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Per- and Polyfluoroalkyl Substances in New Firefighter Turnout Gear Textiles

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Abstract

Turnout gear is increasingly recognized as a potential source of per- and polyfluoroalkyl substance (PFAS) exposure to firefighters. To determine the identity, concentration, and prevalence of PFAS potentially present in new firefighter turnout gear, fifty-three nonvolatile, semivolatile, and volatile PFAS were quantified in twenty textiles used in the construction of firefighter turnout gear. Between one and 17 PFAS were observed and quantified in each textile, with higher numbers of detections, and higher concentrations of PFAS present in moisture barrier and outer shell textiles compared with thermal liner textiles. 6:2 fluorotelomer methacrylate, 6:2 fluorotelomer alcohol, and 6:2 fluorotelomer sulfonic acid are all fluorotelomerization-derived PFAS with six perfluorinated carbons and they were quantified at the highest concentrations of any PFAS, up to 1,520 µg/kg ± 130 µg/kg (mean ± standard deviation of triplicate measurements of single textile), 613 µg/kg ± 15 µg/kg and 393 µg/kg ± 98 µg/kg, respectively. These three PFAS were not detected in outer shells that had not received fluoropolymer treatments, which could indicate their presence is related to the application of side-chain fluorinated polymers. Also widely observed were two compounds with four perfluorinated carbons: perfluorobutane sulfonic acid and perfluorobutane sulfonamide. Perfluorocarboxylic acids, especially those with fewer than six perfluorinated carbons, were nearly universally identified in turnout gear textiles but at concentrations below 40 µg/kg. In contrast, PFAS with eight or more perfluorinated carbons, such as perfluorooctane sulfonic acid, were present at summed concentrations below 2 µg/kg in all textiles. Summed PFAS concentrations varied widely among each textile type which suggests that the amount of PFAS present in new turnout gear may depend on the specific textiles used in gear manufacturing.

Keywords

Durable water repellent; firefighter; moisture barrier; outer shell; per- and polyfluoroalkyl substances; PFAS; turnout gear; thermal liner.

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Preface

To determine whether firefighters may be exposed to per- and polyfluoroalkyl substances (PFAS) present in their turnout gear, Section 338 of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, titled the "Guaranteeing Equipment Safety for Firefighters Act of 2020," directed the National Institute of Standards and Technology (NIST) to "complete a study of the contents and composition of new and unused personal protective equipment worn by firefighters." And further, that this study shall examine "the identity, prevalence, and concentration of per- and polyfluoroalkyl substances (commonly known as ''PFAS'') in the personal protective equipment worn by firefighters…." In response to this directive, the Fire Research Division (FRD) in the NIST Engineering Laboratory began an investigation of PFAS concentrations in new textiles used in the construction of firefighter turnout gear. This investigation commenced with obtaining moisture barrier, outer shell, and thermal liner textiles from a commercial vendor of firefighting equipment. Additionally, two outer shell textiles that had not been treated with a fluoropolymer water repellent were obtained from the Division of Field Studies and Engineering – Field Research Branch of the National Institute of Occupational Safety & Health. The FRD established an analytical laboratory in which procedures for the extraction of PFAS from firefighter turnout gear textiles were developed and performed while analytical methods for PFAS quantitation in extracts of turnout gear textiles were developed through a collaboration with the NIST Chemical Sciences Division (CSD). A team of researchers in the FRD and CSD met routinely to refine experimental approaches, set quality control standards, and discuss results.

This publication contains the first findings of the NIST study on PFAS in firefighter personal protective equipment, detailing the targeted analysis of 53 nonvolatile, semivolatile, and volatile PFAS in textiles used to manufacture firefighter turnout gear. Upcoming reports will quantify PFAS concentrations in assembled gear, including gloves and hoods, as well as address additional requirements of the Guaranteeing Equipment Safety for Firefighters Act of 2020 that instruct NIST to determine the extent to which PFAS are released from turnout gear through the degradation of that gear during its typical use.

Acknowledgments

We thank United States Senator Jeanne Shaheen and her staff for their support of PFAS-fire fighter gear research at NIST. Additionally, we thank Crystal Forester from the National Personal Protective Technology Laboratory (NPPTL) for providing scoured firefighter turnout gear textiles.

Author Contributions

Bruce Benner: Methodology; Investigation; **Rick Davis:** Conceptualization, Funding acquisition; Project administration; Resources; Supervision; **Michelle Donnelly:** Resources; **Samuel Escobar Veras:** Investigation; **Ryan Falkenstein-Smith:** Methodology, Investigation; **Oliva Hernandez:** Investigation; **Kathleen Hoffman:** Investigation; **John Kucklick:** Validation; **Andrew Maizel:** Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing; **Trung Ngu:** Investigation; **Benjamin Place:** Resources, Validation, Writing – review & editing; **Jessica Reiner:** Methodology, Validation, Writing – review & editing; **Catherine Rimmer:** Resources; **Alix Rodowa:** Methodology, Investigation, Validation, Writing – review & editing; **Andre Thompson:** Conceptualization, Investigation, Methodology, Resources, Supervision; **Meghanne Tighe:** Investigation, Supervision; **Nadine Wetzler:** Investigation.

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) comprise a diverse class of anthropogenic materials that include dozens of compounds previously documented in firefighter turnout gear and other high-performance outerwear [1-3]. To impart water resistance to textiles, PFAS are typically added as fluorinated polymers either in porous membranes, such as expanded polytetrafluoroethylene (ePTFE) fluoropolymers, or applied treatments featuring side-chain fluorinated polymers which consist of nonfluorinated polymer backbones and polyfluorinated side chains [4]. PFAS used in the production of side-chain fluorinated polymers are manufactured through one of two processes, electrochemical fluorination (ECF) or fluorotelomerization (FT), and certain molecular structures are considered characteristic of PFAS manufactured by each process [4, 5]. For example, PFAS containing perfluorinated chains connected directly to sulfonamide or sulfonate functional groups are associated with ECF-manufacturing while PFAS with alkyl chains that are perfluorinated except for two non-fluorinated carbons which connect the perfluorinated chain to terminal functional groups are associated with FT-manufacturing [4].

Turnout gear protects firefighters from “thermal, physical, environmental, and bloodborne pathogen hazards encountered during structural firefighting operations [6].” In the United States, performance specifications for turnout gear are specified in the National Fire Protection Association (NFPA) *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* (NFPA 1971) [6] as well as NFPA *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* (NFPA 1851) [7]. Turnout gear typically includes pants and a jacket, each with three layers: an outer shell on the outside of the garment, a moisture barrier beneath the outer shell, and a thermal liner closest to the firefighter’s body [6]. NFPA 1971 § 8.62 (“Light Degradation Resistance Test”) requires that moisture barriers maintain hydrostatic resistance following exposure to simulated sunlight and humidity [6], while NFPA 1971 §7.1.18 specifies a maximum water absorption for outer shell textiles [6]. To meet these specifications, moisture barrier and outer shell textiles may include ePTFE membranes or durable water repellent (DWR) treatments featuring side-chain fluorinate polymers [2].

Examinations of PFAS in firefighter turnout gear and dust from firefighter gear storage facilities have identified fluorinated polymers as well as numerous PFAS classes including perfluorocarboxylic acids (PFCAs), perfluoroalkane sulfonic acids (PFSAs), and n:2 fluorotelomer alcohols (n:2 FTOHs) [1-3, 8]. While PFAS concentrations in fluorinated polymer treated textiles have been shown to increase with weathering, PFAS have also been identified in new turnout gear, which may indicate they are residual materials from fluorinated polymer manufacturing [1, 9]. These residual materials may be PFAS monomers that were not completely incorporated into fluorinated polymers or “processing aids” used in fluorinated polymer production [4]. Historically, long-chain (i.e., containing eight or more perfluorinated carbons) PFCAs were used as processing aids, but these have at least partially been replaced by per- and polyfluoroalkyl ether acids (PPEA) such as 4,8-dioxa-3H-perfluorononanoate (ADONA) or hexafluoropropylene oxide dimer acid (HFPO-DA) [4, 10]. A recent examination of fluoropolymers manufactured in China observed both long-chain PFCAs as well as perfluoropolyethers in the finished products [11].

Employment as a firefighter has been found to correlate with higher serum PFAS concentrations, especially for those directly engaged in firefighting activities [12, 13], and numerous potential PFAS exposure pathways for firefighters have been documented, including fire scenes, aqueous film-forming foams [14], food grown at fire stations [15], and firefighter turnout gear [1-3]. The health effects of PFAS exposure are a subject of extensive ongoing research. For example, cancer incidence data are only available for a subset of known PFAS (e.g., perfluorooctanoic acid [PFOA] and perfluorooctane sulfonic acid [PFOS]) [16, 17]. PFOA has been categorized as a class 2B human carcinogen [18], and the US Environmental Protection Agency (EPA) has classified PFOA and PFOS as likely human carcinogens and HFPO-DA as a suggestive human carcinogen [19-24]. Recent EPA toxicological assessments for HFPO-DA, perfluorobutane sulfonic acid (PFBS), PFOA, and PFOS have cited concern over suppression of vaccine response (PFOA and PFOS), liver lesions (HFPO-DA), and decreased serum thyroid hormone serum concentrations (PFBS) as the critical health effects used to determine chronic reference dose [25-28]. Toxicity studies of oral PFHxS exposure to animals also have reported health effects on the liver, thyroid, and development [29]. Additionally, studies of oral PFNA exposure in rodents have reported adverse effects on the liver, development, and reproductive and immune systems [29].

This publication describes research performed in response to the Fiscal Year 2021 National Defense Authorization Act (H.R. 6395) [30], which directs the National Institute of Standards and Technology (NIST) to "examine…the identity, prevalence, and concentration of per- and polyfluoroalkyl substances…in the personal protective equipment worn by firefighters…." To quantify a broad cross section of PFAS, two extraction protocols and three analytical methods were developed and applied to determine the concentrations of 53 PFAS in 20 turnout gear textiles. The concentrations reported here will provide insight into the type and prevalence of PFAS that firefighters could be exposed to from wearing new turnout gear and will provide a baseline for future examinations of PFAS concentrations in weathered turnout gear.

2. Materials and Methods

2.1. Materials

Ammonium acetate (Optima LC-MS grade), ammonium hydroxide (Optima grade), ethyl acetate (Optima HPLC and GC grade), and water (Optima LC-MS grade) were obtained from Thermo Fisher Scientific (Waltham, MA).[1] Methanol (OmniSolv LC-MS grade) for high performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS) mobile phase solutions was obtained from Supelco (Bellefonte, PA), while methanol (Optima LC-MS grade) for all other purposes was obtained from Thermo Fisher Scientific. Nitrogen gas (Ultra High Purity grade) and helium gas (Ultra High Purity grade) were obtained from Roberts Oxygen (Rockville, MD).

High-performance liquid chromatography (HPLC) vials (2 mL capacity, amber glass) and glass vial inserts (250 µL) were obtained from Agilent Technologies (Santa Clara, CA). Polyethylene 2 mL vial caps for nonvolatile and semivolatile analysis were obtained from Phenomenex (Torrence, CA) while 2 mL vial caps with PTFE/silicone septa for volatile analysis were obtained from

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[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Agilent Technologies. HPLC vials, inserts, and caps were used as received from their vendors. Supelco Analytical (Bellefone, PA) Supelclean ENVI-Carb solid phase extraction (SPE) tubes (6 mL x 500 mg) were rinsed with 20 mL (2 x 10^{-5} m^3) of 0.1 mol/L (10^2 mol/m^3) ammonium hydroxide in methanol and dried prior to use. Glass 20 mL capacity scintillation vials, glass Pasteur pipettes, and polypropylene 15 mL centrifuge tubes (Cole-Parmer Instrument Company, Vernon Hills, IL) were used as received. Syringes (1 mL capacity) and syringe filters (0.22 µm, nylon) were obtained from Thermo Fisher and rinsed with 1 mL (10^{-6} m^3) methanol prior to use.

2.2. Firefighter Turnout Gear Textiles

A variety of turnout gear textiles was purchased in 2020 from a distributor and repairer of firefighter gear, who received the textiles from the original manufacturers. The textiles selected were representative of those commonly used in the construction of firefighter's jacket and pants (e.g., common fabric types, fabric constructions and manufacturers). When textiles differed only by color (same fabric type and construction, and manufacturer) only one color was included in the study. Other factors, such as cost/on sale and availability, were not considered. All textiles were purchased prior to assembly in firefighter turnout gear and were established to comply with the requirements of NFPA 1971 [6]. The textiles in this study were 1.39 m^2 (1.52 m x 0.914 m) each of six moisture barrier (MB-A, MB-B, MB-C, MB-D, MB-E, MB-F), five thermal liner (TL-A, TL-B, TL-C, TL-D, TL-E), and seven outer shell textiles (OS-A, OS-B, OS-C, OS-D, OS-E, OS-F, OS-G).

Two "scoured" outer shell textiles (OS-ASC, OS-FSC) were obtained from the Division of Field Studies and Engineering – Field Research Branch of the National Institute of Occupational Safety & Health. The "scoured" textiles were similar to two other outer shell textiles included in this study (i.e., OS-A and OS-F, respectively), except that no fluorinated polymer treatment had been applied and they were different colors. Due to the lack of DWR treatment, the two scoured outer shell textiles were not established to be NFPA 1971 compliant. Average area densities and pictures of all turnout gear textiles are shown in Appendix A.1 (Table 22).

Moisture barrier textiles were all comprised of an ePTFE membrane with an aramid fiber substrate while outer shell textiles were all comprised of aromatic polyamide (aramid) fiber blends that were woven with either plain, twill, or ripstop weave patterns. Thermal liner textiles consisted of aramid fiber or aramid-blend cloth, with one or two layers of attached aramid fiber batting. Prior to PFAS extractions all textiles were stored in separate sealed plastic containers in the dark at room temperature.

2.3. PFAS Analytical Standards

The selection of PFAS for inclusion in this study was based on previous reports in the scientific literature, the professional experience of NIST researchers related to PFAS and firefighter gear, as well as conversations with subject matter experts outside NIST. Analytical standards were obtained for 53 PFAS including 11 PFCAs, eight PFSAs, six perfluoroalkane sulfonamides (FASA), three per- and polyfluoroalkane sulfonamido acetic acids (FASAA), two perfluoroalkane sulfonamido ethanols (FASE), eight PPEAs, six n:2 FTOHs, three n:2 fluorotelomer methacrylates (n:2 FTMAC), two n:2 fluorotelomer acetates (n:2 FTOAc), and four n:2 fluorotelomer sulfonates (n:2 FTS). Information for all PFAS and their associated reference standards are provided in Table 1 and Appendix A.2 (Tables 23 – 28).

Table 1. Class names and abbreviations as well as individual compound names, abbreviations, analytical method used for quantification (i.e., nonvolatile, semivolatile, or volatile) as well as Chemical Abstract Service Registry Numbers (CAS RN) of all PFAS analyzed in this publication.

Class	Name	CAS RN
Perfluorocarboxylic acids (PFCA)	Perfluorobutanoic acid (PFBA) - nonvolatile	375-22-4
	Perfluoropentanoic acid (PFPeA) - nonvolatile	2706-90-3
	Perfluorohexanoic acid (PFHxA) - nonvolatile	307-24-4
	Perfluoroheptanoic acid (PFHpA) - nonvolatile	375-85-9
	Perfluorooctanoic acid (PFOA) - nonvolatile	335-67-1
	Perfluorononanoic acid (PFNA) - nonvolatile	375-95-1
	Perfluorodecanoic acid (PFDA) - nonvolatile	335-76-2
	Perfluoroundecanoic acid (PFUnDA) - nonvolatile	2058-94-8
	Perfluorododecanoic acid (PFDoDA) - nonvolatile	307-55-1
	Perfluorotridecanoic acid (PFTrDA) - nonvolatile	72629-94-8
	Perfluorotetradacanoic acid (PFTeDA) - nonvolatile	0376-06-07
Perfluoroalkane sulfonic acids (PFSA)	Perfluoropropane sulfonic acid (PFPrS) - nonvolatile	423-41-6
	Perfluorobutane sulfonic acid (PFBS) - nonvolatile	375-73-5
	Perfluoropentane sulfonic acid (PFPeS) - nonvolatile	2706-91-4
	Perfluorohexane sulfonic acid (PFHxS) - nonvolatile	108427-53-8
	Perfluoroheptane sulfonic acid (PFHpS) - nonvolatile	375-92-8
	Perfluorooctane sulfonic acid (PFOS) - nonvolatile	45298-90-6
	Perfluorononane sulfonic acid (PFNS) - nonvolatile	68259-12-1
	Perfluorodecane sulfonic acid (PFDS) - nonvolatile	335-77-3
Perfluoroalkane sulfonamides (FASAs	Perfluorobutane sulfonamide (FBSA) - nonvolatile	30334-69-1
	Perfluorohexane sulfonamide (FHxSA) - nonvolatile	41997-13-1
	Perfluorooctane sulfonamide (FOSA) - nonvolatile	754-91-6
	N-Methyl perfluorobutane sulfonamide (MeFBSA) - semivolatile	68298-12-4
	N-Methyl perfluorooctane sulfonamide (MeFOSA) – semivolatile	31506-32-8
	N-Ethyl perfluorooctane sulfonamide (EtFOSA) - semivolatile	4151-50-2
Perfluoroalkane sulfonamido acetic acids (FASAA)	Perfluorooctane sulfonamido acetic acid (FOSAA) - nonvolatile	2806-24-8
	N-Methyl perfluorooctane sulfonamido acetic acid (MeFOSAA) – nonvolatile	2355-31-9
	N-Ethyl perfluorooctane sulfonamido acetic acid (EtFOSAA) - nonvolatile	2991-50-6
Perfluoroalkane sulonamido ethanols (FASE)	*N*-Methyl perfluorooctane sulfonamido ethanol (MeFOSE) - semivolatile	24448-09-07
	N-Ethyl perfluorooctane sulfonamido ethanol (EtFOSE) - semivolatile	1691-99-2
Per- and polyfluoroalkyl ether acids (PPEA)	Perfluoro-3-methoxypropanoic acid (PF4OPeA) - nonvolatile	377-73-1
	Perfluoro-2-ethoxyethane sulfonic acid (PFEESA) - nonvolatile	113507-82-7
	Perfluoro-4-methoxybutanoic acid (PF5OHxA) - nonvolatile	863090-89-5
	Perfluoro-3,6-dioxaheptanoic acid (3-6-OPFHpA) - nonvolatile	151772-58-6
	Hexafluoropropylene oxide dimer acid (HFPO-DA) - nonvolatile	13252-13-6
	4,8-Dioxa-3H-perfluorononanoate (ADONA) - nonvolatile	958445-44-8
	9-Chlorohexadecafluoro-3-oxanone-1-sulfonic acid (9Cl-PF3ONS) - nonvolatile	756426-58-1
	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS) - nonvolatile	763051-92-9

Table 1. (Continued)

Class	Name	CAS RN
n:2 Fluorotelomer methacrylates (n:2 FTMAC)	6:2 Fluorotelomer methacrylate (6:2 FTMAC) - volatile	2144-53-8
	8:2 Fluorotelomer methacrylate (8:2 FTMAC) - volatile	1996-88-9
	10:2 Fluorotelomer methacrylate (10:2 FTMAC) - volatile	2144-54-9
n:2 Fluorotelomer acetates (n:2 FTOAc)	8:2 Fluorotelomer acetate (8:2 FTOAc) - volatile	37858-05-02
	10:2 Fluorotelomer acetate (10:2 FTOAc) - volatile	37858-05-02
n:2 Fluorotelomer alcohols (n:2 FTOH)	4:2 Fluorotelomer alcohol (4:2 FTOH) - volatile	2043-47-2
	5:2 sFluorotelomer alcohol (5:2 FTOH) - volatile	914637-05-1
	6:2 Fluorotelomer alcohol (6:2 FTOH) - volatile	647-42-7
	7:2 sFluorotelomer alcohol (7:2 FTOH) - volatile	24015-83-6
	8:2 Fluorotelomer alcohol (8:2 FTOH) - volatile	678-39-7
	10:2 Fluorotelomer alcohol (10:2 FTOH) - volatile	87017-97-8
n:2 Fluorotelomer sulfonic acids (n:2 FTS)	4:2 Fluorotelomer sulfonic acid (4:2 FTS) - nonvolatile	757124-72-4
	6:2 Fluorotelomer sulfonic acid (6:2 FTS) - nonvolatile	27619-97-2
	8:2 Fluorotelomer sulfonic acid (8:2 FTS) - nonvolatile	39108-34-4
	10:2 Fluorotelomer sulfonic acid (10:2 FTS) - nonvolatile	120226-60-0

2.4. Chemical Analysis of PFAS in Firefighter Turnout Gear Textiles

Three analytical procedures, referred to in this report as “nonvolatile,” “semivolatile,” and “volatile”, were developed for the quantification of a chemically diverse set of 53 PFAS in firefighter turnout gear textiles. An extraction procedure for nonvolatile PFAS in firefighter turnout gear was derived from the method of Robel et al. [31]. Briefly, isotopically labeled PFAS internal standard solutions were added to turnout gear textile sections (approximately 0.1 g) before PFAS were extracted from the sections by three rounds of sonication in methanol. After each sonication round, extraction solvents were poured off and passed through ENVI-Carb SPE material to remove dyes. Following all three extraction rounds, the extraction solvents were combined and evaporated to dryness under nitrogen before being reconstituted in methanol. Subsequently, this method was adapted for the extraction of semivolatile and nonvolatile PFAS by replacing methanol with ethyl acetate as the extraction solvent and concentrating the extracts to 2 mL (2×10^{-6} m^3) instead of evaporating them to dryness to limit the loss of volatile PFAS. Nonvolatile and semivolatile PFAS were quantified with separate HPLC-MS/MS methods, while volatile PFAS were quantified with gas chromatography-mass spectrometry (GC-MS). Further details of the chemical analysis methods, including information regarding blank correction and the calculation of reporting limits (RL), can be found in Appendix A.

3. Results

Across all 20 examined turnout gear textiles, 26 individual PFAS were quantified above the analyte- and sample-specific RLs, with between one and 17 PFAS quantified in each textile (Fig. 1, Tables 2-21). Perfluorocarboxylic acids, especially those with short perfluorinated chains (i.e., containing fewer than six perfluorinated carbons) were frequently quantified, with perfluorobutanoic acid (PFBA), perfluoropentanoic acid (PFPeA), and perfluorohexanoic acid (PFHxA) observed in 11, 14, and 16 textiles, respectively. Longer chain PFCAs, PFOA, perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA) were each detected in seven textiles while perfluoroheptanoic acid (PFHpA) was detected in nine and textiles. Also widely detected were PFBS and perfluorobutane sulfonamide (FBSA; both were detected in 16 textiles) as well as 6:2 fluorotelomer alcohol (6:2 FTOH; 10 textiles), 6:2 fluorotelomer methacrylate (6:2 FTMAC; 11 textiles), and 6:2 fluorotelomer sulfonic acid (6:2 FTS; seven textiles).

