



PFOMS

PFAS in Firefighters of Michigan Surveillance

Report

**The PFAS in Firefighters of Michigan Surveillance (PFOMS)
Project: Biomonitoring of Per- and Polyfluoroalkyl
Substances (PFAS) in Michigan Firefighters**

2019 – 2024

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SUMMARY

Background: Per- and polyfluoroalkyl substances (PFAS) are a large group of fluorinated chemicals. This group includes chemicals that have high chemical stability (low reactivity with other chemicals), high thermal stability (resistance to being broken down by heat) and the ability to repel both water and oil. These properties have made PFAS useful in a variety of consumer products and industrial applications, including firefighting foams. These properties also allow some PFAS to persist in the environment and accumulate in people's bodies. PFAS-containing firefighting foams include aqueous film forming foam (AFFF), alcohol-resistant AFFF (AR-AFFF) and other Class B fluorinated foams. Due to firefighters' unique potential for occupational exposure to PFAS, whether through use of firefighting foam or exposure to other potential PFAS sources, such as waterproof turnout gear or station dust, firefighters may have higher blood concentrations of PFAS than the U.S. population.

Objectives: The Michigan Department of Health and Human Services (MDHHS) initiated the PFAS in Firefighters of Michigan Surveillance (PFOMS) project to determine average blood concentrations of PFAS in Michigan firefighters and help inform decisions about how to minimize firefighters' exposure to PFAS. This report presents an overview of the methodology used to design the PFOMS project, describes concentrations and prevalence of 39 PFAS among Michigan firefighters and compares PFAS concentrations to the U.S. population (most recent available National Health and Nutrition Examination Survey (NHANES) data) and other firefighter studies, where possible.

Data Collection Period: April 2021-September 2023

Description of the Project: The PFOMS project is a state-wide surveillance of PFAS concentrations in selected Michigan municipal and airport firefighters. PFOMS collected data about occupational and behavioral factors that relate to PFAS exposure by administering an online survey, and measured PFAS concentrations in blood samples collected from firefighters. Samples of drinking water, a potential source of PFAS, were also collected from selected fire stations for testing. One thousand and twenty-three firefighters from 64 fire departments participated in the PFOMS project. This report presents an overview of the methodology used to design the PFOMS project and characterizes firefighters' blood PFAS concentrations by reporting on detection frequencies or prevalence estimates (as applicable), 95th percentiles, geometric means (GM) and 95% confidence intervals (CIs) for all firefighters and for certain subgroups. The report further compares PFOMS geometric means and 95% CIs to the NHANES most recent available data as well as similar metrics reported by other firefighter studies. PFAS water sampling results for fire stations are also reported.

Results: The average age of participants in the PFOMS project was 44.70 years, with the majority being male (91.7%) and of white non-Hispanic ethnicity (86.5%). PFAS* such as PFOS, PFOA, PFHxS, PFNA, PFHpS, PFDA, linear isomers of PFOS, PFOA and PFHxS and branched isomers of PFOS were prevalent in over 95% of Michigan firefighters. Among the measured PFAS, 26 PFAS were prevalent in less than 10% of Michigan firefighters or were below the detection limit. Thirteen PFAS exhibited prevalence of above 60% for which estimates such as geomeans were calculated. Prevalence of certain analytes were found to be higher in Michigan firefighters compared to the U.S. population (20 years and older age group), including PFHpS (97.9% vs 80.1%), PFDA (97.0% vs 89.4%), PFUnA (80.3% vs 69.1%), PFNA (99.8% vs 92.6%), PFBS (11.4% vs 0.8%), PFDoA (10.6% vs 2.6%), MeFOSAA (81.2% vs 58.8%) and PFHpA (54.4% vs 10.9%). Average PFAS blood concentrations for most analytes were lower in Michigan firefighters than the most recent available U.S. population (NHANES) data. Significant

* See **Table S1 in Appendix A** for a list of PFAS abbreviations used in this document.

differences in this were seen with concentrations of PFOA [0.87 micrograms per liter ($\mu\text{g/L}$) (95% CI 0.82-0.92) in PFOMS vs 1.45 $\mu\text{g/L}$ (95% CI 1.35-1.56) in NHANES] and its linear isomer [0.85 $\mu\text{g/L}$ (95% CI 0.80-0.90) in PFOMS vs 1.36 $\mu\text{g/L}$ (95% CI 0.80-0.90) in NHANES], PFHpS [0.17 $\mu\text{g/L}$ (95% CI 0.15-0.18) in PFOMS vs 0.23 $\mu\text{g/L}$ (95% CI 0.20-0.28) in NHANES], PFDA [0.11 $\mu\text{g/L}$ (95% CI 0.10-0.12) in PFOMS vs 0.20 $\mu\text{g/L}$ (95% CI 0.18-0.22) in NHANES], PFUnA [0.05 $\mu\text{g/L}$ (95% CI 0.05-0.06) $\mu\text{g/L}$ in PFOMS vs 0.13 $\mu\text{g/L}$ (95% CI 0.12-0.14) in NHANES] and MeFOSAA [0.06 $\mu\text{g/L}$ (95% CI 0.05-0.06) in PFOMS vs 0.13 $\mu\text{g/L}$ (95% CI 0.12-0.14) in NHANES]. Higher concentrations in Michigan firefighters compared to U.S. population were seen with PFOS [4.85 $\mu\text{g/L}$ (95% CI 4.39-5.36) in PFOMS vs 4.50 $\mu\text{g/L}$ (95% CI 4.15-4.89) in NHANES] and the branched isomer of PFOS [1.73 $\mu\text{g/L}$ (95% CI 1.46-2.05) in PFOMS vs 1.31 $\mu\text{g/L}$ (95% CI 1.18-1.44) in NHANES]. Average blood concentrations of PFOS were also higher in Michigan firefighters compared to two other firefighter studies (Graber et al. (2021) and Trowbridge et al. (2020)). The concentrations at the 95th percentile among Michigan firefighters were higher than those reported in NHANES only for the branched isomer of PFOS [6.52 $\mu\text{g/L}$ (95% CI 5.41-7.62) in PFOMS vs 4.6 $\mu\text{g/L}$ (95% CI 4.10-5.60) in NHANES]. The percentage of Michigan firefighters that exceeded the NHANES 95th percentile concentrations was higher for PFOS (5.7%), PFHxS (5.7%) and branched isomer of PFOS (15.1%). Average concentrations of PFAS commonly found in PFAS-containing foams such as PFHxS [1.05 $\mu\text{g/L}$ (95% CI 0.93-1.17) vs 0.94 $\mu\text{g/L}$ (95% CI 0.81-1.09)], were higher in firefighters from fire departments that currently or in the past used or stored PFAS-containing foam compared to firefighters from fire departments that did not currently or in the past store or use PFAS-containing foam. However, this difference was not statistically significant. Concentrations of other PFAS found in PFAS-containing foams such as PFOS, PFDA, PFNA, PFUnA and MeFOSAA were similar between the two groups. Airport firefighters generally exhibited higher average concentrations of most PFAS compared to non-airport firefighters, except for MeFOSAA [0.05 $\mu\text{g/L}$ (95% CI 0.04-0.07) in airport firefighters vs 0.06 $\mu\text{g/L}$ (95% CI 0.05-0.07) in non-airport firefighters]. Significantly higher average concentrations were observed in airport compared to non-airport firefighters for PFOA [1.11 $\mu\text{g/L}$ (95% CI 0.99-1.25) vs 0.85 $\mu\text{g/L}$ (95% CI 0.80-0.91)], PFOS [8.91 $\mu\text{g/L}$ (95% CI 7.53-10.53) vs 4.70 $\mu\text{g/L}$ (95% CI 4.28-5.17)], PFHxS [1.46 $\mu\text{g/L}$ (95% CI 1.13-1.89) vs 1.00 $\mu\text{g/L}$ (95% CI 0.91-1.10)] and PFHpS [0.25 $\mu\text{g/L}$ (95% CI 0.18-0.33) vs 0.16 $\mu\text{g/L}$ (95% CI 0.13-0.18)]. Compared to the U.S. population, both urban and non-urban airport firefighters showed significantly lower average concentrations of PFUnA and MeFOSAA, and significantly higher average concentrations of PFOS. Urban firefighters exhibited higher average blood concentrations of most PFAS than non-urban firefighters, except for MeFOSAA, PFDA, PFHpS, PFNA and PFUnA. Significant differences were only seen with values of PFOA [0.95 $\mu\text{g/L}$ (95% CI 0.86-1.05) in urban vs 0.79 $\mu\text{g/L}$ (95% CI 0.74-0.85) in non-urban], branched isomer of PFOS [2.14 $\mu\text{g/L}$ (95% CI 1.70-2.71) in urban vs 1.38 $\mu\text{g/L}$ (95% CI 1.14-1.68) in non-urban] and MeFOSAA [0.05 $\mu\text{g/L}$ (95% CI 0.04-0.05) in urban vs 0.07 $\mu\text{g/L}$ (95% CI 0.06-0.08) in non-urban]. Average concentrations of all measured PFAS were similar or lower (PFUnA and MeFOSAA) in other urban, non-urban and City of Detroit firefighters when compared to the U.S. population. For most PFAS, higher average concentrations were observed in males, non-white single race individuals, Hispanics, and participants in higher age, education and income groups. PFAS was not frequently detected in fire station drinking water. None of the water samples from the faucets most often used for drinking water contained PFAS above the comparison values. Only three stations had samples with results that exceeded comparison values, and these were from spigots not used for drinking water that were closest to where water entered the station.

Interpretation: The PFOMS project successfully identified and quantified average PFAS concentrations in the blood of Michigan firefighters. Notably, elevated average blood concentrations and 95th percentiles were observed for PFOS (average blood concentrations only), branched isomers of PFOS and PFHxS (95th percentile only) among Michigan firefighters. However, average blood concentrations for other PFAS generally remained lower or similar compared to the U.S. population and other firefighter studies conducted across the U.S. and

globally. PFAS that are known to be found in PFAS-containing foam, such as PFOS and PFHxS were detected in more than 95% of Michigan firefighters but were found at lower or similar concentrations than the U.S. population. No significant differences were found in concentrations of such PFAS between firefighters from fire departments that currently or in the past used or stored PFAS-containing foam compared to firefighters from fire departments that did not currently or in the past store or use PFAS-containing foam. These results indicate the potential effectiveness of PFAS exposure reduction strategies implemented in 2020 under Public Acts (PA) 133 and 143 in mitigating occupational PFAS exposure among firefighters. However, it is noteworthy that within Michigan, higher concentrations were observed among airport and urban firefighters, highlighting potential variations in exposure across different work environments. Additionally, PFAS concentrations among different demographic groups within Michigan firefighters mirrored trends observed in other studies, suggesting consistent patterns of PFAS exposure across populations. Importantly, analysis of drinking water samples from fire stations suggests that fire station drinking water is unlikely to be a significant source of PFAS exposure for Michigan firefighters.

Next Steps: MDHHS will continue to analyze the data collected under this biomonitoring effort to explore specific occupational and non-occupational activities and behaviors that may contribute to disparities in PFAS exposure disparities between different firefighter subgroups, such as airport and non-airport personnel. Findings of these analyses will not only enhance our understanding of PFAS exposure among firefighters but could also inform targeted interventions and policies aimed at mitigating occupational health risks associated with PFAS exposure in this population.

INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a large group of human-made fluorinated chemicals that are used across a wide array of industries due to the unique properties of certain PFAS, including resistance to heat, water and oil. These compounds, which were first produced in the 1940s, were previously absent from nature but have now been widely found throughout the environment and in human blood¹. PFAS are often referred to as "forever chemicals" because some PFAS can persist in the environment for long periods of time with minimal degradation. Some



PFAS, such as PFOS, can also bioaccumulate in people's bodies because they are not readily eliminated from the body. High concentrations of some PFAS in sources such as food and drinking water are well-documented, and numerous health effects are associated with serum PFAS concentrations¹⁻³. Notably, changes in immune⁴⁻⁶, cardiovascular⁷, kidney^{8,9}, liver^{10,11} and thyroid function¹² have been linked with exposure to some individual PFAS and/or mixtures of PFAS in the general population. In addition, emerging evidence shows that other health effects, including cancer^{13,14} and reproductive health problems^{15,16}, are human health outcomes associated with exposure to some PFAS. Further research is needed to determine how the many PFAS to which people are exposed affect human health.

PFAS exposure becomes particularly important in the case of certain high-risk occupational groups, including firefighters. Due to the nature of their work, firefighters are likely to be exposed to PFAS from several sources, including, but not limited to, firefighting foams, PFAS-treated fire-resistant clothing, contaminated equipment and station dust¹⁷⁻¹⁹.

PFAS-Containing Firefighting Foams



PFAS-containing firefighting foams, such as aqueous film-forming foams (AFFF), alcohol-resistant AFFF (AR-AFFF) and other Class B fluorinated foams, have historically been a significant source of exposure to PFAS for firefighters over several decades. These foams, composed of various PFAS, are engineered to generate a protective film that efficiently cools fires while enveloping flammable fuels. By impeding contact with oxygen, PFAS-containing firefighting foams effectively curb the fire's progression, particularly in the context of Class B fires associated with combustible liquids¹⁷. Key PFAS commonly found in PFAS-containing firefighting foam formulations include PFOS, PFOA, PFHxS^{17, 20-22} and PFHpS^{17,20} among others.

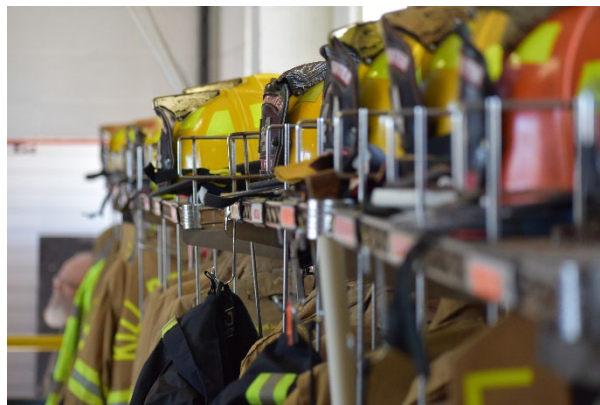
Currently, within the United States, AFFF usage primarily occurs in military and Federal Aviation Administration (FAA)-certified Part 139 airport fire departments²³. Military airports adhered to the MIL-PRF-24385 specification, requiring AFFF formulations to contain PFAS to meet operational needs, until October 2021 when a revision was made that no longer required the use of fluorinated chemicals in firefighting foam^{23,24}. However, any non-fluorinated foam needs to go through FAA approval before it can be used. Civilian airports regulated under Part 139 of the Federal Aviation Regulations maintain prescribed fire response readiness levels, often referred to as Aircraft Rescue Fire Fighting (ARFF) indices²³. These indices encompass various accident response protocols, including the possession of military-specified AFFF formulations and routine equipment testing, which make airport firefighters more likely to be exposed to PFAS.

Beyond military and airport contexts, AFFF is used in diverse settings such as refineries, fuel tank farms and municipal fire departments^{17,25}. Municipal fire departments employ AFFF to extinguish fires involving flammable liquids. For instance, AFFF was used in firefighting efforts at the Carl's Retreading site in Grawn, Michigan, during a tire scraps fire in December 1995. Investigations conducted 25 years later revealed detectable PFAS in groundwater, with concentrations of PFOA ranging up to 92 nanograms per liter (ng/L; equal to parts per trillion [ppt]) and PFOS ranging up to 260 ng/L. If people used this groundwater for drinking water, they would have been exposed to PFAS above the current Michigan Maximum Contaminant Level (MCL) and U.S. Environmental Protection Agency (EPA) MCLs for PFOS (4 ng/L) and PFOA (4 ng/L)[†]. This underscores the potential long-term environmental impact of legacy foam applications.

The popularity of AFFF waned in the early 2000s due to increasing concerns over effects on human health and the environment linked to PFAS. Since that time, there has been a move away from use of legacy PFOS AFFF and long-chain fluorotelomer AFFF toward alternative firefighting foam products. These include modern fluorotelomer AFFF, which contains only short-chain PFAS, and fluorine-free foams, which do not contain PFAS. Despite the reduction in use of PFAS-containing foam, risks stemming from legacy foam applications and contaminated equipment continue to pose challenges^{17,20}. Changing regulatory frameworks and PFAS usage patterns make ongoing surveillance necessary to ensure the safety and health of both firefighting personnel and the surrounding environment.

Other PFAS Exposure Routes in Firefighters

In addition to the use of PFAS-containing firefighting foams, firefighters may encounter PFAS through their personal protective equipment (PPE). The treatment of PPE with PFAS is intended to provide greater water and oil-repellent properties to the gear^{17,26}. However, exposure to PFAS-treated gear can also contribute to firefighters' cumulative PFAS exposure, particularly during prolonged wear or when subjected to conditions of elevated heat or pressure that could lead to the release^{27,28} of certain PFAS like perfluoroalkyl carboxylic acids (PFBA, PFNA), perfluoroalkyl sulphonic acids (PFOS) and other



[†] URL: [EPA.gov/sdwa/and-polyfluoroalkyl-substances-pfas](https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas)

short-chain PFAS like PFBS^{18,26-28}. Other PFAS have also been identified in protective gear. These include perfluoroalkyl acids (PFAAs)^{18,26,27} such as PFOA, PFDA, PFHxA, PFPeA, PFHpA, various fluoroolefins^{18,26,27} (e.g., 6:2 FTS, 8:2 FTS, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH and 12:2 FTOH) and perfluorooctane sulfonamides like EtFOSAA^{18, 27} and MEFOSAA^{18, 26}. Analysis of PFAS in dust wipes taken from turnout gear has confirmed the presence of PFOA, PFNA, PFBS, PFDA and PFUnA¹⁹.

Dust in the indoor environment of fire stations has been identified as another potential source of PFAS exposure. This PFAS may originate from PFAS-treated furniture, carpet, or contaminated gear and equipment^{18-19,27}. Higher concentrations of total fluorine have been found in dust from turnout gear locker rooms compared to living rooms of fire stations, and the composition of the PFAS detected in different rooms was found to reflect the dominant suspected sources in those areas¹⁹. Additionally, firefighters may be exposed via ingestion or inhalation to PFAS-contaminated food, water and air at fire stations²⁰.

Efforts to mitigate firefighters' exposure to PFAS require consideration of the different ways that firefighters can be exposed, including potential exposure from firefighting foam, PPE, dust in fire stations and other non-occupation related sources such as diet or PFAS-contaminated household drinking water.

Purpose of the PFOMS Project

The PFOMS project aims to describe the extent of PFAS exposure among firefighters in Michigan. The objectives are to determine the average blood concentrations of PFAS in Michigan firefighters that will help inform decisions about how to minimize firefighters' exposure to PFAS. By focusing on Michigan's firefighters, the PFOMS project provides a detailed assessment of PFAS exposure among a critical occupational group.

Specific Objectives of this Report

1. Describe the concentrations and detection frequencies of 39 PFAS in blood among Michigan firefighters and various subgroups.
2. Compare participants' blood PFAS concentrations to the National Health and Nutrition Examination Survey (NHANES) results and other firefighter studies across the U.S. and globally, where available.

METHODOLOGY

Sampling Frame and Project Design

The PFOMS sampling frame is comprised of all municipal fire departments in the state of Michigan and fire departments serving FAA Part 139 certified airports²³. The list of the fire departments that met the above inclusion criteria was obtained from the office of the Michigan State Fire Marshal. Michigan Department of Natural Resources firefighters and military firefighters were excluded due to significant variations in their exposures compared to municipal firefighters, requiring distinct handling as special populations.

To obtain a representative sample of Michigan firefighters, PFOMS project used a stratified sampling design, categorizing the fire departments into five strata:

- (1) Non-urban airport fire departments.
- (2) Urban airport fire departments.
- (3) City of Detroit fire department.
- (4) Other non-urban fire departments.
- (5) Other urban fire departments.

Urban was defined in accordance with the U.S. Census²⁹. The Census Bureau identifies two types of urban areas.

- Urbanized Areas (UAs) of 50,000 or more people.
- Urban Clusters (UCs) of at least 2,500 and less than 50,000 people.

Non-urban (rural) was defined as encompassing all population, housing, and territory not included within an urban area.

All fire departments in the urban and non-urban airport strata and randomly selected municipal fire departments throughout the state of Michigan were invited to participate. The City of Detroit fire department was invited and was treated statistically as a stratum.

Note: Airport firefighters are defined as those who work or volunteer at the **non-urban airport fire departments** and **urban airport fire departments**. Non-airport firefighters are those that work or volunteer in the remaining three strata as defined above.

Similarly, urban firefighters are defined as those who work or volunteer at **Other urban fire departments** and the **City of Detroit fire department**, while non-urban firefighters are those who work or volunteer at **Other non-urban fire departments**.

Firefighter Eligibility

All firefighters within a selected airport or non-airport fire department were invited to participate in the PFOMS project, provided they met the following eligibility criteria at the time of their appointment:

- Current career or volunteer firefighter[‡] in the state of Michigan.
- On the current roster of the eligible fire department.

[‡] For this project, a firefighter was defined as having a State of Michigan Firefighter I and/or Firefighter II certification.

- Age 18 years or older.
- Willing to provide a blood sample for PFAS blood testing.

Recruitment

The recruitment strategies included both direct and indirect methods.

Indirect recruitment methods included issuing a press release, project promotion through community partners and presentations and exhibits at firefighting conferences or meetings.

Direct recruitment methods included a combination of multiple mailings, emails, phone calls, fire department visits (as needed) and fire department availability sessions to engage and enroll firefighters. Fire chiefs of the invited fire departments received an “Invitation to participate” email 2-3 months in advance. Three phone call attempts were made to the fire chiefs of the invited fire departments to obtain verbal consent allowing their department to participate in the PFOMS project. This was followed by enrollment of the fire department and scheduling for their blood draw appointment visit. Upon enrollment of the fire department, potential participant recruitment packets were sent out to all firefighters listed on the fire department’s roster, inviting them to participate in the PFOMS project. The project made three outgoing phone calls or email attempts (depending on what the fire department preferred) to recruit potential participants from the fire department’s roster. Firefighters could call or email the project team with the best number and time to call to schedule their appointments. Interested firefighters completed a brief intake survey via phone to assess eligibility and schedule a blood draw appointment. Recruitment rates were continuously monitored to maximize participation across all strata.

Data Collection

Fire departments completed 1) an online questionnaire on Class B foam storage and usage at their fire departments, and 2) scheduled an appointment to provide samples representative of their drinking water from their eligible stations.

