Per- and Polyfluoroalkyl Substances (PFAS) in Textiles Present in Unused Structural Firefighter Turnout Gear and Wildland Gear

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U.S. DEPARTMENT OF COMMERCE

What are PFAS?

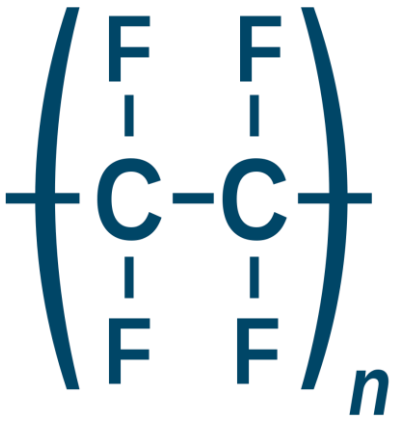
Substances with at least one perfluorinated carbon

Family of >6300 manmade fluorinated chemicals

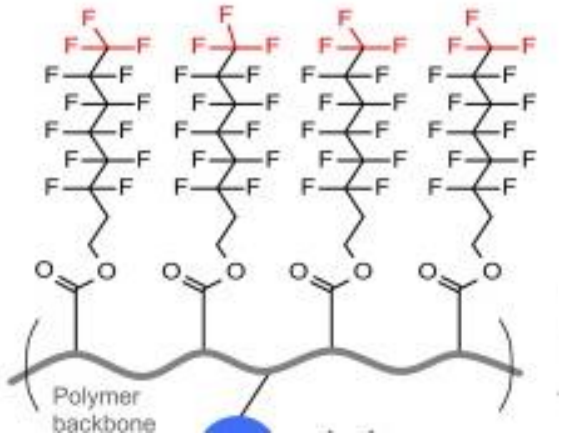
Small to polymeric chemicals, highly fluorinated carbon backbone, may be functionalized

Polymers

Fluoropolymers



Side-chain fluorinated polymers



Non-polymers

Perfluorooctanoic acid (PFOA)

Perfluorooctane sulfonic acid (PFOS)

Properties of PFAS

Water and Stain Resistant	• Effectively repels water and prevents staining
Heat Resistant	• Stable Carbon-Fluorine bonds withstand high temperatures
Surfactant Characteristics (when functionalized)	• Lowers surface tension, enabling better mixing with other substances
Chemical Stability	• Resistant to degradation in the both the environment and the human body
Health and Environmental Concerns	• Persistent in ecosystems; accumulates in soil, water, and living organisms

Firefighter Concerns About PFAS Exposure

The New York Times

Firefighters Battle an Unseen Hazard: Their Gear Could Be Toxic

Published Jan. 26, 2021 Updated Jan. 28, 2021

Joint Statement Regarding

PFAS in Fire Fighter Turnout Gear

The International Association of Fire Fighters (IAFF) and Metropolitan Fire Chiefs Association (Metro Chiefs) have come together to notify members of the adverse health risks from fire fighter turnout gear.

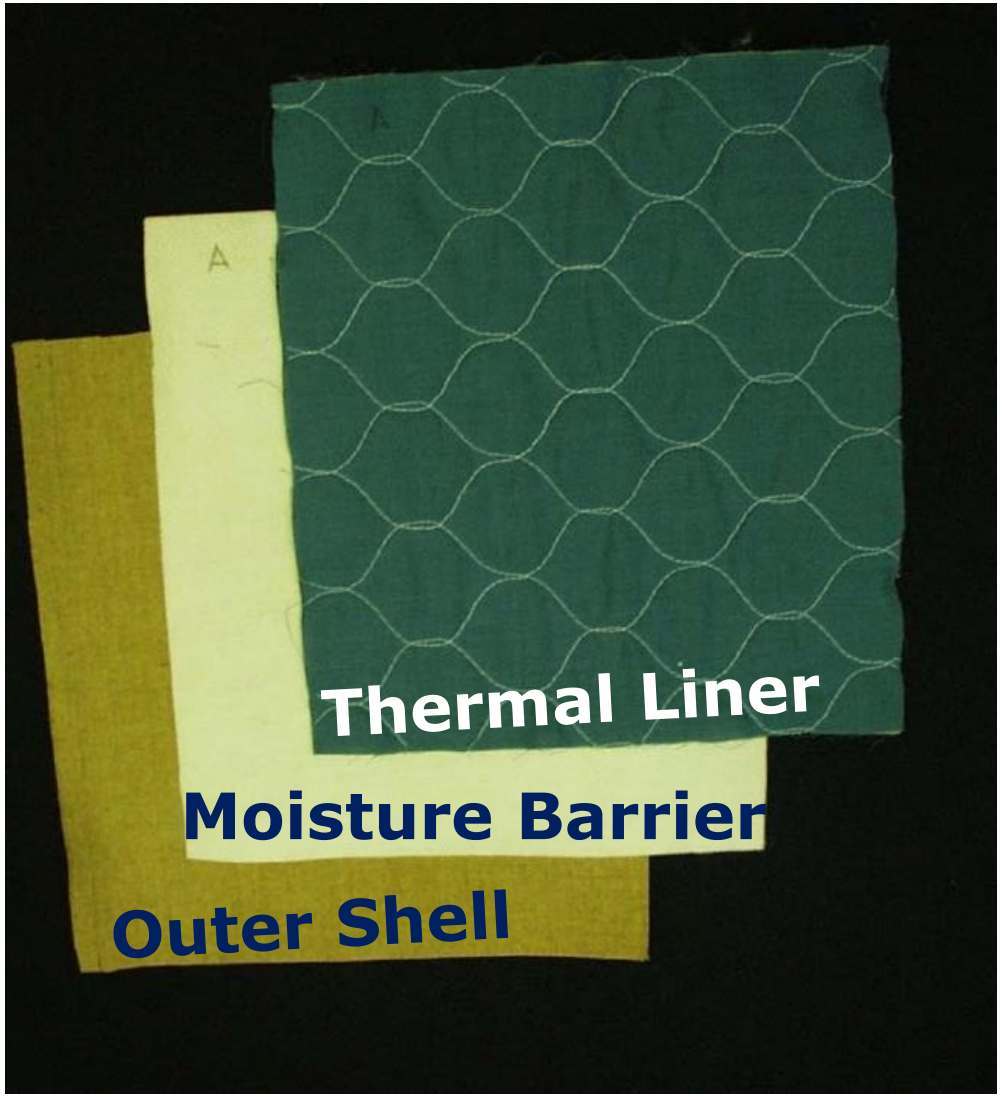
Recent studies have shown that all three layers of fire fighter turnout gear contain Per and Polyfluoroalkyl Substances (PFAS), a class of fluorinated chemicals known as "forever chemicals" which have been linked to cancer and other serious health effects.[1,2] These studies highlight the risks associated with the materials and finishes used in turnout gear even before it is exposed to its first fire.

Firefighters have higher serum PFAS concentrations than the public and are concerned about cancer risk.

Cancer risks from PFAS exposure are not firmly established but are of great concern to firefighters and firefighter unions/trade groups.

Other health risks are more established (e.g., decreased vaccine response).

PFAS Exposure from Firefighting Equipment



Firefighting foams often contain PFAS for their effectiveness in fire suppression

PFAS commonly used in firefighter gear for their water and oil repellency and heat resistance.

Firefighters can be exposed to PFAS through skin absorption or inhalation of contaminated dust from their gear.

NDAA 2020 Mandate: PFAS in FFG

The 2020 National Defense Authorization Act directs NIST to *"examine…the identity, prevalence, and concentration of per- and polyfluoroalkyl substances…in the personal protective equipment worn by firefighters…."*

Identification and quantification of PFAS in firefighting textiles

Analyte List

Method

NIST

PFCA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA	Perfluorocarboxylic acids (C3-C13), all nonvolatile
PFSA	PFPrS, PFBS, PFPeS, PFHxS, PFHpS, PFOS, PFNS, PFDS	Perfluoroalkyl sulfonates (C3-C10), all nonvolatile
FASA	FBSA, MeFBSA, FHxSA, FOSA, MeFOSA, EtFOSA	Perfluoroalkyl sulfonamides (C4-C8), mix of nonvolatile and semivolatile
FASAA	FOSAA, MeFOSAA, EtFOSAA	
FASE	MeFOSE, EtFOSE	
PPEA	PFEESA, PF4OPeA, PF5OHxA, 3-6-OPFHpA, HFPO-DA, ADONA, 9Cl-PF3ONS, 11Cl-PF3OUdS	Ether-containing PFAS (C4-C8), all nonvolatile
n:2 FTAcr	8:2 FTAcr, 10:2 FTAcr	Fluorotelomerization-derived PFAS (C4-C10), all volatile except n:2 FTS, which is nonvolatile
n:2 FTMAC	6:2 FTMAC, 8:2 FTMAC, 10:2 FTMAC	
n:2 FTOAc	8:2 FTOAc, 10:2 FTOAc	
n:2 FTOH	4:2 FTOH, 5:2 FTOH, 6:2 FTOH, 7:2 FTOH, 8:2 FTOH, 10:2 FTOH	
n:2 FTS	4:2 FTS, 6:2 FTS, 8:2 FTS, 10:2 FTS	