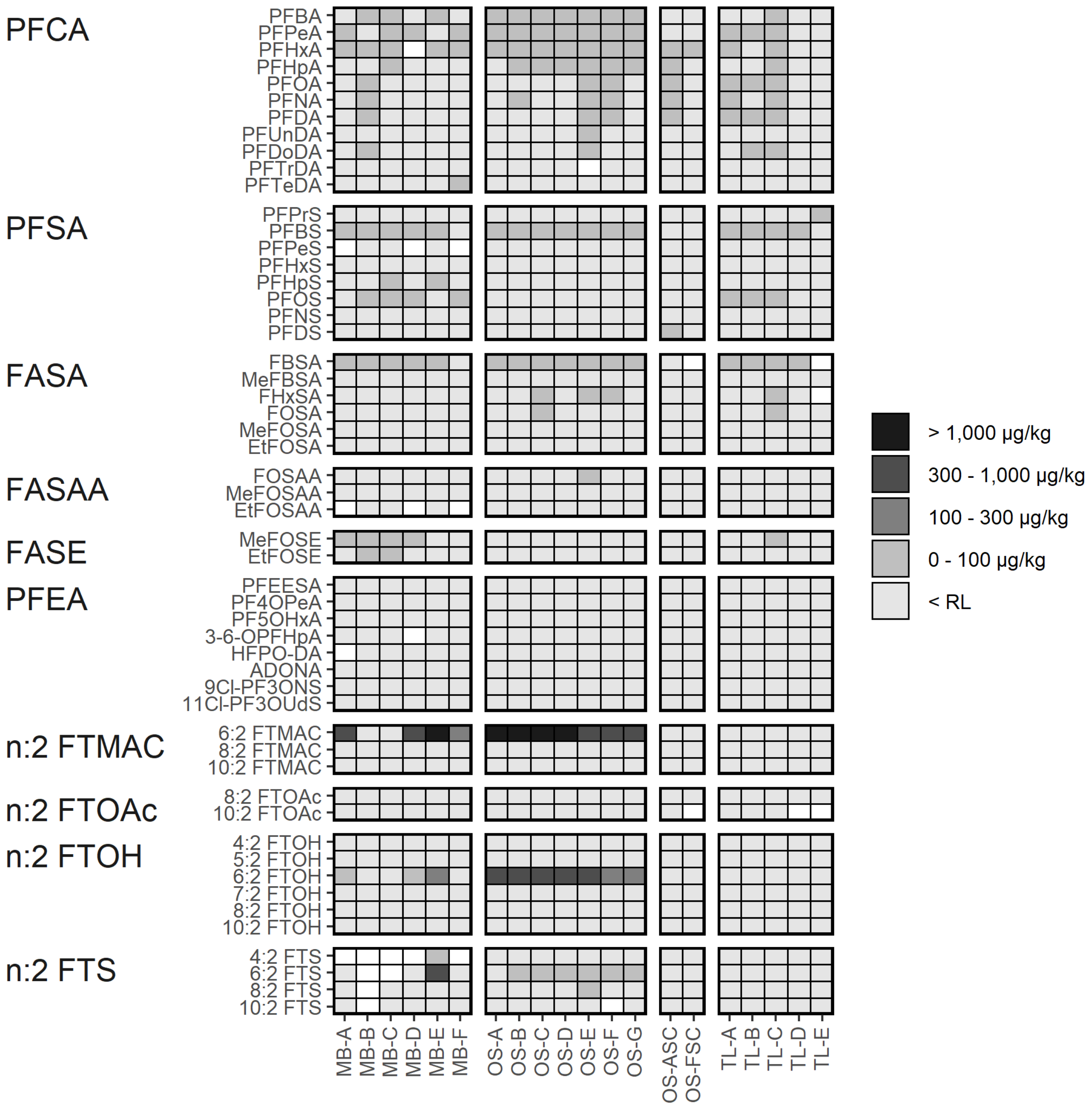

Fig. 1. Average PFAS concentrations determined from triplicate analysis of firefighter turnout gear textiles. Average concentration is indicated by shade (legend at right). Measurements that could not be reported due to QC standards not being met are indicated with white. µg PFAS/kg textile is equivalent to ppb mass ratio. Measured PFAS concentrations in firefighter turnout gear textiles are also presented in Tables 2 - 21.

In each moisture barrier textile, up to 11 individual PFAS were quantified above RLs (Fig. 1, Tables 2 – 7) and the highest individual concentrations were observed for FT-derived PFAS with six perfluorinated carbons: 6:2 FTMAC (up to 1,010 µg/kg ± 86 µg/kg; mean ± standard deviation of triplicate measurements; MB-E; Table 6), 6:2 FTOH (up to 178.9 µg/kg ± 8.3 µg/kg; MB-E; Table 6), and 6:2 FTS (up to 613 µg/kg ± 15 µg/kg; MB-E; Table 6). Summed PFAS concentrations varied widely across moisture barrier textiles from 11.1 µg/kg ± 1.8 µg/kg (sum ± combined standard uncertainty; MB-B; Fig. 2; Table 3) to 1,865 µg/kg ± 88 µg/kg (MB-E; Table 6). The wide range in summed PFAS concentrations derived from the variation in 6:2 FTMAC, 6:2 FTOH, and 6:2 FTS concentrations as summed PFAS concentrations were at least 161 µg/kg ± 51 µg/kg in moisture barrier textiles when at least one of these were detected, compared with at most 64.1 µg/kg ± 2.2 µg/kg when none were.

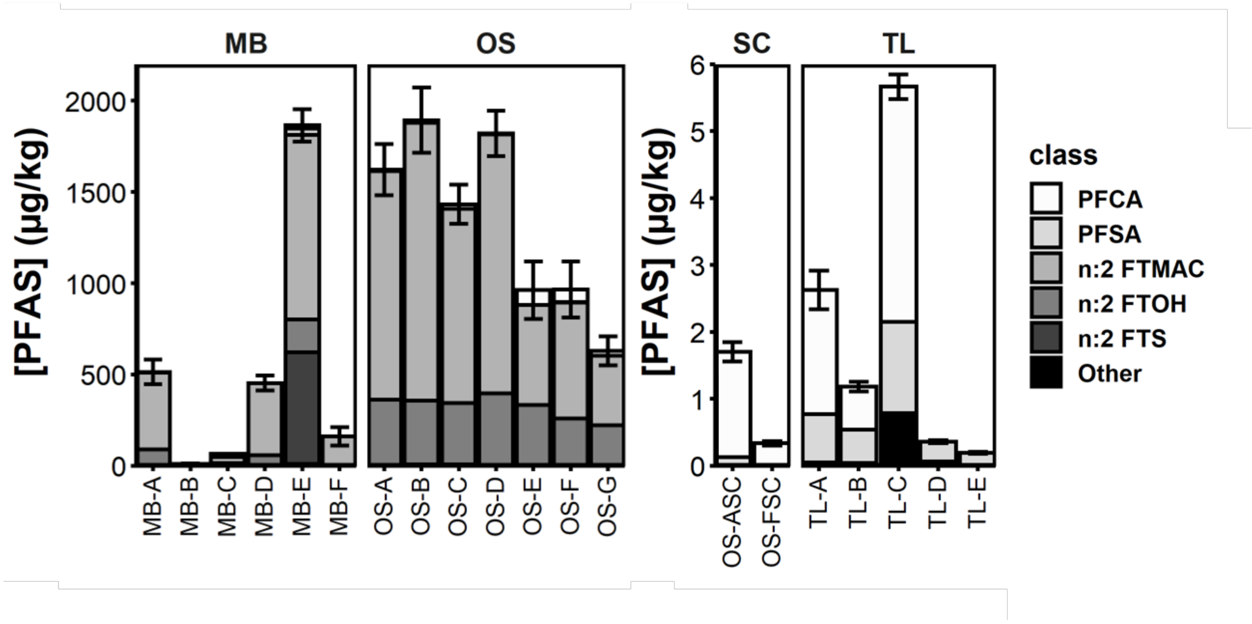

Fig. 2. Summed PFAS concentrations in firefighter turnout gear textiles according to textile type (MB = moisture barrier, OS = outer shell, SC = non-DWR treated outer shell, TL = thermal liner). Error bars indicate the combined standard uncertainty of the summed PFAS concentrations. Bar color indicates PFAS class.

Among DWR treated outer shell textiles, up to 17 individual PFAS were quantified above reporting limits and PFBS, 6:2 FTOH, and 6:2 FTMAC were universally detected while short-chain PFCAs were nearly universally detected (Fig. 1, Tables 8, 10 – 14, 16). Summed PFAS concentrations were more consistent than those observed for moisture barrier textiles, varying from 629 µg/kg ± 79 µg/kg (OS-G; Fig. 2; Table 16) to 1,890 µg/kg ± 180 µg/kg (OS-B; Table 10). 6:2 FTMAC (382 µg/kg ± 43 µg/kg to 1,520 µg/kg ± 130 µg/kg) and 6:2 FTOH (220 µg/kg ± 67 µg/kg to 393 µg/kg ± 98 µg/kg) were recorded in the highest concentrations of any PFAS and together made up at least 91 % of the summed PFAS mass in all treated outer shell textiles. Higher summed PFCA concentrations were observed in treated outer shell textiles than any other textile type, up to 81.4 µg/kg ± 1.4 µg/kg (OS-E; Table 13). However, PFCAs accounted for less than 9 % of the total summed PFAS mass in all treated outer shell textiles.

PFHxA was quantified in both scoured outer shell textiles while four other PFCAs (i.e., PFHpA, PFOA, PFNA, and PFDA) as well as PFDS were also quantified above the reporting limit in OS-ASC (Fig. 1, Tables 9, 15). No semivolatile, volatile, or FT-derived PFAS was quantified above the reporting limit in either scoured outer shell textile. Summed PFAS concentrations in the scoured outer shell textiles were between 0.335 µg/kg ± 0.032 µg/kg (OS-FSC; Fig. 2; Table 14) to 1.70 µg/kg ± 0.15 µg/kg (OS-ASC; Table 9), far below the summed concentrations recorded in treated outer shell textiles. The highest individual PFAS reported in scoured outer shell textiles was PFHxA in OS-ASC (0.59 µg/kg ± 0.122 µg/kg; Table 9).

Between one and 14 PFAS were quantified above the reporting limits in thermal liner textiles, though only a single semivolatile PFAS (i.e., *N*-methyl perfluorooctane sulonamido ethanol in TL-C; Table 19) and no volatile or FT-derived PFAS were quantified above reporting limits in any thermal liner textile. Most widely detected were FBSA and PFBS, which were each quantified in four of five thermal liner textiles, while PFPeA, PFOA, PFDA, and PFOS were each quantified in three of five. Summed PFAS concentrations in thermal liner textiles were much lower than those determined in moisture barrier or treated outer shell textiles and ranged from 0.190 µg/kg ± 0.014 µg/kg (TL-E; Fig. 2; Table 21) to 5.66 µg/kg ± 0.19 µg/kg (TL-C; Table 19). The highest individual PFAS concentration recorded in thermal liner textiles was PFBS in TL-C at 1.23 µg/kg ± 0.08 µg/kg (Table 19).

4. Discussion

6:2 FTMAC and 6:2 FTOH are intermediates in the production of side-chain fluorinated acrylate polymers [4, 32] and have both been previously identified in turnout gear textiles [2, 3]. 6:2 FTMAC and 6:2 FTOH were either both detected, or both not detected, in 19 out of 20 textiles examined here. The presence of these FT-derived PFAS in moisture barrier textiles may indicate that these textiles were treated with side-chain fluorinated polymers in addition to their containing an ePTFE membrane. A related compound, 6:2 FTS is reported here at concentrations (i.e., 613 µg/kg ± 15 µg/kg; MB-E; Table 6) up to over an order of magnitude higher than concentrations seen in other studies of turnout gear (i.e., up to 39.3 µg/kg) [1, 2]. 6:2 FTS has also been identified in high performance outdoor clothing, but at much lower concentrations than other fluorotelomer compounds such as 6:2 FTMAC or 6:2 FTOH [9]. While 6:2 FTS is an established environmental transformation product of other fluorotelomer-derived PFAS [4], the textiles analyzed in this publication were purchased prior to their assembly into turnout gear and stored in the dark at room temperature for approximately one year prior to extraction. Therefore, the detection of 6:2 FTS could indicate the compound is derived from textile manufacturing rather than transformation in the environment. Fluorotelomerization-derived PFAS with more or less than six perfluorinated carbons were not widely detected, with only 4:2 FTS and 8:2 FTS each being quantified in a single textile.

PFBS and FBSA are both ECF-derived PFAS with four perfluorinated carbons. They were both present above the reporting limit in the same 16 textiles and were observed in the highest concentrations (i.e., 8.6 µg/kg to 34 µg/kg) in MB-C and MB-E, which may indicate that they are derived from the same applied treatments. Short-chain PFSAs are used in water and stain repellent treatments, for example PFBS replaced PFOS as the active ingredient in a leading durable water repellent treatment since 2003 [32], and FASAs are raw materials for a range of fluorochemical products including surface protection products [4]. Additionally, the four perfluorinated carbon compounds PFBS and *N*-methyl perfluorobutane sulonamidoethanol (MeFBSE) gave the highest observed PFAS concentrations in two recent investigations of PFAS in firefighter turnout gear [1, 2]. That both FT- and ECF-derived PFAS were widely quantified in the textiles studied here suggests that removing PFAS entirely from turnout gear would require multiple changes to firefighter turnout gear manufacturing.

While no individual PFCA was present above 40 µg/kg in any textile, PFCAs were widely detected with at least one quantified above the reporting limit in 18 out of 20 textiles. This agrees with two previous studies of PFCA concentrations in turnout gear that reported the near universal quantification of short chain PFCAs, and occasional detection of PFCAs with up to 13 perfluorinated carbons, though all at individual concentrations below 40 µg/kg [1, 2]. The near ubiquity of low concentrations of PFCAs may reflect their use as fluoropolymer processing aids [4], indicate contaminated manufacturing facilities [11], or arise from cross-contamination during shipment and storage. That PFCAs were determined here to be present in untreated outer shell textiles at much lower concentrations than in treated outer shell textiles (ΣPFCAs = 0.335 µg/kg ± 0.032 µg/kg to 1.58 µg/kg ± 0.14 µg/kg in untreated outer shells vs. 5.32 µg/kg ± 0.47 µg/kg to 81.4 µg/kg ± 1.4 µg/kg in treated outer shells) could indicate that the application of DWR treatments contributed PFCAs to treated outer shell textiles. PPEAs, replacement polymer processing aids for PFCAs, were not present above reporting limits in any textile (Fig. 1) which agrees with another recent examination of PFAS in firefighter gear that found none of four PPEAs to be present above detection limits in any examined turnout gear layer [2].

The large variation in summed PFAS concentrations among moisture barrier and treated outer shell textiles suggests that the amount of PFAS in new turnout gear varies according to the textiles used in manufacturing that gear (Fig. 2). For example, an article of turnout gear that contained the same mass of each textile layer would have almost six times as much summed mass of the PFAS reported here if it were constructed of MB-E, OS-B, and TL-C compared with a similar garment constructed of MB-B, OS-G, and TL-E. As all moisture barrier, DWR-treated outer shell, and thermal liner textiles examined here met NPFA standards for use in turnout gear, this finding suggests that the amount of PFAS present in new turnout gear might, in some cases, be lowered through the choice of commercially available textiles. However, while the summed PFAS concentrations in some moisture barrier and outer shell textiles approached 2,000 µg/kg, all thermal liner textiles had summed PFAS concentrations under 6 µg/kg. The low summed PFAS concentrations likely reflect the lack of fluorinated polymer treatments in thermal liner textiles that are not subject to moisture repellency standards. That thermal liners are the closest layer to firefighter skin in finished turnout gear could imply lower dermal PFAS exposure to firefighters than would be assumed by summing the PFAS present in all layers. However, other studies have found similar PFAS concentrations in thermal liners as in other turnout gear textiles [1], and the results presented here may be specific to the PFAS and textiles examined in this study.

PFAS concentrations and types in turnout gear vary between this and other recent reports (Fig. 3) [1-3]. However, the use of dissimilar analytical methods and the examination of turnout gear manufactured in earlier decades likely contributed to some of the apparent differences in PFAS concentrations. Peaslee et al. [1] quantified nonvolatile PFAS in turnout gear layers produced between 2008 and 2017 with 2 x 10^3 mol NaOH/m^3 water as an extraction solvent and reported

PFBS concentrations up to 90,400 µg/kg (Fig. 3). However, the use of this basic extraction solution resulted in PFBS measurements in fire station dust that were over 100 times higher than equivalent measurements made with methanol [1]. Therefore the reported PFBS concentrations may be affected by the transformation of other nonpolymer PFAS into PFBS or the base-mediated hydrolysis of fluorinated polymers [33]. PFAS concentrations determined using methanol as an extraction solution may provide better insight into the nonpolymer PFAS concentrations currently present in turnout gear textiles while basic extraction solutions may better probe the amount of nonpolymer PFAS that could be released during textile lifetimes. Muensterman et al. [2] reported summed nonvolatile and volatile PFAS concentrations up to 43,000 µg/kg in firefighter pants layers produced in 2008 or 2019. However, the highest concentrations reported (i.e., MeFBSE at approximately 40,000 µg/kg in two moisture barriers) were determined without the use of a known concentration MeFBSE reference standard.

Fig. 3. Summed PFAS concentrations in individual turnout gear textiles determined here as well as similar measurements from three recent reports [1-3]. Measurements from each report are ordering from left to right in increasing summed concentrations. The textile type (MB for moisture barrier, OS for outer shell, TL for thermal liner, and Unspecified when the specific layers analyzed are not known) is indicated by the marker shade.

Finally, Rewerts et al. [3] measured volatile PFAS in a used turnout gear jacket and quantified n:2 FTOHs with 6, 8, 10, and 12 perfluorinated carbons at individual concentrations up to 1,800 µg/kg (8:2 FTOH). These findings do not align with the results reported here which found PFAS with eight or more perfluorinated carbons were all present at summed concentrations under 2 µg/kg in all textiles. As the textiles examined in this study were commercially available in 2020, the low observed concentrations of long-chain PFAS was likely a result of the US EPA 2010/15 PFOA Stewardship Program, through which eight major producers of fluoropolymers and telomer manufacturers agreed to eliminate PFOA and its likely precursors (i.e., PFAS containing more than six perfluorinated carbons) from products and emissions by 2015. The jacket examined in Rewets et al. [3] was already used by 2018 and may have included textiles manufactured prior to the long chain phaseout. Muensterman et al. [2] also reported the presence of n:2 FTOHs with more than six perfluorinated carbons in turnout gear layers manufactured in 2008, but not in layers manufactured in 2019.

5. Summary

This study utilized a targeted analytical approach to quantify 53 nonvolatile, semivolatile, and volatile PFAS across 20 moisture barrier, outer shell, and thermal liner textiles. Two extraction protocols were developed to maximize the recovery of targeted PFAS while minimizing the potential degradation of other polymer and nonpolymer PFAS. Nonvolatile and semivolatile PFAS were quantified with separate HPLC-MS/MS methods, while volatile PFAS were quantified with GC-MS.

Of the 53 PFAS examined, 27 were quantified below reporting limits in all analyzed textiles, while the remaining 26 were each quantified in between one and 16 textiles. 6:2 FTMAC, 6:2 FTOH, and 6:2 FTS were present in the highest observed concentrations, though they were only present above reporting limits in moisture barrier and DWR-treated outer shell textiles. Summed PFAS concentrations were much higher in moisture barriers and DWR-treated outer shell textiles than in untreated outer shell and thermal liner textiles. Additionally, PFAS concentrations varied within textile types, with largest differences observed among moisture barrier textiles.

This study adds to a growing literature examining firefighter turnout gear that found PFAS concentrations varied both between and within individual types of turnout gear textiles. While this and other studies examined different textiles and utilized dissimilar analytical methods, each provided unique insight into the occurrence of PFAS in turnout gear. Additional research on PFAS in used turnout gear, PFAS transport between gear layers or into firefighters, and the occupational hazards faced by firefighters are all critical to understanding the potential PFAS exposure firefighters face.

6. Future Work

Future work will examine the effect of typical use on the types and concentrations of PFAS in firefighter gear textiles as higher PFAS concentrations have been observed in used fire fighter gear compared with new firefighter gear [1], and exposure to heat, ultraviolet irradiation, and laundering have been found to alter PFAS concentrations in DWR treated textiles [34]. Additionally, efforts currently underway will use high-resolution mass spectrometry to identify a broader swath of PFAS than the 53 compounds quantified here, including screening for previously identified compounds as well as searching for novel PFAS. Other potential sources of PFAS exposure to firefighters will also be evaluated, including other firefighter personal protective equipment such as wildland fire gear, hoods, and gloves, as well as dust collected from fire stations. Finally, future work will evaluate the type and amount of PFAS that are released from firefighter gear textiles upon exposure to simulated sweat.