Enrolled firefighters 1) completed an online questionnaire about PFAS exposure and 2) provided a sample of blood (10 mL) to be tested for PFAS. All participants electronically signed an informed consent form during their blood draw appointment. Appointment confirmation was sent via participants' preferred method (call, email or text) immediately upon scheduling their blood draw appointment, and a reminder was sent one day prior to their appointment. An email was also sent to non-enrollees one day before the start of the fire department’s visit providing them with an additional invitation to participate. Participants were given a \$25 gift card as a thank you for their participation.

Blood and Water Sample Collection, Processing and Laboratory Methods

Blood Sample Collection and Processing

Blood samples were drawn from participants by trained phlebotomists. Blood samples were centrifuged (spun) to remove cells and serum was divided into multiple vials by a trained laboratory technician. Vials were then refrigerated (or frozen, as needed) and transported to the MDHHS laboratory for PFAS testing. The blood collection tubes (glass 10 mL redtop tubes, BD (Franklin Lakes, New Jersey, USA)), transfer pipettes (polypropylene, BD) and aliquot vials (polypropylene 2 mL vials, VWR) used for PFAS testing were pre-screened for

PFAS contamination and handling protocols were in place to prevent cross-contamination. Only collection materials cleared of PFAS background contamination were used in specimen collection and processing.

PFAS testing of serum samples was performed at the accredited MDHHS Bureau of Laboratories in Lansing, Michigan. All blood samples were analyzed at the laboratory within specified turnaround times.

Water Sample Collection

A designated point-of-contact from each selected fire department accompanied trained MDHHS sanitarians to collect drinking water samples from fire stations within a fire department (as applicable) for PFAS testing. When possible, sanitarians collected two samples from each fire station: one from the location where firefighters most often get their drinking water and one from the location closest to where the water enters the station. Due to the large number of fire stations within the City of Detroit fire department, which are all supplied by the same water supply, only four stations (approximately 10%) were selected for water sampling. Water samples were collected in 250 mL high-density polyethylene (HDPE) bottles with screw caps which were lot tested to be free of PFAS background contamination. Collected samples were packed on ice and transported to MDHHS's Bureau of Laboratories in Lansing, Michigan. All water samples were analyzed at the laboratory within the specified hold-times.

PFAS Measurement and Laboratory Methods

Serum and water samples were analyzed for 39 PFAS. Three of these PFAS (PFOA, PFOS and PFHxS) were measured in two different forms, or shapes: linear (L-) and branched (Br-). For these three PFAS, the Bureau of Laboratories can measure the amount of each of the two forms, plus their total. Although samples were analyzed for 39 PFAS, 45 PFAS are reported when including the branched, linear and total summations for PFOA, PFOS and PFHxS.

Serum PFAS

Forty-five PFAS were measured in the aliquoted serum (**Table S1 in Appendix A**). Both linear and branched isomers of three PFAS (PFOA, PFOS and PFHxS) were quantified. Isotopic dilution was performed with labeled analogs of 20 analytes before the extraction. Acetonitrile was added to a serum aliquot to precipitate the protein from the serum matrix. The sample was then processed through a 96-well filtration plate to further clean samples prior to analysis by reverse-phase high-performance liquid chromatography (RP-HPLC) tandem mass spectrometry (MS/MS). The extraction and clean-up process used to isolate PFAS from the serum matrix improves the limits of detection (LOD) by facilitating enrichment of the analytes with respect to the matrix. PFAS were further separated from extraneous compounds in the extract by RP-HPLC. Analyte ions are generated by electrospray ionization and fragment ions specific to each analyte, are produced by collision-induced dissociation (CID). Comparison of relative response factors (analyte area/analog area) with known standard concentration/internal standard concentration ratios yields individual analyte concentrations. This method is applicable to the measurement of PFAS in serum with Method Limits of Quantitation (LOQ) in the low ng/L range.

Water PFAS

The same 45 PFAS that were measured in serum were measured in water (**Table S1 in Appendix A**). Both linear and branched isomers of three of these PFAS (PFOA, PFOS and PFHxS) were quantified. Isotopic dilution was performed with labeled analogs of 20 analytes before the extraction. Solid phase extraction (SPE) using a Weak Anion Exchange (WAX) sorbent in a 96-well plate format was used to isolate PFAS from the water matrix and to

improve the LOD by facilitating enrichment of the analytes with respect to the matrix. PFAS were further separated from extraneous compounds in the extract by reverse-phase HPLC. Analyte ions are generated by electrospray ionization and fragment ions, specific to each analyte, are produced by CID. Comparison of relative response factors (analyte area/analog area) with known standard concentration/internal standard concentration ratios yields individual analyte concentrations. This method is applicable to the measurement of PFAS in water with LOQ in the low ng/L range.

Reporting of Results

Participants were mailed their personal blood PFAS test results and fire station's drinking water PFAS results, if applicable, unless they requested otherwise. All fire chiefs and/or key points-of-contact received PFAS water results for their departments. Health education and explanatory factsheets were included in all mailings and technical staff were available to answer questions from participants about the results.

Data Handling and Analysis

Data Quality Assurance and Control

Quality assurance steps were taken during survey, blood draw appointments and at-station data collection that included the programming of branching logic on electronic instruments, the setting of upper and lower bound limits on free response numeric fields and the use of automated warning messages for skipped or missed questions. Quality checks on all data collection instruments were performed weekly during data collection. Project data were collected and managed using Research Electronic Data Capture (REDCap) tools. REDCap is a secure, web-based application designed to support data capture for research studies^{30,31}.

Statistical Analysis

Descriptive statistics were used to characterize the demographic distribution of PFOMS participants as well as their blood PFAS concentrations in various subgroups. These descriptive analyses included detection frequencies or prevalence estimates (as applicable), 95th percentiles, geometric means (GMs) and their 95% confidence intervals (CIs). The detection frequency of each PFAS describes how often that specific PFAS was found in the blood of PFOMS participants who provided a blood sample, while prevalence estimates with 95% CIs represent the estimated frequency of PFAS detections among Michigan firefighters in general. Participants were selected based on a stratified two-stage sampling design³²: first selecting fire departments, the primary experimental units, within each stratum, followed by voluntary participation of firefighters within departments, the secondary experimental units. The proportion of departments selected varied by stratum, so weighting was necessary to develop unbiased estimates of population parameters. Survey weights (w) were determined by Equation 1:

$$\text{Equation 1: } w = \left(\frac{\text{Total Firefighter Per Department}}{\text{Participating Firefighter Per Department}} \right) \times \left(\frac{\text{Total Departments Per Stratum}}{\text{Participating Departments Per Stratum}} \right)$$

Analyses were performed using SAS[®] PROC SURVEYMEANS and PROC MIXED in Base SAS 9.4, with weights applied. PFAS detection frequencies for PFOMS participant subgroups were calculated using R Statistical Software version 4.3.2. For all analytes where NHANES comparison results are available, the percent of individuals exceeding the NHANES 95th percentile was calculated using R. Density plots were made with R, using the packages ggplot2 version 3.4.2 and ggridges version 0.5.5.

Geometric means for Michigan firefighters were compared to the NHANES geometric means for adults aged 20 years and older from the most recent data year for each available PFAS. The blood PFAS concentrations from NHANES can be thought of as “background” or even as the “expected” concentrations of PFAS for people living in the U.S. All comparisons to NHANES data included here are descriptive, and any differences noted are meant to highlight the likelihood of large or particularly meaningful departures from what is expected. This analysis was limited to analytes that were detected in greater than 60% of Michigan firefighters. When the 95% confidence interval for the geometric means for the Michigan firefighters did not overlap with that for the NHANES population, the difference was considered statistically significant. This is also true for any comparisons made between sampling strata or subpopulations within PFOMS.

PFOMS results were compared to results from nine other firefighter studies^{21,33-40} that reported PFAS blood concentrations. Like NHANES data, comparisons to other firefighting studies describes how different, or similar Michigan firefighters are compared to other firefighters in the U.S. or globally. The minimum, maximum and geometric mean of PFAS concentrations were selected as the comparison measures between Michigan firefighters and the other firefighter studies since these measures provide a general description of the range and central tendency of the observed PFAS concentrations. Comparisons were made for PFOS, PFOA, PFHxS, PFNA and PFDA. These chemicals are of interest because they were reported as being elevated in firefighters compared to the control population in two or more of the nine firefighter studies and were detected in more than 60% of Michigan firefighters. Differences between geometric means for Michigan firefighters and the other firefighter studies were considered statistically significant if the 95% confidence intervals for the geometric means did not overlap. Some studies only reported standard deviations for geometric means, in which case 95% confidence intervals were calculated based on the standard deviation and sample size.

Detection frequencies were calculated for PFAS in fire station drinking water to characterize how often each PFAS was found in the drinking water samples. Detection frequencies for PFAS in water were calculated using R Statistical Software version 4.3.2.

The suppression of counts between one and five (along with complementary suppression) was used for all result reporting. Any cells with counts between one and five are reported as “<6” or are otherwise noted as suppressed. Cells marked with “^” have been suppressed as a method of complementary suppression to prevent back-calculation. Water and blood PFAS measurements that were reported as non-detect (ND) or were lower than the analyte-specific limit of quantification (LOQ) was recoded to a numerical value generated using the following equation:

$$\text{Equation 2: } \frac{\text{Limit of Quantification (LOQ)}}{\sqrt{2}}$$

Values reported as below the reporting limit but above the LOQ were recoded using the formula:

$$\text{Equation 3: } \frac{\text{Reporting Limit (RL)}}{\sqrt{2}}$$

The PFOMS project received a determination notice from the MDHHS Institutional Review Board (IRB) indicating that it does not qualify as human subjects’ research. As a result, projects with this determination are not subject to further review by the IRB or its administrative office.

RESULTS

Participant Characteristics

A total of 1,023 participants provided a blood sample for PFAS testing. Participant characteristics for the PFOMS project are summarized according to sampling strata (non-urban airport, urban airport, City of Detroit, non-urban non-airport and urban non-airport) in **Table 1**. The majority of PFOMS participants were 30-59 years old, both overall and within each stratum. The average age for all participants combined was 44.70 years with a standard deviation of 12.35 years. The racial-ethnic composition of Michigan⁴¹ was reflected in this population as well, with 93.5% of participants identifying as non-Hispanic and 86.5% identifying as white. Similar percentages were seen in each individual stratum except for City of Detroit Fire Department where 30.0% of participants were Black, indigenous or person of color (BIPOC) alone. Most of the PFOMS participants were male (91.7%) and full-time paid employees of the fire department (55.6%). Around 80% of participants in the Non-Urban Non-Airport stratum were volunteer firefighters. Most participants (~82%) had at least some college education and 60.4% reported having a household income at or above \$75,000.

Table 1. Count of PFOMS Participants Demographic Characteristics by Sampling Strata.

Participant Characteristics	Non-Urban Airport (n=40) Count (%) ^{a,b}	Urban Airport (n=126) Count (%) ^{a,b}	City of Detroit (n=197) Count (%) ^{a,b}	Non-Urban Non-Airport (n=356) Count (%) ^{a,b}	Urban Non-Airport (n=304) Count (%) ^{a,b}	Total (n = 1,023) Count (%) ^{a,b}
Average age (standard deviation)	48.9 (10.24)	45.14 (10.42)	44.72 (10.16)	46.08 (14.65)	42.30 (11.27)	44.70 (12.35)
18-29 years	0	12 (9.5)	21 (10.7)	49 (13.8)	39 (12.8)	121 (11.8)
30-39 years	9 (22.5)	27 (21.4)	39 (19.8)	86 (24.2)	93 (30.6)	254 (24.8)
40-49 years	12 (30.0)	35 (27.8)	48 (24.4)	77 (21.6)	88 (29.0)	260 (25.4)
50-59 years	12 (30.0)	46 (36.5)	89 (45.2)	74 (20.8)	64 (21.1)	285 (27.9)
60-69 years	6 (15.0)	6 (4.8)	0	48 (13.5)	15 (4.9)	75 (7.3)
70 years and older	<6	0	0	22 (6.2)	<6	28 (2.7)
Sex						
Male	38 (95.0)	117 (92.9)	184 (93.4)	314 (88.2)	285 (93.8)	938 (91.7)
Female	<6	^	8 (4.1)	39 (11.0)	17 (5.6)	74 (7.2)

Participant Characteristics	Non-Urban Airport (n=40) Count (%)^{a,b}	Urban Airport (n=126) Count (%)^{a,b}	City of Detroit (n=197) Count (%)^{a,b}	Non-Urban Non-Airport (n=356) Count (%)^{a,b}	Urban Non-Airport (n=304) Count (%)^{a,b}	Total (n = 1,023) Count (%)^{a,b}
Race						
Black, Indigenous or person of color (BIPOC) Alone	<6	11 (8.7)	59 (30.0)	<6	<6	76 (7.4)
White Alone	38 (95.0)	107 (84.9)	115 (58.4)	335 (94.1)	290 (95.4)	885 (86.5)
2 or more races	0	<6	10 (5.1)	7 (2.0)	<6	23 (2.3)
Ethnicity						
Hispanic, Latino or Spanish origin	0	^	10 (5.1)	17 (0.03)	<6	36 (3.5)
Not of Hispanic, Latino or Spanish origin	40 (100)	115 (91.3)	175 (88.8)	331 (93.0)	295 (97.0)	956 (93.5)
Household Income						
Less than \$35,000	0	0	0	41 (11.5)	7 (2.3)	48 (4.7)
\$35,000 to less than \$50,000	<6	<6	6 (3.1)	50 (14.0)	16 (5.3)	80 (7.8)
\$50,000 to less than \$75,000	6 (15.0)	12 (9.5)	28 (14.2)	78 (21.9)	46 (15.1)	170 (16.6)
\$75,000 to less than \$100,000	11 (27.5)	33 (26.2)	51 (25.9)	70 (19.7)	63 (20.7)	228 (22.3)
\$100,000 or more	11 (27.5)	64 (50.8)	95 (48.2)	77 (21.6)	143 (47.0)	390 (38.1)
Level of Education						
High school graduate or equivalent (GED) or less	<6	^	25 (12.7)	100 (28.1)	35 (11.5)	173 (16.9)
Some university, college, technical or trade school	16 (40.0)	59 (46.8)	99 (50.3)	114 (32.0)	105 (34.5)	393 (38.4)
Technical or trade school graduate	<6	22 (0.1)	17 (8.7)	32 (9.0)	26 (8.6)	97 (9.5)
University or college graduate	16 (40.0)	36 (29.0)	47 (23.9)	91 (25.6)	113 (37.4)	303 (29.6)
Graduate school or higher	<6	<6	^	15 (4.2)	23 (7.6)	47 (4.6)

Participant Characteristics	Non-Urban Airport (n=40) Count (%)^{a,b}	Urban Airport (n=126) Count (%)^{a,b}	City of Detroit (n=197) Count (%)^{a,b}	Non-Urban Non-Airport (n=356) Count (%)^{a,b}	Urban Non-Airport (n=304) Count (%)^{a,b}	Total (n = 1,023) Count (%)^{a,b}
Firefighter Type						
Full-time paid (employee)	35 (87.5)	120 (95.2)	195 (99.0)	42 (11.8)	177 (58.2)	569 (55.6)
Part-time paid (employee)	<6	<6	0	29 (8.2)	38 (12.5)	77 (7.5)
On-call paid (volunteer)	0	0	0	248 (69.7)	76 (25.0)	324 (31.7)
Not-paid (volunteer)	0	0	0	35 (9.8)	12 (4.0)	47 (4.6)

^aResults may not add up to the total and percentages may not sum to 100% in all categories as results for participants who did not specify an answer to that question are not shown.

^bTo protect participant privacy, counts between one and five have been suppressed.

[^]To protect participant privacy, these cells have been suppressed as a method of complementary suppression to prevent back-calculation.

[†]BIPOC includes Black, Asian, AI/AN (American Indian/Alaskan Native) or NH/PI (Native Hawaiian/Pacific Islander)

Blood PFAS Frequencies and Concentrations

The next two sections of this report describe the prevalence estimates (or detection frequencies) of all blood PFAS and their average concentrations among Michigan firefighters (**Table 2**) followed by subgroup summaries by for sampling strata (**Table 3a**), urban status (**Table 3b**), airport status (**Table 3b**), foam usage and storage (**Table 4**), demographics (**Tables 5-8**), and comparison to data from other firefighter studies across the U.S. and globally (**Tables 9a-9b**). Prevalence estimates for U.S. population are presented in **Table S2** in **Appendix A**.

Blood PFAS Frequencies

Blood PFAS frequencies are reported as prevalence estimates to describe how often PFAS are expected to be detected in Michigan firefighters overall (**Table 2**), and detection frequencies to describe how often PFAS were detected in different PFOMS participant sub-groups (**Table 3-7** and **Tables S3** and **S4**).

The prevalence estimate for each PFAS represents the estimated proportion of Michigan firefighters who have detectable levels of a given PFAS in their blood, based on the sample of Michigan firefighters who participated in PFOMS. This estimate aims to reflect the overall presence of each PFAS in Michigan firefighters. The detection frequency, in contrast, describes how often a specific PFAS was found in the blood of PFOMS participants who provided a blood sample. For example, a 100% prevalence estimate suggests that all Michigan firefighters are likely to have detectable levels of a specific PFAS, while a 100% detection frequency means that specific PFAS was detected in the blood of all PFOMS participants.

The PFOMS project measured 39 PFAS, with considerable variability in prevalence. Key findings included detection of PFOA (100%), PFOS (100%), PFHxS (99.3%), PFNA (99.8%), PFHpS (97.9%) and PFDA (97.0%) in all or nearly all Michigan firefighters (i.e., over 95% prevalence), followed by PFUnA (80.3%), PFecHS (73.4%) and MeFOSAA (81.2%). PFHpA was detected in roughly half (54.4%), while all other measured PFAS fell below 40%. Notably, several PFAS were rarely detected (<1%), including PFTeA, PFOSA, PFMBa, PFPrS, 6:2FTS, PFNS, ADONA, PFHxSA, 4:2FTS, PFBSA and PFMPA. The compounds 11Cl-PF3OUdS, 3:3 FTCA, HFPO-DA (GenX) and PFPeA were not detected within Michigan firefighters. For the three PFAS which were measured as linear and branched isomers (PFOS, PFOA and PFHxS), the two isomer types were detected with equal frequency for PFOS (both 100%), while the linear isomer was more often detected for PFOA and PFHxS (100% for L-PFOA and 14.5% for Br-PFOA; 99.3% for L-PFHxS and 3.7% for Br-PFHxS) (**Table 2**).

Among PFAS with available NHANES comparison data, the prevalence of PFOA, PFOS, PFHxS, EtFOSAA, PFHxA, PFOSA, ADONA and HFPO-DA in Michigan firefighters mirrored national estimates observed in the U.S. population (**Table S2** in **Appendix A**). However, several other PFAS demonstrated statistically significant higher prevalence compared to the U.S. population. PFHpS (97.9% vs 80.1%), PFHpA (54.4% vs 10.9%), PFDA (97.0% vs 89.4%), MeFOSAA (81.2% vs 58.8%), PFNA (99.8% vs 92.6%), PFUnA (80.3 vs 69.1%), PFBS (11.4% vs 0.8%) and PFDoA (10.6 % vs 2.6%) were more prevalent in Michigan firefighters. Only 9Cl-PF3ONS had a significantly lower prevalence among Michigan firefighters than the U.S. population (5.8% vs 13.7%). Importantly, data on detection frequencies for several PFAS studied in PFOMS are currently unavailable for the broader U.S. population. These include one PFAS analyte, PFecHS, which was detected in 73.4% of Michigan firefighters.

The prevalence estimates for Michigan firefighters (**Table 2**), detection frequencies for participants within certain strata and subgroups (**Table 3**; **Table S3**; **Table S4** in **Appendix A**), and detection frequencies for participants within demographic subgroups (**Table 4**; **Table 5**; **Table 6**; **Table 7**) can be seen in tables below.

Blood PFAS 95th Percentiles and Geometrics Means

Percentiles and geometric means provide information about the distribution of PFAS concentrations measured in firefighters. Percentile values show the percentage of firefighters with blood PFAS concentrations below or above that value, while geometric means represent average concentrations. Percentiles and geometric means were calculated for analytes detected in greater than 60% of Michigan firefighters.

Blood PFAS 95th Percentiles

The 95th percentile depicts how highly exposed the Michigan firefighters are at the highest end of the distribution (e.g., the top 5% of PFAS results among Michigan firefighters). This, in turn, informs whether Michigan firefighters may be considered a “highly exposed” population compared to the U.S. population. It answers the question “How highly exposed are those with the most PFAS in their blood?”

The 95th percentile is a calculation commonly reported for PFAS measurements in the U.S. population and is a good indicator of the blood PFAS concentrations observed among those participants with the very highest exposure. The 95th percentile blood concentration is the concentration that 95% of results are below and 5% of results are above. For example, the U.S. population had a higher 95th percentile value than the Michigan firefighters for PFOS, PFOA and many others. This means the blood concentration that marks where the highest 5% of people fall is lower in Michigan compared to the U.S. population. Note: the 95th percentile is not the same as the highest blood PFAS concentration (or “maximum”) measured in any given participant or in all Michigan firefighters.

We report the 95th percentile and the percentage of Michigan firefighters with a blood PFAS concentration at or above the 95th percentile for the U.S. population. The largest difference was seen for the branched isomer of PFOS, where the top 5% of Michigan firefighters had concentrations at or higher than 6.52 µg/L (95% CI 5.41-7.62). Compare this to the U.S. population where the 95th percentile is 4.60 µg/L (95% CI 4.10-5.60). Elevated concentrations were seen in 15.1% of Michigan firefighters for branched isomer of PFOS and 5.7% for PFOS and PFHxS. The 95th percentiles for many PFAS measured in the blood of Michigan firefighters were lower than those observed among the U.S. population (**Table 2**) with significant differences seen in PFOA, PFHpS, PFDA, 9CI-PF3ONS and EtFOSAA. This means the blood concentration that marks where the highest 5% of people fall is lower in Michigan for these analytes compared to the U.S. population. Additionally, for these analytes, the percentage of participants with elevated concentrations was similar or even lower (less than 5%) than what we would expect in the U.S. population. The 95th percentile values for the U.S. population are not available for every PFAS measured in Michigan firefighters.

