluorodecanesulfonic Acid (PFDS)	ND	ND	ng/l	NC		30
Perfluorooctanesulfonamide (FOSA)	ND	ND	ng/l	NC		30
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ND	ND	ng/l	NC		30
Perfluorododecanoic Acid (PFDoA)	1910	1940	ng/l	2		30
Perfluorotridecanoic Acid (PFTrDA)	ND	ND	ng/l	NC		30

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-5 QC Sample: L2271012-06 Client ID: NF GOLD PU 7MM (9)						
Perfluorotetradecanoic Acid (PFTA)	1350	1240	ng/l	8		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C4]Butanoic Acid (MPFBA)	103		100		58-132
Perfluoro[13C5]Pentanoic Acid (M5PFPEA)	85		82		62-163
Perfluoro[2,3,4-13C3]Butanesulfonic Acid (M3PFBS)	78		72		70-131
1H,1H,2H,2H-Perfluoro[1,2-13C2]Hexanesulfonic Acid (M2-4:2FTS)	91		90		12-142
Perfluoro[1,2,3,4,6-13C5]Hexanoic Acid (M5PFHxA)	96		96		57-129
Perfluoro[1,2,3,4-13C4]Heptanoic Acid (M4PFHpA)	**228**	Q	**230**	Q	60-129
Perfluoro[1,2,3-13C3]Hexanesulfonic Acid (M3PFHxS)	82		78		71-134
Perfluoro[13C9]Nonanoic Acid (M9PFNA)	**262**	Q	**250**	Q	59-139
Perfluoro[13C8]Octanesulfonic Acid (M8PFOS)	104		103		69-131
Perfluoro[1,2,3,4,5,6-13C6]Decanoic Acid (M6PFDA)	106		104		62-124
N-Deuteriomethylperfluoro-1-octanesulfonamidoacetic Acid (d3-NMeFOSAA)	**141**	Q	**136**	Q	24-116
Perfluoro[1,2,3,4,5,6,7-13C7]Undecanoic Acid (M7-PFUDA)	116		114		55-137
Perfluoro[13C8]Octanesulfonamide (M8FOSA)	**136**	Q	**125**	Q	5-112
N-Deuterioethylperfluoro-1-octanesulfonamidoacetic Acid (d5-NEtFOSAA)	100		96		27-126
Perfluoro[1,2-13C2]Dodecanoic Acid (MPFDOA)	94		96		48-131
Perfluoro[1,2-13C2]Tetradecanoic Acid (M2PFTEDA)	83		84		22-136

Lab Duplicate Analysis

Project Name: 102027 **Batch Quality Control** **Lab Number:** L2271012

Project Number: Not Specified **Report Date:** 02/01/23

Parameter	Native Sample	Duplicate Sample	Units	RPD	Qual	RPD Limits
Perfluorinated Alkyl Acids by Isotope Dilution - Mansfield Lab Associated sample(s): 05-06 QC Batch ID: WG1732772-5 QC Sample: L2271012-06 Client ID: NF GOLD PU 7MM (9)						
Perfluorooctanoic Acid (PFOA)	ND	ND	ng/l	NC		30
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	792000	728000	ng/l	8		30
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	240000	245000	ng/l	2		30

Surrogate (Extracted Internal Standard)	%Recovery	Qualifier	%Recovery	Qualifier	Acceptance Criteria
Perfluoro[13C8]Octanoic Acid (M8PFOA)	100		100		62-129
1H,1H,2H,2H-Perfluoro[1,2-13C2]Octanesulfonic Acid (M2-6:2FTS)	113		114		14-147
1H,1H,2H,2H-Perfluoro[1,2-13C2]Decanesulfonic Acid (M2-8:2FTS)	100		99		10-162