Table 2. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-A. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.580
PFPeA	0.649 ± 0.022	0.023
PFHxA	3.56 ± 0.08	0.155
PFHpA	<RL	0.510
PFOA	<RL	0.110
PFNA	<RL	0.023
PFDA	<RL	0.023
PFUnDA	<RL	0.031
PFDoDA	<RL	0.023
PFTrDA	<RL	0.023
PFTeDA	<RL	0.131
PFSA (NV)		
PFPrS	<RL	0.021
PFBS	0.065 ± 0.008	0.046
PFPeS	No value[b]	
PFHxS	<RL	0.021
PFHpS	<RL	0.022
PFOS	<RL	0.021
PFNS	<RL	0.022
PFDS	<RL	1.15
FASA (NV, SV)		
FBSA (NV)	<RL	0.047
MeFBSA (SV)	<RL	0.490
FHxSA (NV)	<RL	0.047
FOSA (NV)	<RL	0.047
MeFOSA (SV)	<RL	0.600
EtFOSA (SV)	0.76 ± 0.11	0.278
FASAA (NV)		
FOSAA	<RL	0.023
MeFOSAA	<RL[a]	0.047
EtFOSAA	<RL	2.45
FASE (SV)		
MeFOSE	<RL	0.258
EtFOSE	0.575 ± 0.031	0.023
PPEA (NV)		
PFEESA	<RL	0.019
PF4OPeA	<RL	0.021
PF5OHxA	<RL	0.021
3-6-OPFHpA	<RL	0.021
HFPO-DA	<RL[a]	0.062
ADONA	<RL	0.021
9Cl-PF3ONS	<RL	0.022
11Cl-PF3OUdS	<RL	0.022
n:2 FTMAC (V)		
6:2 FTMAC	420 ± 68	83.2
8:2 FTMAC	<RL	42.6
10:2 FTMAC	<RL	44.8
n:2 FTOAc (V)		
8:2 FTOAc	<RL	44.6
10:2 FTOAc	<RL	8.96
n:2 FTOH (V)		
4:2 FTOH	<RL	46.8
5:2 FTOH	<RL	89.5
6:2 FTOH	88.2 ± 4.6	45.0
7:2 FTOH	<RL	44.8
8:2 FTOH	<RL	87.8
10:2 FTOH	<RL	45.0
n:2 FTS (NV)		
4:2 FTS	<RL[a]	0.044
6:2 FTS	<RL	5.06
8:2 FTS	<RL	0.106
10:2 FTS	<RL	0.105

[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

[b] QC standards not met. Data not reported.

Table 3. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-B. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	1.34 ± 0.11	0.278
PFPeA	<RL	0.086
PFHxA	0.188 ± 0.013	0.161
PFHpA	<RL	0.090
PFOA	0.279 ± 0.054	0.114
PFNA	0.030 ± 0.004	0.024
PFDA	0.319 ± 0.041	0.024
PFUnDA	<RL	0.032
PFDoDA	0.11 ± 0.014	0.024
PFTrDA	<RL	0.024
PFTeDA	<RL	0.135
PFSA (NV)		
PFPrS	<RL	0.022
PFBS	6.7 ± 1.7	0.025
PFPeS	<RL	0.023
PFHxS	<RL	0.022
PFHpS	<RL	0.023
PFOS	0.026 ± 0.004	0.022
PFNS	<RL	0.023
PFDS	<RL	0.059
FASA (NV, SV)		
FBSA (NV)	0.809 ± 0.036	0.031
MeFBSA (SV)	<RL	2.26
FHxSA (NV)	<RL	0.031
FOSA (NV)	<RL	0.042
MeFOSA (SV)	<RL	0.451
EtFOSA (SV)	<RL	0.552
FASAA (NV)		
FOSAA	<RL	0.048
MeFOSAA	<RL	0.024
EtFOSAA	<RL	0.049

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	1.09 ± 0.09	0.256
EtFOSE	0.237 ± 0.023	0.237
PPEA (NV)		
PFEESA	<RL	0.019
PF4OPeA	<RL	0.022
PF5OHxA	<RL	0.054
3-6-OPFHpA	<RL	0.022
HFPO-DA	<RL	0.064
ADONA	<RL	0.022
9Cl-PF3ONS	<RL	0.022
11Cl-PF3OUdS	<RL	0.023
n:2 FTMAC (V)		
6:2 FTMAC	<RL	76.4
8:2 FTMAC	<RL	39.1
10:2 FTMAC	<RL	41.2
n:2 FTOAc (V)		
8:2 FTOAc	<RL	40.9
10:2 FTOAc	<RL	8.23
n:2 FTOH (V)		
4:2 FTOH	<RL	42.9
5:2 FTOH	<RL	82.2
6:2 FTOH	<RL	41.3
7:2 FTOH	<RL	41.1
8:2 FTOH	<RL	80.7
10:2 FTOH	<RL	41.3
n:2 FTS (NV)		
4:2 FTS	<RL[a]	0.0457
6:2 FTS	<RL[a]	5.24
8:2 FTS	<RL[a]	0.110
10:2 FTS	<RL[a]	0.108

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[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

Table 4. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-C. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	14.7 ± 0.28	0.242
PFPeA	0.157 ± 0.026	0.075
PFHxA	2.40 ± 0.23	0.159
PFHpA	0.104 ± 0.010	0.078
PFOA	<RL	0.113
PFNA	<RL	0.024
PFDA	<RL	0.024
PFUnDA	<RL	0.031
PFDoDA	<RL	0.024
PFTrDA	<RL	0.024
PFTeDA	<RL	0.134
PFSA (NV)		
PFPrS	<RL	0.021
PFBS	32.1 ± 2.0	0.022
PFPeS	<RL	0.022
PFHxS	<RL	0.022
PFHpS	0.053 ± 0.004	0.023
PFOS	0.116 ± 0.022	0.061
PFNS	<RL	0.023
PFDS	<RL	0.051
FASA (NV, SV)		
FBSA (NV)	13.1 ± 0.7	0.024
MeFBSA (SV)	<RL	2.96
FHxSA (NV)	<RL	0.027
FOSA (NV)	<RL	0.037
MeFOSA (SV)	<RL	0.593
EtFOSA (SV)	<RL	0.726
FASAA (NV)		
FOSAA	<RL	0.047
MeFOSAA	<RL	0.024
EtFOSAA	<RL	0.048
FASE (SV)		
MeFOSE	0.86 ± 0.18	0.336
EtFOSE	0.61 ± 0.25	0.312
PPEA (NV)		
PFEESA	<RL	0.019
PF4OPeA	<RL	0.021
PF5OHxA	<RL	0.021
3-6-OPFHpA	<RL	0.021
HFPO-DA	<RL	0.064
ADONA	<RL	0.021
9Cl-PF3ONS	<RL	0.022
11Cl-PF3OUdS	<RL	0.022
n:2 FTMAC (V)		
6:2 FTMAC	<RL	91.1
8:2 FTMAC	<RL	46.7
10:2 FTMAC	<RL	49.1
n:2 FTOAc (V)		
8:2 FTOAc	<RL	48.9
10:2 FTOAc	<RL	9.82
n:2 FTOH (V)		
4:2 FTOH	<RL	51.2
5:2 FTOH	<RL	98.0
6:2 FTOH	<RL	49.3
7:2 FTOH	<RL	49.0
8:2 FTOH	<RL	96.3
10:2 FTOH	<RL	49.3
n:2 FTS (NV)		
4:2 FTS	<RL[a]	0.045
6:2 FTS	<RL[a]	5.17
8:2 FTS	<RL	0.108
10:2 FTS	<RL	0.107

[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

Table 5. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-D. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.601
PFPeA	0.364 ± 0.034	0.024
PFHxA	1.31 ± 0.12 [a]	0.161
PFHpA	<RL	0.528
PFOA	<RL	0.114
PFNA	<RL	0.024
PFDA	<RL	0.024
PFUnDA	<RL	0.032
PFDoDA	<RL	0.024
PFTrDA	<RL	0.024
PFTeDA	<RL	0.136
PFSA (NV)		
PFPrS	<RL	0.022
PFBS	0.104 ± 0.003	0.048
PFPeS	No value	
PFHxS	<RL	0.022
PFHpS	<RL	0.023
PFOS	0.086 ± 0.082[b]	0.022
PFNS	<RL	0.023
PFDS	<RL	1.19
FASA (NV, SV)		
FBSA (NV)	0.324 ± 0.045	0.024
MeFBSA (SV)	<RL	2.19
FHxSA (NV)	<RL	0.049
FOSA (NV)	<RL	0.049
MeFOSA (SV)	<RL	0.437
EtFOSA (SV)	<RL	0.535
FASAA (NV)		
FOSAA	<RL	0.048
MeFOSAA	<RL	0.024
EtFOSAA	<RL [a]	0.049
FASE (SV)		
MeFOSE	0.46 ± 0.33	0.248
EtFOSE	<RL	0.230
PPEA (NV)		
PFEESA	<RL	0.019
PF4OPeA	<RL	0.022
PF5OHxA	<RL	0.022
3-6-OPFHpA	<RL [i]	0.022
HFPO-DA	<RL	0.064
ADONA	<RL	0.022
9Cl-PF3ONS	<RL	0.022
11Cl-PF3OUdS	<RL	0.023
n:2 FTMAC (V)		
6:2 FTMAC	395 ± 39	73.9
8:2 FTMAC	<RL	37.9
10:2 FTMAC	<RL	39.9
n:2 FTOAc (V)		
8:2 FTOAc	<RL	39.6
10:2 FTOAc	<RL	7.97
n:2 FTOH (V)		
4:2 FTOH	<RL	41.6
5:2 FTOH	<RL	79.5
6:2 FTOH	56 ± 16	40.0
7:2 FTOH	<RL	39.8
8:2 FTOH	<RL	78.1
10:2 FTOH	<RL	40.0
n:2 FTS (NV)		
4:2 FTS	<RL [a]	0.046
6:2 FTS	<RL	5.24
8:2 FTS	<RL	0.110
10:2 FTS	<RL	0.108

[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

Table 6. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-E. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	16.1 ± 4.4	0.626
PFPeA	<RL	0.025
PFHxA	1.90 ± 0.11	1.18
PFHpA	<RL	0.550
PFOA	<RL	0.119
PFNA	<RL	0.025
PFDA	<RL	0.025
PFUnDA	<RL	0.033
PFDoDA	<RL	0.025
PFTrDA	<RL	0.025
PFTeDA	<RL	0.141
PFSA (NV)		
PFPrS	<RL	0.022
PFBS	34 ± 10	0.050
PFPeS	<RL	0.024
PFHxS	<RL	0.023
PFHpS	0.086 ± 0.021	0.024
PFOS	<RL	0.106
PFNS	<RL	0.024
PFDS	<RL	0.228
FASA (NV, SV)		
FBSA (NV)	8.6 ± 2.5	0.025
MeFBSA (SV)	<RL	2.03
FHxSA (NV)	<RL	0.051
FOSA (NV)	<RL	0.051
MeFOSA (SV)	<RL	0.406
EtFOSA (SV)	<RL	0.497
FASAA (NV)		
FOSAA	<RL	0.050
MeFOSAA	<RL	0.025
EtFOSAA	<RL	0.051
FASE (SV)		
MeFOSE	<RL	0.230
EtFOSE	<RL	0.214
PPEA (NV)		
PFEESA	<RL	0.020
PF4OPeA	<RL	0.022
PF5OHxA	<RL	0.022
3-6-OPFHpA	<RL	0.022
HFPO-DA	<RL	0.067
ADONA	<RL	0.022
9Cl-PF3ONS	<RL	0.023
11Cl-PF3OUdS	<RL	0.024
n:2 FTMAC (V)		
6:2 FTMAC	1011 ± 86	66.8
8:2 FTMAC	<RL	34.2
10:2 FTMAC	<RL	36.0
n:2 FTOAc (V)		
8:2 FTOAc	<RL	36.8
10:2 FTOAc	<RL	7.20
n:2 FTOH (V)		
4:2 FTOH	<RL	37.5
5:2 FTOH	<RL	71.8
6:2 FTOH	178.9 ± 8.3	36.1
7:2 FTOH	<RL	35.9
8:2 FTOH	<RL	70.5
10:2 FTOH	<RL	36.1
n:2 FTS (NV)		
4:2 FTS	0.85 ± 0.27	0.048
6:2 FTS	613 ± 15	1.18
8:2 FTS	<RL	0.114
10:2 FTS	<RL	0.113

Table 7. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in moisture barrier textile MB-F. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.595
PFPeA	0.0853 ± 0.007	0.024
PFHxA	0.880 ± 0.057	0.159
PFHpA	<RL	0.523
PFOA	<RL	0.113
PFNA	<RL	0.024
PFDA	<RL	0.024
PFUnDA	<RL	0.031
PFDoDA	<RL	0.024
PFTrDA	<RL	0.024
PFTeDA	0.27 ± 0.14	0.134
PFSA (NV)		
PFPrS	<RL	0.021
PFBS	<RL	0.048
PFPeS	No value[b]	
PFHxS	<RL	0.022
PFHpS	<RL	0.023
PFOS	0.16 ± 0.16[a]	0.022
PFNS	<RL	0.023
PFDS	<RL	1.18
FASA (NV, SV)		
FBSA (NV)	<RL	0.024
MeFBSA (SV)	<RL	2.48
FHxSA (NV)	<RL	0.048
FOSA (NV)	<RL	0.048
MeFOSA (SV)	<RL	0.496
EtFOSA (SV)	<RL	0.607
FASAA (NV)		
FOSAA	<RL	0.047
MeFOSAA	<RL	0.024
EtFOSAA	<RL [a]	0.048

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.281
EtFOSE	<RL	0.261
PPEA (NV)		
PFEESA	<RL	0.019
PF4OPeA	<RL	0.021
PF5OHxA	<RL	0.021
3-6-OPFHpA	<RL	0.021
HFPO-DA	<RL	0.064
ADONA	<RL	0.021
9Cl-PF3ONS	<RL	0.022
11Cl-PF3OUdS	<RL	0.022
n:2 FTMAC (V)		
6:2 FTMAC	160 ± 51	83.8
8:2 FTMAC	<RL	42.9
10:2 FTMAC	<RL	45.2
n:2 FTOAc (V)		
8:2 FTOAc	<RL	44.9
10:2 FTOAc	<RL	9.03
n:2 FTOH (V)		
4:2 FTOH	<RL	47.1
5:2 FTOH	<RL	90.1
6:2 FTOH	<RL	45.3
7:2 FTOH	<RL	45.1
8:2 FTOH	<RL	88.5
10:2 FTOH	<RL	45.3
n:2 FTS (NV)		
4:2 FTS	<RL [a]	0.045
6:2 FTS	<RL	5.19
8:2 FTS	<RL	0.109
10:2 FTS	<RL	0.107

[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

[b] QC standards not met. Data not reported.

Table 8. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-A. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	2.10 ± 0.04	0.129
PFPeA	1.61 ± 0.04	0.126
PFHxA	3.54 ± 0.28	0.275
PFHpA	<RL	0.491
PFOA	<RL	0.237
PFNA	<RL	0.112
PFDA	<RL	0.112
PFUnDA	<RL	0.112
PFDoDA	<RL	0.065
PFTrDA	<RL	0.077
PFTeDA	<RL	0.142
PFSA (NV)		
PFPrS	<RL	0.103
PFBS	0.128 ± 0.012	0.018
PFPeS	<RL	0.040
PFHxS	<RL	0.039
PFHpS	<RL	0.041
PFOS	<RL	0.049
PFNS	<RL	0.041
PFDS	<RL	0.041
FASA (NV, SV)		
FBSA (NV)	0.217 ± 0.011	0.020
MeFBSA (SV)	<RL	5.14
FHxSA (NV)	<RL	0.020
FOSA (NV)	<RL	0.043
MeFOSA (SV)	<RL	1.24
EtFOSA (SV)	<RL	1.30
FASAA (NV)		
FOSAA	<RL	0.043
MeFOSAA	<RL	0.112
EtFOSAA	<RL	0.136

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.535
EtFOSE	<RL	0.472
PPEA (NV)		
PFEESA	<RL	0.017
PF4OPeA	<RL	0.040
PF5OHxA	<RL	0.019
3-6-OPFHpA	<RL	0.019
HFPO-DA	<RL	0.112
ADONA	<RL	0.020
9Cl-PF3ONS	<RL	0.020
11Cl-PF3OUdS	<RL	0.020
n:2 FTMAC (V)		
6:2 FTMAC	1250 ± 140	483
8:2 FTMAC	<RL	193
10:2 FTMAC	<RL	260
n:2 FTOAc (V)		
8:2 FTOAc	<RL	202
10:2 FTOAc	<RL	104
n:2 FTOH (V)		
4:2 FTOH	<RL	409
5:2 FTOH	<RL	203
6:2 FTOH	362 ± 37	204
7:2 FTOH	<RL	408
8:2 FTOH	<RL	199
10:2 FTOH	<RL	410
n:2 FTS (NV)		
4:2 FTS	<RL	0.105
6:2 FTS	<RL	1.25
8:2 FTS	<RL	0.227
10:2 FTS	<RL	0.228

Table 9. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-ASC. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.216
PFPeA	<RL	0.067
PFHxA	0.58 ± 0.12	0.380
PFHpA	0.176 ± 0.014	0.070
PFOA	0.484 ± 0.039	0.363
PFNA	0.136 ± 0.047	0.096
PFDA	0.206 ± 0.011	0.204
PFUnDA	<RL	0.135
PFDoDA	<RL	0.110
PFTrDA	<RL	0.072
PFTeDA	<RL	0.143
PFSA (NV)		
PFPrS	<RL	0.033
PFBS	<RL	0.019
PFPeS	<RL	0.025
PFHxS	<RL	0.048
PFHpS	<RL	0.024
PFOS	<RL	0.055
PFNS	<RL	0.033
PFDS	0.124 ± 0.046	0.046
FASA (NV, SV)		
FBSA (NV)	<RL	0.024
MeFBSA (SV)	<RL	4.60
FHxSA (NV)	<RL	0.024
FOSA (NV)	<RL	0.033
MeFOSA (SV)	<RL	1.11
EtFOSA (SV)	<RL	1.16
FASAA (NV)		
FOSAA	<RL	0.059
MeFOSAA	<RL	0.046
EtFOSAA	<RL	0.119
FASE (SV)		
MeFOSE	<RL	0.479
EtFOSE	<RL	0.423
PPEA (NV)		
PFEESA	<RL	0.025
PF4OPeA	<RL	0.030
PF5OHxA	<RL	0.042
3-6-OPFHpA	<RL	0.024
HFPO-DA	<RL	0.249
ADONA	<RL	0.024
9Cl-PF3ONS	<RL	0.048
11Cl-PF3OUdS	<RL	0.023
n:2 FTMAC (V)		
6:2 FTMAC	<RL	326
8:2 FTMAC	<RL	173
10:2 FTMAC	<RL	176
n:2 FTOAc (V)		
8:2 FTOAc	<RL	74.8
10:2 FTOAc	<RL	93.3
n:2 FTOH (V)		
4:2 FTOH	<RL	72.4
5:2 FTOH	<RL	182
6:2 FTOH	<RL	183
7:2 FTOH	<RL	73.3
8:2 FTOH	<RL	71.0
10:2 FTOH	<RL	73.6
n:2 FTS (NV)		
4:2 FTS	<RL	0.101
6:2 FTS	<RL	0.155
8:2 FTS	<RL	0.209
10:2 FTS	<RL	0.236

Table 10. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-B. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	2.69 ± 0.080	0.119
PFPeA	2.42 ± 0.060	0.116
PFHxA	6.10 ± 0.18	0.253
PFHpA	1.73 ± 0.17	0.451
PFOA	<RL	0.218
PFNA	0.152 ± 0.030	0.103
PFDA	<RL	0.103
PFUnDA	<RL	0.103
PFDoDA	<RL	0.060
PFTrDA	<RL	0.070
PFTeDA	<RL	0.131
PFSA (NV)		
PFPrS	<RL	0.095
PFBS	0.182 ± 0.010	0.017
PFPeS	<RL	0.037
PFHxS	<RL	0.036
PFHpS	<RL	0.037
PFOS	<RL	0.045
PFNS	<RL	0.038
PFDS	<RL	0.038
FASA (NV, SV)		
FBSA (NV)	0.091 ± 0.010	0.019
MeFBSA (SV)	<RL	4.87
FHxSA (NV)	<RL	0.019
FOSA (NV)	<RL	0.039
MeFOSA (SV)	<RL	1.18
EtFOSA (SV)	<RL	1.23
FASAA (NV)		
FOSAA	<RL	0.039
MeFOSAA	<RL	0.103
EtFOSAA	<RL	0.125
FASE (SV)		
MeFOSE	<RL	0.507
EtFOSE	<RL	0.448
PPEA (NV)		
PFEESA	<RL	0.016
PF4OPeA	<RL	0.037
PF5OHxA	<RL	0.018
3-6-OPFHpA	<RL	0.018
HFPO-DA	<RL	0.103
ADONA	<RL	0.018
9Cl-PF3ONS	<RL	0.018
11Cl-PF3OUdS	<RL	0.018
n:2 FTMAC (V)		
6:2 FTMAC	1520 ± 130	456
8:2 FTMAC	<RL	183
10:2 FTMAC	<RL	246
n:2 FTOAc (V)		
8:2 FTOAc	<RL	191.1
10:2 FTOAc	<RL	98.2
n:2 FTOH (V)		
4:2 FTOH	<RL	387
5:2 FTOH	<RL	192
6:2 FTOH	350 ± 120	193
7:2 FTOH	<RL	386
8:2 FTOH	<RL	189
10:2 FTOH	<RL	388
n:2 FTS (NV)		
4:2 FTS	<RL	0.097
6:2 FTS	5.88 ± 0.14	1.15
8:2 FTS	<RL	0.209
10:2 FTS	<RL	0.21

Table 11. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-C. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	5.11 ± 0.11	0.130
PFPeA	5.19 ± 0.06	0.061
PFHxA	10.4 ± 0.4	0.277
PFHpA	3.37 ± 0.10	0.064
PFOA	<RL	0.330
PFNA	<RL	0.087
PFDA	<RL	0.113
PFUnDA	<RL	0.113
PFDoDA	<RL	0.065
PFTrDA	<RL	0.066
PFTeDA	<RL	0.130
PFSA (NV)		
PFPrS	<RL	0.030
PFBS	0.322 ± 0.043	0.018
PFPeS	<RL	0.023
PFHxS	<RL	0.039
PFHpS	<RL	0.022
PFOS	<RL	0.049
PFNS	<RL	0.030
PFDS	<RL	0.041
FASA (NV, SV)		
FBSA (NV)	0.315 ± 0.021	0.021
MeFBSA (SV)	<RL	3.90
FHxSA (NV)	0.023 ± 0.001	0.021
FOSA (NV)	0.032 ± 0.001	0.030
MeFOSA (SV)	<RL	0.941
EtFOSA (SV)	<RL	0.986
FASAA (NV)		
FOSAA	<RL	0.043
MeFOSAA	<RL	0.042
EtFOSAA	<RL	0.108