Geometric Means

When detection frequencies and 95th percentiles are viewed in combination with the average blood PFAS concentrations among Michigan firefighters, a more complete picture of PFAS exposure is observed. An examination of geometric mean blood PFAS concentrations among Michigan firefighters show how average concentrations among this population compare to the U.S. population.

A geometric mean or “average” is a special type of average commonly used in epidemiological research (hereafter referred to as geometric mean or average). It can be used to compare the average blood concentrations in one group (e.g., PFOMS participants representing Michigan firefighters) to another group (e.g., NHANES participants, representing the U.S. population). Using a geometric mean rather than the more commonly known arithmetic mean helps to reduce the extreme effect of outliers and gives a more representative description of the average blood PFAS concentrations among participants when there are extreme values.

Estimates for the average blood concentrations were calculated for 13 PFAS that were detected in more than 60% of Michigan firefighters, including the branched, linear and total summations for PFOA, PFOS and PFHxS, as applicable (**Table 2**). PFOS had the highest average concentration among all measured PFAS. On average, Michigan firefighters had slightly higher amounts of PFOS [4.85 µg/L (95% CI 4.39-5.36)] in their blood compared to the U.S. population [4.50 µg/L (95% CI 4.15-4.89)], however, the difference was not significant. The higher average amount of PFOS in Michigan firefighters was primarily due to the significantly higher average amount of the branched isomer of PFOS [1.73 µg/L (95% CI 1.46-2.05)] compared to the U.S. population [1.31 µg/L (95% CI 1.18-1.44)]. The average blood concentrations for most PFAS were lower among Michigan firefighters compared to the U.S. population (**Table 2**). The largest differences were seen with PFOA [PFOMS: 0.87 µg/L (95% CI 0.82-0.92) vs NHANES: 1.45 µg/L (95% CI 1.35-1.56)] and its linear isomer [PFOMS: 0.85 µg/L (95% CI 0.80-0.90) vs NHANES: 1.36 µg/L (95% CI 1.26-1.46)], PFHpS [PFOMS: 0.17 µg/L (95% CI 0.15-0.18) vs NHANES: 0.23 µg/L (95% CI 0.20-0.28)], PFDA [PFOMS: 0.11 µg/L (95% CI 0.10-0.12) vs NHANES: 0.20 µg/L (95% CI 0.18-0.22)], PFUnA [PFOMS: 0.05 µg/L (95% CI 0.05-0.06) vs NHANES 0.13 µg/L (95% CI 0.12-0.14)] and MeFOSAA [PFOMS: 0.06 µg/L (95% CI 0.05-0.06) vs NHANES: 0.13 µg/L (95% CI 0.12-0.14)], where Michigan firefighters had significantly lower values than the U.S. population. For other analytes like PFHxS, PFNA and linear isomers of PFOS the geometric mean among all Michigan firefighters were similar to the U.S. population. For still others, like PFeCHS, and linear isomers of PFHxS a value for the U.S. population was not available for comparison.

Table 2. Prevalence estimates, geometric means and 95th percentiles of PFAS blood concentrations for Michigan firefighters (PFOMS) and U.S. population (NHANES).

 Represents significantly **lower** findings compared to the other group.

 Represents significantly **higher** findings compared to the other group.

Analyte	PFOMS Prevalence Estimate (%) and 95% Confidence Interval	PFOMS Geometric Mean and 95% Confidence Interval (µg/L)	NHANES Geometric Mean and 95% Confidence Interval (µg/L) ^a	PFOMS 95th Percentile and 95% Confidence Interval (µg/L)	NHANES 95th Percentile and 95% Confidence Interval (µg/L) ^a	Percentage of PFOMS Participants above NHANES 95th Percentile
PFOS	100 (99.0-100)	4.85 (4.39-5.36)	4.50 (4.15-4.89)	13.98 (12.05-15.92)	15.10 (13.50-17.00)	5.7
L-PFOS ^b	100 (99.0-100)	2.84 (2.60-3.10)	3.11 (2.86-3.38)	8.40 (6.62-10.18)	11.00 (9.50-12.40)	3.9
Br-PFOS ^b	100 (99.0-100)	1.73 (1.46-2.05)	1.31 (1.18-1.44)	6.52 (5.41-7.62)	4.60 (4.10-5.60)	15.1
PFOA	100 (99.0-100)	0.87 (0.82-0.92)	1.45 (1.35-1.56)	1.90 (1.71-2.09)	3.87 (3.27-5.17)	0.2
L-PFOA ^b	100 (99.0-100)	0.85 (0.80-0.90)	1.36 (1.26-1.46)	1.87 (1.69-2.04)	3.80 (3.20-5.10)	0.3
Br-PFOA ^b	14.5 (12.4-16.8)	NC	NC	0.16 (0.09-0.23)	0.20 (<LOD-0.20)	2.8
PFHxS	99.3 (98.4-99.7)	1.02 (0.93-1.11)	1.11 (1.03-1.21)	3.47 (3.06-3.88)	3.80 (3.30-5.90)	5.7
L-PFHxS ^b	99.3 (98.4-99.7)	1.02 (0.93-1.11)	NA	3.47 (3.06-3.88)	NA	NA
Br-PFHxS ^b	3.7 (2.7-5.1)	NC	NA	0.003 (0.003-0.004)	NA	NA
PFNA	99.8 (99.2-100)	0.35 (0.32-0.38)	0.42 (0.37-0.47)	1.03 (0.79-1.28)	1.40 (1.10-2.00)	2.2
PFHpS	97.9 (96.8-98.7)	0.17 (0.15-0.18)	0.23 (0.20-0.28)	0.43 (0.38-0.48)	1.00 (0.50-4.10)	0.8
PFDA	97.0 (95.8-97.9)	0.11 (0.10-0.12)	0.20 (0.18-0.22)	0.35 (0.27-0.44)	0.60 (0.50-0.90)	1.5
PFUnA	80.3 (77.7-82.6)	0.05 (0.05-0.06)	0.13 (0.12-0.14)	0.19 (0.12-0.25)	0.40 (0.30-0.60)	0.7
PFecHS	73.4 (70.6-76.1)	0.04 (0.03-0.04)	NA	0.15 (0.08-0.22)	NA	NA
MeFOSAA	81.2 (78.6-83.5)	0.06 (0.05-0.06)	0.13 (0.12-0.14)	0.43 (0.32-0.54)	0.60 (0.50-0.80)	2.5
PFHpA	54.4 (51.3-57.4)	NC	NC	0.09 (0.07-0.10)	0.10 (0.10-0.20)	3.2
PFPeS	30.6 (27.9-33.5)	NC	NA	0.04 (0.04-0.04)	NA	NA
PFBA	34.4 (31.6-37.4)	NC	NA	0.11 (0.06-0.15)	NA	NA
PFTriA	9.5 (7.8-11.5)	NC	NA	0.03 (0.03-0.04)	NA	NA
PFBS	11.4 (9.6-13.5)	NC	NC	0.04 (0.03-0.05)	<LOD	NC
PFDoA	10.6 (8.8-12.7)	NC	NC	0.04 (0.03-0.05)	<LOD	NC
9CI-PF3ONS	5.8 (4.5-7.4)	NC	NC	0.03 (0.02-0.04)	0.10 (0.10-0.20)	0.0

Analyte	PFOMS Prevalence Estimate (%) and 95% Confidence Interval	PFOMS Geometric Mean and 95% Confidence Interval (µg/L)	NHANES Geometric Mean and 95% Confidence Interval (µg/L) ^a	PFOMS 95th Percentile and 95% Confidence Interval (µg/L)	NHANES 95th Percentile and 95% Confidence Interval (µg/L) ^a	Percentage of PFOMS Participants above NHANES 95th Percentile
PFDS	6.3 (4.9-8.0)	NC	NA	0.03 (0.01-0.04)	NA	NA
EtFOSAA	6.8 (5.4-8.5)	NC	NC	0.03 (0.02-0.04)	0.11 (<LOD-0.15)	0.7
5:3 FTCA	5.5 (4.2-7.1)	NC	NA	0.03 (0.02-0.03)	NA	NA
7:3 FTCA	2.6 (1.7-4.0)	NC	NA	0.02 (0.02-0.02)	NA	NA
8:2FTS	4.0 (2.9-5.3)	NC	NA	0.02 (0.02-0.02)	NA	NA
NFDHA	3.0 (2.0-4.2)	NC	NA	0.02 (0.02-0.02)	NA	NA
PFTeA	0.7 (0.3-1.5)	NC	NA	0.02 (0.01-0.02)	NA	NA
PFEESA	1.0 (0.5-2.0)	NC	NA	0.02 (0.02-0.02)	NA	NA
PFHxA	1.2 (0.6-2.1)	NC	NC	0.01 (0.01-0.02)	<LOD	NC
PFOSA	1 (0.5-1.9)	NC	NC	0.02 (0.02-0.02)	<LOD	NC
PFMBA	<0.6	NC	NA	0.01 (0.01-0.02)	NA	NA
PFPrS	<0.6	NC	NA	0.01 (0.01-0.02)	NA	NA
6:2FTS	<0.6	NC	NA	0.02 (0.02-0.02)	NA	NA
PFNS	<0.6	NC	NA	0.02 (0.02-0.02)	NA	NA
ADONA	<0.6	NC	NC	0.01 (0.01-0.02)	<LOD	NC
PFHxSA	<0.6	NC	NA	0.01 (0.01-0.02)	NA	NA
4:2FTS	<0.6	NC	NA	0.02 (0.02-0.02)	NA	NA
PFBSA	<0.6	NC	NA	0.01 (0.01-0.02)	NA	NA
PFMPA	<0.6	NC	NA	0.01 (0.01-0.02)	NA	NA
11Cl-PF3OUdS	0.0	NC	NA	NC	NA	NA
3:3 FTCA	0.0	NC	NA	NC	NA	NA
HFPO-DA	0.0	NC	NC	NC	<LOD	NC
PFPeA	0.0	NC	NA	NC	NA	NA

Abbreviations: n, number; NC, Not calculated because the analyte was detected in fewer than 60% of participants; NA, Not available from NHANES; µg/L, microgram per liter; <LOD, Less than the limit of detection and is noted for every PFAS in Table S1 in Appendix A; <LOQ, Less than the limit of quantification and is noted for every PFAS in Table S1 in Appendix A.

^aCenters for Disease Control and Prevention, U.S. Department of Health and Human Services. National Report on Human Exposure to Environmental Chemicals. Updated March 2022. <https://www.cdc.gov/exposurereport/>. Accessed July 6, 2023. NHANES geometric means are included for reference for chemicals detected in more than 60% of participants.

^bAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

Bold values represent findings that are significantly different compared to the other group.

Sampling strata

Average blood PFAS concentrations were highest in stratum 2 non-urban airport for most PFAS except for MeFOSAA, which was highest in stratum 4 other non-urban [0.07 µg/L (95% CI 0.06-0.08)], and PFeCHS [0.07 µg/L (95% CI 0.07-0.08)] and PFUnA [0.08 µg/L (95% CI 0.07-0.09)], which were highest in stratum 3 City of Detroit (**Figure 1; Figure 2; Table S3 in Appendix A**). However, most of these differences in average concentrations between these strata were not statistically significant. Concentrations of certain PFAS, such as PFDA, PFeCHS, PFHpS, PFNA, PFHxS, PFOA and linear isomers of PFOA, PFOS and PFHxS, were higher within City of Detroit participants in comparison to stratum 4 and 5 i.e., other non-urban and other urban respectively. Significant differences in these were seen with concentrations of PFeCHS, PFNA, PFUnA, PFHpS and the linear isomer of PFOS. Within stratum 4 and 5 i.e., other non-urban and other urban respectively, concentrations of PFOS, PFOA, PFHxS, PFDA, PFUnA, PFDA, PFNA and PFHpS were lower than stratum 1 urban airport and stratum 2 non-urban airport, with concentrations being significantly lower for PFOS. Average concentrations were also generated for PFHpA (for stratum 2 non-urban airport and stratum 3 City of Detroit) and PFPeS (stratum 3 City of Detroit only) as they were found in more than 60% of participants within these strata. The differences in average concentration for PFHpA between stratum 2 non-urban airport [0.04 µg/L (95% CI 0.03-0.05)] and stratum 3 City of Detroit [0.04 µg/L (95% CI 0.03-0.04)] were not significant.

Compared to the U.S. population, both stratum 1 urban airport and stratum 2 non-urban airport firefighters have significantly higher average concentrations of PFOS and the branched isomer of PFOS (**Figure 1**). Other PFAS such as PFUnA and MeFOSAA were significantly lower in these groups and in stratum 4 other non-urban, stratum 5 other urban and stratum 3 City of Detroit compared to the U.S. population. For most of the other PFAS, where a comparable value was available for the U.S. population, PFOMS participants in all strata had similar or lower average concentrations compared to the U.S. population.

Figure 1: Geometric means with 95% confidence intervals for a select set of PFAS (where detection frequency >60%) in the blood of eligible PFOMS participants by sampling strata.

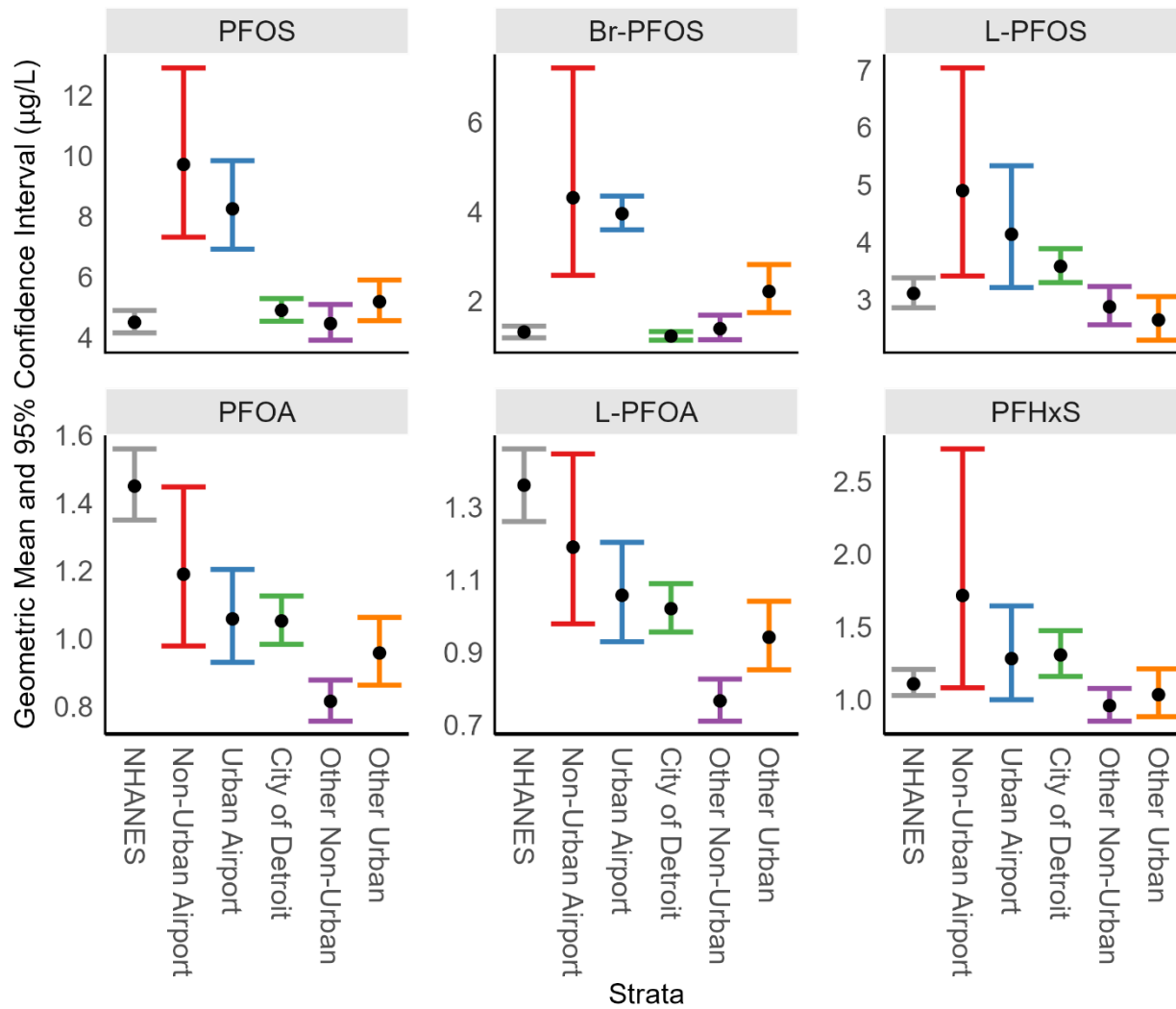


Figure 1 continued: Geometric means with 95% confidence intervals for a select set of PFAS (where detection frequency >60%) in the blood of eligible PFOMS participants by sampling strata.

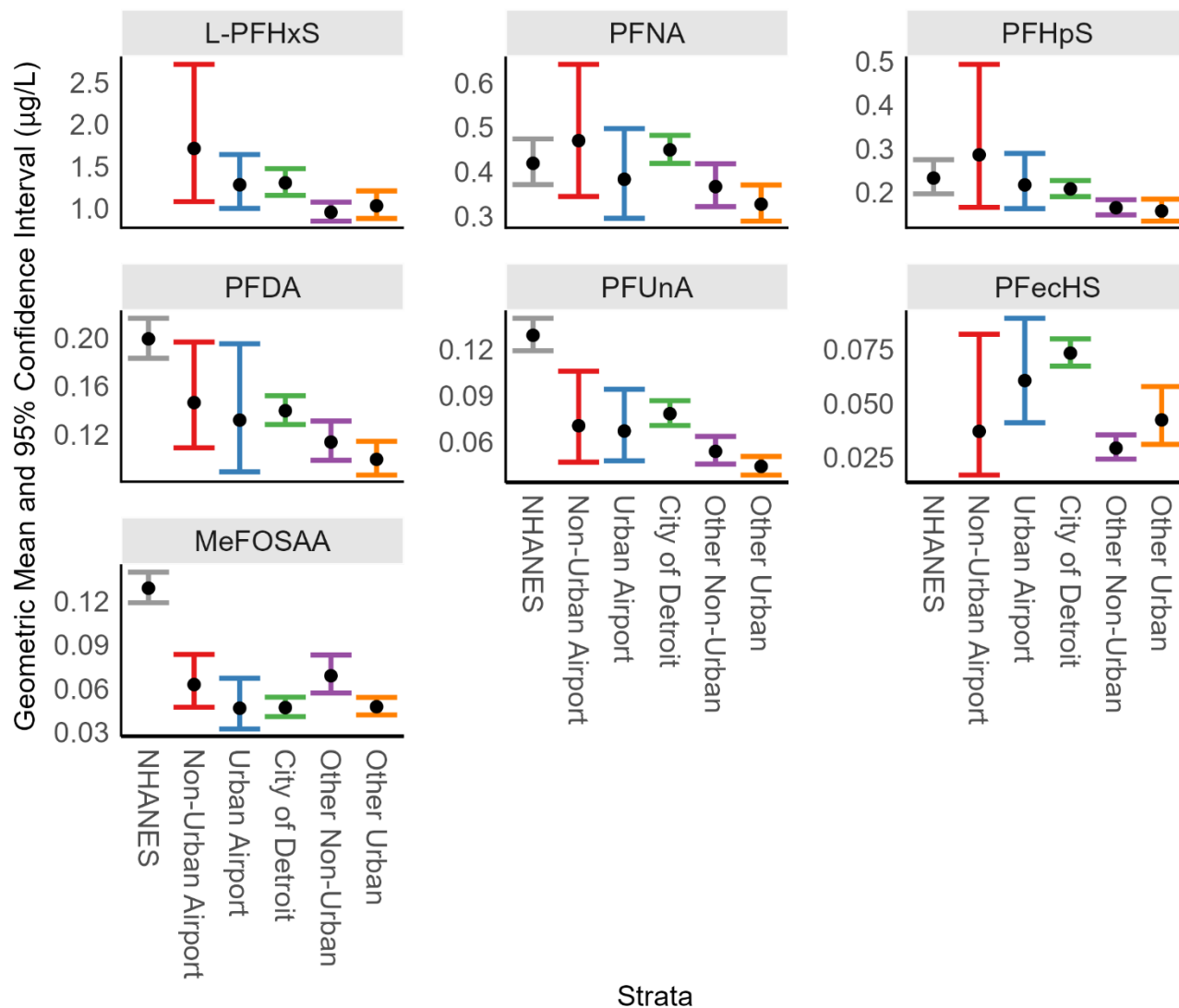


Figure 2. PFAS concentration distributions and geometric means for each PFOMS strata, for chemicals that were detected in the blood of greater than 60% of PFOMS participants. *Figure notes:* The height of each graph represents the number of people who had the concentration of PFAS listed on the x-axis detected in their blood. The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their blood and the low areas indicate that relatively fewer people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations. The red lines, which are equal in height, mark the geometric mean blood PFAS concentrations for PFOMS participants.