Firefighter Gear Textiles

Method

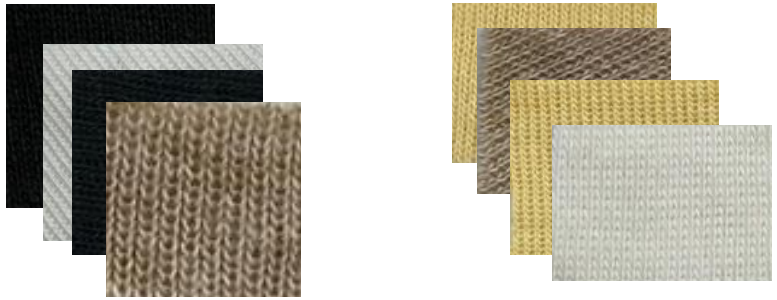
NIST

Structural Firefighter Gear

- 9 Outer Shells
- 6 Moisture Barriers
- 5 Thermal Liners

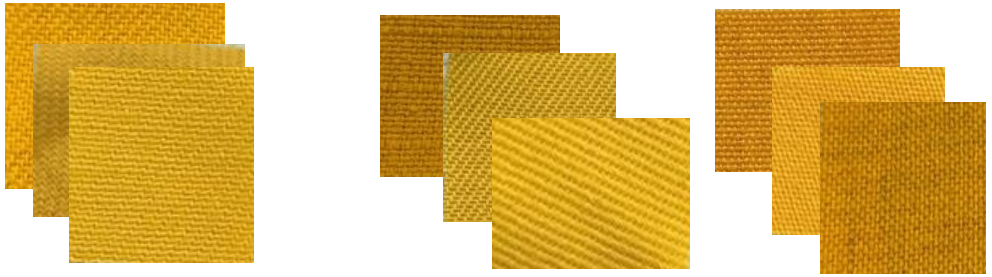
Structural Firefighter Hoods

- 8 Single-Layered Hoods



Wildland Firefighter Gear

- 9 Single-Layered Garments



Structural Firefighter Gloves

- 4 Outer Shells (OS)
- 4 Moisture Barriers (MB)
- 3 Thermal Liners (TL)
- 4 Inner Liners (IL)

Structural Firefighter Gear

Method

NIST

Code	Weight (oz/yd2)	Fabric
OS - A1	6.6	100% aramid blend
OS-A2SC	6.6	100% aramid blend - no waterproofing
OS - B1	6.0	60% para-aramid/40% PBO
OS - C1	6.6	aramid blend/PBO
OS - D1	7.5	para-aramid/PBI
OS - E1	7.2	100% aramid blend
OS - F1	6.9	60% para-aramid/40% PBI
OS-F2SC	6.9	60% para-aramid/40% PBI - no waterproofing
OS - G1	7.5	98% aramid blend/2% other
MB - A1	5	bicomponent ePTFE matrix w/hydrophilic coating
MB - B1	4.6	bicomponent ePTFE matrix w/hydrophilic coating
MB - C1	7	bicomponent ePTFE matrix w/hydrophilic coating
MB - D1	5.5	bicomponent ePTFE matrix w/hydrophilic coating
MB - E1	4.7	laminated bicomponent ePTFE film
MB - F2	5.5	bicomponent ePTFE / polyurethane membrane
TL - A1	7.7	FR cellulosic/para-armid/nylon check weave face
TL - B1	7	rayon/aramid/nylon plain weave face
TL - C1	7.2	100% aramid blend plain weave
TL - D1	7.7	FR cellulosic/para-armid/nylon check weave face
TL - E1	6.8	aramid blend/FR viscose twill weave face

Structural Firefighter Gloves and Hoods

Method

NIST

Code	Outer Shell	Moisture Barrier	Thermal Liner	Inner Liner
GL-A	Top: cowhide leather	ePTFE	aramid blend 8.0 oz/sq yd	not separate, thermal liner is inner liner
	Palm: kangaroo leather			
GL-B	Top: aramid blend fleece knit	Unknown	Top: aramid blend	different material top and palm
	Palm: cowhide leather	100% waterproof	Palm: Modacrylic	
GL-C	Top: 100% para-aramid	ePTFE	aramid blend-fleece	
	Palm: cowhide leather			
GL-D	Goat leather	PTFE	aramid blend	100% Modacrylic

Code	Fabric
HD-A	aramid blend/cellulosic
HD-B	meta-aramid
HD-C	65% oxidized polyacrylonitrile / 35% tri-blend carbon
HD-D	20% meta-aramid / 80% semi-natural fiber
HD-E	20% PBI / 80% rayon
HD-F	20% PBI / 80% semi-natural fiber
HD-G	40% polyimide / 55% semi-natural fiber / 5% para-aramid
HD-H	40% polyimide / 55% semi-natural fiber / 5% para-aramid

Wildland Firefighter Gear

Method

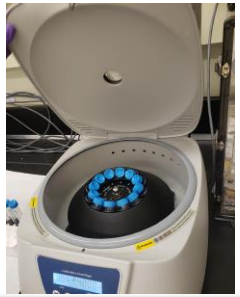
NIST

Code	Item Type	Fabric Weight	Fabric
WL-A	Coat	7.0 oz	98% aramid blend/2% other
WL-B	Coat	7.5 oz	98% aramid blend/2% other
WL-C*	Coat	7.0 oz	88% cotton/12% nylon
WL-D	Pants	7.0 oz	98% aramid blend/2% other
WL-E	Pants	7.0 oz	100% aramid blend
WL-F*	Pants	6.0 oz	98% aramid blend/2% other
WL-G*	Pants	7.0 oz	88% cotton/12% nylon
WL-H**	Shirt	5.8 oz	48% modacrylic/37% semi-natural fiber/15% para-aramid
WL-I***	Shirt	5.8 oz	48% modacrylic/37% semi-natural fiber/15% para-aramid
*labeled non-fluorinated			
** labeled hypoallergenic - no chemcial finishes or coatings			
***labeled not chemically treated			

Nonvolatile PFAS Extraction Method

Method

Samples cut from textiles (approx. 0.1 g)

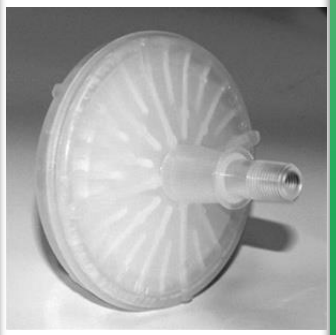


Addition of PFAS target and internal standards

3 Rounds of:

- Addition of methanol extraction solvent
- Sonication at 25 °C for 30 mins
- Centrifugation for 5 mins
- Filtration through graphitized non-porous carbon solid phase extraction tubes

Combined extracts evaporated to dryness under nitrogen at 40°C



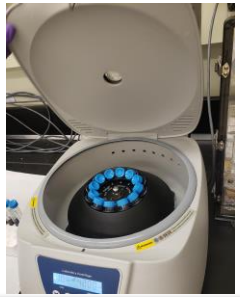
Reconstitution with methanol and filter through nylon syringe filter

Liquid chromatography-tandem mass spectrometry (LC-MS/MS)

Semivolatile and Volatile PFAS Extraction

Method

Samples cut from textiles (approx. 0.1 g)

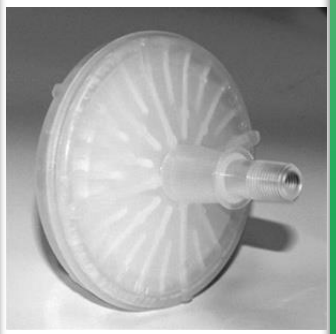


Addition of PFAS target and internal standards

3 Rounds of:

- Addition of **ethyl acetate** extraction solvent
- Sonication at 25 °C for 30 mins
- Centrifugation for 5 mins
- Filtration through graphitized non-porous carbon solid phase extraction tubes