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.406
EtFOSE	<RL	0.359
PPEA (NV)		
PFEESA	<RL	0.017
PF4OPeA	<RL	0.027
PF5OHxA	<RL	0.019
3-6-OPFHpA	<RL	0.019
HFPO-DA	<RL	0.113
ADONA	<RL	0.020
9Cl-PF3ONS	<RL	0.020
11Cl-PF3OUdS	<RL	0.020
n:2 FTMAC (V)		
6:2 FTMAC	1066 ± 68	365
8:2 FTMAC	<RL	146
10:2 FTMAC	<RL	197
n:2 FTOAc (V)		
8:2 FTOAc	<RL	152.9
10:2 FTOAc	<RL	78.6
n:2 FTOH (V)		
4:2 FTOH	<RL	309
5:2 FTOH	<RL	154
6:2 FTOH	335 ± 83	154
7:2 FTOH	<RL	309
8:2 FTOH	<RL	151
10:2 FTOH	<RL	310
n:2 FTS (NV)		
4:2 FTS	<RL	0.092
6:2 FTS	7.26 ± 0.62	0.141
8:2 FTS	<RL	0.190
10:2 FTS	<RL	0.215

Table 12. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-D. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	1.21 ± 0.36	0.118
PFPeA	1.05 ± 0.03	0.076
PFHxA	2.63 ± 0.3	0.432
PFHpA	0.425 ± 0.044	0.080
PFOA	<RL	0.215
PFNA	<RL	0.102
PFDA	<RL	0.102
PFUnDA	<RL	0.102
PFDoDA	<RL	0.059
PFTrDA	<RL	0.070
PFTeDA	<RL	0.129
PFSA (NV)		
PFPrS	<RL	0.037
PFBS	0.115 ± 0.03	0.017
PFPeS	<RL	0.028
PFHxS	<RL	0.035
PFHpS	<RL	0.028
PFOS	<RL	0.044
PFNS	<RL	0.037
PFDS	<RL	0.037
FASA (NV, SV)		
FBSA (NV)	0.047 ± 0.008	0.019
MeFBSA (SV)	<RL	5.22
FHxSA (NV)	<RL	0.019
FOSA (NV)	<RL	0.037
MeFOSA (SV)	<RL	1.26
EtFOSA (SV)	<RL	1.32
FASAA (NV)		
FOSAA	<RL	0.039
MeFOSAA	<RL	0.052
EtFOSAA	<RL	0.124

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.543
EtFOSE	<RL	0.480
PPEA (NV)		
PFEESA	<RL	0.016
PF4OPeA	<RL	0.034
PF5OHxA	<RL	0.017
3-6-OPFHpA	<RL	0.017
HFPO-DA	<RL	0.284
ADONA	<RL	0.018
9Cl-PF3ONS	<RL	0.018
11Cl-PF3OUdS	<RL	0.018
n:2 FTMAC (V)		
6:2 FTMAC	1419 ± 76	491
8:2 FTMAC	<RL	196
10:2 FTMAC	<RL	265
n:2 FTOAc (V)		
8:2 FTOAc	<RL	205.6
10:2 FTOAc	<RL	105.7
n:2 FTOH (V)		
4:2 FTOH	<RL	416
5:2 FTOH	<RL	207
6:2 FTOH	393 ± 98	207
7:2 FTOH	<RL	415
8:2 FTOH	<RL	203
10:2 FTOH	<RL	417
n:2 FTS (NV)		
4:2 FTS	<RL	0.115
6:2 FTS	3.24 ± 0.072	0.176
8:2 FTS	<RL	0.207
10:2 FTS	<RL	0.208

Table 13. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-E. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	16.1 ± 0.3	0.119
PFPeA	20.0 ± 1.1	0.069
PFHxA	37.5 ± 0.7	0.252
PFHpA	6.38 ± 0.32	0.072
PFOA	0.473 ± 0.055	0.217
PFNA	0.286 ± 0.029	0.103
PFDA	0.421 ± 0.044	0.103
PFUnDA	0.125 ± 0.013	0.103
PFDoDA	0.143 ± 0.005	0.114
PFTrDA	<RL[a]	0.070
PFTeDA	<RL	0.130
PFSA (NV)		
PFPrS	<RL	0.034
PFBS	0.152 ± 0.023	0.017
PFPeS	<RL	0.026
PFHxS	<RL	0.036
PFHpS	<RL	0.025
PFOS	<RL	0.045
PFNS	<RL	0.034
PFDS	<RL	0.038
FASA (NV, SV)		
FBSA (NV)	0.394 ± 0.024	0.025
MeFBSA (SV)	<RL	5.12
FHxSA (NV)	0.031 ± 0.003	0.025
FOSA (NV)	<RL	0.034
MeFOSA (SV)	<RL	1.24
EtFOSA (SV)	<RL	1.30
FASAA (NV)		
FOSAA	0.410 ± 0.064	0.039
MeFOSAA	<RL	0.047
EtFOSAA	<RL	0.123

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.533
EtFOSE	<RL	0.471
PPEA (NV)		
PFEESA	<RL	0.016
PF4OPeA	<RL	0.031
PF5OHxA	<RL	0.018
3-6-OPFHpA	<RL	0.018
HFPO-DA	<RL	0.103
ADONA	<RL	0.018
9Cl-PF3ONS	<RL	0.018
11Cl-PF3OUdS	<RL	0.018
n:2 FTMAC (V)		
6:2 FTMAC	550 ± 130	362
8:2 FTMAC	<RL	193
10:2 FTMAC	<RL	195
n:2 FTOAc (V)		
8:2 FTOAc	<RL	83.1
10:2 FTOAc	<RL	103.7
n:2 FTOH (V)		
4:2 FTOH	<RL	80.5
5:2 FTOH	<RL	203
6:2 FTOH	332 ± 87	204
7:2 FTOH	<RL	81.5
8:2 FTOH	<RL	78.9
10:2 FTOH	<RL	81.8
n:2 FTS (NV)		
4:2 FTS	<RL	0.105
6:2 FTS	0.64 ± 0.1	0.160
8:2 FTS	0.268 ± 0.036	0.208
10:2 FTS	<RL	0.245

[a] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

Table 14. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-F. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)	PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)			*FASE (SV)*		
PFBA	11.3 ± 0.4	0.119	**MeFOSE**	<RL	0.483
PFPeA	12.6 ± 0.1	0.116	**EtFOSE**	<RL	0.427
PFHxA	39.3 ± 1.8	0.254			
PFHpA	4.94 ± 0.23	0.453	*PPEA (NV)*		
PFOA	0.362 ± 0.083	0.218	**PFEESA**	<RL	0.016
PFNA	0.185 ± 0.035	0.104	**PF4OPeA**	<RL	0.037
PFDA	0.318 ± 0.016	0.104	**PF5OHxA**	<RL	0.018
PFUnDA	<RL	0.104	**3-6-OPFHpA**	<RL	0.018
PFDoDA	<RL	0.060	**HFPO-DA**	<RL	0.104
PFTrDA	<RL	0.071	**ADONA**	<RL	0.018
PFTeDA	<RL	0.131	**9Cl-PF3ONS**	<RL	0.018
			11Cl-PF3OUdS	<RL	0.018
PFSA (NV)					
PFPrS	<RL	0.095	*n:2 FTMAC (V)*		
PFBS	1.263 ± 0.020	0.017	**6:2 FTMAC**	640 ± 150	328
PFPeS	<RL	0.037	**8:2 FTMAC**	<RL	174
PFHxS	<RL	0.036	**10:2 FTMAC**	<RL	177
PFHpS	<RL	0.037			
PFOS	<RL	0.045	*n:2 FTOAc (V)*		
PFNS	<RL	0.038	**8:2 FTOAc**	<RL	75.2
PFDS	<RL	0.038	**10:2 FTOAc**	<RL	93.8
FASA (NV, SV)			*n:2 FTOH (V)*		
FBSA (NV)	0.355 ± 0.005	0.019	**4:2 FTOH**	<RL	72.8
MeFBSA (SV)	<RL	4.64	**5:2 FTOH**	<RL	183
FHxSA (NV)	0.036 ± 0.003	0.019	**6:2 FTOH**	257 ± 43	184
FOSA (NV)	<RL	0.039	**7:2 FTOH**	<RL	73.7
MeFOSA (SV)	<RL	1.12	**8:2 FTOH**	<RL	71.4
EtFOSA (SV)	<RL	1.17	**10:2 FTOH**	<RL	74.0
FASAA (NV)			*n:2 FTS (NV)*		
FOSAA	<RL	0.039	**4:2 FTS**	<RL	0.097
MeFOSAA	<RL	0.104	**6:2 FTS**	1.69 ± 0.22	1.15
EtFOSAA	<RL	0.126	**8:2 FTS**	<RL	0.210
			10:2 FTS	No value[a]	

[a] QC standards not met. Data not reported.

Table 15. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-FSC. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.228
PFPeA	<RL	0.062
PFHxA	0.335 ± 0.032	0.196
PFHpA	<RL	0.149
PFOA	<RL	0.446
PFNA	<RL	0.144
PFDA	<RL	0.231
PFUnDA	<RL	0.204
PFDoDA	<RL	0.117
PFTrDA	<RL	0.055
PFTeDA	<RL	0.119
PFSA (NV)		
PFPrS	<RL	0.042
PFBS	<RL	0.039
PFPeS	<RL	0.025
PFHxS	<RL	0.051
PFHpS	<RL	0.031
PFOS	<RL	0.050
PFNS	<RL	0.035
PFDS	<RL	0.049
FASA (NV, SV)		
FBSA (NV)	No value[a]	
MeFBSA (SV)	<RL	4.77
FHxSA (NV)	<RL	0.031
FOSA (NV)	<RL	0.076
MeFOSA (SV)	<RL	1.15
EtFOSA (SV)	<RL	1.21
FASAA (NV)		
FOSAA	<RL	0.079
MeFOSAA	<RL	0.047
EtFOSAA	<RL	0.141
FASE (SV)		
MeFOSE	<RL	0.496
EtFOSE	<RL	0.439
PPEA (NV)		
PFEESA	<RL	0.034
PF4OPeA	<RL	0.024
PF5OHxA	<RL	0.053
3-6-OPFHpA	<RL	0.034
HFPO-DA	<RL	0.242
ADONA	<RL	0.027
9Cl-PF3ONS	<RL	0.056
11Cl-PF3OUdS	<RL	0.035
n:2 FTMAC (V)		
6:2 FTMAC	<RL	338
8:2 FTMAC	<RL	346
10:2 FTMAC	<RL	182
n:2 FTOAc (V)		
8:2 FTOAc	<RL	77.5
10:2 FTOAc	<RL[a]	96.7
n:2 FTOH (V)		
4:2 FTOH	<RL	75.1
5:2 FTOH	<RL	192
6:2 FTOH	<RL	396
7:2 FTOH	<RL	76.0
8:2 FTOH	<RL	73.6
10:2 FTOH	<RL	76.3
n:2 FTS (NV)		
4:2 FTS	<RL	0.104
6:2 FTS	<RL	0.184
8:2 FTS	<RL	0.214
10:2 FTS	<RL	0.222

[a] QC standards not met. Data not reported.

[b] Internal standard recovery did not meet QC standards, but all other QC standards met. Therefore, data do not meet QC standards and are not included in figures or this technical note beyond this table where they are included only for informational purposes.

Table 16. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in outer shell textile OS-G. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	4.27 ± 0.02	0.121
PFPeA	4.33 ± 0.11	0.118
PFHxA	12.6 ± 0.5	0.258
PFHpA	4.08 ± 0.10	0.460
PFOA	<RL	0.222
PFNA	<RL	0.105
PFDA	<RL	0.105
PFUnDA	<RL	0.105
PFDoDA	<RL	0.061
PFTrDA	<RL	0.072
PFTeDA	<RL	0.133
PFSA (NV)		
PFPrS	<RL	0.096
PFBS	0.046 ± 0.008	0.017
PFPeS	<RL	0.038
PFHxS	<RL	0.036
PFHpS	<RL	0.038
PFOS	<RL	0.046
PFNS	<RL	0.038
PFDS	<RL	0.039
FASA (NV, SV)		
FBSA (NV)	0.034 ± 0.004	0.019
MeFBSA (SV)	<RL	6.38
FHxSA (NV)	<RL	0.019
FOSA (NV)	<RL	0.040
MeFOSA (SV)	<RL	1.28
EtFOSA (SV)	<RL	1.56
FASAA (NV)		
FOSAA	<RL	0.040
MeFOSAA	<RL	0.105
EtFOSAA	<RL	0.128

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.724
EtFOSE	<RL	0.672
PPEA (NV)		
PFEESA	<RL	0.016
PF4OPeA	<RL	0.038
PF5OHxA	<RL	0.018
3-6-OPFHpA	<RL	0.018
HFPO-DA	<RL	0.105
ADONA	<RL	0.019
9Cl-PF3ONS	<RL	0.018
11Cl-PF3OUdS	<RL	0.019
n:2 FTMAC (V)		
6:2 FTMAC	382 ± 43	216
8:2 FTMAC	<RL	110
10:2 FTMAC	<RL	116
n:2 FTOAc (V)		
8:2 FTOAc	<RL	116
10:2 FTOAc	<RL	23.2
n:2 FTOH (V)		
4:2 FTOH	<RL	121
5:2 FTOH	<RL	232
6:2 FTOH	220 ± 67	117
7:2 FTOH	<RL	116
8:2 FTOH	<RL	228
10:2 FTOH	<RL	117
n:2 FTS (NV)		
4:2 FTS	<RL	0.099
6:2 FTS	2.42 ± 0.17	1.17
8:2 FTS	<RL	0.213
10:2 FTS	<RL	0.214

Table 17. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in thermal liner textile TL-A. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.642
PFPeA	0.152 ± 0.046	0.026
PFHxA	0.636 ± 0.091	0.172
PFHpA	<RL	0.565
PFOA	0.95 ± 0.22	0.122
PFNA	0.045 ± 0.019	0.026
PFDA	0.072 ± 0.029	0.026
PFUnDA	<RL	0.034
PFDoDA	<RL	0.026
PFTrDA	<RL	0.026
PFTeDA	<RL	0.145
PFSA (NV)		
PFPrS	<RL	0.023
PFBS	0.66 ± 0.16	0.051
PFPeS	<RL	0.024
PFHxS	<RL	0.023
PFHpS	<RL	0.024
PFOS	0.061 ± 0.023	0.024
PFNS	<RL	0.025
PFDS	<RL	1.27
FASA (NV, SV)		
FBSA (NV)	0.050 ± 0.016	0.026
MeFBSA (SV)	<RL	2.26
FHxSA (NV)	<RL	0.052
FOSA (NV)	<RL	0.052
MeFOSA (SV)	<RL	0.452
EtFOSA (SV)	<RL	0.553
FASAA (NV)		
FOSAA	<RL	0.051
MeFOSAA	<RL	0.026
EtFOSAA	<RL	0.052
FASE (SV)		
MeFOSE	<RL	0.256
EtFOSE	<RL	0.238
PPEA (NV)		
PFEESA	<RL	0.021
PF4OPeA	<RL	0.023
PF5OHxA	<RL	0.023
3-6-OPFHpA	<RL	0.023
HFPO-DA	<RL	0.069
ADONA	<RL	0.023
9Cl-PF3ONS	<RL	0.024
11Cl-PF3OUdS	<RL	0.024
n:2 FTMAC (V)		
6:2 FTMAC	<RL	76.6
8:2 FTMAC	<RL	39.2
10:2 FTMAC	<RL	41.3
n:2 FTOAc (V)		
8:2 FTOAc	<RL	41.1
10:2 FTOAc	<RL	8.25
n:2 FTOH (V)		
4:2 FTOH	<RL	43.1
5:2 FTOH	<RL	82.4
6:2 FTOH	<RL	41.4
7:2 FTOH	<RL	41.2
8:2 FTOH	<RL	80.9
10:2 FTOH	<RL	41.4
n:2 FTS (NV)		
4:2 FTS	<RL	0.049
6:2 FTS	<RL	5.61
8:2 FTS	<RL	0.118
10:2 FTS	<RL	0.116

Table 18. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in thermal liner textile TL-B. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.274
PFPeA	0.082 ± 0.006	0.022
PFHxA	<RL	0.483
PFHpA	<RL	0.089
PFOA	0.276 ± 0.037	0.106
PFNA	<RL	0.121
PFDA	0.202 ± 0.012	0.022
PFUnDA	<RL	0.029
PFDoDA	0.085 ± 0.007	0.022
PFTrDA	<RL	0.022
PFTeDA	<RL	0.126
PFSA (NV)		
PFPrS	<RL	0.020
PFBS	0.455 ± 0.061	0.025
PFPeS	<RL	0.021
PFHxS	<RL	0.020
PFHpS	<RL	0.021
PFOS	0.039 ± 0.002	0.021
PFNS	<RL	0.021
PFDS	<RL	0.058
FASA (NV, SV)		
FBSA (NV)	0.043 ± 0.006	0.022
MeFBSA (SV)	<RL	2.84
FHxSA (NV)	<RL	0.030
FOSA (NV)	<RL	0.041
MeFOSA (SV)	<RL	0.568
EtFOSA (SV)	<RL	0.695
FASAA (NV)		
FOSAA	<RL	0.044
MeFOSAA	<RL	0.022
EtFOSAA	<RL	0.045

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	0.322
EtFOSE	<RL	0.299
PPEA (NV)		
PFEESA	<RL	0.018
PF4OPeA	<RL	0.020
PF5OHxA	<RL	0.020
3-6-OPFHpA	<RL	0.020
HFPO-DA	<RL	0.060
ADONA	<RL	0.020
9Cl-PF3ONS	<RL	0.021
11Cl-PF3OUdS	<RL	0.021
n:2 FTMAC (V)		
6:2 FTMAC	<RL	95.9
8:2 FTMAC	<RL	49.1
10:2 FTMAC	<RL	51.7
n:2 FTOAc (V)		
8:2 FTOAc	<RL	51.4
10:2 FTOAc	<RL	10.3
n:2 FTOH (V)		
4:2 FTOH	<RL	53.9
5:2 FTOH	<RL	103
6:2 FTOH	<RL	51.9
7:2 FTOH	<RL	51.6
8:2 FTOH	<RL	101
10:2 FTOH	<RL	51.8
n:2 FTS (NV)		
4:2 FTS	<RL	0.042
6:2 FTS	<RL	0.197
8:2 FTS	<RL	0.102
10:2 FTS	<RL	0.100

Table 19. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in thermal liner textile TL-C. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	0.658 ± 0.076	0.190
PFPeA	0.222 ± 0.040	0.059
PFHxA	0.511 ± 0.061	0.335
PFHpA	0.238 ± 0.026	0.062
PFOA	0.855 ± 0.071	0.320
PFNA	0.192 ± 0.051	0.084
PFDA	0.631 ± 0.060	0.180
PFUnDA	<RL	0.119
PFDoDA	0.203 ± 0.015	0.097
PFTrDA	<RL	0.064
PFTeDA	<RL	0.126
PFSA (NV)		
PFPrS	<RL	0.029
PFBS	1.226 ± 0.081	0.017
PFPeS	<RL	0.022
PFHxS	<RL	0.042
PFHpS	<RL	0.021
PFOS	0.142 ± 0.013	0.048
PFNS	<RL	0.029
PFDS	<RL	0.041
FASA (NV, SV)		
FBSA (NV)	0.154 ± 0.004	0.021
MeFBSA (SV)	<RL	2.20
FHxSA (NV)	0.040 ± 0.004	0.021
FOSA (NV)	0.055 ± 0.002	0.029
MeFOSA (SV)	<RL	0.440
EtFOSA (SV)	<RL	0.539
FASAA (NV)		
FOSAA	<RL	0.052
MeFOSAA	<RL	0.040
EtFOSAA	<RL	0.105
FASE (SV)		
MeFOSE	0.537 ± 0.065	0.250
EtFOSE	<RL	0.232
PPEA (NV)		
PFEESA	<RL	0.022
PF4OPeA	<RL	0.026
PF5OHxA	<RL	0.037
3-6-OPFHpA	<RL	0.021
HFPO-DA	<RL	0.219
ADONA	<RL	0.021
9Cl-PF3ONS	<RL	0.042
11Cl-PF3OUdS	<RL	0.021
n:2 FTMAC (V)		
6:2 FTMAC	<RL	74.2
8:2 FTMAC	<RL	38.0
10:2 FTMAC	<RL	40.0
n:2 FTOAc (V)		
8:2 FTOAc	<RL	39.8
10:2 FTOAc	<RL	8.00
n:2 FTOH (V)		
4:2 FTOH	<RL	41.7
5:2 FTOH	<RL	79.8
6:2 FTOH	<RL	40.1
7:2 FTOH	<RL	39.9
8:2 FTOH	<RL	78.4
10:2 FTOH	<RL	40.1
n:2 FTS (NV)		
4:2 FTS	<RL	0.089
6:2 FTS	<RL	0.137
8:2 FTS	<RL	0.184
10:2 FTS	<RL	0.208

Table 20. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in thermal liner textile TL-D. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.190
PFPeA	<RL	0.059
PFHxA	<RL	0.335
PFHpA	<RL	0.062
PFOA	<RL	0.320
PFNA	<RL	0.084
PFDA	<RL	0.180
PFUnDA	<RL	0.119
PFDoDA	<RL	0.097
PFTrDA	<RL	0.064
PFTeDA	<RL	0.126
PFSA (NV)		
PFPrS	<RL	0.029
PFBS	0.298 ± 0.022	0.017
PFPeS	<RL	0.022
PFHxS	<RL	0.042
PFHpS	<RL	0.021
PFOS	<RL	0.048
PFNS	<RL	0.029
PFDS	<RL	0.041
FASA (NV, SV)		
FBSA (NV)	0.0607 ± 0.0003	0.021
MeFBSA (SV)	<RL	1.00
FHxSA (NV)	<RL	0.021
FOSA (NV)	<RL	0.029
MeFOSA (SV)	<RL	0.419
EtFOSA (SV)	<RL	0.420
FASAA (NV)		
FOSAA	<RL	0.052
MeFOSAA	<RL	0.040
EtFOSAA	<RL	0.105

PFAS	Concentration (µg/kg)	RL (µg/kg)
FASE (SV)		
MeFOSE	<RL	1.00
EtFOSE	<RL	0.987
PPEA (NV)		
PFEESA	<RL	0.022
PF4OPeA	<RL	0.026
PF5OHxA	<RL	0.037
3-6-OPFHpA	<RL	0.021
HFPO-DA	<RL	0.220
ADONA	<RL	0.021
9Cl-PF3ONS	<RL	0.042
11Cl-PF3OUdS	<RL	0.021
n:2 FTMAC (V)		
6:2 FTMAC	<RL	70.7
8:2 FTMAC	<RL	72.3
10:2 FTMAC	<RL	38.1
n:2 FTOAc (V)		
8:2 FTOAc	<RL	16.2
10:2 FTOAc	No value[a]	
n:2 FTOH (V)		
4:2 FTOH	<RL	81.0
5:2 FTOH	<RL	158
6:2 FTOH	<RL	82.9
7:2 FTOH	<RL	89.8
8:2 FTOH	<RL	84.6
10:2 FTOH	<RL	82.3
n:2 FTS (NV)		
4:2 FTS	<RL	0.090
6:2 FTS	<RL	0.137
8:2 FTS	<RL	0.184
10:2 FTS	<RL	0.208

[a] QC standards not met. Data not reported.