Project Name: 102027

Project Number: Not Specified

Lab Number: L2271012

Report Date: 02/01/23

Sample Receipt and Container Information

Were project specific reporting limits specified? YES

Cooler Information

Cooler	*Custody Seal*
A	Absent

Container Information

Container ID	*Container Type*	*Cooler*	*Initial pH*	*Final pH*	*Temp deg C*	*Pres*	*Seal*	*Frozen Date/Time*	*Analysis(*)*
L2271012-01A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271012-02A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271012-03A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271012-04A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271012-05A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)
L2271012-06A	Plastic 250ml unpreserved	A	NA		3.8	Y	Absent		A2-537-ISOTOPE(28)

PFAS PARAMETER SUMMARY

Parameter	Acronym	CAS Number
PERFLUOROALKYL CARBOXYLIC ACIDS (PFCAs)		
Perfluorooctadecanoic Acid	PFODA	16517-11-6
Perfluorohexadecanoic Acid	PFHxDA	67905-19-5
Perfluorotetradecanoic Acid	PFTA/PFTeDA	376-06-7
Perfluorotridecanoic Acid	PFTrDA	72629-94-8
Perfluorododecanoic Acid	PFDoA	307-55-1
Perfluoroundecanoic Acid	PFUnA	2058-94-8
Perfluorodecanoic Acid	PFDA	335-76-2
Perfluorononanoic Acid	PFNA	375-95-1
Perfluorooctanoic Acid	PFOA	335-67-1
Perfluoroheptanoic Acid	PFHpA	375-85-9
Perfluorohexanoic Acid	PFHxA	307-24-4
Perfluoropentanoic Acid	PFPeA	2706-90-3
Perfluorobutanoic Acid	PFBA	375-22-4
PERFLUOROALKYL SULFONIC ACIDS (PFSAs)		
Perfluorododecanesulfonic Acid	PFDoDS/PFDoS	79780-39-5
Perfluorodecanesulfonic Acid	PFDS	335-77-3
Perfluorononanesulfonic Acid	PFNS	68259-12-1
Perfluorooctanesulfonic Acid	PFOS	1763-23-1
Perfluoroheptanesulfonic Acid	PFHpS	375-92-8
Perfluorohexanesulfonic Acid	PFHxS	355-46-4
Perfluoropentanesulfonic Acid	PFPeS	2706-91-4
Perfluorobutanesulfonic Acid	PFBS	375-73-5
Perfluoropropanesulfonic Acid	PFPrS	423-41-6
FLUOROTELOMERS		
1H,1H,2H,2H-Perfluorododecanesulfonic Acid	10:2FTS	120226-60-0
1H,1H,2H,2H-Perfluorodecanesulfonic Acid	8:2FTS	39108-34-4
1H,1H,2H,2H-Perfluorooctanesulfonic Acid	6:2FTS	27619-97-2
1H,1H,2H,2H-Perfluorohexanesulfonic Acid	4:2FTS	757124-72-4
PERFLUOROALKANE SULFONAMIDES (FASAs)		
Perfluorooctanesulfonamide	FOSA/PFOSA	754-91-6
N-Ethyl Perfluorooctane Sulfonamide	NEtFOSA	4151-50-2
N-Methyl Perfluorooctane Sulfonamide	NMeFOSA	31506-32-8
PERFLUOROALKANE SULFONYL SUBSTANCES		
N-Ethyl Perfluorooctanesulfonamido Ethanol	NEtFOSE	1691-99-2
N-Methyl Perfluorooctanesulfonamido Ethanol	NMeFOSE	24448-09-7
N-Ethyl Perfluorooctanesulfonamidoacetic Acid	NEtFOSAA	2991-50-6
N-Methyl Perfluorooctanesulfonamidoacetic Acid	NMeFOSAA	2355-31-9
PER- and POLYFLUOROALKYL ETHER CARBOXYLIC ACIDS		
2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic Acid	HFPO-DA	13252-13-6
4,8-Dioxa-3h-Perfluorononanoic Acid	ADONA	919005-14-4
CHLORO-PERFLUOROALKYL SULFONIC ACIDS		
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid	11Cl-PF3OUdS	763051-92-9
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid	9Cl-PF3ONS	756426-58-1
PERFLUOROETHER SULFONIC ACIDS (PFESAs)		
Perfluoro(2-Ethoxyethane)Sulfonic Acid	PFEESA	113507-82-7
PERFLUOROETHER/POLYETHER CARBOXYLIC ACIDS (PFPCAs)		
Perfluoro-3-Methoxypropanoic Acid	PFMPA	377-73-1
Perfluoro-4-Methoxybutanoic Acid	PFMBA	863090-89-5
Nonafluoro-3,6-Dioxaheptanoic Acid	NFDHA	151772-58-6