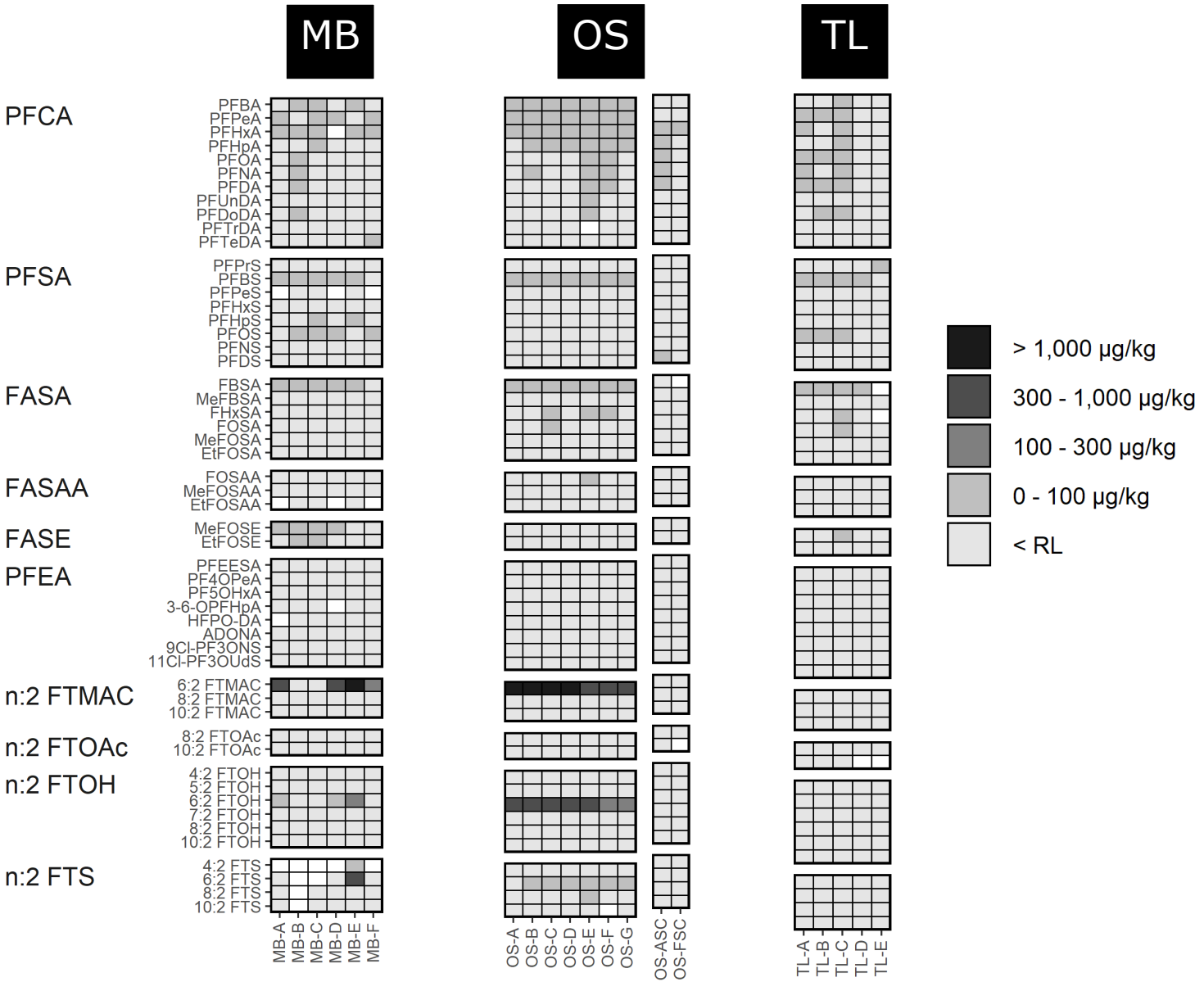
Combined extracts evaporated to **2 mL** under nitrogen at 35 °C



Filter through nylon syringe filter

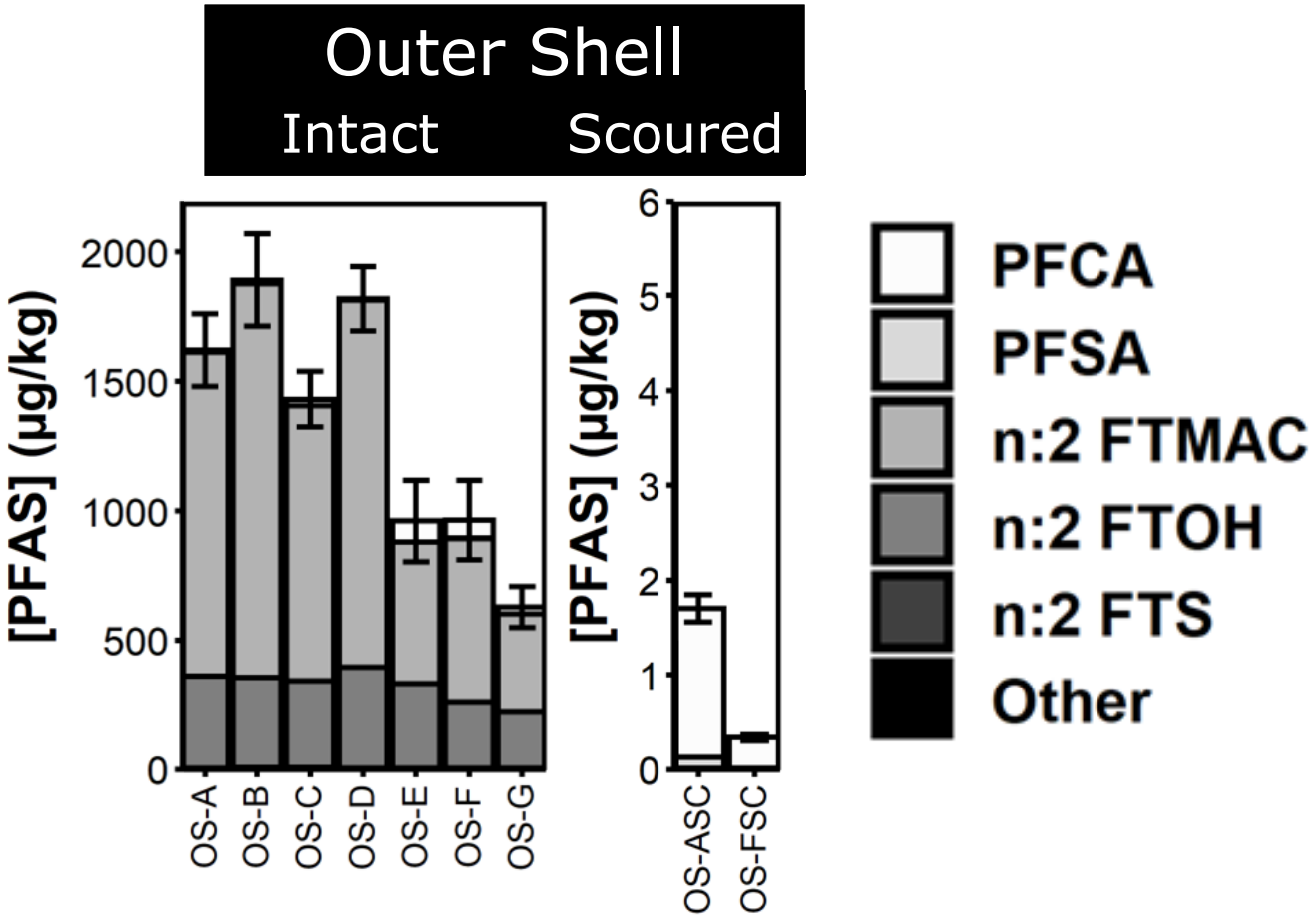
GC-MS for volatile PFAS; LC-MS/MS for semivolatile PFAS