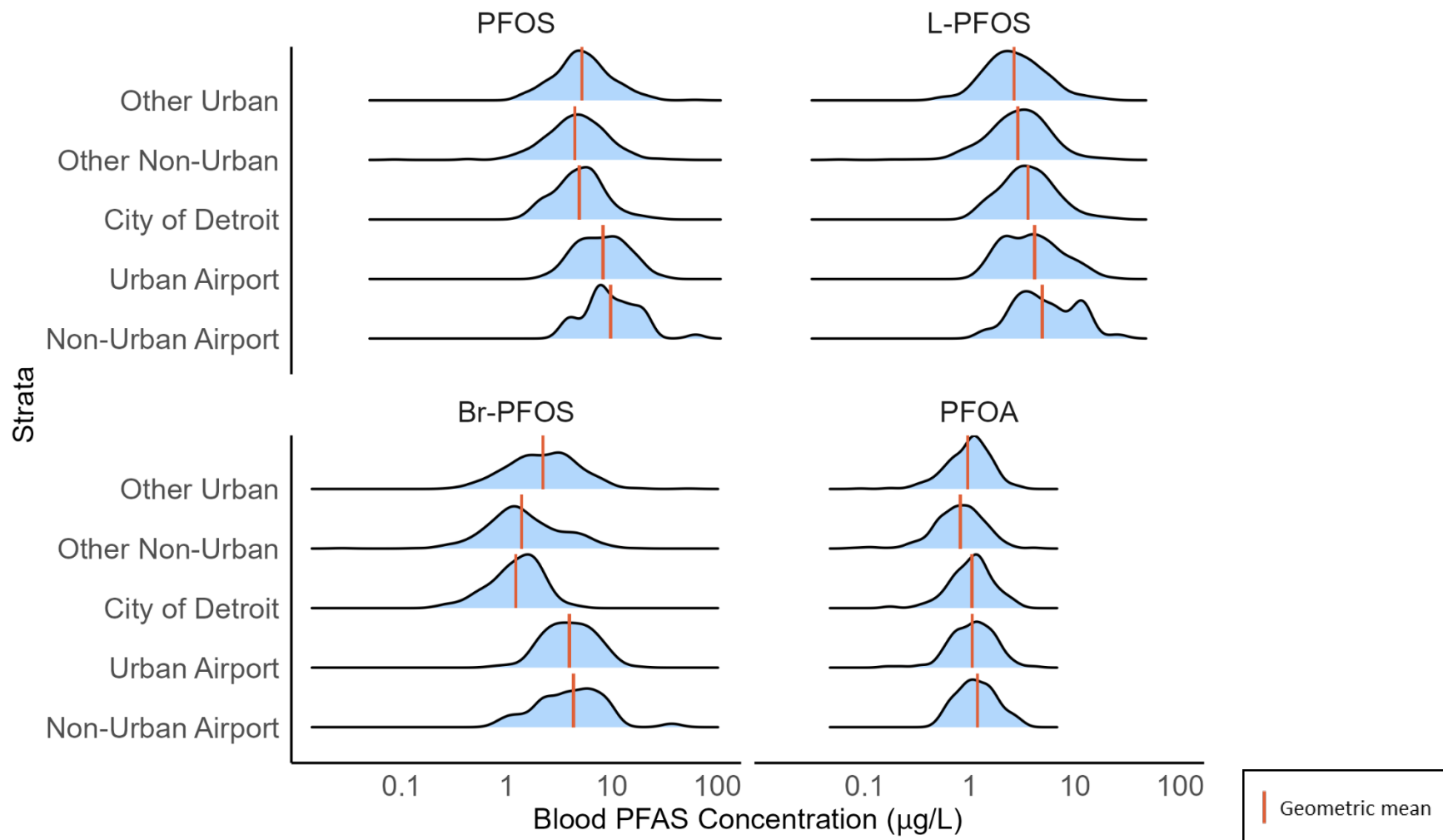


Figure 2 continued. PFAS concentration distributions and geometric means for each PFOMS strata, for chemicals detected in the blood of greater than 60% of PFOMS participants. *Figure notes:* The height of each graph represents the number of people who had the concentration of PFAS listed on the x-axis detected in their blood. The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their blood and the low areas indicate that relatively fewer people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations. The red lines, which are equal in height, mark the geometric mean blood PFAS concentrations for PFOMS participants.

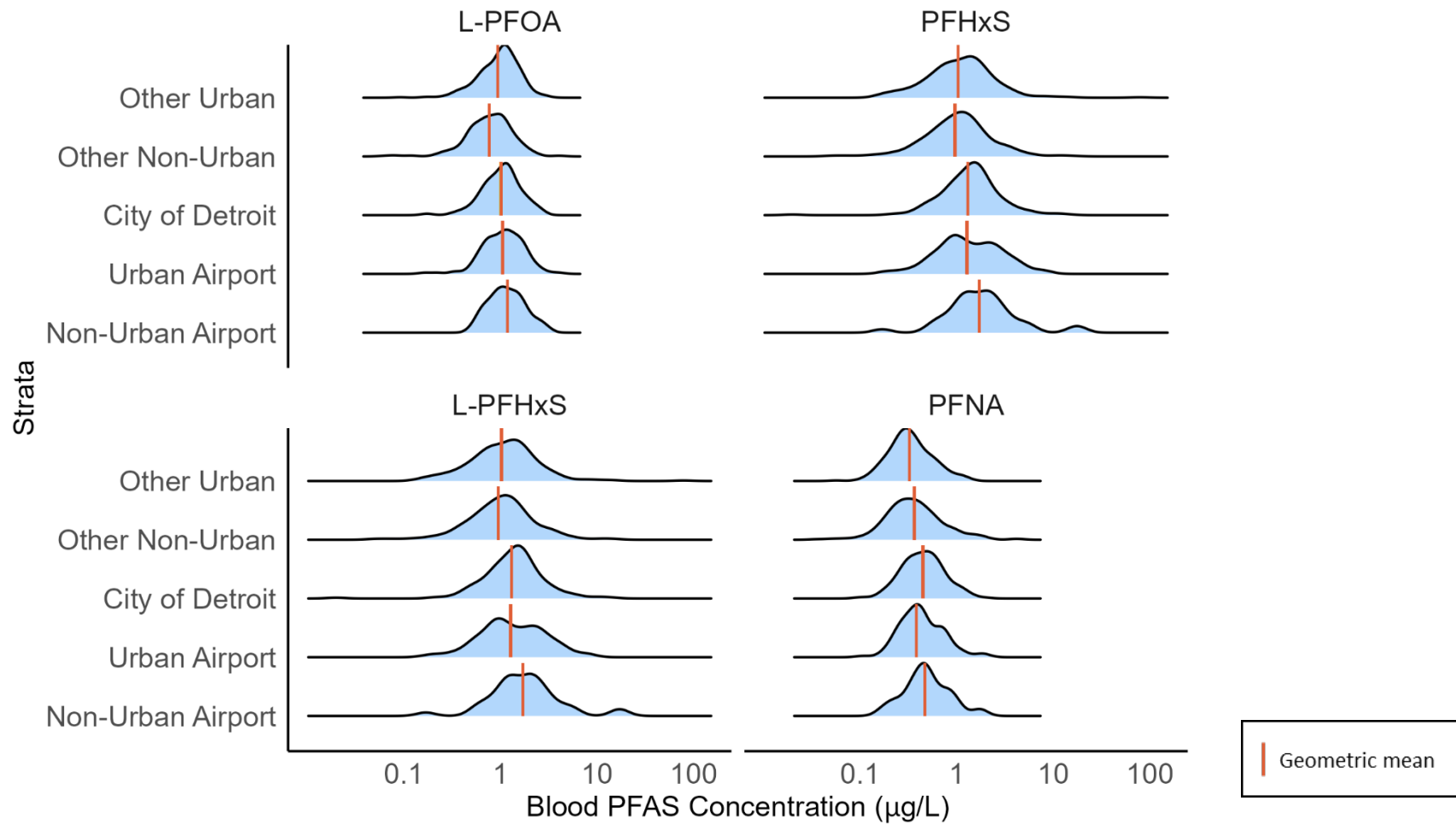
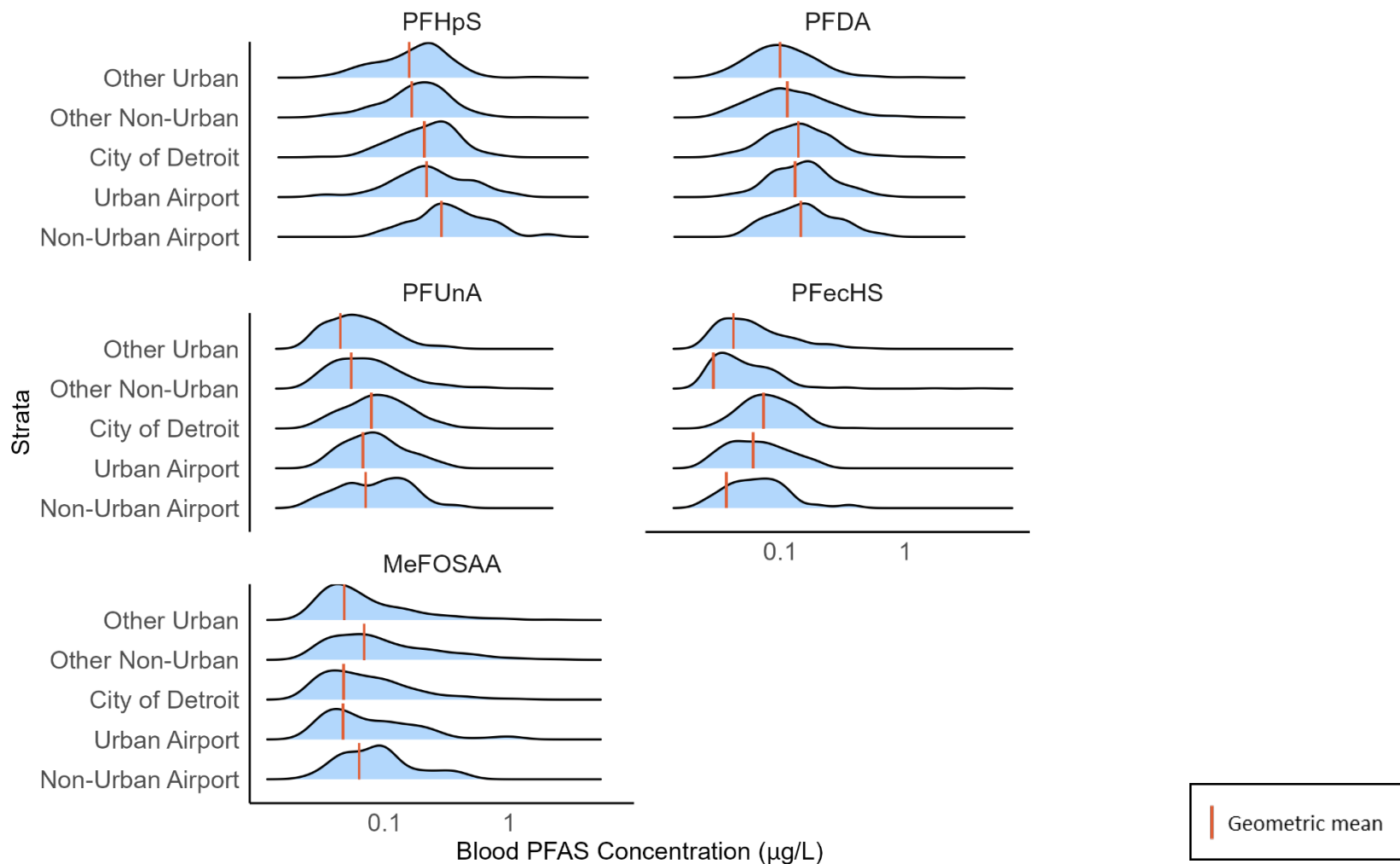


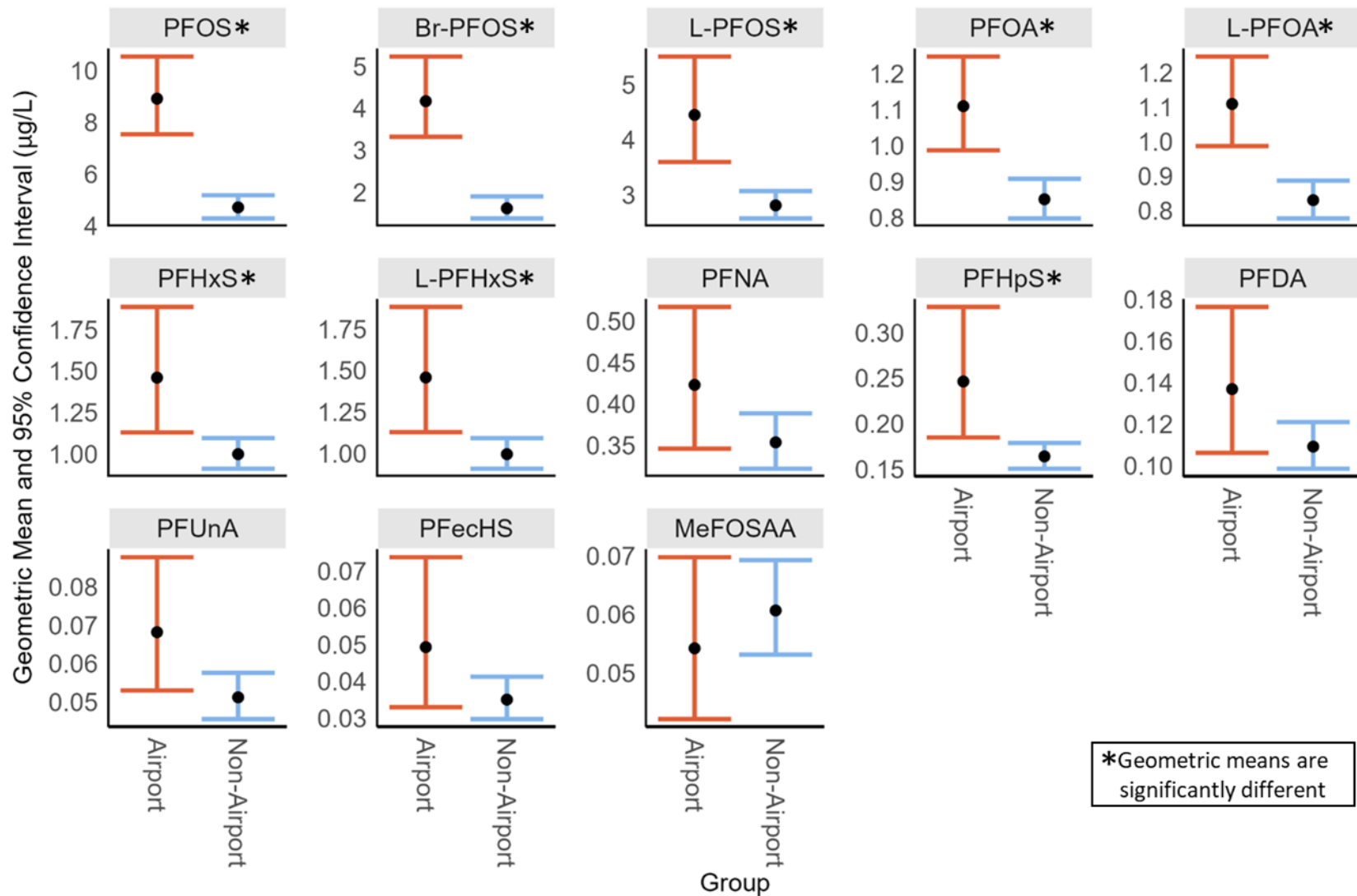
Figure 2 continued. PFAS concentration distributions and geometric means for each PFOMS strata, for chemicals that were detected in the blood of greater than 60% of PFOMS participants. *Figure notes:* The height of each graph represents the number of people who had the concentration of PFAS listed on the x-axis detected in their blood. The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their blood and the low areas indicate that relatively fewer people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations. The red lines, which are equal in height, mark the geometric mean blood PFAS concentrations for PFOMS participants.



Airport vs non-airport firefighters

Airport firefighters (n=166) had higher average concentrations of most PFAS compared to their non-airport counterparts (n=857) (**Figure 3; Table S4 in Appendix A**). Significantly higher average concentrations were seen with PFOS [airport: 8.91 µg/L (95% CI 7.53-10.53) vs non-airport: 4.70 µg/L (95% CI 4.28-5.17)], PFOA [airport: 1.11 µg/L (95% CI 0.99-1.25) vs non-airport: 0.85 µg/L (95% CI 0.80-0.91)], PFHxS [airport: 1.46 µg/L (95% CI 1.13-1.89) vs non-airport: 1.00 µg/L (95% CI 0.91-1.10)], PFHpS [airport: 0.25 µg/L (95% CI 0.19-0.33) vs non-airport: 0.16 µg/L (95% CI 0.15-0.18)], linear isomer of PFOS [airport: 4.45 µg/L (95% CI 3.60-5.52) vs non-airport: 2.81 µg/L (95% CI 2.57-3.07)], linear isomer of PFOA [airport: 1.11 µg/L (95% CI 0.99-1.25) vs non-airport: 0.83 µg/L (95% CI 0.78-0.89)], linear isomer of PFHxS [airport: 1.46 µg/L (95% CI 1.13-1.88) vs non-airport: 1.00 µg/L (95% CI 0.91-1.09)] and branched isomer of PFOS [airport: 4.17 µg/L (95% CI 3.33-5.23) vs non-airport: 1.62 µg/L (95% CI 1.38-1.91)]. PFAS such as PFNA, PFDA, PFUnA, PFeCHS and MeFOSAA showed similar average concentrations among airport and non-airport firefighters.

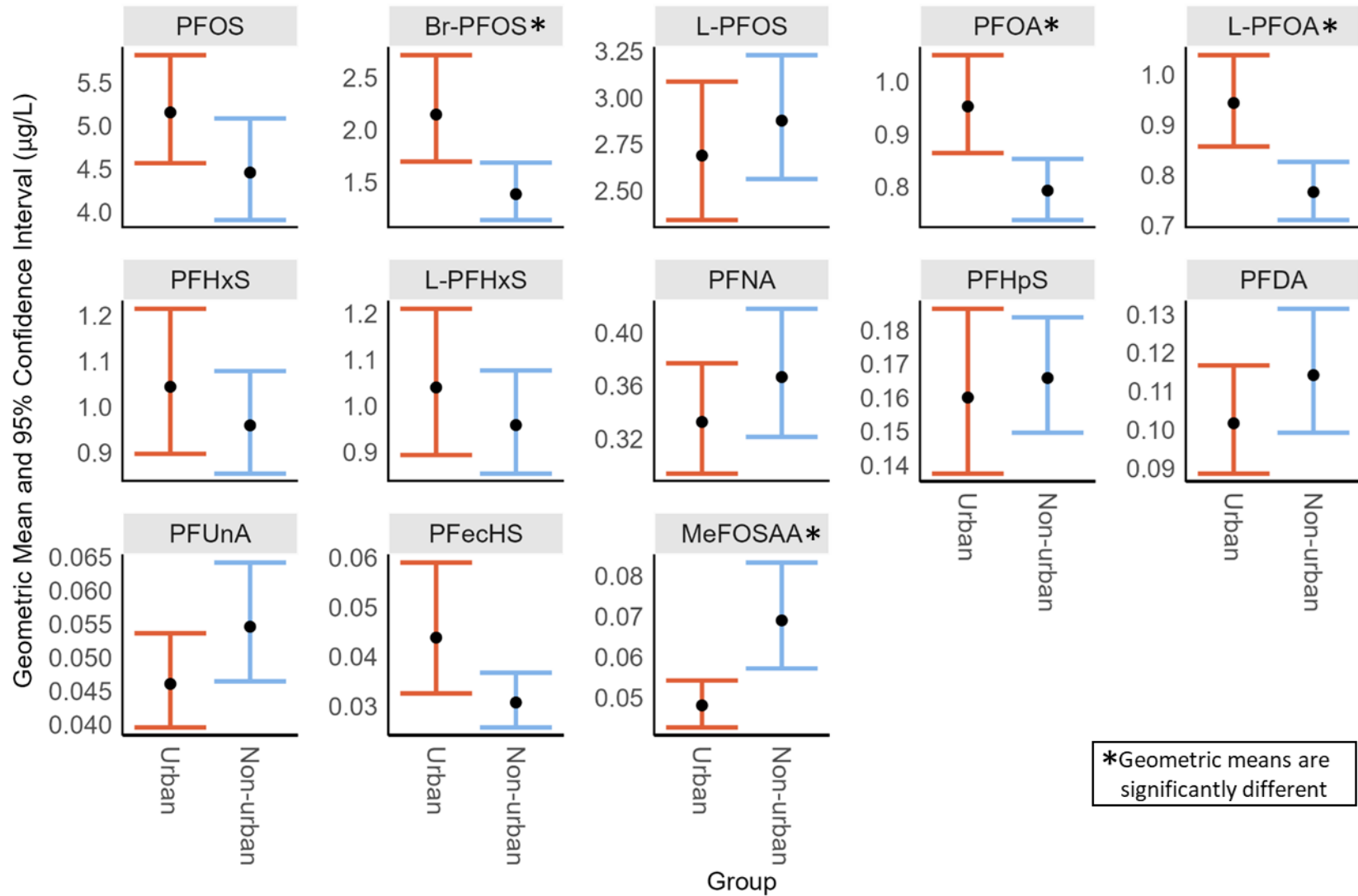
Figure 3: Geometric means with 95% confidence intervals for a select set of PFAS (where detection frequency >60%) in the blood of eligible PFOMS participants for airport (n=166) vs non-airport firefighters (n=857).



Urban vs non-urban firefighters

Excluding airport-based participants, we compared firefighters from urban (Detroit and other urban fire departments, n=501) and non-urban (other non-urban fire departments, n=356) fire departments which revealed mixed findings (**Figure 4; Table S4 in Appendix A**). Urban firefighters exhibited higher average concentrations of specific PFAS, including PFOA, PFOS, PFHxS, PFecHS, linear isomers of PFOA and PFHxS and the branched isomer of PFOS. However, only PFOA [urban: 0.95 µg/L (95% CI 0.86-1.05), non-urban: 0.79 µg/L (95% CI 0.74-0.85)], linear isomer of PFOA [urban: 0.94 µg/L (95% CI 0.86-1.04), non-urban: 0.77 µg/L (95% CI 0.71-0.83)] and the branched isomer of PFOS [urban: 2.14 µg/L (95% CI 1.70-2.71), non-urban: 1.38 µg/L (95% CI 1.14-1.68)] showed a statistically significant difference. Non-urban firefighters had higher average concentrations of PFDA, PFHpS, PFNA, PFUnA and the linear isomer of PFOS, with significantly higher concentration of MeFOSAA [urban: 0.05 µg/L (95% CI 0.04-0.05), non-urban: 0.07 µg/L (95% CI 0.06-0.08)]. Average concentrations were also generated for PFHpA [0.02 µg/L (95% CI 0.017-0.026)] for urban strata as it was found in more than 60% of participants within this group. PFHpA was detected in less than 60% of participants from non-urban fire departments, so an average value was not calculated for comparison to the urban strata.

Figure 4: Geometric means with 95% confidence intervals for a select set of PFAS (where detection frequency >60%) in the blood of eligible PFOMS participants for urban non-airport (n=501) vs non-urban non-airport (n=356) firefighters.



PFAS-containing Class B foam exposure

Firefighters from fire departments that responded “yes” to using or storing PFAS-containing foam currently or in the past were grouped in the “PFAS-containing foam exposure at fire department” category (n=867) and others were grouped in “No PFAS-containing foam exposure at fire department” (n=113) (**Table 3**). Firefighters from fire departments who did not respond to the PFAS-containing foam survey were excluded from this analysis. The concentration of PFAS such as PFHxS [1.05 µg/L (95% CI 0.93-1.17) vs 0.94 µg/L (95% CI 0.81-1.09)], commonly found in PFAS-containing foams, was higher in firefighters in the PFAS-containing foam exposure category, as expected, although none of these differences were statistically significant. Lower concentrations in this category were seen with MeFOSAA, PFDA, PFNA and PFUnA were other analytes with lower concentrations. Unexpectedly, the average concentration of PFOS was lower in the PFAS-containing foam exposure category, however, it is noteworthy that the confidence intervals in the no PFAS-containing foam category were wider, indicating a less precise estimate of the average.