Table 21. PFAS concentrations and reporting limits (RL; µg PFAS/kg textile) in thermal liner textile TL-E. Analytical method indicated with NV for nonvolatile, SV for semivolatile, or V for volatile.

PFAS	Concentration (µg/kg)	RL (µg/kg)
PFCA (NV)		
PFBA	<RL	0.800
PFPeA	<RL	0.025
PFHxA	<RL	0.128
PFHpA	<RL	0.088
PFOA	<RL	0.135
PFNA	<RL	0.026
PFDA	<RL	0.076
PFUnDA	<RL	0.039
PFDoDA	<RL	0.025
PFTrDA	<RL	0.073
PFTeDA	<RL	0.047
PFSA (NV)		
PFPrS	0.190 ± 0.014	0.026
PFBS	<RL	0.022
PFPeS	<RL	0.024
PFHxS	<RL	0.057
PFHpS	<RL	0.024
PFOS	<RL	0.048
PFNS	<RL	0.024
PFDS	<RL	0.058
FASA (NV, SV)		
FBSA (NV)	No value[a]	
MeFBSA (SV)	<RL	0.825
FHxSA (NV)	No value[a]	
FOSA (NV)	<RL	0.041
MeFOSA (SV)	<RL	0.345
EtFOSA (SV)	<RL	0.346
FASAA (NV)		
FOSAA	<RL	0.050
MeFOSAA	<RL	0.025
EtFOSAA	<RL	0.051
FASE (SV)		
MeFOSE	<RL	0.826
EtFOSE	<RL	0.814
PPEA (NV)		
PFEESA	<RL	0.020
PF4OPeA	<RL	0.023
PF5OHxA	<RL	0.023
3-6-OPFHpA	<RL	0.023
HFPO-DA	<RL	0.040
ADONA	<RL	0.023
9Cl-PF3ONS	<RL	0.024
11Cl-PF3OUdS	<RL	0.024
n:2 FTMAC (V)		
6:2 FTMAC	<RL	65.1
8:2 FTMAC	<RL	66.7
10:2 FTMAC	<RL	35.1
n:2 FTOAc (V)		
8:2 FTOAc	<RL	14.9
10:2 FTOAc	No value[a]	
n:2 FTOH (V)		
4:2 FTOH	<RL	74.6
5:2 FTOH	<RL	145
6:2 FTOH	<RL	76.4
7:2 FTOH	<RL	82.7
8:2 FTOH	<RL	77.9
10:2 FTOH	<RL	75.9
n:2 FTS (NV)		
4:2 FTS	<RL	0.068
6:2 FTS	<RL	0.195
8:2 FTS	<RL	0.116
10:2 FTS	<RL	0.114

[a] QC standards not met. Data not reported.

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Appendix A. Experimental Details

A.1. Firefighter Turnout Gear

The area densities and images of cuttings for all examined firefighter turnout gear textile are shown in Table 22.

Table 22. Area densities (mean ± standard deviation of triplicate measurements; kg/m²) and images of firefighter turnout gear textiles evaluated in this technical note.

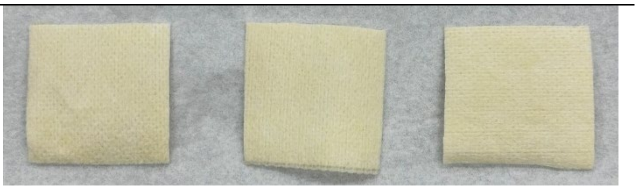
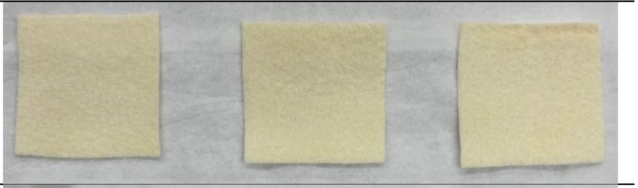
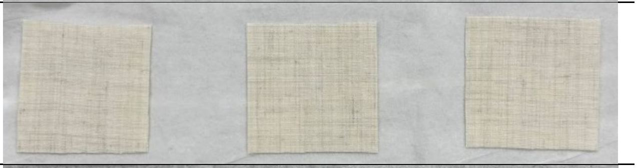
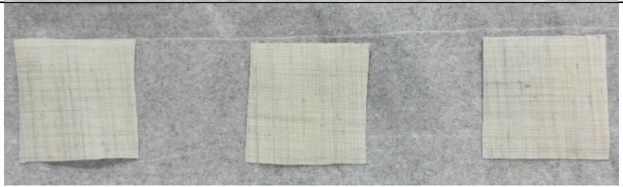
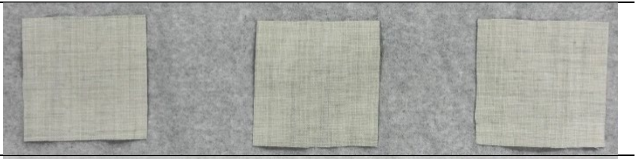
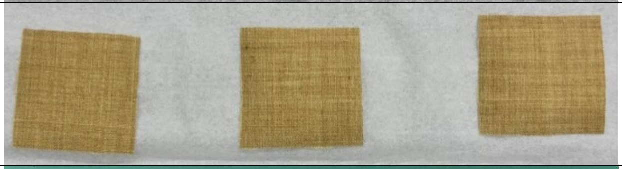
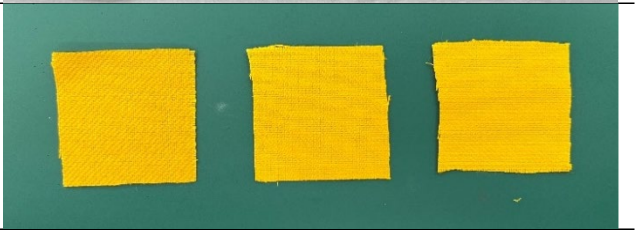
Textile	**Area Density (kg/m²)**	**Image**
MB-A	0.1672 ± 0.0026	
MB-B	0.1533 ± 0.0015	
MB-C	0.2540 ± 0.0011	
MB-D	0.2049 ± 0.0037	
MB-E	0.1675 ± 0.0012	
MB-F	0.2128 ± 0.0031	
OS-A	0.2244 ± 0.0070	

Table 22. (Continued)

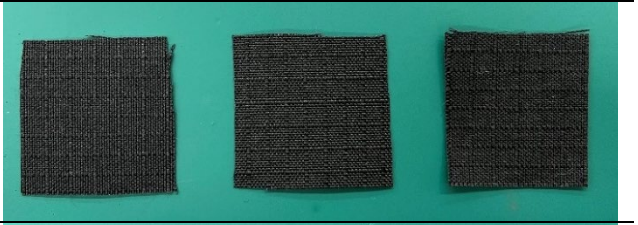
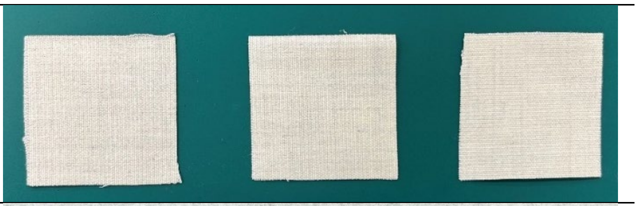
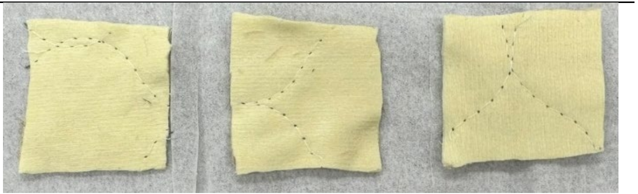
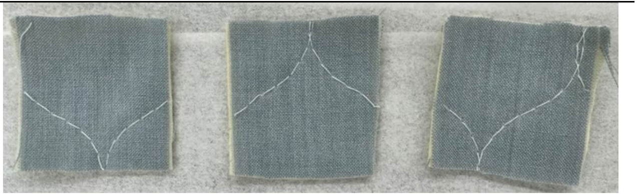
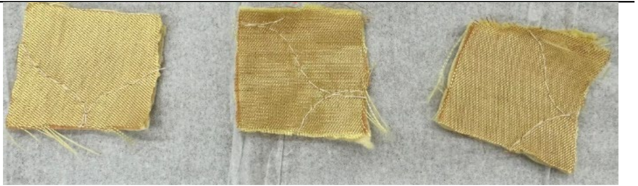
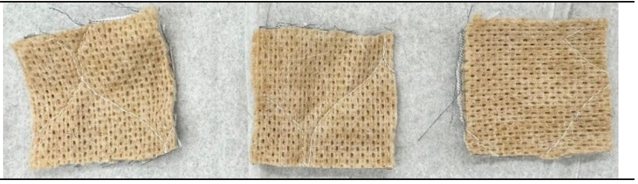
Textile	Area Density (kg/m^2)	Image
OS-ASC	0.2093 ± 0.0027	
OS-B	0.2635 ± 0.0055	
OS-C	0.2333 ± 0.0093	
OS-D	0.2619 ± 0.0085	
OS-E	0.2461 ± 0.0114	
OS-F	0.2574 ± 0.0016	
OS-FSC	0.2178 ± 0.0073	

Table 22. (Continued)

Textile	Area Density (kg/m^2)	Image
OS-G	0.2779 ± 0.0046	
TL-A	0.3428 ± 0.0087	
TL-B	0.3813 ± 0.0147	
TL-C	0.37.7 ± 0.0019	
TL-D	0.3533 ± 0.0043	
TL-E	0.3412 ± 0.0106	

A.2. PFAS Standards

Analytical standards (Table 23) and isotopically labeled standards (Table 24) for nonvolatile PFAS as well as semivolatile PFAS (Tables 25 and 26) were obtained from Wellington Laboratories (Guelph, Ontario, Canada). Analytical standards and isotopically labeled standards for volatile PFAS (Tables 27 and 28) were obtained from Wellington Laboratories and Synquest Laboratories (Alachua, FL).

NIST Reference Materials (RMs) 8446 Perfluorinated Carboxylic Acids and Perfluorooctane Sulfonamide in Methanol (8446) and 8447 Perfluorinated Sulfonic Acids in Methanol (8447) were obtained for use as quality control samples (Tables 29 and 30).

Table 23. Nonvolatile PFAS analytical standards obtained from Wellington Laboratories, with full analyte names, CAS RN, and abbreviations (bold), and analyte concentrations with expanded maximum combined percent relative uncertainty. PFHxS, PFOS, MeFOSAA, and EtFOSAA in PFAC30PAR were present as a mixture of structural isomers.

Standard	Contents	Concentration
PFAC30PAR	Perfluoro-n-butanoic acid (375-22-4; **PFBA**), Perfluoro-n-pentanoic acid (2706-90-3; **PFPeA**), Perfluoro-n-hexanoic acid (307-24-4; **PFHxA**), Perfluoro-n-heptanoic acid (375-85-9; **PFHpA**), Perfluoro-n-octanoic acid (335-67-1; PFOA), Perfluoro-n-nonanoic acid (375-95-1; **PFNA**), Perfluoro-n-decanoic acid (335-76-2; **PFDA**), Perfluoro-n-undecanoic acid (2058-94-8; **PFUnDA**), Perfluoro-n-dodecanoic acid (307-55-1; **PFDoDA**), Perfluoro-n-tridecanoic acid (72629-94-8; **PFTrDA**), Perfluoro-n-tetradecanoic acid (0376-06-07; **PFTeDA**), Perfluoro-1-butanesulfonamide (30334-69-1; **FBSA**), Perfluoro-1-hexanesulfonamide (41997-13-1; **FHxSA**), Perfluoro-1-octanesulfonamide (754-91-6; **FOSA**), Tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-propanoic acid (13252-13-6; HFPO-DA), N-methylperfluoro-1-octanesulfonamidoacetic acid (2355-31-9; **N-MeFOSAA**), N-ethylperfluoro-1-octanesulfonamidoacetic acid (2991-50-6, N-EtFOSAA), Potassium perfluorobutanesulfonate (29420-49-3; **PFBS**), Sodium perfluoropentanesulfonate (630402-22-1; **PFPeS**), Potassium perfluorohexanesulfonate (3871-99-6; **PFHxS**), Sodium perfluoroheptanesulfonate (21934-50-9; **PFHpS**), Potassium perfluorooctanesulfonate (2795-39-3; **PFOS**), Sodium perfluorononanesulfonate (98789-57-2; **PFNS**), Sodium perfluorodecanesulfonate (2806-15-7; **PFDS**), Sodium 1H,1H,2H,2H,-perfluoro-1-hexanesulfonate (27619-93-8; **4:2 FTS**), Sodium 1H,1H,2H,2H,-perfluoro-1-octanesulfonate (27619-94-9; **6:2 FTS**), Sodium 1H,1H,2H,2H,-perfluoro-1-decanesulfonate (27619-96-1; **8:2 FTS),** Sodium dodecafluoro-3H-4,8-dioxanonatoate; **NaDONA**), Potassium 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate (73606-19-6; **9Cl-PF3ONS**), Potassium 11-chloroeicosafluoro-3-oxaundecane-1-sulfonate (83329-89-9; **11Cl-PF3OUdS**)	1.00 ± 0.05 µg/mL in methanol/isopropanol (6%)/water (< 1%)
PFAC-MXG	Perfluoro-4-oxapentenoic acid (377-73-1; **PF4OPeA**), Perfluoro-5-oxahexanoic acid (863090-89-5; **PF5OHxA**), Perfluoro-3,6-dioxaheptanoic acid (151772-58-6; **3,6-OPFHpA**), Potassium perfluoro(2-ethoxyethane)sulfonic acid (**PFEESA**)	2.0 ± 0.1 µg/mL in methanol/water (<1%)
L-PFPrS	Sodium perfluoropropanesulfonate (359868-82-9; **PFPrS**)	50.0 ± 2.5 µg/mL in methanol
FOSAA	Perfluorooctane sulfonamidoacetic acid (2806-24-6; **FOSAA**)	50.0 ± 2.5 µg/mL in methanol/water (<1%)
10:2FTS	Sodium 1H,1H,2H,2H,-perfluoro-1-dodecanesulfonate (**10:2 FTS**)	50.0 ± 2.5 µg/mL in methanol

Table 24. Nonvolatile isotopically labeled PFAS internal and injection standards obtained from Wellington Laboratories, with full analyte names, and analyte concentrations with expanded maximum combined percent relative uncertainty where provided.

Standard	Contents	Concentration
MPFAC-24ES	Perfluoro-n-[13C4]butanoic acid, Perfluoro-n-[13C5]pentanoic acid, Perfluoro-n-[1,2,3,4,6-13C5]hexanoic acid, Perfluoro-n-[1,2,3,4-13C4]heptanoic acid, Perfluoro-n-[13C8]octanoic acid, Perfluoro-n-[13C9]nonanoic acid, Perfluoro-n-[1,2,3,4,5,6-13C5]decanoic acid, Perfluoro-n-[1,2,3,4,5,6,7-13C7]undecanoic acid, Perfluoro-n-[1,2-13C2]dodecanoic acid, Perfluoro-n-[1,2-13C2]tetradecanoic acid, Sodium perfluoro-1-[2,3,4-13C3]-butanesulfonate, Sodium perfluoro-1-[1,2,3-13C3]-hexanesulfonate, Sodium perfluoro-1-[13C8]-octanesulfonate, Perfluoro-1-[13C8]octanesulfonamide, N-methyl-d3-perlfuoro-1-octanesulfonamid acetic acid, N-ethyl-d5-perfluoro-1-octanesulfonamido acetic acid, Sodium 1H, 1H, 2H, 2H-perfluoro-1-[1,2-13C2]-hexane sulfonate, Sodium 1H, 1H, 2H, 2H-perfluoro-1-[1,2-13C2]-octane sulfonate, Sodium 1H, 1H, 2H, 2H-perlfuoro-1-[1,2-13C2]-decane sulfonate	1.00 ± 0.05 µg/mL in methanol/isopropanol (2%)/water (<1%)
M3HFPO-DA	Tetrafluoro(heptafluoropropoxy)[$^{13}C_3$]propanoic acid	50.0 ± 2.5 µg/mL in methanol
MPFAC-C-IS	Perfluoro-n-[2,3,4-13C3]butanoic acid (**PFBA-INJ**), Perfluoro-n-[1,2,3,4-13C4]octanoic acid (**PFOA -INJ**), Perfluoro-n-[1,2-13C2]decanoic acid (**PFDA -INJ)**, Sodium perfluoro-1-[1,2,3,4-13C4]-octanesulfonate (**PFOS -INJ**)	50.0 ± 2.5 µg/mL in methanol/water (<1%)

Table 25. Semivolatile PFAS analytical standards purchased from Wellington Laboratories including full analyte names, CAS RN, abbreviations (bold), and analyte concentrations with expanded maximum combined percent relative uncertainty where provided.

Standard	Contents	Concentration
N-MeFBSA-M	Nonafluoro-N-methylbutancesulfonamide (6829-12-4; **MeFBSA**)	50 ± 2.5 µg/mL
N-MeFOSA-M	Heptadecafluoro-N-methyloctancesulfonamide (31506-32-8; **MeFOSA**)	50 ± 2.5 µg/mL
N-EtFOSA-M	Heptadecafluoro-N-ethyloctancesulfonamide (4151-50-2; **EtFOSA**)	50 ± 2.5 µg/mL
N-MeFOSE-M	2-(N-methylperfluoro-1-octanesulfonamido)-ethanol (24448-09-7; **MeFOSE**)	50 ± 2.5 µg/mL
N-EtFOSE-M	2-(N-ethylperfluoro-1-octanesulfonamido)-ethanol (1691-99-2; **EtFOSE**)	50 ± 2.5 µg/mL

Table 26. Semivolatile isotopically labeled PFAS internal standards obtained from Wellington Laboratories, with full analyte names, and analyte concentrations with expanded maximum combined percent relative uncertainty where provided.

Standard	Contents	Concentration
d-N-MeFOSA-M	N-methy-d3-perflouro-1-octanesulfonamide	50 ± 2.5 µg/mL
d-N-EtFOSA	N-ethyl-d5-perfluoro-1-octanesulfonamide	50 ± 2.5 µg/mL
d7-N-MeFOSE-M	2-(N-methyl-d3-perfluoro-1-octanesulfonamido)ethan-d4-ol	50 ± 2.5 µg/mL
d9-N-EtFOSE-M	2-(N-ethyl-d5-perfluoro-1-octanesulfonamido)ethan-d4-ol	50 ± 2.5 µg/mL

Table 27. Volatile target PFAS analytical standards, supplier, full analyte names, CAS RN, abbreviations (bold), and analyte concentrations with expanded maximum combined percent relative uncertainty where provided.

Standard	Contents	Concentration
FBET (Wellington Laboratories)	2-Perflourobutyl ethanol (2043-47-2; **4:2 FTOH**)	50 ± 2.5 µg/mL in methanol
5:2sFTOH (Wellington Laboratories)	1-Perfluoropentyl ethanol (914637-05-1; **5:2 FTOH**)	50 ± 2.5 µg/mL in methanol
FHET (Wellington Laboratories)	2-Perfluorohexyl ethanol (647-42-7; **6:2 FTOH**)	50 ± 2.5 µg/mL in methanol
7:2sFTOH (Wellington Laboratories)	1-Perfluoroheptyl ethanol (24015-83-6; **7:2 FTOH**)	50 ± 2.5 µg/mL in methanol
FOET (Wellington Laboratories)	2-Perfluorooctyl ethanol (678-39-7; **8:2 FTOH**)	50 ± 2.5 µg/mL in methanol
FDET (Wellington Laboratories)	2-Perfluorodecyl ethanol (865-86-1; 10**:2 FTOH**)	50 ± 2.5 µg/mL in methanol
8:2 FTOAc (Wellington Laboratories)	1H, 1H, 2H, 2H-Perfluorodecyl acetate (37858-04-1; **8:2 FTOAc**)	48.5 ± 2.4 µg/mL in isooctane
10:2FTOAc (Wellington Laboratories)	1H, 1H, 2H, 2H-Perfluorododecyl acetate (37858-05-2; **10:2 FTOAc**)	50 ± 2.5 µg/mL in isooctane
2324-3-46 (Synquest Laboratories)	1H, 1H, 2H, 2H-Perfluorooctyl methacrylate (2144-53-8; **6:2 FTMAC**)	Neat (97 % Purity)
2324-3-42 (Synquest Laboratories)	1H, 1H, 2H, 2H-Perfluorodecyl methacrylate (1996-88-9; **8:2 FTMAC**)	Neat (97 % Purity)
2324-3-Y5 (Synquest Laboratories)	1H, 1H, 2H, 2H-Perfluorododecyl methacrylate (2144-54-9; **10:2 FTMAC**)	Neat (97 % Purity)

Table 28. Volatile internal standard PFAS purchased from Wellington Laboratories, including full analyte names, and analyte concentrations with expanded maximum combined percent relative uncertainty where provided.

Standard	Contents	Concentration
MFBET	2-Perfluorobutyl-[1,1,2,2-$^2H_4$]-ethanol	48.5 ± 2.4 µg/mL in methanol
MFHET	2-Perfluorohexyl-[1,1-$^2H_2$]-[1,2-$^{13}C_2$]-ethanol	50 ± 2.5 µg/mL in methanol
MFOET	2-Perfluorooctyl-[1,1-$^2H_2$]-[1,2-$^{13}C_2$]-ethanol	50 ± 2.5 µg/mL in methanol
MFDET	2-Perfluorodecyl-[1,1-$^2H_2$]-[1,2-$^{13}C_2$]-ethanol	50 ± 2.5 µg/mL in methanol

Table 29. Reference mass fractions for NIST Reference Material 8446 including mean value and expanded uncertainty with 95 % confidence.

PFAS	Mass Fraction (mg/kg)
PFHxA	59.1 ± 1.4
PFHpA	76.0 ± 7.2
PFOA	54.8 ± 2.2
PFNA	63.0 ± 1.4
PFDA	58.1 ± 4.0
PFUdA	62.8 ± 6.5
PFDoDA	59.5 ± 7.0
PFTrDA	62.9 ± 2.8
PFTeDA	58.0 ± 3.8
PFBA	43 ± 11
PFPeA	60.9 ± 0.9
FOSA	66.9 ± 1.7

Table 30. Reference mass fractions NIST Reference Material 8447 including mean value and expanded uncertainty with 95 % confidence.