PFAS in Firefighter Gear Textiles



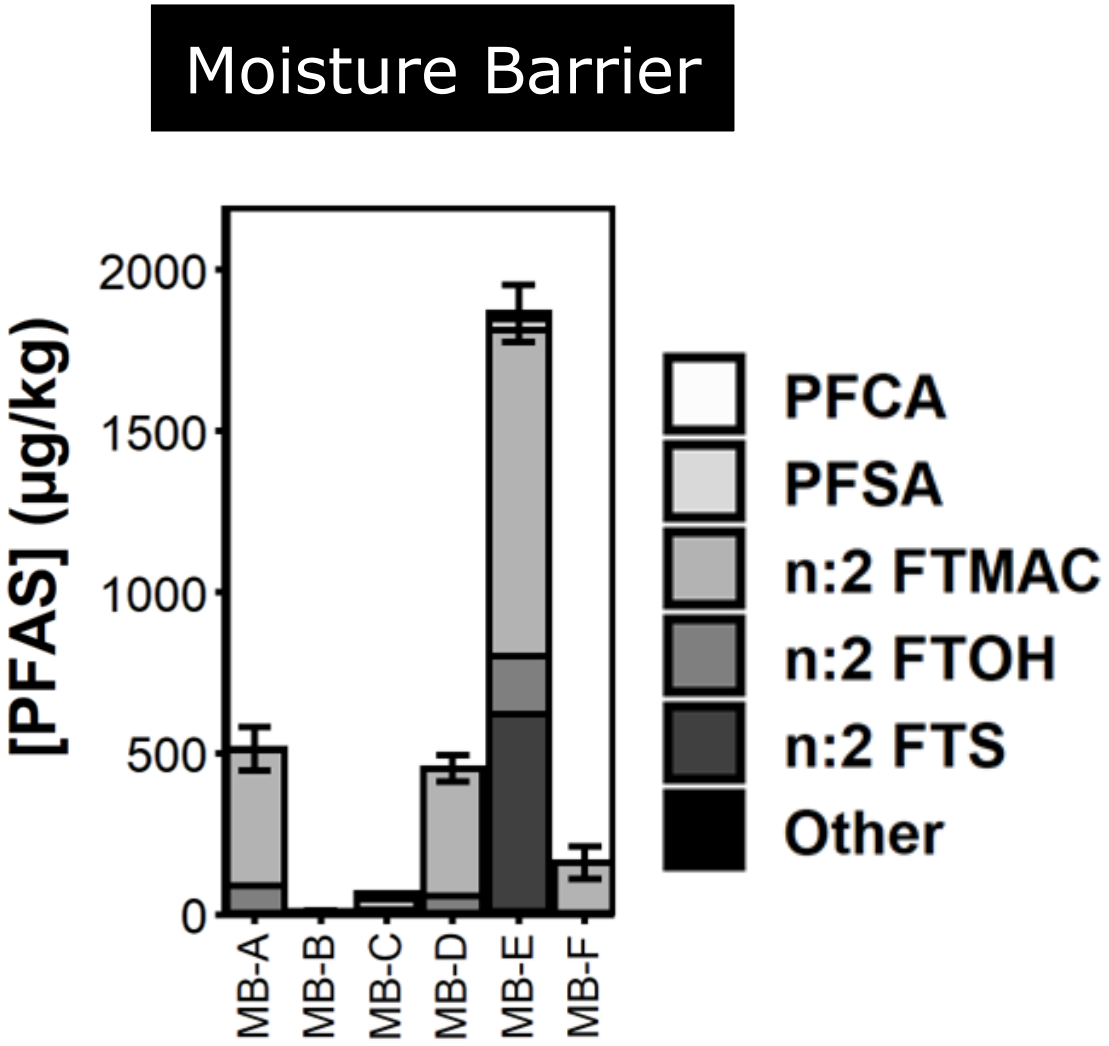
- 26 unique PFAS quantified above reporting limits across all 20 moisture barrier (MB), outer shell (OS), and thermal liner (TL) textiles.
- Between 1-17 individual PFAS in each textile detected.
- Highest concentrations are fluorotelomerization derived compounds with 6 perfluorinated carbons.
- Perfluorocarboxylic acids (PFCA) detected widely at lower concentrations.

PFAS in Outer Shell Textiles



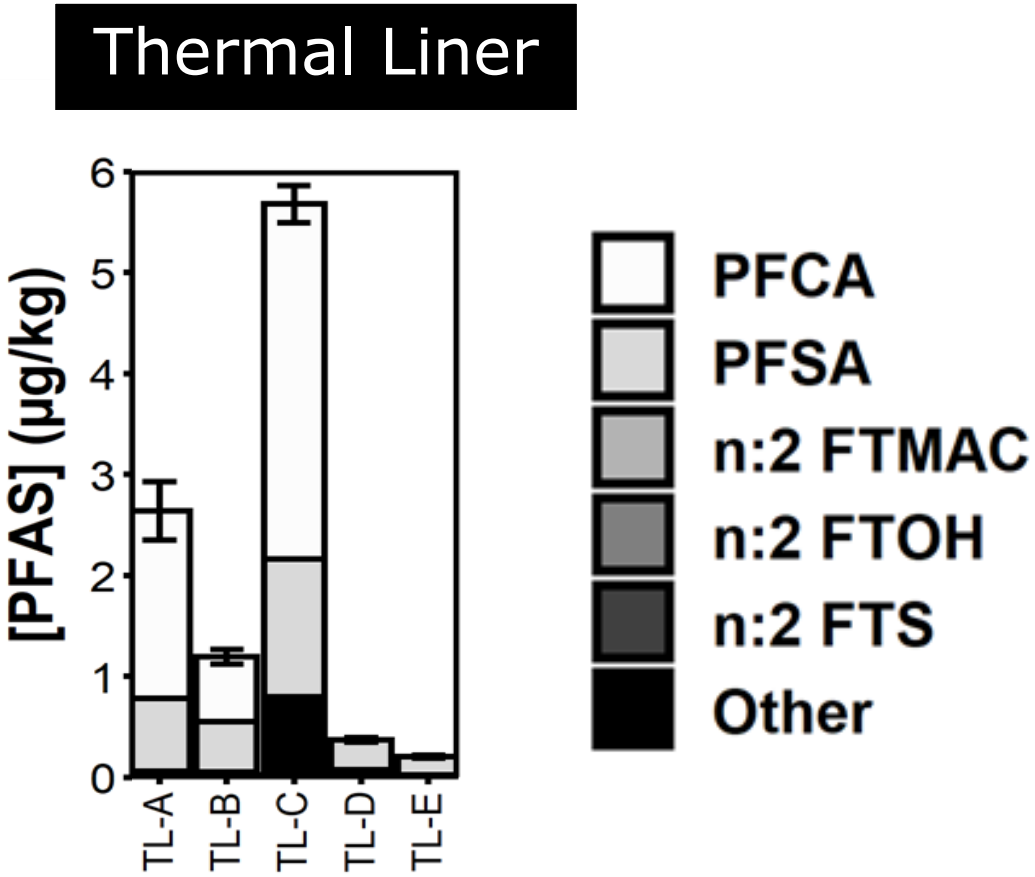
- Summed PFAS > 500 µg/kg in all intact outer shells, < 2 µg/kg in scoured.
- Total PFAS concentrations ranged from 629 µg/kg ± 79 µg/kg (OS-G) to 1,890 µg/kg ± 180 µg/kg (OS-B).
- 6:2 FTMAC, 6:2 FTOH present in all intact outer shells, but not identified in scoured textiles.

PFAS in Moisture Barrier Textiles



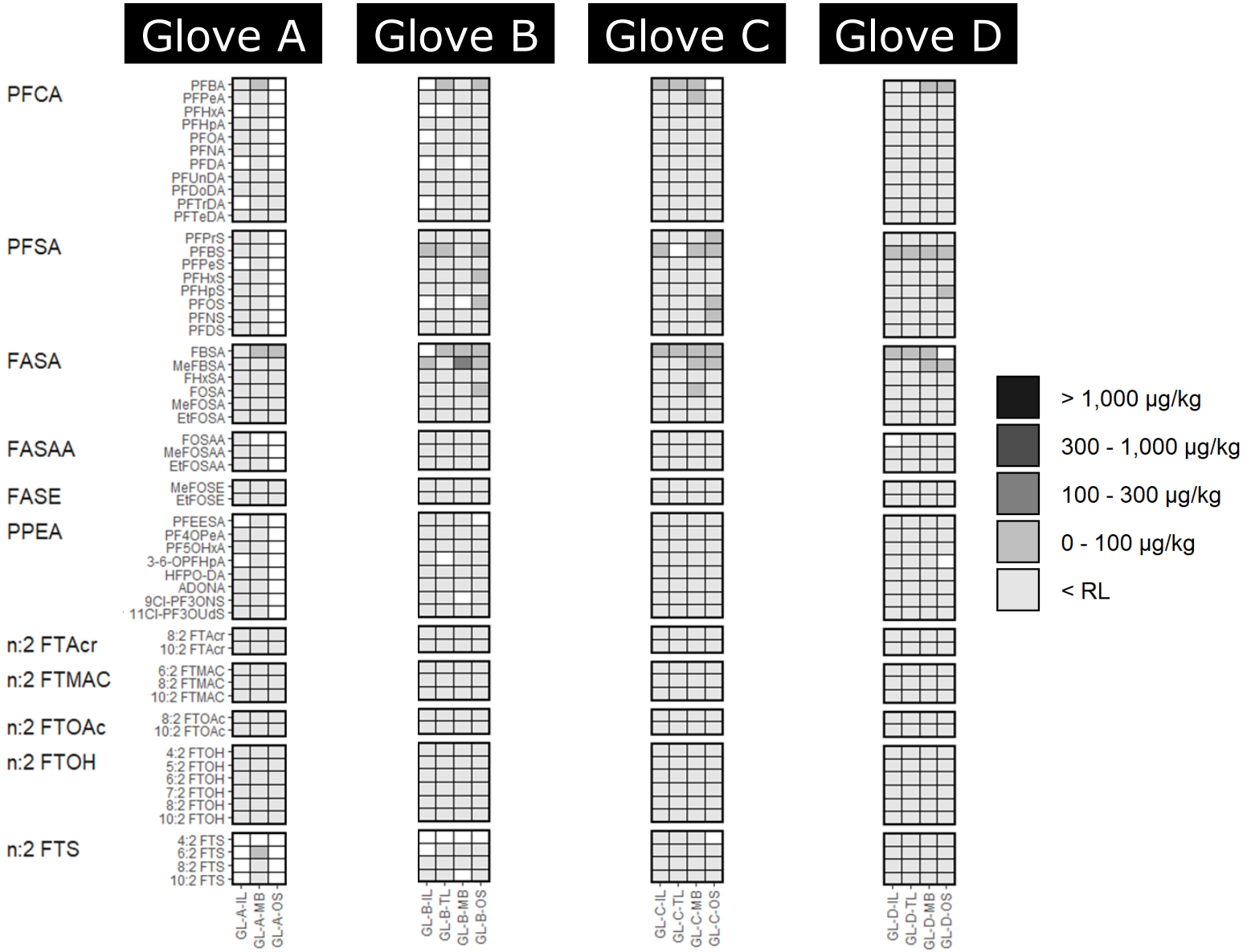
- Summed PFAS concentrations showed highest variation of any textile type, from 11.1 µg/kg ± 1.8 µg/kg to 1865 µg/kg ± 88 µg/kg.
- Where present, 6:2 FTMAC, 6:2 FTOH, 6:2 FTS were the highest concentration PFAS.