Table 3: Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (with detection frequency >60%) in blood of eligible PFOMS participants by PFAS-containing foam used or stored at the fire department (FD).

PFAS-containing Foam Used or Stored at FD (n= 980)	PFAS-containing Foam at FD ^a (n=867)		No PFAS-containing Foam at FD ^a (n=113)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	4.80 (4.35-5.30)	100	4.87 (3.78-6.27)
Br-PFOS	100	1.81 (1.52-2.16)	100	1.55 (1.08-2.24)
L-PFOS	100	2.79 (2.55-3.06)	100	3.06 (2.38-3.94)
PFOA	100	0.88 (0.81-0.95)	100	0.82 (0.72-0.95)
L-PFOA	100	0.86 (0.79-0.93)	100	0.80 (0.70-0.91)
PFHxS	99.4	1.05 (0.93-1.17)	99.1	0.94 (0.81-1.09)
L-PFHxS	99.4	1.04 (0.93-1.17)	99.1	0.94 (0.81-1.09)
PFNA	98.8	0.35 (0.31-0.38)	100	0.40 (0.32-0.51)
PFHpS	98.3	0.17 (0.15-0.19)	98.2	0.17 (0.14-0.20)
PFDA	95.7	0.11 (0.10-0.12)	97.3	0.13 (0.10-0.17)
PFUnA	81.5	0.05 (0.04-0.06)	85.0	0.06 (0.05-0.09)
PFecHS	83.0	0.04 (0.03-0.04)	73.5	0.04 (0.03-0.05)
MeFOSAA	77.3	0.05 (0.05-0.06)	83.2	0.08 (0.05-0.13)

Abbreviations: n, number; GM, geometric means; FD, Fire Department; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter

^aFirefighters belonging to fire departments who completed the Class B foam survey were categorized into Class B foam exposure categories based on responses of the survey. Firefighters from fire departments who did not respond to the Class B foam survey were excluded from the analysis.

PFAS by demographics

Age

Analyzing participants by age groups (18-39 [n=375], 40-59 [n=545], 60+ [n=103]), higher average concentrations of most PFAS in the oldest group (60+) were observed (**Table 4**). This trend held true for PFOS, PFDA, PFNA, PFUnA, PFHpS, MeFOSAA and the linear isomer of PFOS. Notably, MeFOSAA [60+ years: 0.11 µg/L (95% CI 0.08-0.14) vs 18-39 years: 0.05 µg/L (95% CI 0.04-0.05)], PFDA [60+ years: 0.14 µg/L (95% CI 0.111-0.17) vs 18-39 years: 0.10 µg/L (95% CI 0.09-0.110)], PFUnA [60+ years: 0.07 µg/L (95% CI 0.054-0.09) vs 18-39 years: 0.04 µg/L (95% CI 0.04-0.051)] and PFHpS [60+ years: 0.21 µg/L (95% CI 0.17-0.25) vs 18-39 years: 0.12 µg/L (95% CI 0.11-0.14)] average concentrations in the 60+ age group were significantly higher compared to the 18-39-year-olds. In addition, PFOS [40-59 years: 5.09 µg/L (95% CI 4.61-5.63) vs 18-39 years: 4.11 µg/L (95% CI 3.72-4.54) and the branched isomer of PFOS [40-59 years: 1.95 µg/L (95% CI 1.66-2.28) vs 18-39 years: 1.40 µg/L (95% CI 1.19-1.65)] average concentrations in the 40-59 age group were significantly higher compared to the 18-39-year-olds. The average concentrations for PFecHS, PFHxS, PFOA and the linear isomers of PFHxS and PFOA were similar across the age groups. Average concentrations were also generated for PFHpA for ages 40-59 [0.03 µg/L (95% CI 0.02-0.03)] and 60+ [0.03 µg/L (95% CI 0.02-0.03) µg/L] as it was found in more than 60% of participants within these groups.

Sex

Male firefighters (n=938) exhibited higher average concentrations of nearly all measured PFAS compared to their female counterparts (n=74), except for MeFOSAA (**Table 4**). Statistically significant differences were observed in PFOA, PFOS, PFHxS, PFecHS, PFHpS, the branched isomer of PFOS and the linear isomers of PFOA and PFHxS. While female firefighters had a higher average concentration of MeFOSAA [females: 0.07 µg/L (95% CI 0.05-0.10) vs males: 0.06 µg/L (95% CI 0.05-0.07)], this difference was not statistically significant. It is important to note that this analysis was constrained by the small sample size of females, resulting in wider confidence intervals (e.g., PFOA (95% CI 0.57-0.81 µg/L), PFHxS (95% CI 0.31-0.61 µg/L), MeFOSAA (95% CI 0.05-0.10 µg/L)).

Table 4: Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in the blood of eligible PFOMS participants by age and sex.

- Represents significantly **lower** findings compared to 1 or more other groups.
- Represents significantly **higher** findings compared to 1 or more other groups.

Subgroup	Age Categories (n=1,023)						Sex (n=1,012)			
	18-39 years (n=375)		40-59 years (n=545)		60+ years (n=103)		Male (n=938)		Female (n=74)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	4.11 (3.72-4.54)	100	5.09 (4.61-5.63)	100	5.51 (4.18-7.27)	100	4.99 (4.53-5.51)	100	3.53 (3.07-4.06)
Br-PFOS	100	1.40 (1.19-1.65)	100	1.95 (1.66-2.28)	100	1.81 (1.31-2.49)	100	1.86 (1.58-2.18)	100	1.02 (0.83-1.26)
L-PFOS	100	2.47 (2.25-2.72)	100	2.91 (2.65-3.19)	100	3.39 (2.58-4.46)	100	2.91 (2.66-3.18)	100	2.3 (1.94-2.73)
PFOA	100	0.80 (0.74-0.88)	100	0.89 (0.82-0.96)	100	0.86 (0.74-1.01)	100	0.88 (0.83-0.94)	100	0.68 (0.57-0.81)
L-PFOA	100	0.78 (0.71-0.85)	100	0.87 (0.80-0.95)	100	0.83 (0.70-0.99)	100	0.86 (0.80-0.92)	100	0.66 (0.55-0.79)
PFHxS	98.8	0.93 (0.80-1.07)	99.8	1.10 (1.00-1.21)	99.2	0.88 (0.66-1.17)	99.9	1.08 (0.99-1.18)	99.9	0.44 (0.31-0.61)
L-PFHxS	98.8	0.92 (0.80-1.07)	99.8	1.10 (1.00-1.21)	99.2	0.88 (0.67-1.16)	93.2	1.08 (0.99-1.18)	93.2	0.43 (0.31-0.60)
PFNA	98.8	0.31 (0.28-0.35)	98.8	0.35 (0.32-0.38)	100	0.44 (0.36-0.54)	99.3	0.36 (0.33-0.40)	95.9	0.28 (0.24-0.33)
PFHpS	96.8	0.12 (0.11-0.14)	98.7	0.19 (0.18-0.21)	99.2	0.21 (0.17-0.25)	99.1	0.18 (0.17-0.20)	85.1	0.08 (0.06-0.10)
PFDA	95.7	0.10 (0.09-0.110)	96.3	0.11 (0.10-0.12)	95.4	0.14 (0.111-0.17)	96.1	0.11 (0.10-0.12)	94.6	0.09 (0.08-0.11)
PFUnA	76.4	0.04 (0.04-0.051)	84.2	0.05 (0.05-0.06)	84.7	0.07 (0.054-0.09)	82.4	0.05 (0.05-0.06)	74.3	0.05 (0.04-0.06)
PFecHS	76.7	0.03 (0.03-0.04)	83.7	0.04 (0.03-0.04)	79.8	0.04 (0.03-0.05)	82.0	0.04 (0.03-0.04)	58.1	0.02 (0.02-0.03)
MeFOSAA	74.4	0.05 (0.04-0.05)	79.8	0.06 (0.05-0.07)	82.4	0.11 (0.08-0.14)	78.6	0.06 (0.05-0.07)	74.3	0.07 (0.05-0.10)
PFHpA ^b	NC	NC	62.2	0.03 (0.02-0.03)	61.1	0.03 (0.02-0.03)	NC	NC	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter.

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^bValues for PFHpA were calculated for only those categories within sub-groups where detection was above 60%.

Bold values represent findings that are significantly different compared to one or more other groups. An additional decimal place is shown for some CIs to better show significant differences to the other group.

Race and Ethnicity

Firefighters belonging to non-white single-race groups (BIPOC (Black, Asian, AI/AN, NH/PI*) alone) (n=76) showed higher average concentrations for most PFAS reported except for PFHpS, PFDA and MeFOSAA (**Table 5**). Average concentration for PFecHS 0.05 µg/L (95% CI 0.04-0.07) in non-white single-race was higher than white 0.04 µg/L (95% CI 0.03-0.04) and two or more races 0.03 µg/L (95% CI 0.01-0.04). The differences were not statistically significant. Average concentrations were also generated for PFHpA for non-white single-race groups (BIPOC [Black, Asian, AI/AN, NH/PI*] alone) [0.02 µg/L (95% CI 0.01-0.03)], and two or more races [0.02 µg/L (95% CI 0.01-0.04)] as it was found in more than 60% of participants within these groups. Examination of ethnicity revealed that the Hispanic group (n=36) exhibited the highest average concentrations for six PFAS compared to the non-Hispanic group (n=956). However, none of the observed differences reached statistical significance. Like sex, this analysis was also constrained by small sample size within the Hispanic group, resulting in wider confidence intervals.

* AI/AN: American Indian/Alaskan Native; NH/PI: Native Hawaiian/Pacific Islander

Table 5: Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in the blood of eligible PFOMS participants by race and ethnicity.

Subgroup	Race (n=984)						Ethnicity (n=992)			
	Black, Indigenous, or Person of Color (BIPOC)† Alone (n=76)		White Alone (n=885)		2 or more Races (n=23)		Hispanic, Latino, or Spanish Origin (n=36)		Not of Hispanic, Latino, or Spanish Origin (n=956)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	5.89 (3.88-8.96)	100	4.85 (4.42-5.31)	100	5.78 (3.85-8.70)	100	4.64 (3.66-5.87)	100	4.86 (4.42-5.34)
Br-PFOS^a	100	2.57 (1.52-4.35)	100	1.76 (1.51-2.06)	100	2.17 (1.27-3.69)	100	1.85 (1.39-2.47)	100	1.77 (1.51-2.07)
L-PFOS^a	100	3.12 (2.14-4.55)	100	2.85 (2.61-3.10)	100	3.39 (2.35-4.89)	100	2.59 (1.99-3.38)	100	2.86 (2.62-3.13)
PFOA	100	0.90 (0.71-1.13)	100	0.86 (0.80-0.91)	100	0.89 (0.64-1.23)	100	0.93 (0.77-1.12)	100	0.86 (0.80-0.91)
L-PFOA^a	100	0.87 (0.68-1.10)	100	0.84 (0.78-0.89)	100	0.88 (0.63-1.22)	100	0.89 (0.76-1.04)	100	0.84 (0.78-0.89)
PFHxS	98.7	1.13 (0.73-1.73)	99.4	1.00 (0.91-1.10)	100	1.05 (0.60-1.85)	100	1.11 (0.91-1.36)	99.4	1.00 (0.91-1.10)
L-PFHxS^a	98.7	1.13 (0.73-1.73)	99.4	1.00 (0.91-1.10)	100	1.05 (0.60-1.85)	100	1.11 (0.91-1.36)	99.4	0.99 (0.90-1.09)
PFNA	100	0.37 (0.27-0.50)	99.0	0.36 (0.33-0.39)	95.7	0.35 (0.23-0.54)	94.4	0.29 (0.24-0.35)	99.2	0.36 (0.33-0.39)
PFHpS	98.7	0.16 (0.12-0.23)	98.0	0.17 (0.15-0.18)	100	0.19 (0.13-0.28)	97.2	0.20 (0.17-0.23)	98.1	0.17 (0.15-0.18)
PFDA	97.4	0.11 (0.07-0.15)	95.9	0.11 (0.10-0.12)	87.0	0.11 (0.06-0.20)	91.7	0.09 (0.07-0.12)	96.0	0.11 (0.10-0.12)
PFUnA	89.5	0.07 (0.04-0.10)	80.9	0.05 (0.05-0.06)	78.3	0.06 (0.04-0.11)	75.0	0.03 (0.03-0.05)	81.9	0.05 (0.05-0.06)
PFecHS	94.7	0.05 (0.04-0.07)	79.3	0.04 (0.03-0.04)	60.9	0.03 (0.01-0.04)	80.6	0.04 (0.03-0.05)	80.3	0.04 (0.03-0.04)
MeFOSAA	73.7	0.03 (0.02-0.06)	79.1	0.06 (0.05-0.07)	60.9	0.04 (0.01-0.11)	80.6	0.05 (0.03-0.08)	78.3	0.06 (0.05-0.07)

Subgroup	Race (n=984)						Ethnicity (n=992)			
	Black, Indigenous, or Person of Color (BIPOC)† Alone (n=76)		White Alone (n=885)		2 or more Races (n=23)		Hispanic, Latino, or Spanish Origin (n=36)		Not of Hispanic, Latino, or Spanish Origin (n=956)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFHpA	78.9	0.02 (0.01-0.03)	NC	NC	60.9	0.02 (0.01-0.04)	NC	NC	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

†BIPOC includes Black, Asian, AI/AN (American Indian/Alaskan Native) or NH/PI (Native Hawaiian/Pacific Islander)

Values for PFHpA were calculated for only those groupings where detection was above 60%.

Education

Firefighters with at least some university, college, technical or trade school (n=393) had higher average concentrations of most PFAS compared with a high school graduate or equivalent (GED) or lower (n=173) (**Table 6**). An exception was observed with MeFOSAA, where the highest average concentrations were found among those with a high school diploma or equivalent (GED) or lower [0.07 µg/L (95% CI 0.06-0.08)] compared to firefighters with at least some university, college, technical or trade school [0.06 µg/L (95% CI 0.05-0.08)]. Furthermore, firefighters with graduate school or higher (n=47) demonstrated the highest concentrations across all PFAS. Nevertheless, it is crucial to note that these observed differences were not statistically significant for most PFAS except for PFOA [graduate school or higher: 1.01 µg/L (95% CI 0.88-1.16) vs high school graduate or equivalent (GED) or lower: 0.77 µg/L (95% CI 0.69-0.87)]. Average concentrations were generated for PFHpA for those with a high school diploma or equivalent (GED) or lower [0.02 µg/L (95% CI 0.02-0.03)] as it was found in more than 60% of participants within this group. For all other education groups, PFHpA was detected in less than 60% of participants, so no average values were calculated for comparison to the high school graduate or equivalent (GED) or lower group.

Table 6: Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in the blood of eligible PFOMS participants by level of education.

□ Represents significantly **lower** findings compared to 1 or more other groups.

□ Represents significantly **higher** findings compared to 1 or more other groups.

Level of Education (n=1,013)	High school graduate or equivalent (GED) or less (n=173)		Some university, college, technical or trade school (n=393)		Technical or trade school graduate (n=97)		University or college graduate (n=303)		Graduate school or higher (n=47)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	3.99 (3.42-4.65)	100	5.21 (4.64-5.84)	100	4.82 (4.13-5.62)	100	4.83 (4.35-5.35)	100	5.76 (4.32-7.67)
Br-PFOS	100	1.39 (1.15-1.69)	100	1.89 (1.60-2.23)	100	1.65 (1.32-2.05)	100	1.73 (1.45-2.06)	100	2.15 (1.52-3.02)
L-PFOS	100	2.39 (2.05-2.79)	100	3.05 (2.73-3.42)	100	2.95 (2.55-3.42)	100	2.82 (2.53-3.14)	100	3.27 (2.44-4.37)
PFOA	100	0.77 (0.69-0.87)	100	0.89 (0.82-0.97)	100	0.91 (0.78-1.07)	100	0.86 (0.78-0.95)	100	1.01 (0.88-1.16)
L-PFOA	100	0.75 (0.66-0.84)	100	0.87 (0.80-0.94)	100	0.89 (0.76-1.04)	100	0.84 (0.76-0.93)	100	1.00 (0.87-1.15)
PFHxS	98.8	0.83 (0.69-1.00)	99.2	1.00 (0.88-1.13)	100	1.00 (0.79-1.28)	99.7	1.10 (0.96-1.27)	100	1.14 (0.92-1.41)
L-PFHxS	98.8	0.83 (0.68-1.00)	99.2	1.00 (0.88-1.13)	100	1.00 (0.79-1.28)	99.7	1.10 (0.95-1.26)	100	1.14 (0.92-1.41)
PFNA	99.4	0.32 (0.28-0.37)	99.0	0.37 (0.33-0.41)	97.7	0.37 (0.32-0.43)	99.3	0.34 (0.30-0.38)	97.7	0.44 (0.33-0.59)
PFHpS	97.7	0.15 (0.13-0.17)	97.5	0.17 (0.15-0.19)	100	0.17 (0.14-0.20)	98.7	0.16 (0.14-0.19)	97.9	0.18 (0.15-0.22)
PFDA	97.1	0.10 (0.09-0.12)	96.2	0.11 (0.10-0.13)	90.7	0.11 (0.09-0.13)	96.7	0.11 (0.10-0.12)	95.7	0.13 (0.09-0.18)
PFUnA	76.9	0.05 (0.04-0.06)	84.2	0.05 (0.04-0.06)	78.4	0.05 (0.04-0.07)	83.8	0.05 (0.04-0.06)	76.6	0.06 (0.04-0.09)
PFecHS	68.8	0.03 (0.02-0.04)	84.5	0.04 (0.03-0.05)	82.5	0.04 (0.03-0.05)	81.8	0.04 (0.03-0.04)	72.3	0.04 (0.02-0.05)
MeFOSAA	87.3	0.07 (0.06-0.08)	78.1	0.06 (0.05-0.08)	72.2	0.05 (0.04-0.07)	75.2	0.05 (0.04-0.06)	78.7	0.06 (0.04-0.09)

Level of Education (n=1,013)	High school graduate or equivalent (GED) or less (n=173)		Some university, college, technical or trade school (n=393)		Technical or trade school graduate (n=97)		University or college graduate (n=303)		Graduate school or higher (n=47)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFHpA^b	61.3	0.02 (0.02-0.03)	NC	NC	NC	NC	NC	NC	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^bValues for PFHpA were calculated for only those groupings where detection was above 60%.

Bold values represent findings that are significantly different compared to one or more other groups.

Income

Further analysis of firefighters across various income levels (less than \$20,000 [n=10], \$20,000 to less than \$35,000 [n=38], \$35,000 to less than \$50,000 [n=80], \$50,000 to less than \$75,000 [n=170], \$75,000 to less than \$100,000 [n=228] and \$100,000 or more [n=390]), revealed a trend where concentrations of most PFAS increased with higher income levels (**Table 7**). The highest concentrations were observed among firefighters with a household income of \$100,000 or more annually (n=390). Like the pattern observed with education, an exception to this trend was noted with MeFOSAA, where the highest concentrations were found among firefighters with the lowest income level, i.e., earning less than \$20,000 annually (n=10). This analysis was constrained by a low sample size within this group, resulting in wider confidence intervals. Average concentrations were generated for PFHpA for \$20,000 to less than \$35,000 [0.03 µg/L (95% CI 0.02-0.03)] and \$75,000 to less than \$100,000 [0.03 µg/L (95% CI 0.02-0.03)] as it was found in more than 60% of participants within these groups.

Table 7: Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in the blood of eligible PFOMS participants by income.

□ Represents significantly **lower** findings compared to 1 or more other groups.

□ Represents significantly **higher** findings compared to 1 or more other groups.

Household Income (n=916)	Less than \$20,000 (n=10)		\$20,000 to less than \$35,000 (n=38)		\$35,000 to less than \$50,000 (n=80)		\$50,000 to less than \$75,000 (n=170)		\$75,000 to \$100,000 (n=228)		\$100,000 or more (n=390)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	4.30 (2.23-8.28)	100	4.16 (2.76-6.27)	100	4.51 (3.89-5.23)	100	4.75 (4.08-5.54)	100	4.73 (4.18-5.36)	100	5.32 (4.79-5.92)
Br-PFOS	100	1.76 (0.88-3.54)	100	1.27 (0.81-2.00)	100	1.52 (1.23-1.89)	100	1.69 (1.35-2.10)	100	1.67 (1.39-1.99)	100	1.98 (1.69-2.31)
L-PFOS	100	2.37 (1.22-4.60)	100	2.57 (1.70-3.89)	100	2.82 (2.45-3.24)	100	2.82 (2.43-3.27)	100	2.81 (2.47-3.21)	100	3.07 (2.74-3.45)
PFOA	100	0.77 (0.57-1.05)	100	0.71 (0.56-0.90)	100	0.77 (0.66-0.88)	100	0.86 (0.79-0.94)	100	0.91 (0.82-1.00)	100	0.94 (0.87-1.02)
L-PFOA	100	0.76 (0.56-1.04)	100	0.68 (0.52-0.87)	100	0.74 (0.65-0.86)	100	0.84 (0.77-0.92)	100	0.89 (0.80-0.98)	100	0.93 (0.85-1.01)
PFHxS	100	0.83 (0.56-1.24)	97.4	0.69 (0.45-1.06)	98.8	0.82 (0.64-1.04)	94.4	0.94 (0.82-1.09)	99.1	1.01 (0.87-1.18)	100	1.23 (1.10-1.38)
L-PFHxS	100	0.83 (0.56-1.24)	97.4	0.69 (0.46-1.05)	98.8	0.82 (0.65-1.03)	94.4	0.94 (0.81-1.08)	99.1	1.00 (0.86-1.18)	100	1.23 (1.10-1.38)
PFNA	100	0.35 (0.21-0.59)	100	0.35 (0.25-0.47)	100	0.35 (0.30-0.41)	99.4	0.34 (0.30-0.39)	98.7	0.37 (0.33-0.42)	99.2	0.38 (0.34-0.43)
PFHpS	90.0	0.13 (0.06-0.27)	97.4	0.13 (0.10-0.18)	97.5	0.15 (0.12-0.17)	98.2	0.16 (0.14-0.18)	98.2	0.17 (0.15-0.19)	99.0	0.19 (0.16-0.21)
PFDA	90.0	0.09 (0.05-0.19)	94.7	0.11 (0.08-0.16)	97.5	0.11 (0.09-0.14)	95.9	0.11 (0.09-0.12)	95.9	0.11 (0.10-0.13)	96.2	0.12 (0.10-0.13)
PFUnA	70.0	0.04 (0.02-0.10)	71.1	0.06 (0.04-0.08)	80.0	0.05 (0.04-0.07)	81.8	0.05 (0.04-0.06)	81.8	0.05 (0.04-0.06)	85.1	0.05 (0.05-0.06)
PFecHS	40.0	0.02 (0.01-0.032)	55.3	0.03 (0.02-0.04)	72.5	0.03 (0.02-0.03)	75.9	0.03 (0.03-0.04)	75.9	0.04 (0.03-0.05)	86.2	0.04 (0.034-0.05)

Household Income (n=916)	Less than \$20,000 (n=10)		\$20,000 to less than \$35,000 (n=38)		\$35,000 to less than \$50,000 (n=80)		\$50,000 to less than \$75,000 (n=170)		\$75,000 to \$100,000 (n=228)		\$100,000 or more (n=390)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
MeFOSAA	90.0	0.13 (0.06-0.29)	89.5	0.08 (0.06-0.13)	91.3	0.08 (0.06-0.10)	75.9	0.06 (0.05-0.07)	75.9	0.06 (0.05-0.07)	75.4	0.05 (0.04-0.05)
PFHpA^b	NC	NC	60.5	0.03 (0.02-0.03)	NC	NC	NC	NC	60.1	0.03 (0.02-0.03)	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^bValues for PFHpA were calculated for only those groupings where detection was above 60%.