PFAS	Mass Fraction (mg/kg)
PFBS	42.3 ± 2.3
PFHxS	55.2 ± 1.7
PFOS	56.6 ± 2.5

A.3. Extraction and Analysis of PFAS in Firefighter Turnout Gear Textiles

A.3.1. Extraction of Nonvolatile PFAS

An extraction procedure for nonvolatile PFAS in turnout gear textiles was developed by adapting the method of Robel et al. [1]. Target and internal standard working solutions were prepared by gravimetric dilution of commercially obtained PFAS standards in methanol. Nonvolatile PFAS extraction batches consisted of forty-eight individual samples, including three batch blanks (solvent blanks for the analysis of OS-ASC and OS-FSC or textile blanks containing OS-FSC for the remaining textiles), one in-house reference textile (OS-FRM), and eleven sets of quadruplicate cuttings of experimental textiles. For each textile blank and experimental textile, sections of approximately 0.1 g (10^{-4} kg; approximately 0.01 m x 0.01 m; mass known) were cut with methanol-rinsed scissors and placed into pre-weighed 15 mL centrifuge tubes. When thermal liner textiles were sectioned, they were cut so that all layers were present in roughly equal areas. One sample of each quadruplicate experimental textile was selected for matrix spiking with approximately 0.1 mL (10^{-7} m^3; mass known) of a target working solution which contributed approximately 10 µg PFAS/kg textile of all nonvolatile target PFAS. Following the addition of matrix spikes to selected experimental textiles, all samples were capped and allowed to equilibrate at room temperature for 15 h – 20 h. Subsequently, approximately 0.1 mL (10^{-7} m^3; mass known) of an internal standard working solution was added to all samples, which contributed approximately 10 µg PFAS/kg textile of isotopically labeled nonvolatile internal standard PFAS. All samples were then capped and allowed to equilibrate at room temperature for at least 1 h.

After equilibration with the internal standard working solution, 5 mL (5×10^{-6} m^3) of methanol was added to all samples, which were then vortexed and sonicated at 25 °C for 30 min. Samples were then centrifuged for 5 min at 2325 relative centrifugal field and the supernatants were decanted directly into the barrels of ENVI-Carb SPE cartridges (500 mg, 6 mL) that had previously been rinsed with 20 mL (2×10^{-5} m^3) of 0.1 mol/L (10^2 mol/m^3) ammonium hydroxide in methanol. The decanted supernatants were then pushed through the SPE cartridges into 20 mL scintillation vials with positive pressure. Two additional rounds of methanol addition, sonication, centrifugation, and ENVI-Carb treatment were performed, and the extracts from each round of the same textile sample were passed through the same SPE cartridge and combined in a single 20 mL scintillation vial. Finally, each SPE cartridge was rinsed with 5 mL (5×10^{-6} m^3) of 0.1 mol/L (10^2 mol/m^3) ammonium hydroxide in methanol that was collected and combined with the previously collected extracts that had passed through the same cartridge. The combined extracts were stored at -20 °C for 15 h – 20 h and then evaporated to dryness at 40 °C under nitrogen. The dried extracts were reconstituted in 0.5 mL (5×10^{-7} m^3) of methanol that contained approximately 2×10^3 µg/m^3 of nonvolatile injection standards (i.e., PFBA-INJ, PFOA-INJ, PFDA-INJ, PFOS-INJ) and passed through 0.22 µm methanol-rinsed syringe filters. The filtered extracts were collected in amber glass HPLC vials and stored at -20 °C in the dark until HPLC-MS/MS analysis.

A.3.2. Extraction of Semivolatile and Volatile PFAS

Semivolatile and volatile PFAS were extracted simultaneously with a method derived from the nonvolatile PFAS extraction method, except for the differences described below. Target and internal standards solutions were prepared in ethyl acetate rather than methanol. Samples selected for matrix spiking were spiked with approximately 0.2 mL (2 x 10^{-7} m^3; mass known) of a diluted target working solution which added approximately 10^4 µg PFAS/kg textile for n:2 FTMACs, 2 x 10^3 µg PFAS/kg textiles for other volatile target PFAS, and 4 x 10 µg PFAS/kg textile for semivolatile PFAS. Approximately 0.2 mL (2 x 10^{-7} m^3; mass known) of an internal standard working solution was added to all samples, which added approximately 2 x 10^3 µg PFAS/kg textile for all volatile PFAS internal standards and 4 x 10 µg PFAS/kg textile for all semivolatile PFAS internal standards. Ethyl acetate was used as an extraction solvent rather than methanol and extracts were concentrated to approximately 2 mL (2 x 10^{-6} m^3; mass known) at 35 °C on a nitrogen evaporator.

Extracts for volatile PFAS analysis were analyzed by GC-MS without further processing, while extracts for semivolatile PFAS analysis were diluted 1:4 (masses known) with an ethyl acetate solution containing approximately 2.5 x 10^3 µg injection standard PFAS/m^3 before analysis by HPLC-MS/MS.

A.3.3. HPLC-MS/MS Analysis of Nonvolatile and Semivolatile PFAS

Thirty-seven nonvolatile and five semivolatile PFAS in firefighter textile extracts were quantified with separate HPLC-MS/MS methods that both used negative mode electrospray ionization. Method development for HPLC-MS/MS methods included the optimization of a liquid chromatography method, the optimization of MS source and gas parameters, and the optimization of multiple reaction monitoring (MRM) parameters.

The separation of nonvolatile and semivolatile PFAS was performed with an Agilent 1260 LC instrument. Potential PFAS contamination of this instrument was mitigated by replacing fluoropolymer tubing with equivalent polyetheretherketone (PEEK) tubing wherever possible as well as the use of PEEK in-line solvent filters. An Agilent Eclipse Plus C18 (4.6 mm x 50 mm, 5 µm) column was installed between the pump and autosampler to prevent PFAS present in the mobile phase solutions from eluting simultaneously with PFAS present in the injected samples. During analysis sample vials were kept at 10 °C. For both methods, 5 µL (5 x 10^{-9} m^3) sample volumes were injected onto one (nonvolatile analysis) or two (semivolatile analysis) Agilent DIOL guard columns (4.6 mm x 12.5 mm, 6 µm), connected to an Agilent Poroshell 120 EC-C18 guard column (4.6 mm x 5 mm, 2.7 µm) and an Agilent Poroshell 120 EC-C18 analytical column (4.6 mm x 100 mm, 2.7 µm). The guard and analytical columns were kept at 40 °C. A binary gradient elution was used (Table 31) with mobile phase A consisting of 9.5 mmol/L (9.5 mol/m^3) ammonium acetate, 0.5 mmol/L (0.5 mol/m^3) ammonium hydroxide in water and mobile phase B consisting of 9.5 mmol/L (9.5 mol/m^3) ammonium acetate, 0.5 mmol/L (0.5 mol/m^3) ammonium hydroxide in methanol. Flow from the analytical column was directed to waste from 0 min to 4.25 min and to the ion source from 4.25 min to 18 min. The optimized MS/MS method parameters for nonvolatile and semivolatile PFAS analysis are described in Tables 32 - 34.

Table 31. HPLC mobile phase gradient used for the analysis of nonvolatile and semivolatile PFAS.

Time (min)	**Flow Rate (mL/min)**	**B (%)**
0	0.6	10
0.5	0.6	50
18	0.6	99
23	0.6	99
23.5	0.6	10
31.5	0.6	10

Table 32. PFAS-specific MRM parameters for nonvolatile PFAS analysis: Precursor and product ion m/z (M1 and M2, respectively), depolarization energy (DP), collision energy (CE), collision cell exit potential (CXP), entrance potential (EP), and LC retention time (RT). Qualifier ions are indicated with "-q." Injection standard ions are indicated with "INJ." Internal standard ions (IS) were analyzed with the same electronic settings as the corresponding target PFAS.

PFAS	M$_1$/M$_2$	DP	CE	CXP	EP	RT (min)	IS	IS M$_1$/M$_2$
PFBA	213/169	-25	-12	-15	-10	4.66	$^{13}C_4$-PFBA	217/172
PFPeA	263/219	-15	-12	-21	-10	5.81	$^{13}C_5$-PFPeA	268/223
PFHxA	313/269	-5	-14	-35	-10	7.22	$^{13}C_4$-PFHxA	318/273
PFHxA-q	313/119	-25	-26	-11	-10	7.22	$^{13}C_4$-PFHxA	318/273
PFHpA	363/319	-30	-14	-35	-10	8.80	$^{13}C_4$-PFHpA	367/322
PFHpA-q	363/169	-40	-22	-15	-10	8.80	$^{13}C_4$-PFHpA	367/322
PFOA	413/369	-5	-12	-41	-10	10.39	$^{13}C_8$-PFOA	421/376
PFOA-q	413/169	-50	-26	-19	-10	10.39	$^{13}C_8$-PFOA	421/376
PFNA	463/419	-35	-14	-33	-10	11.85	$^{13}C_9$-PFNA	472/427
PFNA-q	463/219	-35	-26	-23	-10	11.85	$^{13}C_9$-PFNA	472/427
PFDA	513/469	-5	-14	-21	-10	13.14	$^{13}C_6$-PFDA	519/474
PFDA-q	513/219	-65	-26	-23	-10	13.14	$^{13}C_6$-PFDA	519/474
PFUnDA	563/519	-65	-18	-55	-10	14.28	$^{13}C_7$-PFUnDA	570/525
PFUnDA-q	563/269	-55	-28	-29	-10	14.28	$^{13}C_7$-PFUnDA	570/525
PFDoDA	613/569	-75	-20	-29	-10	15.24	$^{13}C_2$-PFDoDA	615/570
PFDoDA-q	613/269	-5	-30	-29	-10	15.24	$^{13}C_2$-PFDoDA	615/570
PFTrDA	663/619	-70	-20	-29	-10	16.09	$^{13}C_2$-PFDoDA	615/570
PFTrDA-q	663/269	-55	-32	-27	-10	16.09	$^{13}C_2$-PFDoDA	615/570
PFTeDA	713/669	-50	-20	-33	-10	16.82	$^{13}C_2$-PFTeDA	715/670
PFTeDA-q	713/369	-95	-32	-37	-10	16.82	$^{13}C_2$-PFTeDA	715/670
PFPrS	248.9/80	-105	-44	-15	-10	4.97	$^{13}C_4$-PFBS	302/99
PFPrS-q	248.9/99	-50	-42	-15	-10	4.97	$^{13}C_4$-PFBS	302/99
PFBS	299/80	-105	-50	-9	-10	6.01	$^{13}C_4$-PFBS	302/99
PFBS-q	299/99	-75	-46	-15	-10	4.97	$^{13}C_4$-PFBS	302/99
PFPeS	349/80	-100	-62	-15	-10	7.39	$^{13}C_3$-PFHxS	402/99
PFPeS-q	349/99	-115	-54	-11	-10	7.39	$^{13}C_3$-PFHxS	402/99
PFHxS	399/80	-65	-60	-13	-10	8.80	$^{13}C_3$-PFHxS	402/99
PFHxS-q	399/99	-110	-52	-7	-10	8.80	$^{13}C_3$-PFHxS	402/99
PFHpS	449/80	-85	-72	-15	-10	10.45	$^{13}C_3$-PFOS	507/99
PFHpS-q	449/99	-140	-60	-13	-10	10.45	$^{13}C_3$-PFOS	507/99
PFOS	499/80	-155	-74	-7	-10	11.70	$^{13}C_3$-PFOS	507/99
PFOS-q	499/99	-140	-56	-9	-10	11.70	$^{13}C_3$-PFOS	507/99
PFNS	549/80	-110	-82	-7	-10	13.11	$^{13}C_3$-PFOS	507/99
PFNS-q	549/99	-50	-70	-9	-10	13.11	$^{13}C_3$-PFOS	507/99
PFDS	599/80	-215	-80	-17	-10	14.23	$^{13}C_3$-PFOS	507/99
PFDS-q	599/99	-180	-70	-5	-10	14.23	$^{13}C_3$-PFOS	507/99
FBSA	298/78	-60	-32	-7	-10	6.86	$^{13}C_8$-FOSA	509/78
FHxSA	398/78	-60	-42	-13	-10	10.53	$^{13}C_8$-FOSA	509/78

Table 32. (Continued).

PFAS	M_1/M_2	DP	CE	CXP	EP	RT (min)	IS	IS M_1/M_2
FHxSA-q	398/169	-110	-40	-19	-10	10.53	$^{13}C_8$-FOSA	509/78
FOSA	498/78	-90	-64	-9	-10	13.56	$^{13}C_8$-FOSA	509/78
FOSA-q	498/169	-110	-44	-13	-10	13.56	$^{13}C_8$-FOSA	509/78
MeFBSA	312/219	-35	-24	-21	-10	9.90	$^{2}H_3$-MeFOSA	515/169
MeFOSA	512/169	-105	-40	-17	-10	15.60	$^{2}H_3$-MeFOSA	515/169
MeFOSA-q	512/219	-105	-38	-33	-10	15.60	$^{2}H_3$-MeFOSA	515/169
EtFOSA	526/169	-105	-40	-17	-10	16.27	$^{2}H_3$-EtFOSA	531/169
EtFOSA-q	526/219	-105	-38	-33	-10	16.27	$^{2}H_3$-EtFOSA	531/169
FOSAA	559/498	-115	-38	-55	-10	12.97	$^{2}H_3$-MeFOSAA	573/419
FOSAA-q	559/419	-130	-36	-51	-10	12.97	$^{2}H_3$-MeFOSAA	573/419
N-MeFOSAA	570/419	-70	-26	-41	-10	13.60	$^{2}H_3$-MeFOSAA	573/419
N-MeFOSAA-q	570/512	-95	-28	-23	-10	13.60	$^{2}H_3$-MeFOSAA	573/419
N-EtFOSAA	584/419	-105	-26	-21	-10	14.15	$^{2}H_5$-EtFOSAA	589/419
N-EtFOSAA-q	584/526	-95	-30	-55	-10	14.15	$^{2}H_5$-EtFOSAA	589/419
4:2 FTS	327/307	-65	-26	-15	-10	7.09	$^{13}C_2$-4:2 FTS	329/81
4:2 FTS-q	327/81	-85	-36	-11	-10	7.09	$^{13}C_2$-4:2 FTS	329/81
6:2 FTS	427/407	-130	-32	-43	-10	10.31	$^{13}C_2$-6:2 FTS	429/409 or 429/81
6:2 FTS-q	427/81	-110	-56	-9	-10	10.31	$^{13}C_2$-6:2 FTS	429/409 or 429/81
8:2 FTS	527/507	-130	-34	-51	-10	13.15	$^{13}C_2$-8:2 FTS	529/509
8:2 FTS-q	527/81	-115	-70	-11	-10	13.15	$^{13}C_2$-8:2 FTS	529/509
10:2 FTS	627/607	-130	-42	-55	-10	15.29	$^{13}C_2$-8:2 FTS	529/509
10:2 FTS-q	627/81	-185	-70	-5	-10	15.29	$^{13}C_2$-8:2 FTS	529/509
HFPO-DA	329/285	-15	-10	-31	-10	7.66	$^{13}C_3$-HFPO-DA	332/287
HFPO-DA-q	329/169	-25	-16	-13	-10	7.66	$^{13}C_3$-HFPO-DA	332/287
ADONA	377/251	-50	-18	-33	-10	9.00	$^{13}C_4$-PFHpA	367/322
ADONA-q	377/85	-50	-36	-33	-10	9.00	$^{13}C_4$-PFHpA	367/322
9Cl-PF3ONS	531/351	-125	-34	-35	-10	12.58	$^{13}C_3$-PFOS	507/99
9Cl-PF3ONS-q	533/353	-125	-34	-35	-10	12.58	$^{13}C_3$-PFOS	507/99
11Cl-PF3OUdS	631/451	-125	-42	-47	-10	14.75	$^{13}C_3$-PFOS	507/99
11Cl-PF3OUdS-q	633/453	-125	-42	-47	-10	14.75	$^{13}C_3$-PFOS	507/99
PF4OPeA	229/85	-35	-20	-7	-10	5.06	$^{13}C_4$-PFBA	217/172
PF5OHxA	279/85	-25	-22	-17	-10	6.19	$^{13}C_5$-PFPeA	268/223
3,6-OPFHpA	295/201	-5	-12	-21	-10	6.95	$^{13}C_4$-PFHxA	318/273
PFEESA	315/135	-30	-36	-17	-10	6.55	$^{13}C_4$-PFBS	302/99
PFBA-INJ	213/169	-25	-12	-15	-10	5.1	N/A	N/A
PFOA -INJ	413/369	-5	-12	-41	-10	11.1	N/A	N/A
PFDA -INJ	513/469	-5	-14	-21	-10	13.9	N/A	N/A
PFOS -INJ	499/80	-155	-74	-7	-10	12.6	N/A	N/A

Table 33. MRM parameters for semivolatile PFAS: Precursor and product ion m/z (M1 and M2), depolarization energy (DP), collision energy (CE), collision cell exit potential (CXP), entrance potential (EP), and LC retention time (RT). Qualifier ions are indicated with "-q." Injection standard ions are indicated with "INJ." Internal standard ions were analyzed with the same electronic settings as the corresponding target PFAS.

PFAS	M_1/M_2	DP	CE	CXP	EP	RT (min)	IS	IS M_1/M_2
MeFBSA	312/219	-35	-24	-21	-10	9.7	d_3-MeFOSA	515/169
MeFOSA	512/169	-105	-40	-17	-10	16.1	d_3-MeFOSA	515/169
MeFOSA-q	512/219	-105	-38	-33	-10	16.1	d_3-MeFOSA	515/169
EtFOSA	526/169	-105	-40	-17	-10	16.9	d_3-EtFOSA	531/169
EtFOSA-q	526/219	-105	-38	-33	-10	16.9	d_3-EtFOSA	531/169
MeFOSE	616/59	-70	-42	-11	-10	16.5	d_3-MeFOSE	623/59
EtFOSE	630/59	-70	-52	-11	-10	17.2	d_3-EtFOSE	639/59
PFBA-INJ	213/169	-25	-12	-15	-10	5.1	N/A	N/A
PFOA -INJ	413/369	-5	-12	-41	-10	11.1	N/A	N/A
PFDA -INJ	513/469	-5	-14	-21	-10	13.9	N/A	N/A
PFOS -INJ	499/80	-155	-74	-7	-10	12.6	N/A	N/A

Table 34. Optimized source and gas parameters for nonvolatile and semivolatile PFAS analysis.

Parameter	Value
Collision Gas (CAD)	9
Curtain Gas supply (CUR)	20 psi
Gas 1 (nebulizer gas; GS1)	50 psi
Gas 2 (heater gas; GS2)	50 psi
IonSpray Voltage (IS)	-4500 V
Temperature (TEM)	450 °C

Extracted ion chromatograms of nonvolatile PFAS are shown in Figs. 4 - 9. Extracted ion chromatograms of semivolatile PFAS are shown in Figs. 10 and 11. Extracted ion chromatograms of injection standard PFAS for both nonvolatile and semivolatile PFAS analysis are shown in Fig. 12.

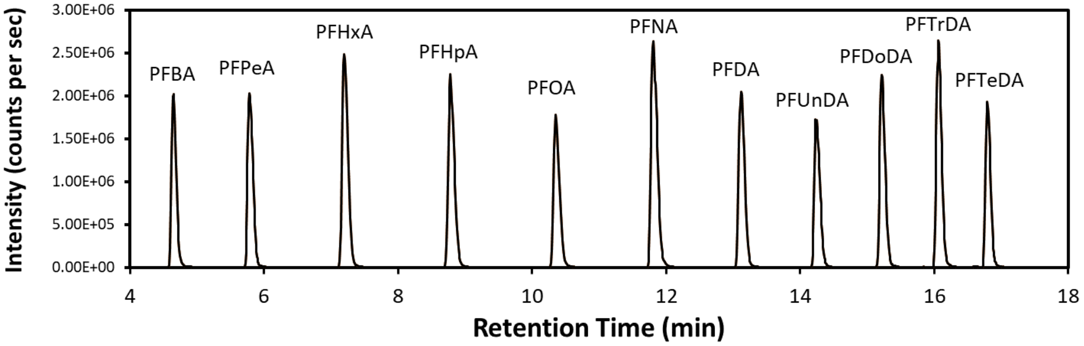


Fig. 4. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each perfluorocarboxylic acid (PFCA) in a calibration standard.

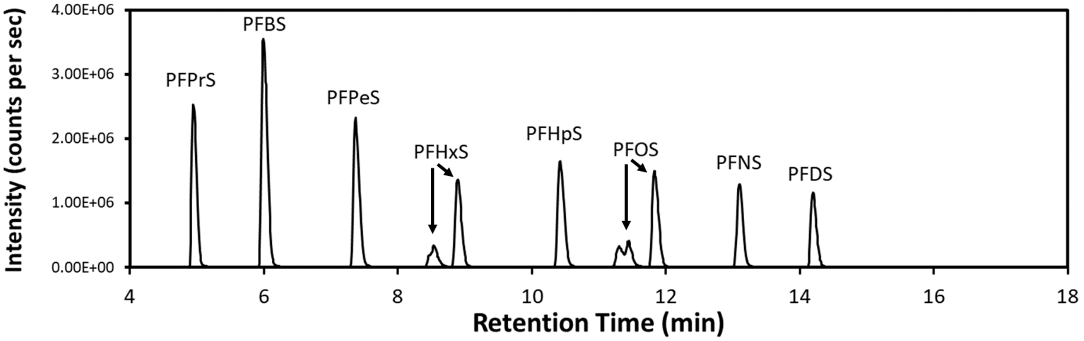


Fig. 5. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each perfluoroalkane sulfonic acid (PFSA) in a calibration standard. Peaks derived from branched isomers of PFHxS and PFOS precede the linear isomer peaks

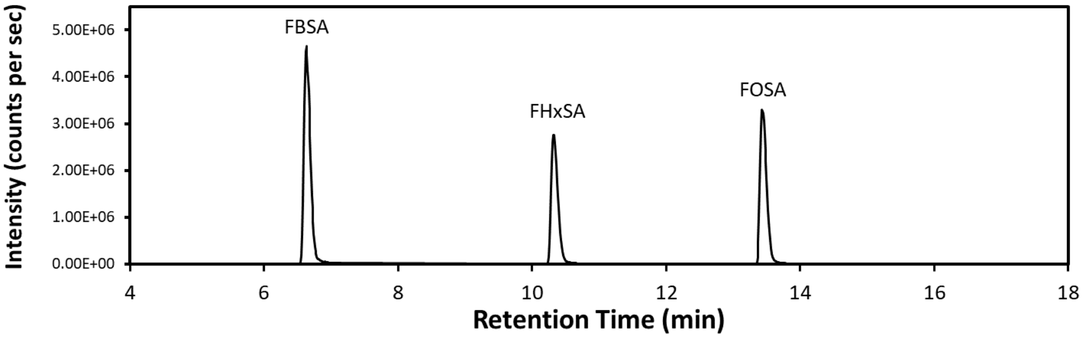


Fig. 6. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each perfluoroalkane sulfonamide (FASA) in a calibration standard.