PFAS PARAMETER SUMMARY

Parameter	Acronym	CAS Number
FLUOROTELOMER CARBOXYLIC ACIDS (FTCAs)		
3-Perfluoroheptyl Propanoic Acid	7:3FTCA	812-70-4
2H,2H,3H,3H-Perfluorooctanoic Acid	5:3FTCA	914637-49-3
3-Perfluoropropyl Propanoic Acid	3:3FTCA	356-02-5

GLOSSARY

Acronyms

DL - Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the limit of quantitation (LOQ). The DL includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

EDL - Estimated Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the reporting limit (RL). The EDL includes any adjustments from dilutions, concentrations or moisture content, where applicable. The use of EDLs is specific to the analysis of PAHs using Solid-Phase Microextraction (SPME).

EMPC - Estimated Maximum Possible Concentration: The concentration that results from the signal present at the retention time of an analyte when the ions meet all of the identification criteria except the ion abundance ratio criteria. An EMPC is a worst-case estimate of the concentration.

EPA - Environmental Protection Agency.

LCS - Laboratory Control Sample: A sample matrix, free from the analytes of interest, spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes.

LCSD - Laboratory Control Sample Duplicate: Refer to LCS.

LFB - Laboratory Fortified Blank: A sample matrix, free from the analytes of interest, spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes.

LOD - Limit of Detection: This value represents the level to which a target analyte can reliably be detected for a specific analyte in a specific matrix by a specific method. The LOD includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

LOQ - Limit of Quantitation: The value at which an instrument can accurately measure an analyte at a specific concentration. The LOQ includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

Limit of Quantitation: The value at which an instrument can accurately measure an analyte at a specific concentration. The LOQ includes any adjustments from dilutions, concentrations or moisture content, where applicable. (DoD report formats only.)

MDL - Method Detection Limit: This value represents the level to which target analyte concentrations are reported as estimated values, when those target analyte concentrations are quantified below the reporting limit (RL). The MDL includes any adjustments from dilutions, concentrations or moisture content, where applicable.

MS - Matrix Spike Sample: A sample prepared by adding a known mass of target analyte to a specified amount of matrix sample for which an independent estimate of target analyte concentration is available. For Method 332.0, the spike recovery is calculated using the native concentration, including estimated values.

MSD - Matrix Spike Sample Duplicate: Refer to MS.

NA - Not Applicable.

NC - Not Calculated: Term is utilized when one or more of the results utilized in the calculation are non-detect at the parameter's reporting unit.

NDPA/DPA - N-Nitrosodiphenylamine/Diphenylamine.

NI - Not Ignitable.

NP - Non-Plastic: Term is utilized for the analysis of Atterberg Limits in soil.

NR - No Results: Term is utilized when 'No Target Compounds Requested' is reported for the analysis of Volatile or Semivolatile Organic TIC only requests.

RL - Reporting Limit: The value at which an instrument can accurately measure an analyte at a specific concentration. The RL includes any adjustments from dilutions, concentrations or moisture content, where applicable.

RPD - Relative Percent Difference: The results from matrix and/or matrix spike duplicates are primarily designed to assess the precision of analytical results in a given matrix and are expressed as relative percent difference (RPD). Values which are less than five times the reporting limit for any individual parameter are evaluated by utilizing the absolute difference between the values; although the RPD value will be provided in the report.