Bold values represent findings that are significantly different compared to one or more other groups.

Comparison with Other Firefighter Studies

Results from the PFOMS project were compared to results from other firefighter studies^{21,33-40} across the U.S. and globally. This provides an indication of whether Michigan firefighters tended to have higher or lower blood PFAS concentrations than firefighters from other studies (**Table 8a; Table 8b**). Comparisons were made for PFOS, PFOA, PFHxS, PFNA and PFDA. These chemicals are of interest because they were reported as being elevated in firefighters compared to the control population in two or more of the nine firefighter studies and were detected in more than 60% of Michigan firefighters.

Michigan firefighters had lower geometric means than most of the other firefighter studies. Geometric mean concentrations reported in the other firefighter studies were significantly higher than Michigan firefighters for two^{33,40} of the four studies that reported values for PFOS, three^{33,34,38} of the four studies that reported values for PFOA, six^{33,34,36,37,38,40} of the six studies that reported values for PFHxS, five^{33,34,37,38,40} of the six studies that reported values for PFNA and four^{33,34,37,38} of the five studies that reported values for PFDA. None of the firefighter studies reported geometric mean concentrations of these PFAS that were significantly lower than Michigan firefighters. Some of the studies reported that geometric means for PFOA⁴⁰, PFNA³⁶ and PFDA³⁶ were higher but not significantly different from PFOMS. Only two studies^{34,38} reported geometric means for PFOS that were lower but not significantly different than PFOMS.

PFOMS participants more often had higher maximum concentrations compared to the other firefighter studies. Most of the firefighter studies reported lower maximum concentrations of PFHxS^{33,35,36,39,40}, PFNA^{21,33,35,36,39,40}, and PFDA^{21,35,36,39} compared to PFOMS participants. For PFOA, however, maximum concentrations in most of the firefighter studies^{21,33,38,39,40} were higher than for PFOMS participants. For PFOS, maximum concentrations were higher for three of the studies^{21,38,40} and lower^{33,35,39} for the other three compared to PFOMS participants. The types of firefighters that participated in the studies, where the firefighters worked, what year the study was conducted, and other factors may affect the results that were obtained in those studies. **Table S5 in Appendix A** provides further information on the firefighters who participated in each of the studies.

Table 8a. Minimum, geometric mean, and maximum PFAS concentrations for Michigan firefighters (PFOMS) compared to other firefighter studies.

☐ Represents significantly **higher** findings compared to Michigan firefighters.

	Sample Size (n)	PFOS			PFOA			PFHxS		
		Min µg/L	GM (95% CI) µg/L	Max µg/L	Min µg/L	GM (95% CI) µg/L	Max µg/L	Min µg/L	GM (95% CI) µg/L	Max µg/L
PFOMS (2021-2023)	1,023	0.09	4.85 (4.39-5.36)	62.54	0.07	0.87 (0.82-0.92)	4.3	ND	1.02 (0.93-1.11)	78.78
Řiháčková et al. (2023) ³⁵	52	0.40	NA	17.00	0.10	NA	2.53	0.10	NA	3.67
*Burgess et al. (2023) - Fire Dept. A ³⁶	77	NA	NA	NA	NA	NA	NA	0.70	3.24 (2.90-3.58)	12.50
*Burgess et al. (2023) - Fire Dept. B ³⁶	59	NA	NA	NA	NA	NA	NA	0.60	1.90 (1.47-2.33)	11.10
*Burgess et al. (2023) - Fire Dept. C ³⁶	59	NA	NA	NA	NA	NA	NA	1.20	3.78 (3.36-4.20)	17.30
*Burgess et al. (2023) - Fire Dept. D ³⁶	61	NA	NA	NA	NA	NA	NA	0.40	1.77 (1.30-2.24)	15.00
Goodrich et al. (2021) ³⁷	197	NA	NA	NA	NA	NA	NA	NA	2.50 (2.29-2.74)	NA
Graber et al. (2021) ³⁴	116	NA	4.25 (3.76-4.80)	NA	NA	2.07 (1.89-2.26)	NA	NA	1.83 (1.61-2.09)	NA
Trowbridge et al. (2020) ³⁸	86	0.54	4.11 (3.68-4.59)	81	0.29	1.15 (1.05-1.25)	5.18	0.22	3.79 (3.24-4.43)	90.57
Dobraca et al. (2015) ³³	101	NA	12.50 (11.34-13.78)	46.60	NA	3.75 (3.37-4.17)	18.10	NA	2.26 (2.00-2.54)	13.20
Rotander et al. (2015) ²¹	149	3.40	NA	391	0.30	NA	18	0.70	NA	277.00
Shaw et al. (2013) ³⁹	12	3.00	NA	59.00	2.00	NA	12.00	0.30	NA	2.00
Jin et al. (2011) ⁴⁰	36	0.25	24.37 (20.18-28.56)	67.50	0.25	37.69 (0.00-116.13)	7,535.60	0.25	4.77 (3.59-5.95)	14.60

Abbreviations: NA, not available; ND, not detected; n, number; GM, geometric means; 95% CI, 95% confidence intervals; Min, minimum; Max, maximum; µg/L, microgram per liter. **Bold** values represent findings that are significantly different compared to Michigan firefighters (PFOMS (2021-2023)).

*This study measured PFAS in firefighters from four separate departments.

Table 8b. Minimum, geometric mean and maximum PFAS concentrations for Michigan firefighters (PFOMS) compared to other firefighter studies.

☐ Represents significantly **higher** findings compared to Michigan firefighters.

	Sample Size (n)	PFNA			PFDA		
		Min µg/L	GM (95% CI) µg/L	Max µg/L	Min µg/L	GM (95% CI) µg/L	Max µg/L
PFOMS (2021-2023)	1,023	ND	0.35 (0.32-0.38)	4.41	ND	0.11 (0.10-0.12)	1.64
Řiháčková et al. (2023) ³⁵	52	0.10	NA	0.99	ND	NA	0.58
*Burgess et al. (2023) - Fire Dept. A ³⁶	77	0.20	0.42 (0.14-0.70)	1.70	0.10	0.25 (0.00-0.51)	0.60
*Burgess et al. (2023) - Fire Dept. B ³⁶	59	0.30	0.57 (0.19-0.95)	2.40	ND	0.22 (0.00-0.65)	1.40
*Burgess et al. (2023) - Fire Dept. C ³⁶	59	0.20	0.60 (0.26-0.94)	1.30	ND	0.18 (0.00-0.58)	0.50
*Burgess et al. (2023) - Fire Dept. D ³⁶	61	0.20	0.64 (0.25-1.03)	1.40	ND	0.19 (0.00-0.62)	0.50
Goodrich et al. (2021) ³⁷	197	NA	0.44 (0.41-0.48)	NA	NA	0.23 (0.22-0.25)	NA
Graber et al. (2021) ³⁴	116	NA	0.97 (0.89-1.05)	NA	NA	0.31 (0.29-0.33)	NA
Trowbridge et al. (2020) ³⁸	86	0.15	0.67 (0.61-0.74)	4.49	ND	0.25 (0.23-0.28)	3.69
Dobraca et al. (2015) ³³	101	NA	1.15 (1.06-1.25)	4.23	NA	0.90 (0.78-1.03)	4.60
Rotander et al. (2015) ²¹	149	0.09	NA	2.40	ND	NA	0.99
Shaw et al. (2013) ³⁹	12	1.00	NA	4.00	0.20	NA	1.00
Jin et al. (2011) ⁴⁰	36	0.25	1.56 (1.30-1.82)	4.40	NA	NA	NA

Abbreviations: n, number; NA, not available; ND, not detected; GM, geometric means; 95% CI, 95% confidence intervals; Min, minimum;

Max, maximum; µg/L, microgram per liter. **Bold** values represent findings that are significantly different compared to Michigan firefighters (PFOMS (2021-2023)).

*This study measured PFAS in firefighters from four separate departments.

Water PFAS Frequencies and Concentrations

The PFOMS project collected 238 water samples from 122 fire stations. This included 118 samples from locations where firefighters most often get their drinking water and 120 samples from locations closest to where drinking water enters the station, often a water spigot or some other location not used for drinking water. Eighty-one of the stations were supplied by municipal water and 41 were supplied by private wells. Forty-nine of the stations had either some type of drinking water filter or water softener installed. PFAS was only detected in 19 (7.9%) of the 238 samples. These detections occurred at 13 different stations, six of which were supplied by private drinking water wells and seven by municipal water. The most frequently detected PFAS was PFBS (range non-detect (ND)-3.92 ng/L), which was detected in eight samples. Other detected PFAS include PFOA (range ND-22.22 ng/L), PFHxA (range ND-18.86 ng/L), PFHxS (range ND-12.74 ng/L), PFOSA (range ND-9.70 ng/L), PFOS (range ND-31.78 ng/L), PFUnA (range ND-3.11 ng/L), MeFOSAA (range ND-52.57 ng/L), 6:2 FTS (range ND-62.31 ng/L), PFNA (range ND-2.94 ng/L), PFHpA (range ND-20.65 ng/L) and 8:2 FTS (range ND-3.10 ng/L). Of the PFAS with comparison values, only three samples from three different stations had detections of either PFOS or PFOA above the MDHHS Comparison Values⁴² (Table S6 in Appendix A).

All three of these Comparison Value exceedances were inconsistent with PFAS monitoring data showing no PFAS exceedances for the public water systems that supplied the stations. In all cases, the available information suggested that the source of PFAS was specific to the faucet or spigot that was sampled. One of the exceedances occurred in a sample collected from the location most often used for drinking water, which was a drinking water fountain. The PFAS team recommended that the drinking water fountain be taken offline, and that sampling be performed to determine if PFAS was present in any other taps within the station. A sample collected from a utility sink faucet, closest to where water enters the station did not contain any PFAS detections, consistent with PFAS sampling data for the water system that supplies the station. The other two exceedances occurred in samples taken from outdoor or garage spigots closest to where water enters the stations. At one of these stations, the spigot was resampled and no PFAS were detected above the Comparison Values. At both stations, samples from the most-used drinking water faucet did not contain PFAS above the Comparison Values. Potential sources of PFAS associated with these three locations could be internal plumbing or PFAS-containing materials in the case of the drinking water fountain, and potential transfer of PFAS contamination from fire hoses or other sources for the two outdoor or garage spigots.

DISCUSSION

Data collected and analyzed as part of the PFOMS project provide useful information about PFAS exposure among Michigan firefighters. This data describes the average concentrations at which these PFAS are found in Michigan firefighters as well as compares those to the concentrations found in the U.S. population, where possible, and to those reported in other firefighter studies. This report and its accompanying brief describe the following:

1. Blood PFAS results observed among Michigan firefighters, and comparison of average concentrations to the U.S. population.
2. Average Blood PFAS concentrations in airport vs non-airport firefighters.
3. Average Blood PFAS concentrations in urban vs non-urban firefighters.
4. Average Blood PFAS concentrations in multiple demographic categories.
5. Blood PFAS concentrations in Michigan firefighters vs those reported in other firefighter studies.

Additionally, the results of drinking water PFAS sampling at fire stations are shared here (**Table S6 in Appendix A**).

Blood PFAS Frequencies and Concentrations in All Michigan Firefighters

Overall, PFOA, PFOS and PFHxS were found in the blood of all Michigan firefighters. This was expected, as national and international studies show blood from most people contains these three PFAS. However, although the detection frequencies of PFOA, PFOS and PFHxS from Michigan firefighters mirror those seen in the U.S. population, the concentrations at which they were detected tended to be lower among Michigan firefighters than for the U.S. population except for PFOS and a branched isomer of PFOS. This pattern is potentially explained by Michigan's PFAS mitigation policies including Public Acts (PA) 133⁴³ and 143⁴⁴ banning training with Class B AFFF foam, mandatory reporting of foam discharges and the Michigan Department of Environment, Great Lakes, and Energy (EGLE's) collection program that removed over 69,400 gallons of PFAS-containing foam from fire departments by 2024. Combined, these measures likely reduced exposure to newer short-chain PFAS while PFOS persists due to its environmental stability, historical accumulation in fire station environments and continued presence in legacy gear containing durable water repellent finishes.

PFOMS data also show that some PFAS less commonly found in the U.S. population are common among Michigan firefighters. For example, MeFOSAA was found in 81.2% of Michigan firefighters, but nationwide the detection rate of MeFOSAA in the U.S. population is just 58.8%. Other PFAS with detection frequencies that were higher than expected included PFNA, PFHpS, PFBS, PFDA, PFDoA, PFHpA and PFUnA. These PFAS were detected in a significantly greater proportion of Michigan firefighters than expected when compared to the U.S. population, where such comparison was possible. Some PFAS, such as PFecHS, which have not been measured in the U.S. population, were frequently detected in Michigan firefighters. This PFAS was also not reported in the other reviewed firefighter studies.

PFAS such as PFHxA, PFPeA, fluorotelomers (6:2 FTS, and 4:2 FTS) and perfluorooctane sulfonamides like EtFOSAA that are known to be found in protective gear^{18,27,28} showed little (less than 10%) to no detection in Michigan firefighters. In addition, several other PFAS²⁰⁻²², such as PFHxA, PFDS, PFBS, PFNS, etc. known to be found in PFAS-containing foams showed low (less than 15%) to no detection. This may be because Michigan firefighters had minimal exposure to these PFAS, or because exposure occurred long enough in the past to eliminate these PFAS from the body. Some of these PFAS, such as PFBS, have relatively short half-lives which would allow for more rapid elimination from the body. For example, if a participant were exposed to PFBS in the past, most (94%) of that would be eliminated from the body after about 111 days of no exposure due to its relatively short half-life of approximately 28 days, compared to other PFAS which may have half-lives in the years to decades range⁴.

Average concentration estimates were calculated for the 13 PFAS detected in more than 60% of Michigan firefighters, while 95th percentiles were determined for all measured PFAS (**Table 2**). These estimates were lower for Michigan firefighters compared to the U.S. population for all analytes except PFOS (average concentration was higher for Michigan) and branched isomers of PFOS (average and 95th percentile concentrations were higher for Michigan). Although Michigan firefighters had a higher average concentration of PFOS, the difference was not statistically significant. Michigan firefighters had significantly lower average and 95th percentile concentrations of PFOA compared to the U.S. population. The similar or lower average concentrations of legacy PFAS, such as PFOS and PFOA, among Michigan firefighters compared to the U.S. population suggests that efforts to phase out the use of these PFAS in firefighting foam¹⁷ have been successful in reducing blood concentrations of these PFAS in firefighters. In addition, firefighters who worked at fire departments where PFAS-containing foam was used or

stored had similar average PFAS concentrations compared to firefighters who worked at departments where no PFAS-containing foam was used or stored. This suggests that even if firefighting foam is present within a department, it may not necessarily translate into greater average PFAS exposure among firefighters. Other PFAS such as PFHpS, PFDA, PFUnA and MeFOSAA were detected more frequently in Michigan firefighters compared to the U.S. population, but at lower average concentrations, which could indicate relatively wide-spread, lower-level exposure to these PFAS. Potential occupational sources of these PFAS include PFAS containing foam¹⁷, fire station dust^{19,27}, and protective gear^{18,25,27}. These findings suggest the need to investigate behaviors and practices that could contribute to Michigan firefighters' exposure to these PFAS.

Average Blood PFAS Concentrations in Airport vs Non-Airport Firefighters

In examining PFAS frequencies and concentrations among airport versus non-airport firefighters, notable disparities emerged that warrant careful consideration.

Civilian airports, regulated under Part 139 of the Federal Aviation Regulations, adhered to stringent fire response readiness protocols, commonly known as Aircraft Rescue Fire Fighting (ARFF) indices^{24,23} until changes in regulations were made in October 2021. These protocols encompassed specific accident response measures, including the utilization of military-specification AFFF formulations and routine equipment testing. Consequently, airport firefighters faced a heightened probability of exposure to PFAS-containing foam compared to their non-airport counterparts, as such stringent requirements did not typically apply to non-airport firefighting operations. Moreover, non-airport firefighters are mandated to follow recommendations outlined by state regulatory bodies such as the State Fire Marshal within the Bureau of Fire Services (BFS) at the Michigan Department of Licensing and Regulatory Affairs (LARA) and EGLE, further minimizing the likelihood of potential work-related PFAS exposure²⁸.

Our findings revealed significantly higher concentrations of certain PFAS, including PFOA, PFOS, PFHxS, PFHpS, linear isomers of PFOS, PFOA and PFHxS, as well as the branched isomer of PFOS, among airport firefighters compared to non-airport firefighters, and significantly higher concentrations of PFOS among airport firefighters compared to U.S. population. These PFAS are commonly found in various formulations of PFAS-containing foams¹⁷ used in firefighting activities at airports. Concentrations of other PFAS such as PFNA, PFDA, PFUnA and PFeCHS were also found to be higher in airport firefighters, although these differences were not significant. PFeCHS, in particular, has previously been associated with airports⁴⁵. This PFAS has been used in aircraft hydraulic fluids as a corrosion inhibitor and has been frequently detected in the environment near airports. Some studies have found increasing concentrations of PFeCHS in water and biota with closer proximity to airports, which supports the association of this PFAS with airports⁴⁵. Overall, these findings suggest that PPE, station dust or other occupational sources may also contribute to airport firefighters' cumulative PFAS exposure. The observed differences underscore the heightened risk of occupational PFAS exposure among airport firefighters, where the use of PFAS-containing foams is most prevalent.

Average Blood PFAS Concentrations in Urban vs Non-Urban Non-Airport Firefighters

The comparison of average PFAS concentrations among different groups of firefighters has been the subject of several studies^{34,46,47}, with a recent focus primarily on volunteer firefighters^{34,46}. However, there is a notable gap in

the literature regarding PFAS concentrations in urban versus non-urban firefighters. The PFOMS project aimed to address this gap by examining PFAS concentrations in these two distinct groups.

Results revealed interesting trends in PFAS concentrations between other urban and other non-urban firefighters. Specifically, we found that concentrations of legacy PFAS, such as PFOA and PFOS, were higher in urban firefighters compared to their non-urban counterparts. City of Detroit firefighters had the highest concentrations of certain legacy and other PFAS compared to other urban and non-urban areas, with significant differences observed for some (PFOA, PFOS, PFHxS, linear isomer of PFOS, PFOA and PFHxS, PFUnA and PFNA).

Moreover, elevated concentrations of specific PFAS, such as MeFOSAA, PFDA³⁴, PFHpS and PFUnA, were seen among other non-urban firefighters. These analytes are known to be associated with fire station dust^{19,22} and protective gear^{18,22,27} suggesting potential sources of exposure among these firefighters. Such sources could contribute to the observed higher concentrations of these PFAS among other non-urban firefighters. These results suggest potential variation in PFAS exposure patterns between urban and non-urban firefighters, warranting further investigation into contributing factors such as occupational practices (e.g., time spent at fire stations, number of calls and fire incidents, using or training with Class B foam) and behaviors (e.g., gear storage, decontamination procedure and frequency).

Average Blood PFAS Concentrations by Various Demographics

Significantly higher average concentrations of most PFAS were observed in males compared to females, consistent with findings from other studies⁴⁸ across various populations. This pattern is likely attributable to the presence of female-specific PFAS excretion routes, such as menstruation, pregnancy and breastfeeding². Similar trends were observed concerning age, race and ethnicity, with higher concentrations noted among older individuals, non-white single-race individuals and Hispanics, aligning with existing literature and exposure assessments conducted in other communities⁴⁹⁻⁵⁷. Data also revealed higher concentrations of certain PFAS among individuals with higher levels of education and income. These findings align with a recent study focusing on firefighters³⁴, which reported a positive association between PFAS concentrations and higher education levels. However, it is essential to note that there are wide confidence intervals, particularly among individuals with graduate school education or higher, which can be attributed to the small sample size in this subgroup (n=47), giving less precise estimates.

Blood PFAS Results in Michigan Firefighters vs Other Firefighter Studies

Michigan firefighters that participated in PFOMS more often had lower geometric means and higher maximum PFAS concentrations than reported in other firefighter studies^{21,33-40} across the U.S. and globally. Results for PFOS, PFOA, PFHxS, PFNA and PFDA were compared between studies. For each of these chemicals, Michigan firefighters' geometric means were significantly lower than at least some of the other studies. Geometric means for Michigan firefighters were not significantly higher than any of the other studies. One factor that may contribute to this pattern is the more recent data collection period for Michigan firefighters compared to the other studies. As actions are taken to reduce firefighters' exposure to PFAS in the U.S. and elsewhere, average concentrations of certain PFAS in firefighters could be expected to decline over time. As a result, the relatively lower geometric means among Michigan firefighters for some PFAS could represent less exposure among this group, or perhaps similar past exposure with subsequent elimination of PFAS in the intervening years between the other firefighting studies and PFOMS.