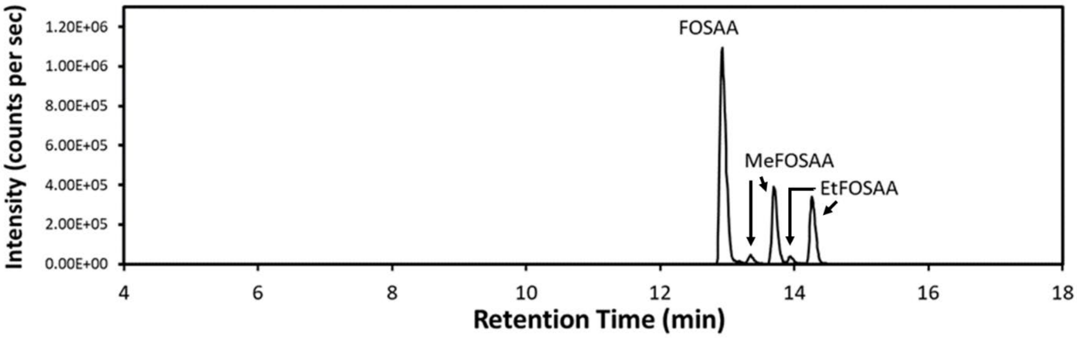


Fig. 7. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each per- and polyfluoroalkane sulfonamido acetic acid (FASAAs) in a calibration standard. Peaks derived from branched isomers of MeFOSAA and EtFOSAA precede the linear isomer peaks

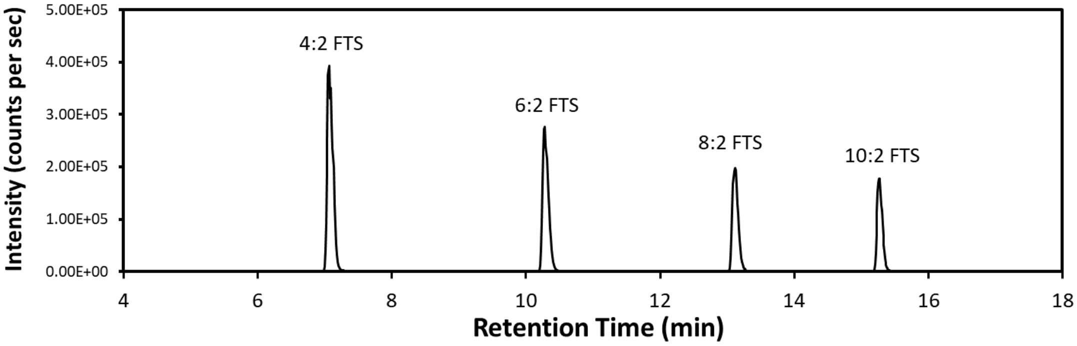


Fig. 8. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each n:2 fluorotelomer sulfonate PFAS in a calibration standard.

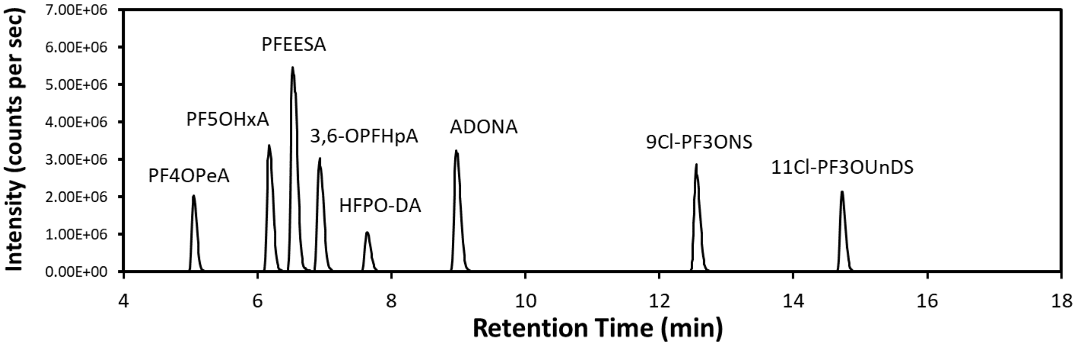


Fig. 9. Extracted ion chromatogram from injection of 5 µL (5 x 10^{-9} m^3) of approximately 50 ng/mL (5 x 10^4 µg/m^3) of each PPEA in a calibration standard.

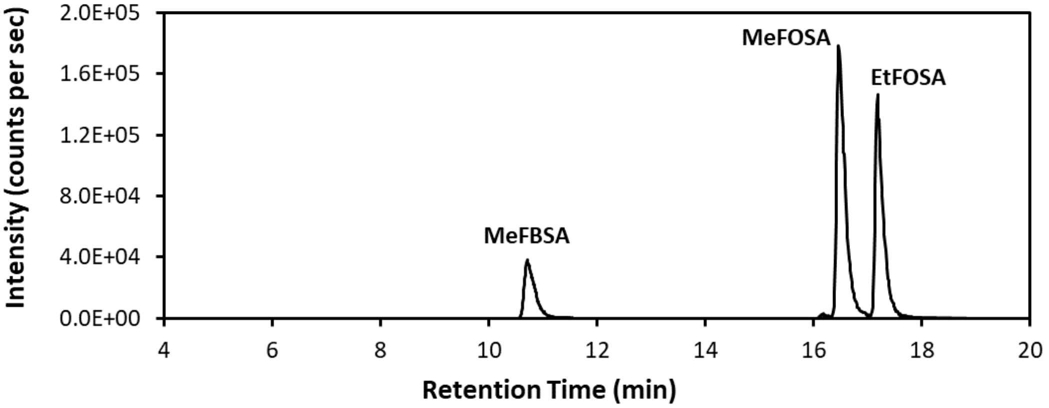


Fig. 10. Extracted ion chromatograms from injection of 5 µL (5 x 10^{-9} m^3) of approximately 10 ng/mL (10^4 µg/m^3) each of MeFBSA, MeFOSA, and EtFOSA in a calibration standard.

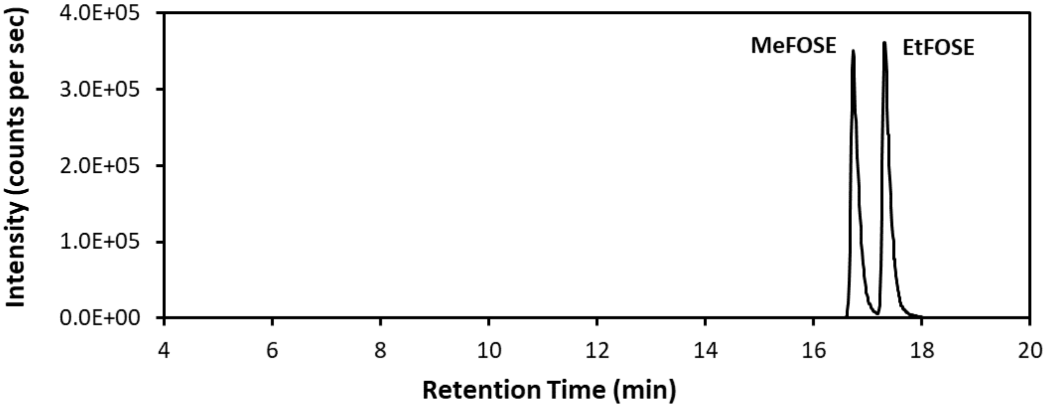


Fig. 11. Extracted ion chromatograms from injection of 5 µL (5 x 10^{-9} m^3) of approximately 10 ng/mL (10^4 µg/m^3) each of MeFOSE and EtFOSE in a calibration standard.

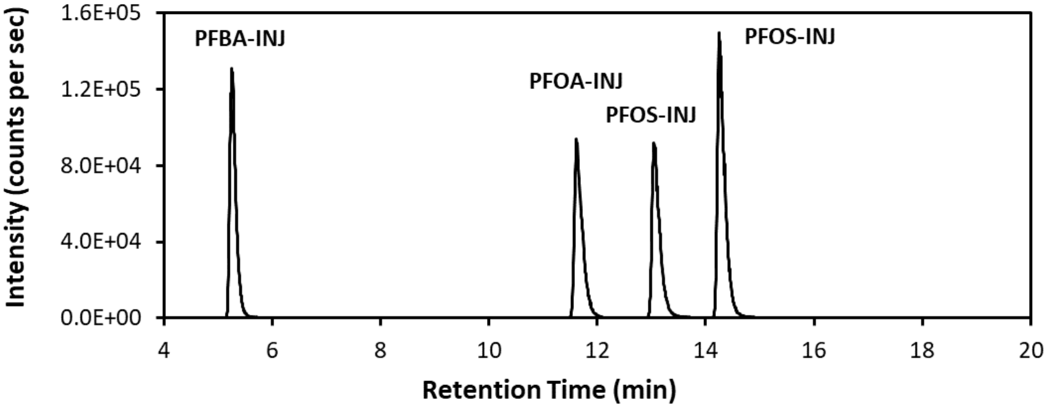


Fig. 12. Extracted ion chromatograms from injection of 5 µL (5 x 10^{-9} m^3) of approximately 2 ng/mL(2 x 10^3 µg/m^3) of each injection standard PFAS.

A.3.4. GC-MS Analysis of Volatile PFAS

Eleven volatile PFAS in firefighter textile extracts were quantified with GC-MS with electron impact ionization. GC-MS method development included the identification of primary and secondary ions for each target and isotopically labeled internal standard volatile PFAS and the optimization of a gas chromatography method.

Separation and detection were performed on an Agilent 6890 gas chromatograph with an Agilent 5973A mass spectrometer. 3 µL (3 x 10^{-9} m^3) sample aliquots were injected with a Gerstel MPS2 autosampler into a split/splitless port at 280 ºC and onto a 1 m × 0.53 mm polar deactivated/uncoated retention gap connected directly with a press-tight connector to a 30 m × 0.25 mm Stabilwax-DB column (Restek, Bellefonte, PA, 0.25 µm phase thickness) operated at a constant helium carrier flow of 2 mL/min (average linear velocity = 51 cm/s). The column temperature program began with an initial temperature of 45 ºC for a 1.6 min hold followed by a 2 ºC/min increase to 64 ºC, then a 5 ºC/min to 110 ºC and a final ramp 20 ºC/min to 210 ºC with a 15 min hold at this final temperature. The interface temperature was set at 220 ºC. Retention times for target and internal standard volatile PFAS, as well as primary and secondary ions for each target PFAS, are shown in Table 35. Extracted ion chromatograms of volatile PFAS are shown in Figs. 13-15.

Table 35. Optimized primary (quantifier) and secondary (qualifier) ions (m/z), retention times, and internal standards for each target analyte

Analyte	Primary/Secondary Ions	Retention Time (min)	Internal Standard
4:2 FTOH	244/196	11.3	$^{2}H_{4}$-4:2 FTOH
5:2 FTOH	219/255	12.1	$^{2}H_{4}$-4:2 FTOH
6:2 FTOH	344/363	13.9	$^{2}H_{2}$-$^{13}C_{2}$-6:2 FTOH
7:2 FTOH	319/399	14.7	$^{2}H_{2}$-$^{13}C_{2}$-6:2 FTOH
8:2 FTOH	405/444	16.6	$^{2}H_{2}$-$^{13}C_{2}$-8:2 FTOH
10:2 FTOH	505/544	19.2	$^{2}H_{2}$-$^{13}C_{2}$-10:2 FTOH
8:2 FTOAc	506/486	12.2	$^{2}H_{4}$-4:2 FTOH
10:2 FTOAc	606/527	16.2	$^{2}H_{2}$-$^{13}C_{2}$-8:2 FTOH
6:2 FTMAC	432/433	12.9	$^{2}H_{4}$-4:2 FTOH
8:2 FTMAC	532/533	16.3	$^{2}H_{2}$-$^{13}C_{2}$-8:2 FTOH
10:2 FTMAC	632/633	19.5	$^{2}H_{2}$-$^{13}C_{2}$-10:2 FTOH
M4:2 FTOH	248/-	11.1	N/A
M6:2 FTOH	344/-	13.8	N/A
M8:2 FTOH	448/-	16.5	N/A
M10:2 FTOH	509/-	18.9	N/A

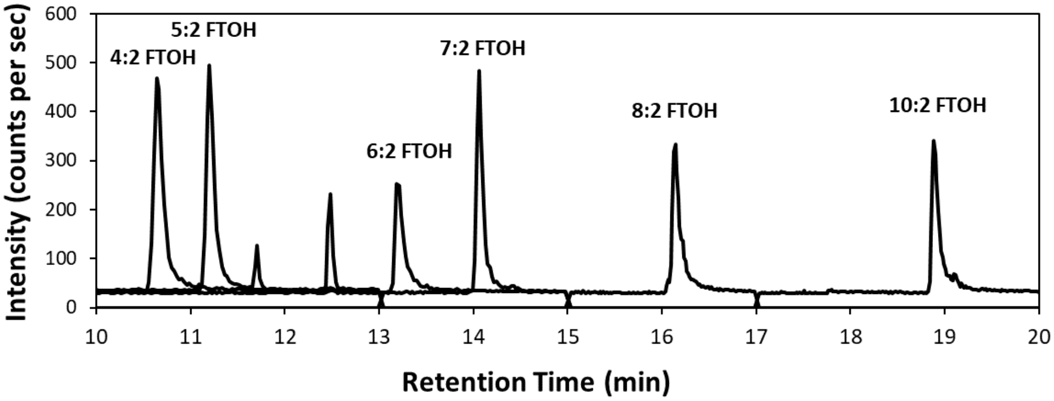


Fig. 13. Extracted ion chromatograms from injection of 3 µL (3 x 10^{-9} m^3) of a calibration standard containing approximately 200 ng/mL (2 x 10^5 µg/m^3) of each of five fluorotelomer alcohols.

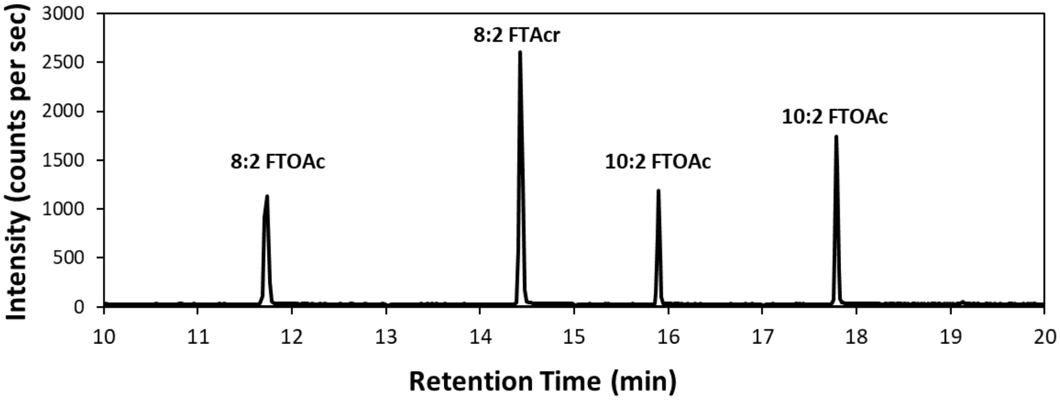


Fig. 14. Extracted ion chromatograms from injection of 3 µL (3 x 10^{-9} m^3) of a calibration standard containing approximately 200 ng/mL (2 x 10^5 µg/m^3) each of two fluorotelomer acetates and two fluorotelomer acrylates.

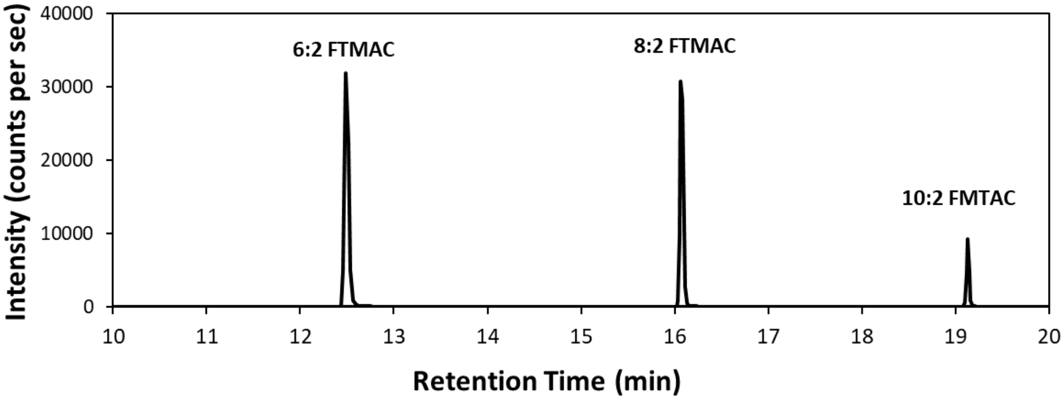


Fig. 15. Extracted ion chromatograms from injection of 3 µL (3 x 10^{-9} m^3) of a calibration standard containing approximately 1,000 ng/mL (10^6 µg/m^3) each of 6:2 and 8:2 fluorotelomer methacrylate as well as approximately 500 ng/mL (5 x 10^5 µg/m^3) of 10:2 fluorotelomer methacrylate.

A.4. Quality Control Materials

For the analysis of nonvolatile, semivolatile, and volatile PFAS quality control solutions including calibration standards, continuing calibration verification solutions, and continuing calibration blank solutions were made by the dilution of commercially available analytical standards. For nonvolatile PFAS, NIST RMs 8446 and 8447 were used as calibration verification solutions. To demonstrate extraction reproducibility, four hundred sections of an outer shell textile were prepared so that one could be extracted with each experimental batch.

A.4.1. Nonvolatile PFAS

For the quantification of nonvolatile PFAS in turnout gear textiles commercially obtained target standard (Table 23), internal standard (Table 24), and injection standard (i.e., PFBA-INJ, PFOA-INJ, PFDA-INJ, PFOS-INJ; Table 24) solutions were gravimetrically diluted in methanol using methanol-rinsed glassware to create working solutions. Each nonvolatile PFAS analytical sequence included thirteen calibration standards, prepared in methanol, with target PFAS present at approximately 0.005 ng/mL to 50 ng/mL (5 $\mu g/m^3$ to 5 x 10^4 $\mu g/m^3$; equivalent to approximately 2.5 x 10^{-2} µg PFAS/kg textile to 2.5 x 10^2 µg PFAS/kg textile) and internal standard and injection standard PFAS present at approximately 2,000 ng/mL (2 x 10^3 $\mu g/m^3$; equivalent to approximately 10 µg PFAS/kg textile).

All thirteen PFAS calibration solutions were analyzed at the start and end of each nonvolatile PFAS analytical sequence. Continuing calibration verifications (CCVs; target PFAS concentrations approximately 5 ng/mL; 5 x 10^3 $\mu g/m^3$; internal and injection standard PFAS at approximately 2 ng/mL; 2 x 10^3 $\mu g/m^3$) and continuing calibration blanks (CCBs; target PFAS concentrations 0 ng/mL; internal and injection standard PFAS at approximately 2 ng/mL; 2 x 10^3 $\mu g/m^3$) were analyzed after every ten textile extract samples.

NIST RMs 8446 (Table 29) and 8447 (Table 30) were gravimetrically diluted with methanol in methanol-rinsed volumetric glassware and mixed with internal and injection standards (target PFAS concentrations approximately 1.25 ng/mL; 1.25 x 10^3 $\mu g/m^3$; internal and injection standard PFAS present at approximately 2 ng/mL; 2 x 10^3 $\mu g/m^3$). The diluted RM solutions were analyzed immediately following the first analysis of calibration standards.

A.4.2. Semivolatile PFAS

For the quantitation of semivolatile PFAS in turnout gear textiles commercially obtained target standard (Table 25), internal standard (Table 26), and injection standard (i.e., PFBA-INJ, PFOA-INJ, PFDA-INJ, PFOS-INJ; Table 24) solutions were gravimetrically diluted in ethyl acetate using methanol-rinsed volumetric glassware to create working solutions. Eleven semivolatile PFAS calibration standards were prepared in ethyl acetate, with target PFAS present at approximately 0.005 ng/mL to 10 ng/mL (5 $\mu g/m^3$ to 10^4 $\mu g/m^3$; equivalent to approximately 0.1 µg PFAS/kg textile to 200 µg PFAS/kg textile) and internal standard and injection standard PFAS present at approximately 2 ng/mL (2 x 10^3 $\mu g/m^3$; equivalent to approximately 40 µg PFAS/kg textile).

All eleven calibration solutions were analyzed at the start and end of each semivolatile PFAS analytical sequence. CCVs (target PFAS concentrations approximately 2.5 ng/mL; 2.5 x 10^3 $\mu g/m^3$

with internal and injection standard PFAS at approximately 2 ng/mL; 2 x 10^3 µg/m^3) and CCBs (nonvolatile target PFAS concentrations 0 ng/mL with internal and injection standard PFAS at approximately 2 ng/mL; 2 x 10^3 µg/m^3) were prepared and analyzed after every ten samples.

A.4.3. Volatile PFAS

For the quantification of volatile PFAS in turnout gear textiles commercially obtained target PFAS (Table 27) and internal standard PFAS (Table 28) solutions were gravimetrically diluted in ethyl acetate using methanol-rinsed glassware to create working solutions. Each GC-MS volatile PFAS analytical sequence included eight calibration standards, prepared in ethyl acetate, with target PFAS present at a range of approximately 5 ng/mL to 1,000 ng/mL (5 x 10^3 µg/m^3 to 10^6 µg/m^3) of 6:2 FTOH, 6:2 FTMAC, 8:2 FTMAC, and 10:2 FTMAC as well as approximately 0.5 ng/mL to 200 ng/mL (5 x 10^2 µg/m^3 to 2 x 10^5 µg/m^3) of the remaining volatile target PFAS (10^5 µg/m^3 was equivalent to approximately 10^3 µg/kg textile). Internal standard PFAS were present at approximately 10^5 µg/m^3 in all calibration standards.