PFAS in Thermal Liner Textiles



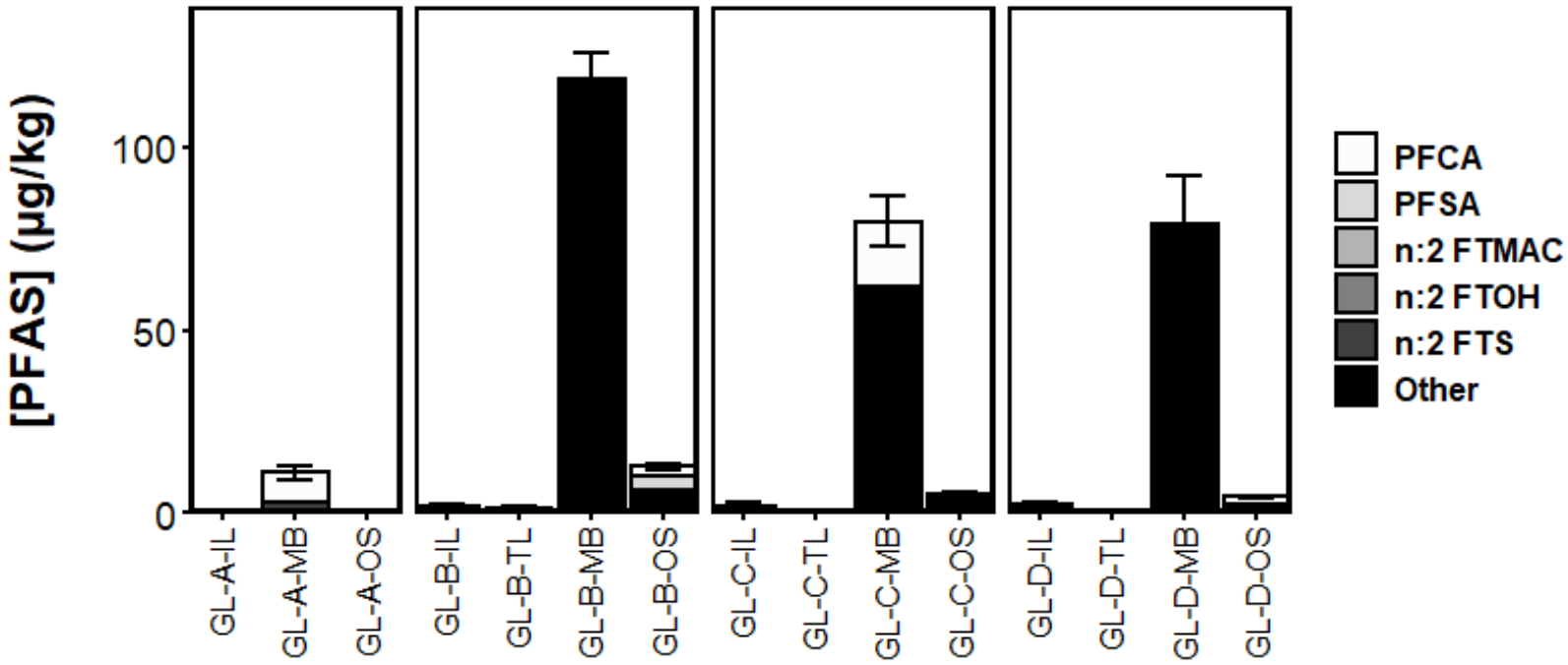
- Total PFAS concentrations ranged from 0.190 µg/kg ± 0.014 µg/kg (TL-E) to 5.66 µg/kg ± 0.19 µg/kg (TL-C).
- 6:2 FTMAC, 6:2 FTOH, and 6:2 FTS were not detected, with highest individual PFAS being PFBS in TL-C at 1.23 µg/kg ± 0.08 µg/kg.
- Thermal liners are layered closest to firefighter skin, may indicate lower firefighter PFAS exposure.

PFAS in Firefighter Glove Textiles



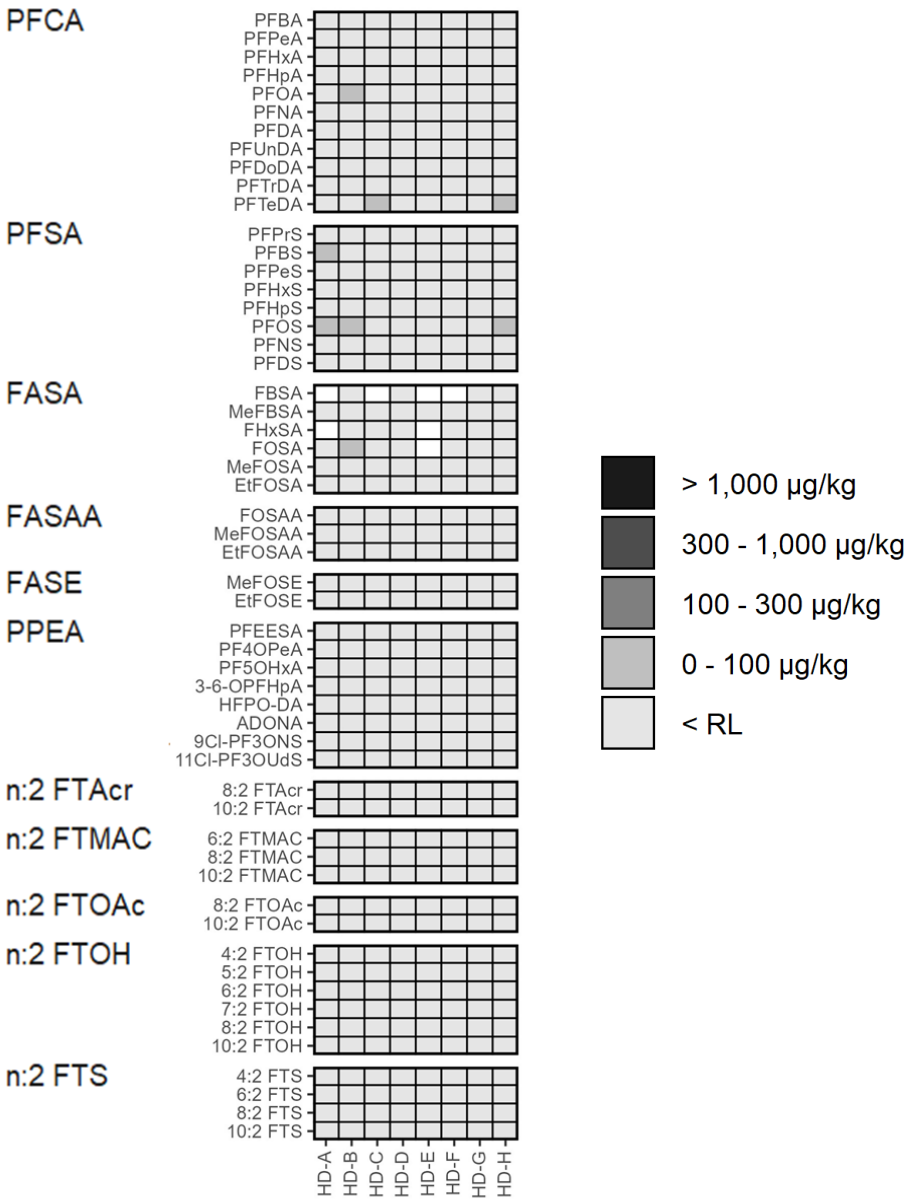
- 12 unique PFAS quantified above reporting limits across all 15 glove layers.
- Between 0-7 individual PFAS in each textile detected.
- Highest concentrations are Perfluoroalkyl sulfonamides (FASA) with 4 perfluorinated carbons.
- Perfluorobutane sulfonic acids (PFBS) detected at lower concentrations.