In contrast to geometric means, PFOMS maximum concentrations were often, but not always, higher than those reported in the other firefighter studies. The results suggest that while the firefighters that participated in PFOMS on average tended to have blood PFAS concentrations that were lower or like most other firefighter studies, the firefighters with the highest concentrations often had higher levels than those reported in other studies.

Water PFAS Frequencies and Concentrations

PFAS was not frequently detected in fire station drinking water. In the 8% of samples where PFAS was detected, concentrations were typically below MDHHS Comparison Values⁴². Only three stations had results that exceeded MDHHS Comparison Values. One of these stations was resampled and found to no longer have detections above the Comparison Values. In all these cases, the stations were supplied by public water systems that are monitored for PFAS and did not have elevated PFAS detections. The sources of PFAS for these sampling locations were specific to the faucet or spigot that was sampled. The results indicate that PFAS contamination in the municipal water systems and private wells that supply fire station drinking water is not common among the fire departments that participated in PFOMS.

LIMITATIONS

The findings of this report come with several limitations that warrant consideration in the interpretation of results. Firstly, certain analyses were constrained by small sample sizes, resulting in wider confidence intervals, particularly evident in categories such as the number of firefighters in non-urban airport strata or those identifying as Hispanic. Secondly, there is a potential for volunteer bias, as firefighters from fire departments with known PFAS exposure may have participated at higher rates, potentially skewing the representation of PFAS exposure concentrations. Thirdly, there are several considerations when it comes to comparing Michigan firefighter averages to the U.S. population. Characteristics of PFOMS participants differ significantly from that of the U.S. population. For example, 91.7% of PFOMS participants were male vs 50.1% in the U.S. population (**Table S1 in Appendix A**). Additionally, due to the decline in blood PFAS concentrations observed over time among the U.S. population, all comparisons in this report were based on the most recent NHANES data available at the time of analysis, which ranged from 2011 to 2018. However, as newer NHANES (e.g., 2021-2023) or the Michigan Chemical Exposure Monitoring (MiChEM) data becomes available, it may alter our understanding of Michigan data trends. Comparing average PFAS concentrations in Michigan firefighters to Michigan adults provides a more accurate assessment of occupational exposure within a shared geographic and environmental context, as both groups are subject to similar regional background exposures. NHANES data represent a national average that may not reflect Michigan-specific environmental factors. In comparing detection frequencies between PFOMS and NHANES, it is important to note that PFOMS used a PFAS test method with lower reporting limits than NHANES, and this could account for some of the differences in detection frequencies that were observed. Moreover, it is essential to acknowledge that various occupational, physiological and behavioral factors can influence PFAS exposure and elimination. The distribution of these factors may differ between Michigan firefighters and the broader U.S. population. For instance, airport firefighters, subject to federal regulations, represent a distinct subgroup. Failure to account for the proportion of airport firefighters in the analysis could lead to skewed results not reflective of the overall firefighting population with PFAS exposure. Additionally, it is important to investigate self-reported occupational and non-occupational factors in various subgroups that may influence PFAS exposure

and elimination, which may alter the above findings and hence is a limitation of this report. Future reports will provide detailed insights into these factors, enhancing the contextual understanding of the findings.

CONCLUSIONS

The findings of the PFOMS project show that firefighters have been exposed to PFAS, whether through PFAS-containing foam, station dust, turnout gear or non-occupational sources such as residential drinking water, dietary sources and consumer products. The PFOMS project was successfully able to determine the average blood concentrations for 13 PFAS that were detected in more than 60% of Michigan firefighters as well as those in various sub-groups, for the 2021-2023 data collection period. PFOMS data reveals that while over 95% of PFOMS firefighters had detectable blood concentrations of various PFAS, including PFOA, PFOS, PFHxS, PFNA, PFHpS and PFDA, the geometric mean concentrations observed were often lower compared to those found in the U.S. population. However, PFOS concentrations (total and branched isomer) were an exception with concentrations trending higher in the Michigan firefighters. Furthermore, when comparing Michigan firefighters to findings from other studies across the U.S. and globally, our data indicate relatively lower blood PFAS concentrations among Michigan firefighters. Notably, airport firefighters demonstrated higher average concentrations of certain PFAS compared to non-airport firefighters, with significant differences observed in specific compounds such as PFOS, PFOA, PFHxS and branched isomers of PFOS. Urban firefighters exhibited heightened concentrations of legacy PFAS, while non-urban counterparts showed elevated levels of different PFAS variants. Additionally, male firefighters tended to have higher average blood PFAS concentrations than females, consistent with broader trends observed in PFAS studies across diverse populations. Interestingly, PFAS analytes such as certain fluorotelomers (e.g., 6:2 FTS and 4:2 FTS), and perfluorooctane sulfonamides like EtFOSAA that are known to be found in protective gear showed little (less than 10%) to no detection in Michigan firefighters.

These findings suggest potential disparities in exposure between various subgroups. This highlights the importance of considering contextual factors and occupational practices when interpreting PFAS exposure data among firefighters. Therefore, further analysis is warranted to better understand the specific factors driving differences in PFAS concentrations between different subgroups. MDHHS will continue to analyze the data collected under this biomonitoring effort to explore specific occupational and non-occupational activities and behaviors that may contribute to PFAS exposure disparities between different firefighter subgroups, such as airport and non-airport personnel. Findings of these analyses will not only enhance our understanding of PFAS exposure among firefighters but could also inform targeted interventions and policies aimed at mitigating occupational health risks associated with PFAS exposure in this population. Lastly, state regulatory agencies can consider the PFOMS findings about PFAS concentrations in blood of Michigan firefighters for policy development.

PUBLIC HEALTH RECOMMENDATIONS

To reduce firefighters' exposure to PFAS and ensure responsible use of PFAS-containing foam, it is important for fire departments to follow federal¹⁷ and state⁵⁸ recommendations to reduce and report the use of PFAS-containing foam. Additionally, firefighters should continue to follow PFAS exposure reduction strategies as stated in Public Acts 133⁴³ and 143⁴⁴ for mitigating occupational PFAS exposure among firefighters. Firefighters should follow all applicable fire department guidelines for use of personal protective equipment, decontamination after fire responses and routine cleaning of gear⁵⁹. By operationalizing these guidelines^{43,44,58}, fire departments will

significantly reduce the impact of PFAS on human health and the environment. In addition to these measures, further actions are recommended based on PFOMS findings. Use of fluorine-free foams (F3) should be promoted in alignment with FAA²⁴ guidance, particularly at Michigan airports where signals for elevated exposure were observed.

To start a conversation about whether personalized medical action is warranted, firefighters with concerns about how PFAS detected in their blood could affect their personal health should share their individual PFAS results with their health care provider.

While the findings of this report do not conclusively prove increased exposure to Michigan firefighters in comparison to the general population, further analyses are recommended to identify potential occupational predictors associated with PFAS exposure that may be masked in aggregate data.

REFERENCES

1. Sunderland EM, Hu XC, Dassuncao C, Tokranov AK, Wagner CC, Allen JG. A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects. *J Expo Sci Environ Epidemiol.* 2019;29(2):131-147. doi:10.1038/s41370-018-0094-1
2. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Perfluoroalkyls. U.S. Department of Health and Human Services; 2021.
3. De Silva AO, Armitage JM, Bruton TA, et al. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environ Toxicol Chem.* 2021;40(3):631-657. doi:10.1002/etc.4935
4. Zhang X, Xue L, Deji Z, et al. Effects of exposure to per- and polyfluoroalkyl substances on vaccine antibodies: A systematic review and meta-analysis based on epidemiological studies. *Environ Pollut.* 2022;306:119442. doi:10.1016/j.envpol.2022.119442
5. Antoniou E, Colnot T, Zeegers M, Dekant W. Immunomodulation and exposure to per- and polyfluoroalkyl substances: an overview of the current evidence from animal and human studies. *Arch Toxicol.* 2022;96(8):2261-2285. doi:10.1007/s00204-022-03303-4
6. Von Holst H, Nayak P, Dembek Z, et al. Perfluoroalkyl substances exposure and immunity, allergic response, infection, and asthma in children: review of epidemiologic studies. *Heliyon.* 2021;7(10):e08160. doi:10.1016/j.heliyon.2021.e08160
7. Meneguzzi A, Fava C, Castelli M, Minuz P. Exposure to Perfluoroalkyl Chemicals and Cardiovascular Disease: Experimental and Epidemiological Evidence. *Front Endocrinol.* 2021;12:706352. doi:10.3389/fendo.2021.706352
8. Conway BN, Badders AN, Costacou T, Arthur JM, Innes KE. Perfluoroalkyl substances and kidney function in chronic kidney disease, anemia, and diabetes. *Diabetes Metab Syndr Obes.* 2018;11:707-716. doi:10.2147/DMSO.S173809
9. Stanifer JW, Stapleton HM, Souma T, Wittmer A, Zhao X, Boulware LE. Perfluorinated Chemicals as Emerging Environmental Threats to Kidney Health: A Scoping Review. *Clin J Am Soc Nephrol.* 2018;13(10):1479-1492. doi:10.2215/CJN.04670418
10. Costello E, Rock S, Stratakis N, et al. Exposure to per- and Polyfluoroalkyl Substances and Markers of Liver Injury: A Systematic Review and Meta-Analysis. *Environ Health Perspect.* 2022;130(4):46001. doi:10.1289/EHP10092
11. Wang P, Liu D, Yan S, Cui J, Liang Y, Ren S. Adverse Effects of Perfluorooctane Sulfonate on the Liver and Relevant Mechanisms. *Toxics.* 2022;10(5)doi:10.3390/toxics10050265
12. Coperchini F CL, Ricci G, Magri F, Rotondi M, Imbriani M, Chiovato L. Thyroid Disrupting Effects of Old and New Generation PFAS. *Front Endocrinol.* 2021;doi:doi: 10.3389/fendo.2020.612320.
13. Steenland K, Winquist A. PFAS and Cancer, a scoping review of the epidemiologic evidence. *Environ Res.* 2021;March(194)
14. Barry V, Winquist A, Steenland K. Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. *Environ Health Perspect.* 2013;121(11-12), 1313-1318.

15. Ding N, Harlow SD, Randolph JF, Jr., Loch-Carusio R, Park SK. Perfluoroalkyl and polyfluoroalkyl substances (PFAS) and their effects on the ovary. *Hum Reprod Update*. 2020;26(5):724-752. doi:10.1093/humupd/dmaa018
16. Szilagyi JT, Avula V, Fry RC. Perfluoroalkyl Substances (PFAS) and Their Effects on the Placenta, Pregnancy, and Child Development: a Potential Mechanistic Role for Placental Peroxisome Proliferator Activated Receptors (PPARs). *Curr Environ Health Rep*. 2020;7(3):222-230. doi:10.1007/s40572-020-00279-0
17. 3 Firefighting Foams – PFAS — Per- and Polyfluoroalkyl Substances. Updated September 2023. Accessed August 14, 2023. <https://pfas-1.itrcweb.org/3-firefighting-foams/>
18. Davis RD, Donnelly M, Escobar Veras S, et al. Per- and Polyfluoroalkyl Substances in New Firefighter Turnout Gear Textiles. National Institute of Standards and Technology; 2023. <https://doi.org/10.6028/NIST.TN.2248>
19. Young AS, Sparer-Fine EH, Pickard HM, Sunderland EM, Peaslee GF, Allen JG. Per- and polyfluoroalkyl substances (PFAS) and total fluorine in fire station dust. *J Expo Sci Environ Epidemiol*. 2021;31(5):930-942. doi:10.1038/s41370-021-00288-7
20. Rosenfeld PE, Spaeth KR, Remy LL, et al. Perfluoroalkyl substances exposure in firefighters: Sources and implications. *Environmental Research*. 2023;220:115164. doi:10.1016/j.envres.2022.115164
21. Rotander A, Toms LML, Aylward L, Kay M, Mueller JF. Elevated levels of PFOS and PFHxS in firefighters exposed to aqueous film forming foam (AFFF). *Environment International*. 2015;82:28-34. doi:10.1016/j.envint.2015.05.005
22. Wang Y, Chang W, Wang L, et al. A review of sources, multimedia distribution and health risks of novel fluorinated alternatives. *Ecotoxicol Environ Saf*. 2019;182:109402. doi:10.1016/j.ecoenv.2019.109402
23. What is Part 139? – Part 139 Airport Certification | Federal Aviation Administration. Accessed July 19, 2024. https://www.faa.gov/airports/airport_safety/part139_cert/what-is-part-139
24. Part 139 CERTALERT 23-01: New Military Specification for Performance-Based Standards for Fluorine-Free Aircraft Fire Fighting Foam. Federal Aviation Administration. https://www.faa.gov/airports/airport_safety/certalerts/part_139_certalert_23_01.
25. Industrial uses and potential impact of PFAS-based fire suppressants. *Industrial Safety & Hygiene News*. Updated March 6, 2020. Accessed August 14, 2023. <https://www.ishn.com/articles/112383-industrial-uses-and-potential-impact-of-pfas-based-fire-suppressants>
26. Muensterman DJ, Titley IA, Peaslee GF, et al. Disposition of Fluorine on New Firefighter Turnout Gear. *Environ Sci Technol*. 2022;56(2):974-983. doi:10.1021/acs.est.1c06322
27. Peaslee GF, Wilkinson JT, McGuinness SR, et al. Another Pathway for Firefighter Exposure to Per- and Polyfluoroalkyl Substances: Firefighter Textiles. *Environ Sci Technol Lett*. 2020;7(8):594-599. doi:10.1021/acs.estlett.0c00410
28. Maizel AC, Thompson A, Tighe M et al. Per- and Polyfluoroalkyl Substances in Firefighter Turnout Gear Textiles Exposed to Abrasion, Elevated Temperature, Laundering, or Weathering. National Institute of Standards and Technology; 2023. doi:10.6028/nist.tn.2260
29. Bureau UC. 2010 Urban Area FAQs. *Census.gov*. Accessed February 14, 2024. <https://www.census.gov/programs-surveys/geography/about/faq/2010-urban-area-faq.html>

30. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform.* 2009;42(2):377-81. doi:10.1016/j.jbi.2008.08.010 20.
31. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: Building an international community of software platform partners. *J Biomed Inform.* 2019;95:103208. doi:10.1016/j.jbi.2019.103208
32. W.G. Cochran 1977. *Sampling Techniques*, John Wiley and Sons, New York, Equation 11.30 page 305.
33. Dobraca D, Israel L, McNeel S, et al. Biomonitoring in California firefighters: metals and perfluorinated chemicals. *J Occup Environ Med.* 2015;57(1):88-97. doi:10.1097/JOM.0000000000000307
34. Graber JM, Black TM, Shah NN, et al. Prevalence and Predictors of Per- and Polyfluoroalkyl Substances (PFAS) Serum Levels among Members of a Suburban US Volunteer Fire Department. *IJERPH.* 2021;18(7):3730. doi:10.3390/ijerph18073730
35. Řiháčková K, Pindur A, Komprdová K, et al. The exposure of Czech firefighters to perfluoroalkyl substances and polycyclic aromatic hydrocarbons: CELSPAC - FIREexpo case-control human biomonitoring study. *Sci Total Environ.* 2023;881:163298. doi:10.1016/j.scitotenv.2023.163298
36. Burgess JL, Fisher JM, Nematollahi A, et al. Serum per- and polyfluoroalkyl substance concentrations in four municipal US fire departments. *Am J Ind Med.* 2023;66(5):411-423. doi:10.1002/ajim.23413
37. Goodrich JM, Calkins MM, Caban-Martinez AJ, et al. Per- and polyfluoroalkyl substances, epigenetic age and DNA methylation: a cross-sectional study of firefighters. *Epigenomics.* 2021;13(20):1619-1636. doi:10.2217/epi-2021-0225
38. Trowbridge J, Gerona RR, Lin T, et al. Exposure to Perfluoroalkyl Substances in a Cohort of Women Firefighters and Office Workers in San Francisco. *Environ Sci Technol.* 2020;54(6):3363-3374. doi:10.1021/acs.est.9b05490
39. Shaw SD, Berger ML, Harris JH, et al. Persistent organic pollutants including polychlorinated and polybrominated dibenzo-p-dioxins and dibenzofurans in firefighters from Northern California. *Chemosphere.* 2013;91(10):1386-1394. doi:10.1016/j.chemosphere.2012.12.070
40. Jin C, Sun Y, Islam A, Qian Y, Ducatman A. Perfluoroalkyl Acids Including Perfluorooctane Sulfonate and Perfluorohexane Sulfonate in Firefighters. *Journal of Occupational and Environmental Medicine.* 2011;53(3):324-328.
41. U.S. Census Bureau QuickFacts: Michigan. Accessed October 17, 2023. <https://www.census.gov/quickfacts/fact/table/MI/RHI125222>
42. Michigan Science Advisory Workgroup – Health Based Drinking Water Value Recommendations for PFAS in Michigan. Accessed February 20, 2026. <https://www.michigan.gov/-/media/Project/Websites/PFAS-Response/Reports/2019-Health-Based-Drinking-Water-Value-Recommendations-PFAS-MI.pdf?rev=1779be946a5c41439f1db4f3eeaec4ec>
43. Michigan Legislature—Section 29.369c. Accessed February 9, 2024. [https://www.legislature.mi.gov/\(S\(fvlefderrr0c00xgoq3vu5h0\)\)/mileg.aspx?page=getobject&objectname=mcl-29-369c&query=on](https://www.legislature.mi.gov/(S(fvlefderrr0c00xgoq3vu5h0))/mileg.aspx?page=getobject&objectname=mcl-29-369c&query=on)
44. Michigan Legislature—Section 408.1014r. Accessed February 9, 2024. [https://www.legislature.mi.gov/\(S\(fvlefderrr0c00xgoq3vu5h0\)\)/mileg.aspx?page=getobject&objectname=mcl-408-1014r&query=on](https://www.legislature.mi.gov/(S(fvlefderrr0c00xgoq3vu5h0))/mileg.aspx?page=getobject&objectname=mcl-408-1014r&query=on)

45. Michigan Department of Health and Human Services. Whitepaper: Perfluoroethylcyclohexane Sulfonate (PFECHS) – Current Knowledge of Physiochemical Properties, Environmental Contamination and Toxicity; 2020. <https://www.michigan.gov/-/media/Project/Websites/PFAS-Response/Workgroups/Human-Health/White-Paper-Physiochemical-Properties-Environmental-Contamination-Toxicity-PFECHS.pdf?rev=b86a48ec037549b29dbbace62c98fec8>
46. Hwang J, Taylor R, Macy G, Golla V. Comparison of Use, Storage, and Cleaning Practices for Personal Protective Equipment Between Career and Volunteer Firefighters in Northwestern Kentucky in the United States. *Journal of Environmental Health*. 2019;82(5):8.
47. Dahm MM, Bertke S, Allee S, Daniels RD. Creation of a retrospective job-exposure matrix using surrogate measures of exposure for a cohort of US career firefighters from San Francisco, Chicago and Philadelphia. *Occup Environ Med*. 2015;72(9):670-677. doi:10.1136/oemed-2014-102790
48. Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR PFAS Exposure Assessments Final Report. Published online January 4, 2023. doi:10.15620/cdc:122063
49. Agency for Toxic Substances and Disease Registry. Martinsburg Berkeley County West Virginia Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/ATSDR-PFAS-BerkeleyCounty-Report-508.pdf>.
50. Agency for Toxic Substances and Disease Registry. Westfield Hampden County Massachusetts Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2021. <https://www.atsdr.cdc.gov/pfas/docs/hampden-county-report-508.pdf>. Accessed July 6, 2023.
51. Minnesota Environmental Public Health Tracking Program. East Metro PFC3 Biomonitoring Project December 2015 Report to the Community. Minnesota Department of Health; 2015. <https://www.health.state.mn.us/communities/environment/biomonitoring/docs/pfc2015communityreport.pdf>.
52. Agency for Toxic Substances and Disease Registry. New Castle County Delaware near New Castle Air National Guard Base Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/ATSDR-PFAS-EA-Site-C-NewCastleCounty-Report-508.pdf>.
53. Agency for Toxic Substances and Disease Registry. Airway Heights Spokane County, Washington Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/ATSDR-PFAS-EA-Site-D-SpokaneCounty-Report-508.pdf>
54. Agency for Toxic Substances and Disease Registry. Lubbock County Texas, near Reese Technology Center Per and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/Lubbock-County-Report-508.pdf>.
55. Agency for Toxic Substances and Disease Registry. Security-Widefield El Paso County, Colorado Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/El-Paso-Report-508.pdf>
56. Agency for Toxic Substances and Disease Registry. Moose Creek Fairbanks North Star Borough, Alaska Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment Report. U.S. Department of Health and Human Services; 2022. <https://www.atsdr.cdc.gov/pfas/docs/Fairbanks-Report-508.pdf>
57. New York State Center for Environmental Health. Information Sheet: Hoosick Falls Area PFOA Biomonitoring Group-Level Results. New York State Department of Health; 2018. <https://www.health.ny.gov/environmental/investigations/hoosick/docs/infosheetgroupplong.pdf>

58. Firefighting Foam and PFAS. Accessed February 9, 2024.

<https://www.michigan.gov/pfasresponse/investigations/firefighting-foam>

59. Best Management Practices for the Use of AFFF. Accessed October 11, 2024.

<https://www.michigan.gov/pfasresponse/-/media/Project/Websites/PFAS-Response/Workgroups/Fire-Stations/AFFF-Best-Management-Practices.pdf?rev=4eccff380ff147e9bdee27ea9cbce596>

REPORT PREPARATION

Priyashi Manani, MPH, BDS

Lead Epidemiologist, Environmental Health Bureau
Michigan Department of Health and Human Services

Jacob Carrick, M.S.

Lead Toxicologist, Environmental Health Bureau
Michigan Department of Health and Human Services

Carissa Hueter, MPH

Epidemiologist, Environmental Health Bureau
Michigan Department of Health and Human Services

Jennifer Gray, Ph.D., DABT

Senior Toxicologist, Environmental Health Bureau
Michigan Department of Health and Human Services

Elizabeth Wasilevich, Ph.D., MPH

Division Director, Environmental Health Bureau
Michigan Department of Health and Human Services

Matthew Geiger, DrPH, M.S.

Division Director and Co-Principal Investigator, Division of Chemistry and Toxicology
Michigan Department of Health and Human Services

Kory Groetsch, M.S.