All eight calibration solutions were analyzed at the start and end of each GC-MS analytical sequence. CCVs (target PFAS concentrations approximately 50 ng/mL; 5 x 10^4 µg/m^3 with internal and injection standard PFAS at approximately 100 ng/mL; 10^5 µg/m^3) and CCBs (target PFAS concentrations 0 ng/mL with internal and injection standard PFAS at approximately 100 ng/mL; 10^5 µg/m^3) were analyzed after every ten textile extract samples.

A.4.4. Method Reproducibility Material (OS-FRM)

Four hundred sections of an outer shell textile (OS-F) were cut, weighed, and stored in polypropylene 15 mL capacity centrifuge tubes as OS-FRM (average ± standard deviation of masses: 0.0997 g ± 0.006 g). Twelve sections were randomly selected with the Microsoft Excel function =rand()) sections were analyzed for nonvolatile PFAS and a separate twelve randomly selected sections were analyzed for semivolatile and volatile PFAS. Subsequent extraction batches included one randomly selected OS-FRM section and the reported PFAS concentrations were determined with each extraction batch to demonstrate extraction reproducibility.

A.5. Data Processing and Sequence Quality Control Parameters

A.5.1. Nonvolatile and Semivolatile PFAS

For nonvolatile and semivolatile PFAS analysis, peak integration was performed in SCIEX Analyst 1.6.3 with a smoothing width of 7 points. PFAS identification in samples was confirmed by retention time matching with calibration solutions. For nonvolatile and semivolatile PFAS analysis, calibration slopes and intercepts were determined with $1/x^2$-weighted linear regressions of the ratio of target:internal standard peak areas against the ratio of target:internal standard nominal concentrations. Weighted linear regressions were used to allow a single linear regression to be applied to a wider calibration range than would be possible with unweighted linear regressions. Direct comparisons of weighted and unweighted linear regressions determined that reported textile concentrations varied by less than 10 % between the two methods. Calibration standards were only included in the calibration regression if their calculated value was within 70 %

- 130 % of their nominal value for both the initial and final calibrations. Calibration regressions were only considered acceptable if at least five consecutive calibration standards recovered within 70 % - 130 % of their nominal value for both the initial and final calibrations.

Target PFAS mass in analyzed solutions (i.e., QC solutions and textile extracts) were determined by Eq. (1), where "PFAS mass" is the mass of a target PFAS present in a prepared QC solution or textile extract, "IS mass" is the mass of associated internal standard in the same solution or extract, "Calibration Slope" is the calibration slope determined from the linear regression of calibration standard solutions, "Peak Area-PFAS" is the observed peak area from the target PFAS chromatogram, "Peak Area-IS" is the observed peak area from the associated internal standard chromatogram, and "Calibration Intercept" is the calibration intercept determined from the linear regression of the calibration standard solutions:

$$PFAS\ mass\ (ng) = \frac{IS\ mass\ (ng)}{Calibration\ Slope} \times \left\{ \left(\frac{Peak\ Area - PFAS}{Peak\ Area - IS} \right) - Calibration\ Intercept \right\} \tag{1}$$

For nonvolatile PFAS analysis gravimetric dilutions of RMs 8446 and 8447 were analyzed after the initial calibration curves and data was only reported from analytical sequences in which recovery of 70 % to 130 % of the reference values was obtained for all PFAS with reported reference mass fractions. For both nonvolatile and semivolatile PFAS analysis, data was only reported from textile extracts that were bracketed with CCVs with recovery of 70 % to 130 %, except values that were reported as below the reporting limit ("<RL") when CCV recovery was over 130 %.

Internal standard and injection standard recoveries in textile extracts were determined by comparison of the observed internal response factor (i.e., peak area/nominal concentration) with the average response factor recorded in the calibration standards. Data was not reported when the associated internal standard recoveries were outside of 50 % to 150 % for more than one of three triplicate unspiked textile extracts. Data was not reported when the associated injection standard recoveries were outside of 70 % to 130 % for more than one of three triplicate unspiked textile extracts.

Matrix spike recoveries were determined to be the fraction of additional PFAS mass recovered in the spiked extracts compared with the average concentration recorded in the triplicate non-spiked extracts. Data was not reported when the associated matrix spike recovery was outside of 70 % to 130 %, with two exceptions. First, data was reported when matrix spike recovery was outside of 70 % to 130 % if the added concentration (µg PFAS/kg textile) from the matrix spike was less than the average concentration recorded in the triplicate unspiked extracts of the same sample. Second, data was also reported when associated with matrix spikes that had recovery over 130 % if the reported PFAS concentration was "< RL."

Consistent PFAS concentrations were recorded in solvent only and OS-FSC textile blank extracts within analytical batches and therefore nonvolatile and semivolatile PFAS concentrations in sample textile extracts were blank corrected by the average concentration recorded in the solvent only or OS-FSC textile blanks. PFAS concentrations in textiles were then calculated by Eq. (2), where "PFAS in Textile" is the PFAS concentration in a sample textile, "PFAS mass" is the PFAS mass in the textile extract determined from Eq. (1), "Extract Vol." is the extract volume which was the nominal solution volume for nonvolatile PFAS analysis and the measured solution volume for semivolatile PFAS analysis, "Ave. Blank" is the average concentration recorded in the OS-FSC textile blank extracts for all textiles except for scoured outer shells where it is the average concentration recorded in solvent only extraction blanks, and "Sample Mass" is the mass of extracted textile:

$$PFAS\ in\ Textile(ng/g) = \left[\frac{PFAS\ mass\ (ng)}{Extract\ Vol.(mL)} - Ave.Blank\ (\frac{ng}{mL})\right] \times \frac{Extract\ Vol.(mL)}{Sample\ Mass\ (g)} \qquad (2)$$

Extract volumes for nonvolatile PFAS analysis were presumed to be 0.5 mL (5 x 10^{-7} m^3) while extract masses for semivolatile PFAS analysis were determined gravimetrically.

A.5.2. Volatile PFAS

Peak integration for volatile PFAS analysis was performed with Agilent MassHunter. PFAS identification in samples was confirmed by retention time matching with calibration solutions. PFAS calibration slopes and intercepts were determined with 1/x-weighted linear regressions of the ratio of target:internal standard peak areas against the ratio of target:internal standard nominal concentrations. Calibration standard regressions met the same standards as applied for nonvolatile and semivolatile PFAS analysis. PFAS mass in injected solutions were determined by Eq. (1).

Secondary ion ratios were determined as the ratio of peak areas of the primary and secondary ions for each PFAS and are reported by comparison of the ratios determined in each extract with the average ratios determined in the four highest concentration calibration points. Data was only reported when associated with secondary ion ratios between 70 % - 130 % of the average ratio in the four highest calibration standards. Data was only reported when associated with internal standard and matrix spike recoveries that met the same standards as applied for nonvolatile and semivolatile PFAS analysis.

Volatile PFAS concentrations in solvent only and OS-FSC textile blank extracts were either consistent (6:2 FTMAC) or indistinguishable from zero (all other analytes), and therefore PFAS concentrations in sample textile extracts were blank corrected by the average concentration recorded in the OS-FSC textile blanks, except for scoured outer shell textiles which had extract concentrations blank corrected by the average concentration of solvent only extraction blanks. PFAS concentrations in textiles were then calculated by Eq. (2).

A.5.3. Reporting Limits

Target PFAS reporting limits in textile extracts (µg/m^3) were determined for each analyte in each extraction batch as the average concentration in triplicate solvent only or OS-FSC textile blank extracts plus the higher of either (a) three times the standard deviation among the associated blanks or (b) the nominal concentration of the lowest calibrant for which recovery of 70 % - 130% was obtained. Reporting limits were calculated for each textile extract (µg/kg) by multiplying the analyte- and batch-specific reporting limit (µg/m^3) by the extract concentration factor (m^3

extract/kg extracted textile). Determined average reporting limits associated with all triplicate measurements are provided with those measurements (Tables 2-21). For reporting consistency, PFAS concentrations in firefighter turnout gear textiles were only reported when at least two of the triplicate extracts had concentrations above the reporting limit.

A.6. Quality Control Results

Reporting limits and blank derived background correction concentrations were determined for each PFAS within each extraction batch. Additionally, all nonvolatile PFAS calibrations were confirmed with independent calibration verification solutions (i.e., NIST RMs 8446 & 8447) and all nonvolatile, semivolatile, and volatile extraction batches included the analysis of an in-house reference textile (i.e., OS-FRM).

A.6.1. Textile Extraction Blanks and Background Correction

OS-FSC was a “scoured” outer shell textiles that had not received DWR treatment. Prior to the extraction of other sample textiles, extracts of OS-FSC were prepared and compared against solvent-only extraction blanks to evaluate their potential use as textile extraction blank materials. This initial analysis of OS-FSC with solvent only extraction blanks found that all PFAS were present below reporting limits and this textile which was subsequently used as an extraction blank material for the determination of blank correction amounts and reporting limits in the remaining moisture barrier, outer shell, and thermal liner sample textiles. A subsequent analysis of OS-FSC, again with solvent only extraction blanks, did find measurable PFHxA concentrations (0.335 µg/kg ± 0.032 µg/kg; Table 15), while no other nonvolatile, semivolatile, or volatile PFAS was observed above the reporting limits. This may indicate that the PFHxA concentrations reported here in the examined moisture barrier, outer shell, and thermal liner textiles, which were determined by comparison with OS-FSC-containing textile extraction blanks, underestimate the true PFHxA concentrations in those textiles. However, the PFHxA concentration reported in OS-FSC is similar to the reporting limits in the remaining textiles (0.128 µg/kg – 1.18 µg/kg) and far below the mean PFHxA concentrations measured in the remaining textiles (6.5 µg/kg).

A.6.2. Reporting Limits

Reporting limits determined for each measurement are shown in Tables 2 – 21. Histograms of the reporting limits for measurements made with each of the three analytical methods are shown in Fig. 18. Virtually all the reporting limits for nonvolatile (729 out of 733) and semivolatile (82 out of 100) PFAS measurements were < 2 µg/kg. Reporting limits for volatile PFAS were much higher, 237 reported volatile GC measurements were associated with reporting limits over 7 µg/kg and 83 measurements were associated with reporting limits over 100 µg/kg.

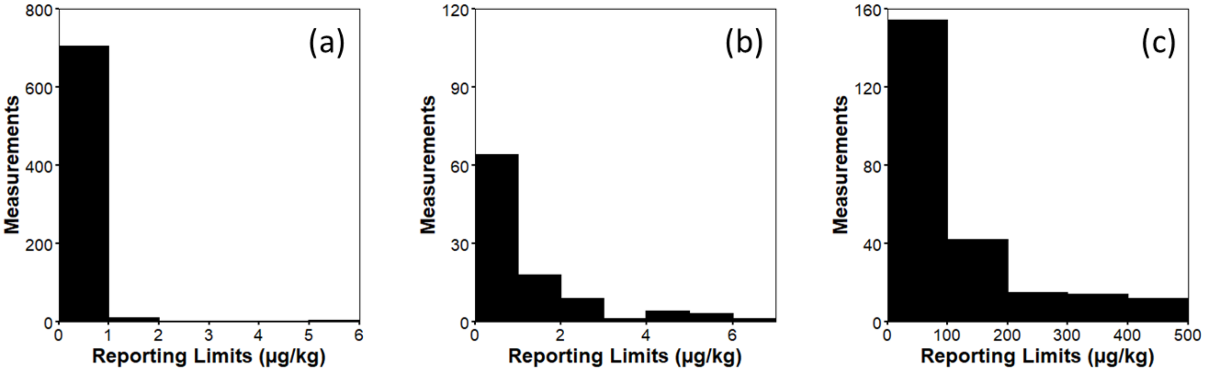


Fig. 16. Histograms of reporting limits for individual measurements of (a) all nonvolatile PFAS (binwidth = 1 µg/kg), (b) all semivolatile PFAS (binwidth = 1 µg/kg), and (c) all volatile PFAS (binwidth = 100 µg/kg).

A.6.3. NIST Reference Materials 8446 and 8447

Nonvolatile PFAS concentrations in extracts of firefighter turnout gear textiles were determined across four analytical sequences. Gravimetric dilutions of NIST RMs 8446 Perfluorinated Carboxylic Acids and Perfluorooctane Sulfonamide in Methanol as well as 8447 Perfluorinated Sulfonic Acids in Methanol were prepared and analyzed with each sequence and measured concentrations were between 84.3 % - 119 % of the reference values for all analytes (Fig. 16) The recovery of all NIST RM 8446 and 8447 analytes suggests that calibration regressions determined with each nonvolatile analytical sequence were consistent and accurate.

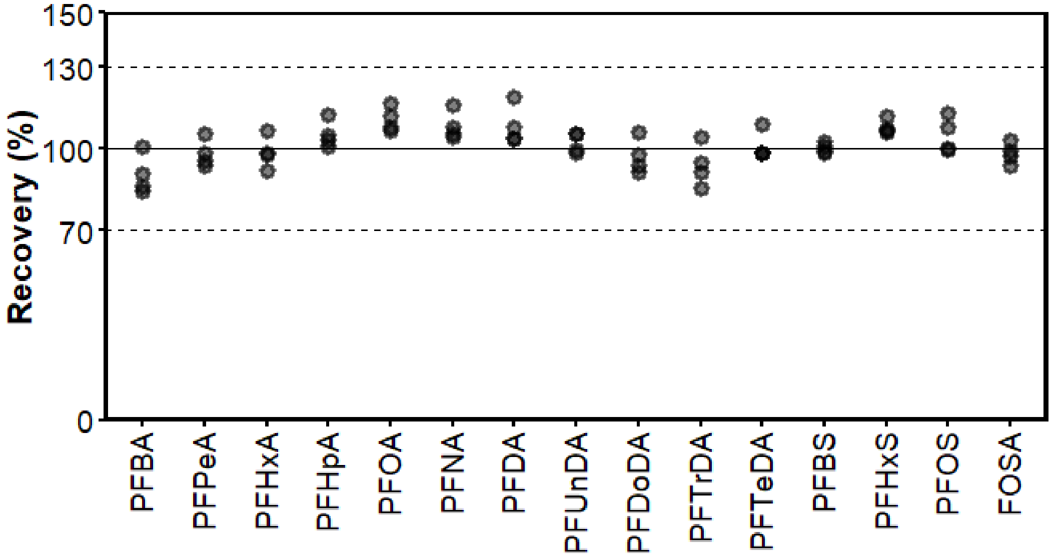


Fig. 17. Recoveries of reference PFAS in NIST reference materials 8446 and 8447 across four nonvolatile PFAS analytical batches. 100 % recovery is indicated with a solid line while 70 % and 130 % recoveries are indicated with dashed lines.

A.6.4. Method Reproducibility Material (OS-FRM)

As described above, 400 cuttings of OS-FRM were prepared and 12 cuttings were extracted and analyzed for nonvolatile PFAS while a separate 12 cuttings were extracted and analyzed for semivolatile and volatile PFAS. Ten volatile PFAS, one semivolatile PFAS, and two volatile PFAS were quantified above the reporting limits in at least 10 of 12 replicate OS-FRM extracts and the averages and standard deviations of measured concentrations are shown in Table 36. While seven of the 13 PFAS quantified in OS-FRM were PFCAs with between three and eight perfluorinated carbons, they only accounted for 7.2 % of the summed PFAS mass while 6:2 FTOH and 6:2 FTMAC, both volatile fluorotelomer-based PFAS with six perfluorinated carbons accounted for 92.6 % of the summed PFAS mass.

Differences in reporting limits among nonvolatile PFAS (typically on the order of 0.1 µg/kg), semivolatile PFAS (typically on the order of 1 µg/kg), and volatile PFAS (typically on the order of 100 µg/kg) may contribute to the identification of more nonvolatile PFAS despite volatile PFAS being present at higher concentrations.

Table 36. Average and standard deviation of PFAS concentrations (ug/kg) in twelve replicates of OS-FRM. PFAS concentrations that were below the reporting limit were not included in average and standard deviation calculations.

PFAS	(µg/kg)
Nonvolatile PFAS	
PFBA	11.69 ± 0.48
PFPeA	12.81 ± 0.73
PFHxA	38.1 ± 3.2
PFHpA	5.37 ± 0.43
PFOA	0.369 ± 0.075
PFNA	0.214 ± 0.048
PFDA	0.316 ± 0.051
PFBS	1.38 ± 0.29
FBSA	0.333 ± 0.018
FHxSA	0.0345 ± 0.005
Semivolatile PFAS	
MeFOSE	0.53 ± 0.12
Volatile PFAS	
6:2 FTOH	273 ± 39
6:2 FTMAC	613 ± 107

After the initial analysis of twelve replicates of OS-FRM, each subsequent extraction batch included a single cutting of OS-FRM to determine extraction consistency. For these subsequent extraction batches, the recovery of all analytes where concentrations over 0.5 µg/kg were reported in the initial analysis are shown in Fig. 17. Except for a single analysis each of PFHpA (137 %) and 6:2 FTOH (55.1 %) all reported measurements of these higher concentration PFAS were between 88.1 – 119 %, which suggests that extraction procedures were performed consistently among extraction batches.

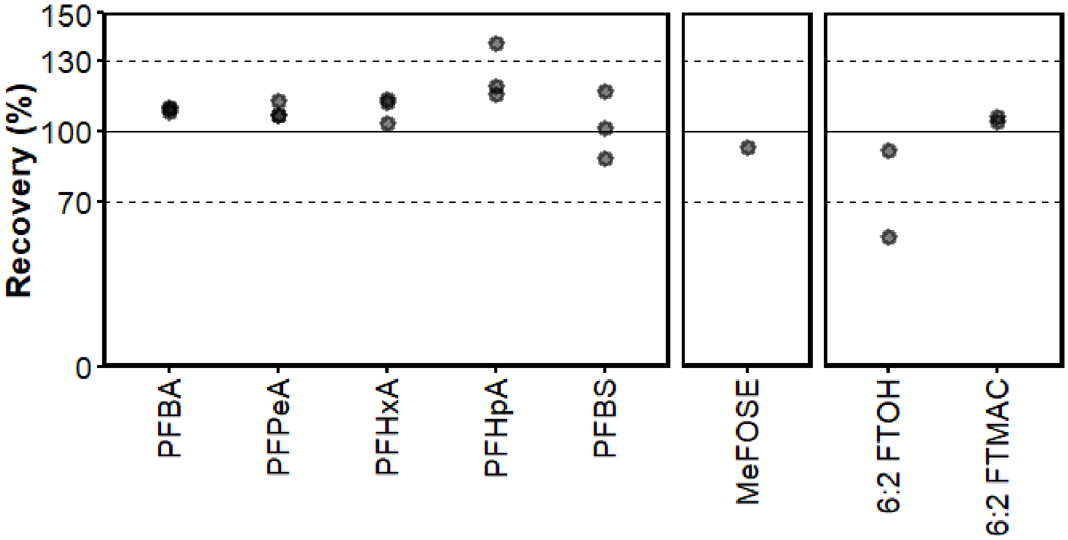


Fig. 18. OS-FRM recovery across four nonvolatile/LC batches, one semivolatile batch, and two GC batches. 100 % recovery is indicated with a solid line while 70 % and 130 % recoveries are indicated with dashed lines.

A.7. Appendix References

[1] Robel AE, Marshall K, Dickinson M, Lunderberg D, Butt C, Peaslee G, Stapleton HM, Field JA (2017) Closing the mass balance on fluorine on papers and textiles. Environmental Science & Technology 51(16):9022-9032. https://doi.org/10.1021/acs.est.7b02080

A.8. Abbreviations

6:2 FTMAC
6:2 fluorotelomer methacrylate

6:2 FTOH
6:2 fluorotelomer alcohol

6:2 FTS
6:2 fluorotelomer sulfonate

ADONA
4,8-dioxa-3H-perfluorononanoate

CAS RN
Chemical Abstract Service Registry Number

CCB
Continuing calibration blank

CCV
Continuing calibration verification

CE
Collision energy

CSD
Chemical Sciences Division

CXP
Collision cell exit potential

DP
Depolarization energy

DWR
Durable water repellent

ECF
Electrochemical fluorination

EP
Entrance potential

ePTFE
Expanded polytetrafluoroethylene

FASA
Perfluoroalkane sulfonamide

FASAA
Per- and polyfluoroalkane sulfonamido acetic acid

FASE
Perfluoroalkane sulfonamido ethanol

FBSA
Perfluorobutane sulfonamide

FRD
Fire Research Division

FT
Fluorotelomerization

GC-MS
Gas chromatography-mass spectrometry

HFPO-DA
Hexafluoropropylene oxide dimer acid

HPLC
High performance liquid chromatography

INJ
Injection standard

IS
Internal standard

LC
Liquid chromatography

MB
Moisture barrier

MeFBSE
N-Methyl perfluorobutane sulfonamidoethanol

MRM
Multiple reaction monitoring

MS
Mass spectrometry

MS/MS
Tandem mass spectrometry

m/z
mass-to-charge ratio

n:2 FTOAc
n:2 fluorotelomer acetate

n:2 FTOH
n:2 fluorotelomer alcohol

n:2 FTMAC
n:2 fluorotelomer methacrylate

n:2 FTS
n:2 fluorotelomer sulfonate

MeFASE
N-Methylperfluoroalkyl sulfonamidoethanol

NFPA
National Fire Protection Association

NIST
National Institute of Standards and Technology

OS
Outer shell

PEEK
Polyetheretherketone

PFAS
Per- and polyfluoroalkyl substances

PFBA
Perfluorobutanoic acid

PFBS
Perfluorobutane sulfonic acid

PFCA
Perfluorocarboxylic acid

PFDA
Perfluorodecanoic acid

PFHpA
Perfluoroheptanoic acid

PFHxA
Perfluorohexanoic acid

PFPeA
Perfluoropentanoic acid

PFNA
Perfluorononanoic acid

PFOA
Perfluorooctanoic acid

PFOS
Perfluorooctane sulfonic acid

PFSA
Perfluoroalkane sulfonic acid

PPEA
Per- and polyfluoroalkyl ether acid

PTFE
Polytetrafluoroethylene

QC
Quality control

RL
Reporting limit

RM
Reference material

RT
Retention time

SC
“Scoured” outer shell

SPE
Solid phase extraction

TL
Thermal liner