PFAS in Firefighter Glove Textiles (cont.)



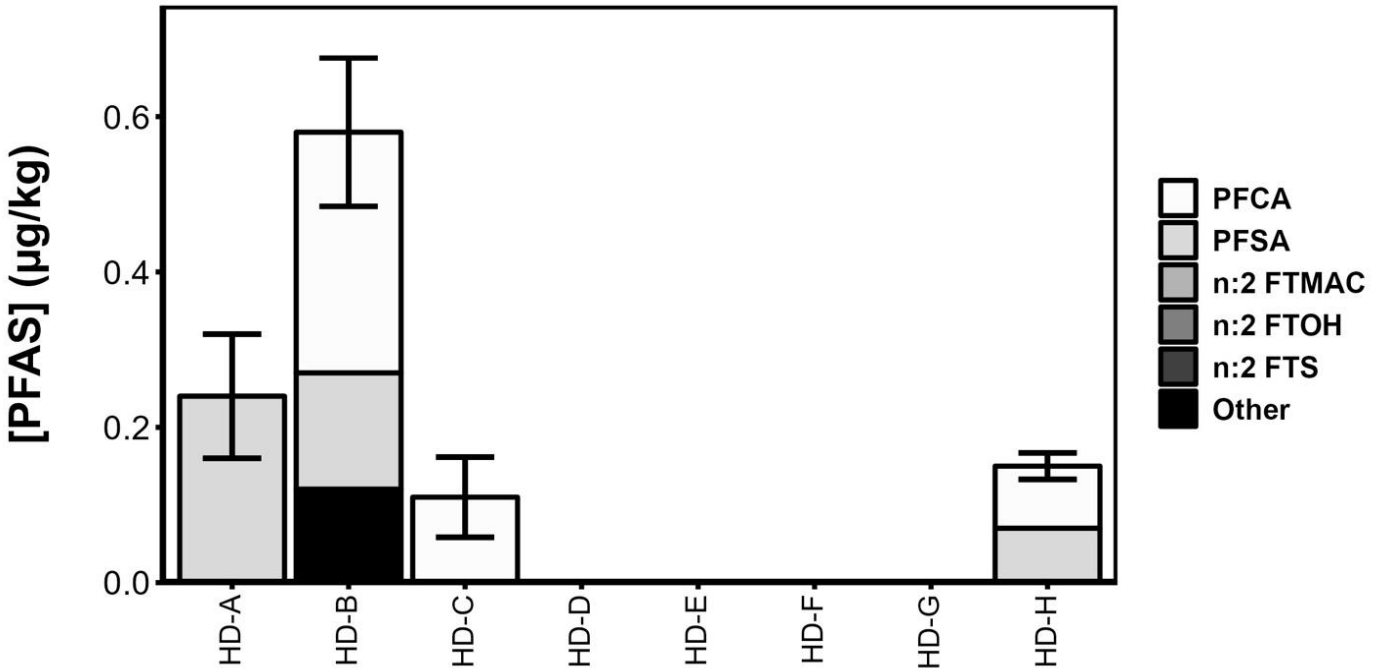
- Total PFAS levels in all glove layers were below 150 µg/kg.
- Moisture barrier layers contained the highest PFAS concentrations among all glove layers.
- Highest individual PFAS concentrations measured was MeFBSA, at 117.2 µg/kg ± 7.0 µg/kg (GL-B-MB).

PFAS in Firefighter Hood Textiles



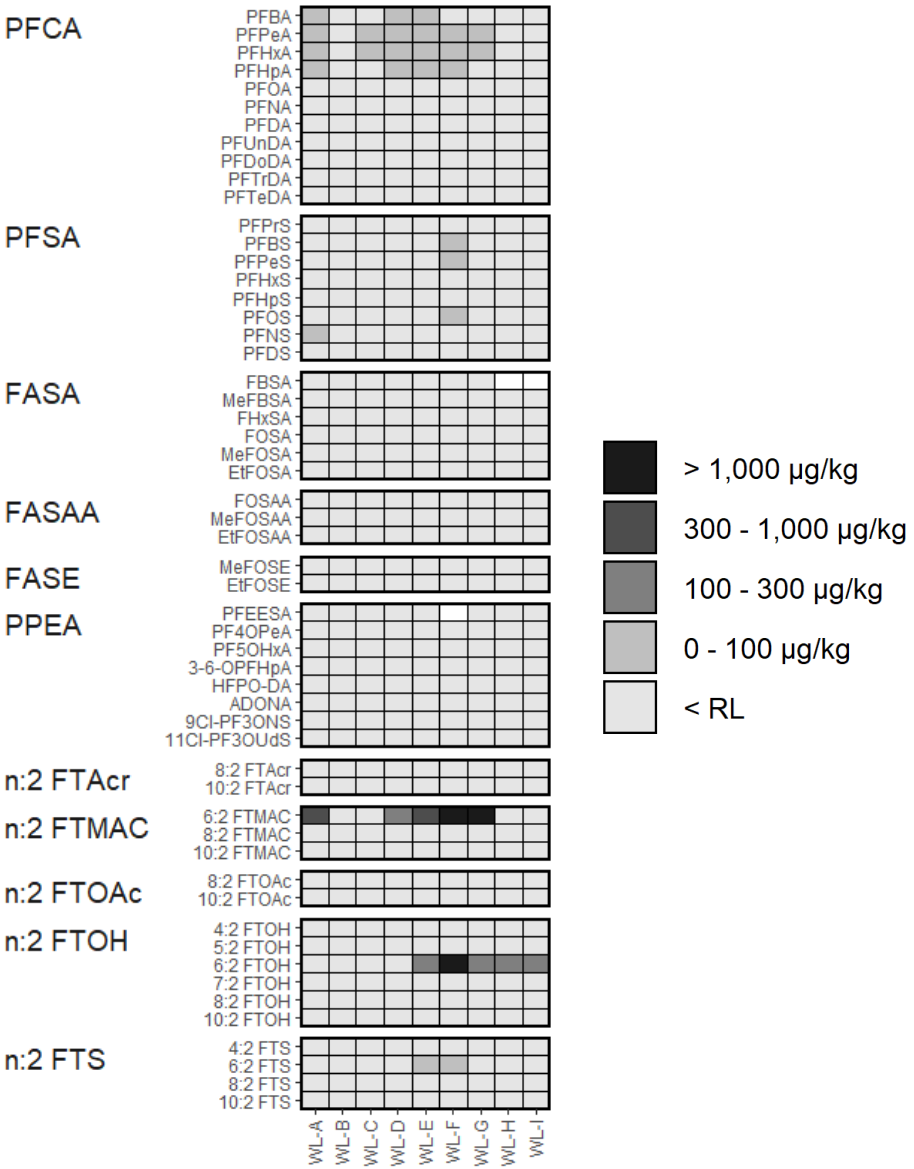
- 5 unique PFAS quantified above reporting limits across all 8 firefighter hoods.
- Between 0-3 individual PFAS in each textile detected.
- Perfluorooctanesulfonic acid (PFOS) was detected in 3 hoods at concentrations up to 0.15 ± 0.07 µg/kg.

PFAS in Firefighter Hood Textiles (cont.)