SRM - Standard Reference Material: A reference sample of a known or certified value that is of the same or similar matrix as the associated field samples.

STLP - Semi-dynamic Tank Leaching Procedure per EPA Method 1315.

TEF - Toxic Equivalency Factors: The values assigned to each dioxin and furan to evaluate their toxicity relative to 2,3,7,8-TCDD.

TEQ - Toxic Equivalent: The measure of a sample's toxicity derived by multiplying each dioxin and furan by its corresponding TEF and then summing the resulting values.

TIC - Tentatively Identified Compound: A compound that has been identified to be present and is not part of the target compound list (TCL) for the method and/or program. All TICs are qualitatively identified and reported as estimated concentrations.

Report Format: Data Usability Report

Footnotes

2 - The reference for this analyte should be considered modified since this analyte is absent from the target analyte list of the original method.

Terms

Analytical Method: Both the document from which the method originates and the analytical reference method. (Example: EPA 8260B is shown as 1,8260B.) The codes for the reference method documents are provided in the References section of the Addendum.
Chlordane: The target compound Chlordane (CAS No. 57-74-9) is reported for GC ECD analyses. Per EPA,this compound "refers to a mixture of chlordane isomers, other chlorinated hydrocarbons and numerous other components." (Reference: USEPA Toxicological Review of Chlordane, In Support of Summary Information on the Integrated Risk Information System (IRIS), December 1997.)
Difference: With respect to Total Oxidizable Precursor (TOP) Assay analysis, the difference is defined as the Post-Treatment value minus the Pre-Treatment value.
Final pH: As it pertains to Sample Receipt & Container Information section of the report, Final pH reflects pH of container determined after adjustment at the laboratory, if applicable. If no adjustment required, value reflects Initial pH.
Frozen Date/Time: With respect to Volatile Organics in soil, Frozen Date/Time reflects the date/time at which associated Reagent Water-preserved vials were initially frozen. Note: If frozen date/time is beyond 48 hours from sample collection, value will be reflected in 'bold'.
Gasoline Range Organics (GRO): Gasoline Range Organics (GRO) results include all chromatographic peaks eluting from Methyl tert butyl ether through Naphthalene, with the exception of GRO analysis in support of State of Ohio programs, which includes all chromatographic peaks eluting from Hexane through Dodecane.
Initial pH: As it pertains to Sample Receipt & Container Information section of the report, Initial pH reflects pH of container determined upon receipt, if applicable.
PAH Total: With respect to Alkylated PAH analyses, the 'PAHs, Total' result is defined as the summation of results for all or a subset of the following compounds: Naphthalene, C1-C4 Naphthalenes, 2-Methylnaphthalene, 1-Methylnaphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Fluorene, C1-C3 Fluorenes, Phenanthrene, C1-C4 Phenanthrenes/Anthracenes, Anthracene, Fluoranthene, Pyrene, C1-C4 Fluoranthenes/Pyrenes, Benz(a)anthracene, Chrysene, C1-C4 Chrysenes, Benzo(b)fluoranthene, Benzo(j)+(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Perylene, Indeno(1,2,3-cd)pyrene, Dibenz(ah)+(ac)anthracene, Benzo(g,h,i)perylene. If a 'Total' result is requested, the results of its individual components will also be reported.
PFAS Total: With respect to PFAS analyses, the 'PFAS, Total (5)' result is defined as the summation of results for: PFHpA, PFHxS, PFOA, PFNA and PFOS. In addition, the 'PFAS, Total (6)' result is defined as the summation of results for: PFHpA, PFHxS, PFOA, PFNA, PFDA and PFOS. For MassDEP DW compliance analysis only, the 'PFAS, Total (6)' result is defined as the summation of results at or above the RL. Note: If a 'Total' result is requested, the results of its individual components will also be reported.
Total: With respect to Organic analyses, a 'Total' result is defined as the summation of results for individual isomers or Aroclors. If a 'Total' result is requested, the results of its individual components will also be reported. This is applicable to 'Total' results for methods 8260, 8081 and 8082.