Bureau Director and Co-Principal Investigator, Environmental Health Bureau
Michigan Department of Health and Human Services

Appendix

Appendix A: Supplemental Information

Table S1. PFAS analytes and their abbreviations.

Abbreviation	Name	CAS Number	MDHHS Serum Method LOQ (µg/L)	NHANES Serum Method LOD (µg/L)	Most Recent NHANES Serum Data Year ^c	MDHHS Water Method RL (ng/L)
PFOS	Perfluorooctanesulfonic acid (branched and linear)	1763-23-1	NA ^a	NA ^b	2017-2018	NA ^a
L-PFOS	Perfluorooctanesulfonic acid (linear)	NA	0.0215	0.10	2017-2018	2
Br-PFOS	Perfluorooctanesulfonic acid (branched)	NA	0.0117	0.10	2017-2018	2
PFOA	Perfluorooctanoic acid (branched and linear)	335-67-1	NA ^a	NA ^b	2017-2018	NA ^a
L-PFOA	Perfluorooctanoic acid (linear)	NA	0.0214	0.10	2017-2018	2
Br-PFOA	Perfluorooctanoic acid (branched)	NA	0.025	0.10	2017-2018	2
PFHxS	Perfluorohexanesulfonic acid (branched and linear)	355-46-4	NA ^a	0.10	2017-2018	NA ^a
L-PFHxS	Perfluorohexanesulfonic acid (linear)	NA	0.0136	NA	NA ^d	2
Br-PFHxS	Perfluorohexanesulfonic acid (branched)	NA	0.0036	NA	NA ^d	2
PFNA	Perfluorononanoic acid	375-95-1	0.0178	0.10	2017-2018	2
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	0.0158	0.10	2017-2018	2
PFDA	Perfluorodecanoic acid	335-76-2	0.0215	0.10	2017-2018	2
PFUnA	Perfluoroundecanoic acid	2058-94-8	0.0181	0.10	2017-2018	2
PFecHS	Perfluoroethylcyclohexane sulfonate	646-83-3	0.0104	NA	NA ^d	2
MeFOSAA	N-Methylperfluorooctane sulfonamidoacetic acid	2355-31-9	0.0104	0.10	2017-2018	2
PFHpA	Perfluoroheptanoic acid	375-85-9	0.0110	0.10	2013-2014	2
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	0.0212	NA	NA ^d	2
PFBA	Perfluorobutanoic acid	375-22-4	0.0227	NA	NA ^d	6
PFTriA	Perfluorotridecanoic acid	72629-94-8	0.0202	NA	NA ^d	2
PFBS	Perfluorobutanesulfonic acid	375-73-5	0.0080	0.10	2013-2014	2
PFDoA	Perfluorododecanoic acid	307-55-1	0.0134	0.10	2015-2016	2
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonate	756426-58-1	0.0175	0.10	2017-2018	2

Abbreviation	Name	CAS Number	MDHHS Serum Method LOQ (µg/L)	NHANES Serum Method LOD (µg/L)	Most Recent NHANES Serum Data Year ^c	MDHHS Water Method RL (ng/L)
PFDS	Perfluorodecanesulfonic acid	335-77-3	0.0163	NA	NA ^d	5
EtFOSAA	N-Ethylperfluorooctane sulfonamidoacetic acid	2991-50-6	0.0150	0.10	2011-2012	2
5:3 FTCA	2H,2H,3H,3H-Perfluorooctanoic acid (3-perfluoropentyl propanoic acid)	914637-49-3	0.0209	NA	NA ^d	5
7:3 FTCA	2H,2H,3H,3H-Perfluorodecanoic acid (3-perfluoroheptyl propanoic acid)	812-70-4	0.0163	NA	NA ^d	5
8:2FTS	1H, 1H, 2H, 2H, perfluorodecane sulfonic acid	39108-34-4	0.0126	NA	NA ^d	2
NFDHA	Nonafluoro-3,6-dioxaheptanoic acid	151772-58-6	0.0226	NA	NA ^d	2
PFTeA	Perfluorotetradecanoic acid	376-06-7	0.0171	NA	NA ^d	2
PFEESA	Perfluoro (2-ethoxyethane) sulfonic acid	113507-82-7	0.0184	NA	NA ^d	2
PFHxA	Perfluorohexanoic acid	307-24-4	0.0101	0.10	2017-2018	2
PFOSA	Perfluorooctanesulfonamide	754-91-6	0.0217	0.10	2011-2012	2
PFMBA	Perfluoro-4-methoxybutanoic acid	863090-89-5	0.0128	NA	NA ^d	2
PFPrS	Perfluoropropanesulfonic acid	423-41-6	0.0089	NA	NA ^d	2
6:2FTS	1H, 1H, 2H, 2H, perfluorooctane sulfonic acid	27619-97-2	0.0234	NA	NA ^d	2
PFNS	Perfluorononanesulfonic acid	68259-12-1	0.0244	NA	NA ^d	2
ADONA	Dodecafluoro-3H-4,8-dioxanonanoate or 4,8-dioxa-3Hperfluorononanoic acid (ADONA)	919005-14-4	0.0126	0.10	2017-2018	2
PFHxSA	Perfluorohexanesulfonamide	41997-13-1	0.0123	NA	NA ^d	2
4:2FTS	1H, 1H, 2H, 2H, perfluorohexane sulfonic acid	757124-72-4	0.0241	NA	NA ^d	2
PFBSA	Perfluorobutanesulfonamide	30334-69-1	0.0133	NA	NA ^d	2
PFMPA	Perfluoro-3-methoxypropanoic acid	377-73-1	0.0088	NA	NA ^d	2
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonate	763051-92-9	0.0149	NA	NA ^d	2
3:3 FTCA	2H,2H,3H,3H-perfluorohexanoic acid (3-perfluoropropyl propanoic acid)	356-02-5	0.0219	NA	NA ^d	5
HFPO-DA	Hexafluoropropylene oxide dimer acid (GenX)	13252-13-6	0.0236	0.10	2017-2018	2
PFPeA	Perfluoropentanoic acid	2706-90-3	0.0130	NA	NA ^d	5

Abbreviations: NA, not applicable; LOQ, limit of quantitation; LOD, limit of detection; RL, reporting limit; $\mu\text{g/L}$, microgram per liter; ng/L , nanogram per liter.

^aCalculated sums do not have limit of quantifications (LOQs) or reporting limits (RLs).

^bBeginning with NHANES 2013-14, there is no limit of detection (LOD) for PFOA and PFOS because these values are a calculated sum.

^cCenters for Disease Control and Prevention. Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2021, Volume One. 2021.

^dThe analyte was not measured in NHANES.

Table S2. PFAS prevalence estimates for Michigan Firefighters and the U.S. population for PFAS measured in NHANES or detected in more than 60% of PFOMS participants.

Represents significantly **lower** findings compared to U.S. population.
 Represents significantly **higher** findings compared to U.S. population.

Abbreviation	PFOMS Prevalence Estimates (%) and 95% Confidence Interval	NHANES Prevalence Estimates (%) and 95% Confidence Interval	Total NHANES Participants (n)	NHANES Participants at or Above Detection Limit (n)	Most Recent NHANES Data Year ^a
PFOS ^b	100 (99.0-100)	NA ^b	NA ^b	NA ^b	2017-2018
L-PFOS	100 (99.0-100)	99.6 (99.1-99.8)	1,616	1,610	2017-2018
Br-PFOS	100 (99.0-100)	99.0 (98.4-99.4)	1,616	1,600	2017-2018
PFOA ^b	100 (99.0-100)	NA ^b	NA ^b	NA ^b	2017-2018
L-PFOA	100 (99.0-100)	99.6 (99.1-99.8)	1,616	1,609	2017-2018
Br-PFOA	14.5 (12.4-16.8)	9.3 (8.0-10.8)	1,616	150	2017-2018
PFHxS	99.3 (98.4-99.7)	99.2 (98.6-99.5)	1,616	1,603	2017-2018
L-PFHxS	99.3 (98.4-99.7)	NA	NA	NA	NA
PFNA	99.8 (99.2-100)	92.6 (91.3-93.8)	1,616	1,497	2017-2018
PFHpS	97.9 (96.8-98.7)	80.1 (78.0-82.1)	1,404	1,125	2017-2018
PFDA	97.0 (95.8-97.9)	89.4 (87.8-90.8)	1,616	1,445	2017-2018
PFUnA	80.3 (77.7-82.6)	69.1 (66.8-71.3)	1,616	1,116	2017-2018
PFecHS	73.4 (70.6-76.1)	NA	NA	NA	NA
MeFOSAA	81.2 (78.6-83.5)	58.8 (56.4-61.2)	1,616	950	2017-2018
PFHpA	54.4 (51.3-57.4)	10.9 (9.6-12.5)	1,766	193	2013-2014
PFBS	11.4 (9.6-13.5)	0.8 (0.5-1.3)	1,766	14	2013-2014
PFDoA	10.6 (8.8-12.7)	2.6 (2.0-3.5)	1,640	43	2015-2016
9CI-PF3ONS	5.8 (4.5-7.4)	13.7 (12.0-15.6)	1,404	193	2017-2018
EtFOSAA	6.8 (5.4-8.5)	5.7 (4.7-7.0)	1,560	89	2011-2012
PFHxA	1.2 (0.6-2.1)	0.50 (0.2-1.0)	1,404	7	2017-2018
PFOSA	1.0 (0.5-1.9)	0.80 (0.4-1.3)	1,560	12	2011-2012
ADONA	<0.6	0	1,404	0	2017-2018
HFPO-DA	<0.6	0.1 (0.0-0.4)	1,404	1	2017-2018

Abbreviation: NA, not applicable.

^aCenters for Disease Control and Prevention. Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2021, Volume One. 2021.

^bBeginning with NHANES 2013-14, there is no limit of detection (LOD) for PFOA and PFOS because these values are a calculated sum. As a result, the number of NHANES participants at or above the detection limit, total number of NHANES participants and NHANES detection frequency is not reported for PFOS and PFOA.

Bold values represent findings that are significantly different compared to the U.S. population.

Table S3. Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in blood of eligible PFOMS participants by sampling strata.

- Represents significantly **lower** findings compared to 1 or more other groups.
- Represents significantly **higher** findings compared to 1 or more other groups.
- Represents significantly **lower** and significantly **higher** findings compared to other groups.

Sampling Strata (n=1,023)	Non-Urban Airport (n=40)		Urban Airport (n=126)		City of Detroit (n=197)		Other Non-Urban (n=356)		Other Urban (n=304)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	9.71 (7.31-12.90)	100	8.25 (6.91-9.84)	100	4.90 (4.54-5.28)	100	4.46 (3.91-5.09)	100	5.18 (4.55-5.90)
Br-PFOS ^a	100	4.31 (2.58-7.21)	100	3.95 (3.59-4.35)	100	1.22 (1.13-1.32)	100	1.38 (1.14-1.68)	100	2.22 (1.74-2.82)
L-PFOS ^a	100	4.90 (3.41-7.04)	100	4.14 (3.21-5.34)	100	3.58 (3.30-3.89)	100	2.88 (2.56-3.23)	100	2.65 (2.29-3.06)
PFOA	100	1.19 (0.98-1.45)	100	1.06 (0.93-1.20)	100	1.04 (0.97-1.11)	100	0.79 (0.74-0.85)	100	0.95 (0.86-1.05)
L-PFOA ^a	100	1.19 (0.98-1.45)	100	1.06 (0.93-1.20)	100	1.02 (0.96-1.09)	100	0.77 (0.71-0.83)	100	0.94 (0.85-1.04)
PFHxS	100	1.72 (1.08-2.72)	100	1.28 (1.00-1.65)	99.0	1.31 (1.16-1.47)	98.9	0.96 (0.85-1.08)	100	1.04 (0.88-1.21)
L-PFHxS ^a	100	1.71 (1.08-2.72)	100	1.28 (1.00-1.64)	99.0	1.30 (1.16-1.47)	98.9	0.96 (0.85-1.08)	100	1.03 (0.88-1.21)
PFNA	100	0.47 (0.34-0.64)	92.9	0.38 (0.29-0.50)	100	0.45 (0.42-0.48)	99.7	0.37 (0.32-0.42)	100	0.33 (0.29-0.37)
PFHpS	97.5	0.29 (0.17-0.49)	98.4	0.22 (0.16-0.29)	99.0	0.21 (0.19-0.23)	97.2	0.17 (0.15-0.18)	98.7	0.16 (0.13-0.18)
PFDA	100	0.15 (0.11-0.20)	81.0	0.13 (0.09-0.19)	100	0.14 (0.13-0.15)	96.6	0.11 (0.10-0.13)	98.4	0.10 (0.09-0.11)
PFUnA	95.0	0.07 (0.05-0.11)	76.2	0.07 (0.05-0.09)	93.4	0.08 (0.07-0.09)	80.3	0.05 (0.05-0.06)	77.0	0.04 (0.04-0.05)
PFecHS	75.0	0.04 (0.02-0.08)	87.3	0.06 (0.04-0.09)	95.9	0.07 (0.07-0.08)	67.1	0.03 (0.03-0.04)	83.9	0.04 (0.03-0.06)

Sampling Strata (n=1,023)	Non-Urban Airport (n=40)		Urban Airport (n=126)		City of Detroit (n=197)		Other Non-Urban (n=356)		Other Urban (n=304)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
MeFOSAA	85.0	0.06 (0.05-0.08)	67.5	0.05 (0.03-0.07)	76.1	0.05 (0.04-0.05)	82.3	0.07 (0.06-0.08)	78.6	0.05 (0.04-0.05)
PFHpA^b	77.5	0.04 (0.03-0.05)	NC	NC	84.26	0.04 (0.03-0.04)	NC	NC	NC	NC
PFPeS	NC	NC	NC	NC	72.59	0.03 (0.03-0.03)	NC	NC	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter.

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^bValues for PFHpA and PFPeS were calculated for only those groupings where detection was above 60%.

Bold values represent findings that are significantly different compared to one or more other strata.

Table S4. Summary of detection frequencies and geometric means with 95% confidence intervals for a select set of PFAS (where detection >60%) in blood of eligible PFOMS participants for airport vs non-airport firefighters and urban vs non-urban non-airport firefighters.

□ Represents significantly **lower** findings compared to the other group.

□ Represents significantly **higher** findings compared to the other group.

Subgroup	Airport vs Non-Airport Firefighters (n=1,023)				Urban vs Non-Urban Non-Airport Firefighters (n=857)			
	Airport (n=166)		Non-Airport (n=857)		Urban ^a (n=501)		Non-Urban (n=356)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFOS	100	8.91 (7.53-10.53)	100	4.70 (4.28-5.17)	100	5.16 (4.57-5.82)	100	4.46 (3.91-5.09)
Br-PFOS	100	4.17 (3.33-5.23)	100	1.62 (1.38-1.91)	100	2.14 (1.70-2.71)	100	1.38 (1.14-1.68)
L-PFOS	100	4.45 (3.60-5.52)	100	2.81 (2.57-3.07)	100	2.69 (2.34-3.09)	100	2.88 (2.56-3.23)
PFOA	100	1.11 (0.99-1.25)	100	0.85 (0.80-0.91)	100	0.95 (0.86-1.05)	100	0.79 (0.74-0.85)
L-PFOA	100	1.11 (0.99-1.25)	100	0.83 (0.78-0.89)	100	0.94 (0.86-1.04)	100	0.77 (0.71-0.83)
PFHxS	100	1.46 (1.13-1.89)	99.3	1.00 (0.91-1.10)	99.6	1.04 (0.90-1.21)	99.0	0.96 (0.85-1.08)
L-PFHxS	100	1.46 (1.13-1.88)	99.3	1.00 (0.91-1.09)	99.6	1.04 (0.89-1.21)	99.0	0.96 (0.85-1.08)
PFNA	94.6	0.42 (0.35-0.52)	99.9	0.35 (0.32-0.39)	100	0.33 (0.29-0.38)	99.7	0.37 (0.32-0.42)
PFHpS	98.2	0.25 (0.19-0.33)	98.1	0.16 (0.15-0.18)	98.8	0.16 (0.14-0.19)	97.2	0.17 (0.15-0.18)
PFDA	85.5	0.14 (0.11-0.18)	98.0	0.11 (0.10-0.12)	99.0	0.10 (0.09-0.12)	97.0	0.11 (0.10-0.13)
PFUnA	80.7	0.07 (0.05-0.09)	82.1	0.05 (0.05-0.06)	83.4	0.05 (0.04-0.05)	80.3	0.05 (0.05-0.06)
PFecHS	84.3	0.05 (0.03-0.07)	79.7	0.04 (0.03-0.04)	88.6	0.04 (0.03-0.06)	67.1	0.03 (0.03-0.04)
MeFOSAA	71.7	0.05 (0.04-0.07)	79.6	0.06 (0.05-0.07)	77.6	0.05 (0.04-0.05)	82.3	0.07 (0.06-0.08)

Subgroup	Airport vs Non-Airport Firefighters (n=1,023)				Urban vs Non-Urban Non-Airport Firefighters (n=857)			
	Airport (n=166)		Non-Airport (n=857)		Urban ^a (n=501)		Non-Urban (n=356)	
	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L	% Detect	GM (95% CI) µg/L
PFHpA^c	NC	NC	NC	NC	61.7	0.02 (0.02-0.03)	NC	NC

Abbreviations: n, number; GM, geometric means; 95% CI, 95% confidence intervals; NC, not calculated; µg/L, microgram per liter

^aUrban includes the strata Urban Non-Airport and City of Detroit. Non-Urban includes only the Other Non-Urban strata.

^bAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^cValues for PFHpA were calculated for only those categories within sub-groups where detection was above 60%.

Bold values represent findings that are significantly different compared to the other group.

Table S5. Description of study participants for the PFOMS project and other firefighter studies.

Study	Sample Size (n)	Participants
PFOMS (2021-2023)	1,023	Firefighters from Michigan.
Řiháčková et al. (2023) ³⁶	52	Male firefighters (excluding new trainees) from the Czech Republic.
Burgess et al. (2023) - Fire Dept. A ³⁷	77	Male firefighters from departments in the Southwestern, Southeastern, or Northeastern U.S.
Burgess et al. (2023) - Fire Dept. B ³⁷	59	
Burgess et al. (2023) - Fire Dept. C ³⁷	59	
Burgess et al. (2023) - Fire Dept. D ³⁷	61	
Goodrich et al. (2021) ³⁸	197	Firefighters from Arizona, California, and Massachusetts.
Graber et al. (2021) ³⁵	116	Non-Hispanic white, male, volunteer firefighters from New Jersey.
Trowbridge et al. (2020) ³⁹	86	Female firefighters from California.
Dobraca et al. (2015) ²⁴	101	Firefighters from one county in southern California.
Rotander et al. (2015) ²¹	149	Firefighters working at AFFF training facilities in Australia.
Shaw et al. (2013) ⁴⁰	12	Firefighters from California who had worked in the fire service for at least 5 years and responded to fire scenes at least 20 times in the last 5 years. Their blood was sampled within 24 hours of responding to a fire.
Jin et al. (2011) ⁴²	36	Firefighters from West Virginia and Ohio who were part of a larger population in a region with PFOA contamination of drinking water.

Table S6. Summary of fire station water sampling data showing number of samples and stations with PFAS detections, number of samples and stations with exceedances of the MDHHS Comparison Values⁴² and maximum PFAS concentrations.

☐ Represents an exceedance of the MDHHS Comparison Value.

Analyte	Samples (n=238) with Detections Count (%)	Stations (n=122) with Detections Count (%)	Samples (n=238) with Exceedances Count (%)	Stations (n=122) with Exceedances Count (%)	Maximum Concentration (ng/L)	MDHHS Comparison Value (ng/L)
6:2FTS	2 (0.8)	2 (1.6)	0 (0.0)	0 (0.0)	62.31	NA
MeFOSAA	2 (0.8)	1 (0.8)	0 (0.0)	0 (0.0)	52.57	NA
PFOS	3 (1.3)	3 (2.5)	2 (0.8)	2 (1.6)	31.78	8
Br-PFOS ^a	2 (0.8)	2 (1.6)	0 (0.0)	0 (0.0)	17.24	NA
L-PFOS ^a	3 (1.3)	3 (2.5)	0 (0.0)	0 (0.0)	18.43	NA
PFOA	5 (2.1)	5 (4.1)	1 (0.4)	1 (0.8)	22.22	8
Br-PFOA ^a	1 (0.4)	1 (0.8)	0 (0.0)	0 (0.0)	2.85	NA
L-PFOA ^a	5 (2.1)	5 (4.1)	0 (0.0)	0 (0.0)	19.37	NA
PFHpA	1 (0.4)	1 (0.8)	0 (0.0)	0 (0.0)	20.65	NA
PFHxA	5 (2.1)	5 (4.1)	0 (0.0)	0 (0.0)	18.86	400,000
PFHxS	4 (1.7)	3 (2.5)	0 (0.0)	0 (0.0)	12.74	51
Br-PFHxS ^a	1 (0.4)	1 (0.8)	0 (0.0)	0 (0.0)	2.15	NA
L-PFHxS ^a	4 (1.7)	3 (2.5)	0 (0.0)	0 (0.0)	10.6	NA
PFOSA	4 (1.7)	3 (2.5)	0 (0.0)	0 (0.0)	9.7	NA
PFBS	8 (3.4)	5 (4.1)	0 (0.0)	0 (0.0)	3.92	420
PFUnA	3 (1.3)	2 (1.6)	0 (0.0)	0 (0.0)	3.11	NA
8:2FTS	1 (0.4)	1 (0.8)	0 (0.0)	0 (0.0)	3.1	NA
PFNA	1 (0.4)	1 (0.8)	0 (0.0)	0 (0.0)	2.94	6
Other PFAS ^b	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	<RL	NA

Abbreviations: n, number; ng/L, nanogram per liter; NA, not available; <RL, less than the reporting limit.

^aAnalytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

^bOther PFAS: 11Cl-PF3OUdS, 3:3 FTCA, 4:2FTS, 5:3 FTCA, 7:3 FTCA, 9Cl-PF3ONS, ADONA, EtFOSAA, HFPO-DA, NFDHA, PFBA, PFBSA, PFDA, PFDoA, PFDS, PFecHS, PFEESA, PFHpS, PFHxSA, PFMBA, PFMPA, PFNS, PFPeA, PFPeS, PFPrS, PFTeA, PFTriA.

Bold values represent number of samples or stations with exceedances.



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