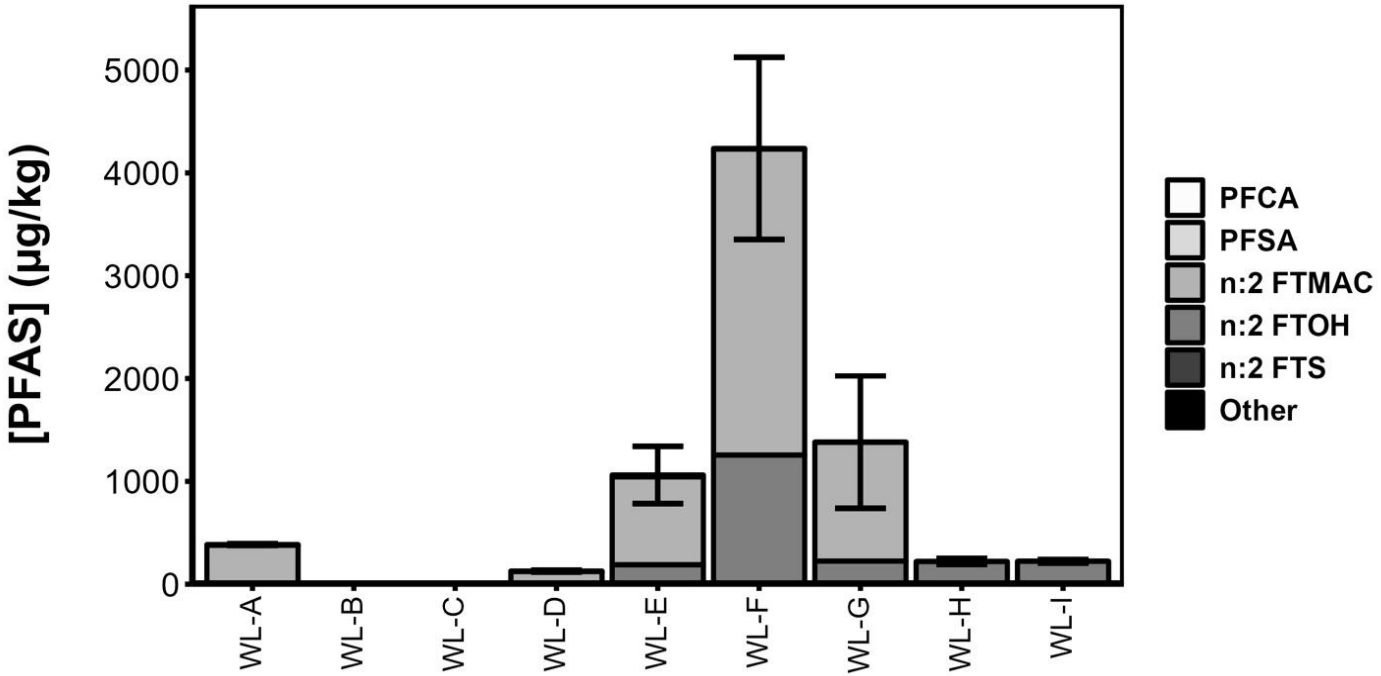
- Total PFAS levels in all hood layers were below 1 µg/kg.
- Highest summed PFAS concentration totaled 0.6 µg/kg ± 0.1 µg/kg (HD-B).
- Perfluorocarboxylic Acids (PFCA), Perfluorosulfonic Acid (PFSA), and perfluorooctanesulfonamide (FOSA) accounted for 100% of the PFAS detected in hoods.

PFAS in Wildland Firefighter Textiles



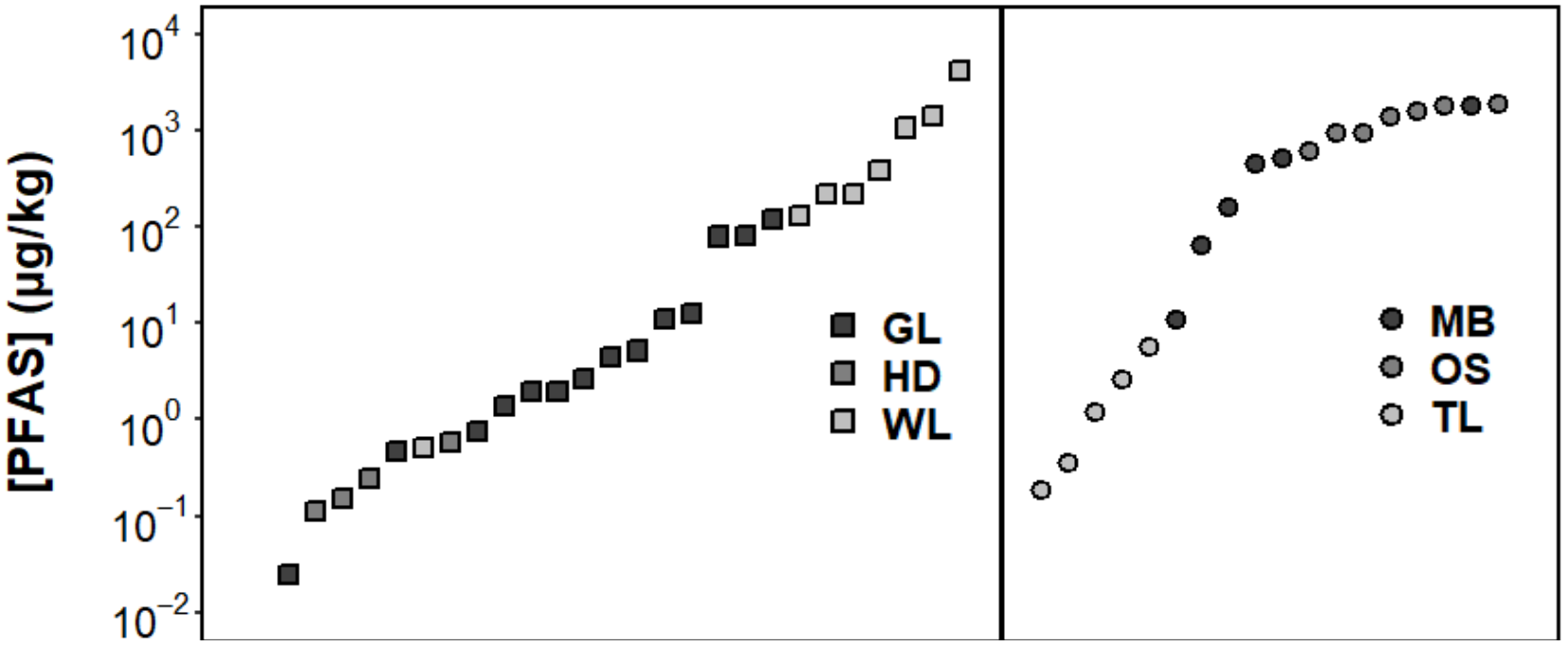
- 11 unique PFAS quantified above reporting limits across all 20 textiles.
- Between 0-9 individual PFAS in each textile detected.
- Highest concentrations are fluorotelomerization derived compounds with 6 perfluorinated carbons.
- Perfluorocarboxylic acids (PFCA) detected widely at lower concentrations.

PFAS in Wildland Firefighter Textiles (cont.)



- Summed PFAS concentrations varied from no PFAS detected to 4240 µg/kg ± 890 µg/kg in WL-F.
- Highest individual concentrations measured:
  - 6:2 FTMAC detected at up to 2980 µg/kg ± 820 µg/kg
  - 6:2 FTOH detected at up to 1250 µg/kg ± 330 µg/kg
- 6:2 FTMAC and 6:2 FTOH contributed over 95% of the total summed PFAS in 7 of 9 wildland firefighter gear textiles.

Summed PFAS Comparisons



Highest Wildland (WL)

4240 µg/kg ± 890 µg/kg

Highest Outer Shell (OS)

1890 µg/kg ± 180 µg/kg

Highest Moisture Barrier (MB)

1865 µg/kg ± 88 µg/kg

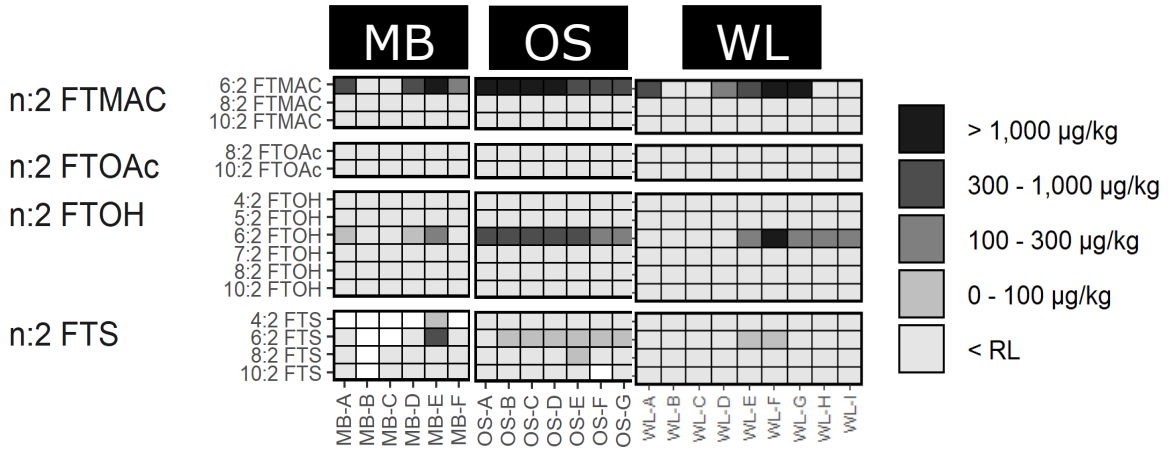
Highest Glove (GL)