Data Qualifiers

K - Spectra identified as "Aldol Condensates" are byproducts of the extraction/concentration procedures when acetone is introduced in the process.

L - The analyte was detected above the reporting limit in the associated method blank. Flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank. For MCP-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank. For DOD-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte at less than ten times (10x) the concentration found in the blank AND the analyte was detected above one-half the reporting limit (or above the reporting limit for common lab contaminants) in the associated method blank. For NJ-Air-related projects, flag only applies to associated field samples that have detectable concentrations of the analyte above the reporting limit. For NJ-related projects (excluding Air), flag only applies to associated field samples that have detectable concentrations of the analyte, which was detected above the reporting limit in the associated method blank or above five times the reporting limit for common lab contaminants (Phthalates, Acetone, Methylene Chloride, 2-Butanone).

M - Co-elution: The target analyte co-elutes with a known lab standard (i.e. surrogate, internal standards, etc.) for co-extracted analyses.

N - Concentration of analyte was quantified from diluted analysis. Flag only applies to field samples that have detectable concentrations of the analyte.

O - Concentration of analyte exceeds the range of the calibration curve and/or linear range of the instrument.

P - The ratio of quantifier ion response to qualifier ion response falls outside of the laboratory criteria. Results are considered to be an estimated maximum concentration.

Q - The concentration may be biased high due to matrix interferences (i.e, co-elution) with non-target compound(s). The result should be considered estimated.

R - The analysis of pH was performed beyond the regulatory-required holding time of 15 minutes from the time of sample collection.

S - The lower value for the two columns has been reported due to obvious interference.

T - Estimated value. This represents an estimated concentration for Tentatively Identified Compounds (TICs).

N - Reporting Limit (RL) exceeds the MCP CAM Reporting Limit for this analyte.

Report Format: Data Usability Report

Data Qualifiers

ND - Not detected at the reporting limit (RL) for the sample.

NJ - Presumptive evidence of compound. This represents an estimated concentration for Tentatively Identified Compounds (TICs), where the identification is based on a mass spectral library search.

S - The RPD between the results for the two columns exceeds the method-specified criteria.

T - The quality control sample exceeds the associated acceptance criteria. For DOD-related projects, LCS and/or Continuing Calibration Standard exceedences are also qualified on all associated sample results. Note: This flag is not applicable for matrix spike recoveries when the sample concentration is greater than 4x the spike added or for batch duplicate RPD when the sample concentrations are less than 5x the RL. (Metals only.)

U - Analytical results are from sample re-analysis.

RE - Analytical results are from sample re-extraction.

T - Analytical results are from modified screening analysis.

W - The surrogate associated with this target analyte has a recovery outside the QC acceptance limits. (Applicable to MassDEP DW Compliance samples only.)

AA - The batch matrix spike and/or duplicate associated with this target analyte has a recovery/RPD outside the QC acceptance limits. (Applicable to MassDEP DW Compliance samples only.)

REFERENCES

135 Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) using Isotope Dilution. Alpha SOP 23528.

LIMITATION OF LIABILITIES

Alpha Analytical performs services with reasonable care and diligence normal to the analytical testing laboratory industry. In the event of an error, the sole and exclusive responsibility of Alpha Analytical shall be to re-perform the work at it's own expense. In no event shall Alpha Analytical be held liable for any incidental, consequential or special damages, including but not limited to, damages in any way connected with the use of, interpretation of, information or analysis provided by Alpha Analytical.

We strongly urge our clients to comply with EPA protocol regarding sample volume, preservation, cooling, containers, sampling procedures, holding time and splitting of samples in the field.