118.9 µg/kg ± 7.1 µg/kg

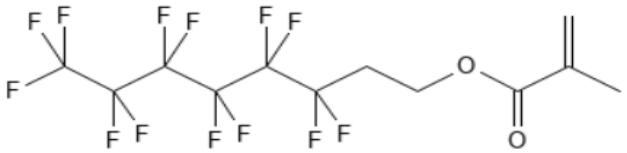
Highest Hood (HD)

0.6 µg/kg ± 0.1 µg/kg

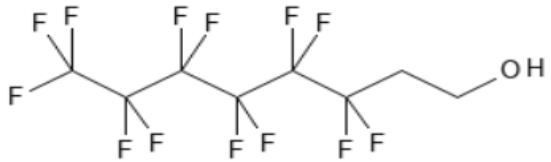
Implications



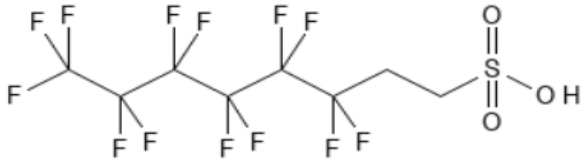
6:2 fluorotelomer methacrylate (**6:2 FTMAC**)



6:2 fluorotelomer alcohol (**6:2 FTOH**)



6:2 fluorotelomer sulfonate (**6:2 FTS**)



- Three PFAS account for vast majority of identified PFAS mass.
- Allows targeting of PFAS toxicology and epidemiology efforts.
- Summed PFAS concentrations vary in textiles, will vary in gear.

Takeaways

- Multiple PFAS compounds are present in firefighter textiles, but a small number of manufacturing residues account for most of the total PFAS mass.

- While total PFAS concentrations differ across gear, this does not directly indicate higher exposure risk or adverse health effects.

Acknowledgments

Fire Research Division
Engineering Laboratory

Rick D. Davis
Michelle Donnelly
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Ryan Falkenstein-Smith
Olivia Hernandez
Kathleen Hoffman
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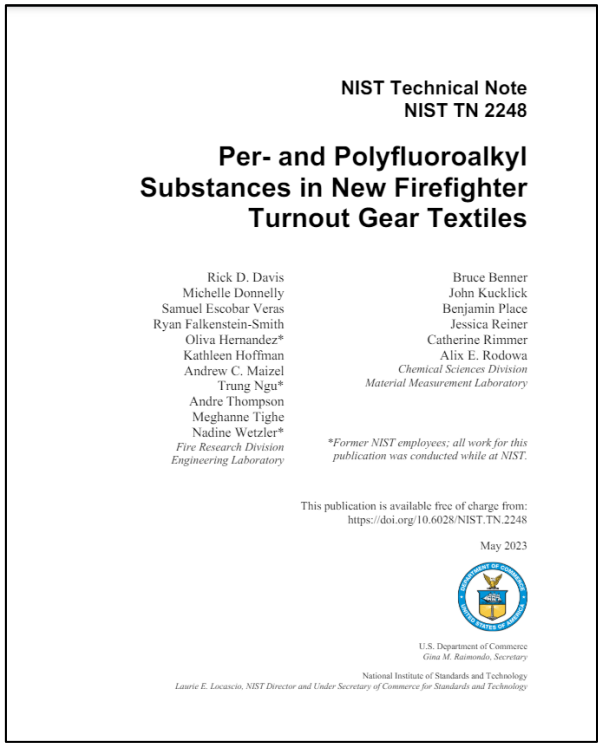
For More Information



NIST Technical Note
NIST TN 2248

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**Former NIST employees; all work for this publication was conducted while at NIST.*

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.2248

May 2023

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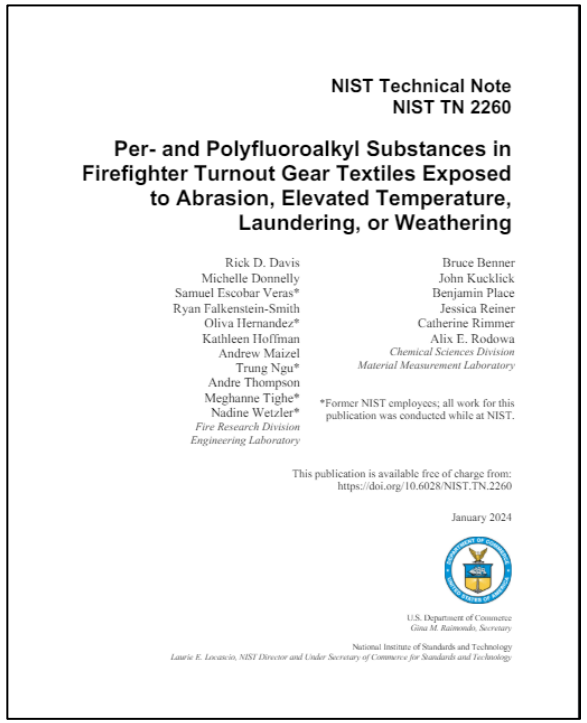
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
Laurie E. Locascio, NIST Director and Under Secretary of Commerce for Standards and Technology



NIST Technical Note
NIST TN 2260

Per- and Polyfluoroalkyl Substances in Firefighter Turnout Gear Textiles Exposed to Abrasion, Elevated Temperature, Laundering, or Weathering

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January 2024

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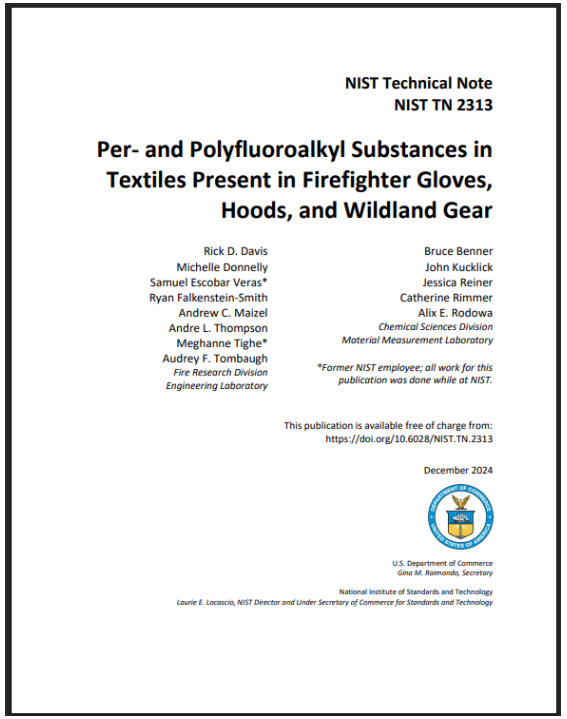

NIST Technical Note
NIST TN 2313

Per- and Polyfluoroalkyl Substances in Textiles Present in Firefighter Gloves, Hoods, and Wildland Gear

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December 2024

U.S. Department of Commerce
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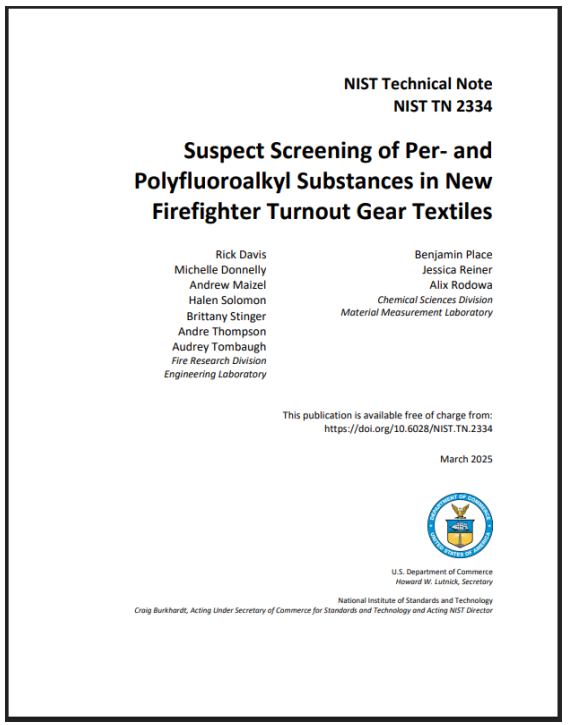

NIST Technical Note
NIST TN 2334

Suspect Screening of Per- and Polyfluoroalkyl Substances in New Firefighter Turnout Gear Textiles

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This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.2334

March 2025

U.S. Department of Commerce
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