Certification Information

The following analytes are not included in our Primary NELAP Scope of Accreditation:

Westborough Facility
EPA 624/624.1: m/p-xylene, o-xylene, Naphthalene
EPA 625/625.1: alpha-Terpineol
EPA 8260C/8260D: NPW: 1,2,4,5-Tetramethylbenzene; 4-Ethyltoluene, Azobenzene; SCM: Iodomethane (methyl iodide), 1,2,4,5-Tetramethylbenzene; 4-Ethyltoluene.
EPA 8270D/8270E: NPW: Dimethylnaphthalene,1,4-Diphenylhydrazine, alpha-Terpineol; SCM: Dimethylnaphthalene,1,4-Diphenylhydrazine.
SM4500: NPW: Amenable Cyanide; SCM: Total Phosphorus, TKN, NO2, NO3.

Mansfield Facility
SM 2540D: TSS
EPA 8082A: NPW: PCB: 1, 5, 31, 87,101, 110, 141, 151, 153, 180, 183, 187.
EPA TO-15: Halothane, 2,4,4-Trimethyl-2-pentene, 2,4,4-Trimethyl-1-pentene, Thiophene, 2-Methylthiophene, 3-Methylthiophene, 2-Ethylthiophene, 1,2,3-Trimethylbenzene, Indan, Indene, 1,2,4,5-Tetramethylbenzene, Benzothiophene, 1-Methylnaphthalene. **Biological Tissue Matrix:** EPA 3050B

The following analytes are included in our Massachusetts

DEP Scope of Accreditation Westborough Facility:

Drinking Water
EPA 300.0: Chloride, Nitrate-N, Fluoride, Sulfate; **EPA 353.2**: Nitrate-N, Nitrite-N; **SM4500NO3-F**: Nitrate-N, Nitrite-N; **SM4500F-C, SM4500CN-CE, EPA 180.1, SM2130B, SM4500Cl-D, SM2320B, SM2540C, SM4500H-B, SM4500NO2-B EPA 332**: Perchlorate; **EPA 524.2:** THMs and VOCs; **EPA 504.1:** EDB, DBCP.
Microbiology: **SM9215B; SM9223-P/A, SM9223B-Colilert-QT,SM9222D**.

Non-Potable Water
SM4500H,B, EPA 120.1, SM2510B, SM2540C, SM2320B, SM4500CL-E, SM4500F-BC, SM4500NH3-BH: Ammonia-N and Kjeldahl-N, **EPA 350.1**:
Ammonia-N, **LACHAT 10-107-06-1-B**: Ammonia-N, **EPA 351.1, SM4500NO3-F, EPA 353.2**: Nitrate-N**, SM4500P-E, SM4500P-B, E, SM4500SO4-E, SM5220D, EPA 410.4, SM5210B, SM5310C, SM4500CL-D, EPA 1664, EPA 420.1, SM4500-CN-CE, SM2540D, EPA 300: Chloride, Sulfate, Nitrate.**
EPA 624.1: Volatile Halocarbons & Aromatics,
EPA 608.3: Chlordane, Toxaphene, Aldrin, alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, Dieldrin, DDD, DDE, DDT, Endosulfan I, Endosulfan II, Endosulfan sulfate, Endrin, Endrin Aldehyde, Heptachlor, Heptachlor Epoxide, PCBs **EPA 625.1**: SVOC (Acid/Base/Neutral Extractables), **EPA 600/4-81-045**: PCB-Oil.
Microbiology: **SM9223B-Colilert-QT; Enterolert-QT, SM9221E, EPA 1600, EPA 1603, SM9222D.**

Mansfield Facility:

Drinking Water
EPA 200.7: Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Na, Ag, Ca, Zn. **EPA 200.8:** Al, Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Mn, Ni, Se, Ag, TL, Zn. **EPA 245.1** Hg.
EPA 522, EPA 537.1.

Non-Potable Water
EPA 200.7: Al, Sb, As, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Se, Ag, Na, Sr, TL, Ti, V, Zn.
EPA 200.8: Al, Sb**,** As, Be, Cd, Cr, Cu, Fe, Pb, Mn, Ni, K, Se, Ag, Na, TL, Zn.
EPA 245.1 Hg.
SM2340B