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Serum Concentration of Selected Per- and Polyfluoroalkyl Substances (PFAS) by Industry and Occupational Groups Among US Adult Workers, NHANES 2005–2014

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Abstract

Purpose: Per- and polyfluoroalkyl substances (PFAS) are associated with multiple health effects including pregnancy-induced hypertension and pre-eclampsia, increased serum hepatic enzymes, increased in serum lipids, decreased antibody response to vaccines, and decreased birth weight. Millions of US workers are exposed to PFAS at their workplaces. Our objective was to estimate the serum levels of the five PFAS that are most frequently detected in the US general population(perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), perfluorodecanoic acid (PFDA), and perfluorononanoic acid (PFNA)) among US adult workers.

This article is a U.S. Government work and is in the public domain in the USA.

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Author Contributions

Ja K. Gu: conception or design of the study, statistical analysis and interpretation of results, writing – original draft, final approval of version to be published. **Luenda E. Charles:** conception or design of the study, writing – original draft, interpretation of results, final approval of version to be published, supervision. **Choi Seung Lim:** writing – review and editing, final approval of version to be published. **Anna Mnatsakanova, Stacey Anderson, and Lisa Dzubak:** Study administration, writing – review and editing, interpretation of data, final approval of version to be published. **Erin McCanlies:** interpretation of results, writing and editing of the manuscript, final approval of version to be published.

Disclosure by AJIM Editor of Record

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

Ethics Statement

The National Health and Nutrition Examination Survey (NHANES) data were approved by the Research Ethics Review Board of the National Center for Health Statistics. For this study, a secondary data analysis, publicly available NHANES data were used, and National Institute for Occupational Safety and Health Internal Review Board approval was not required.

Conflicts of Interest

The authors declare no conflicts of interest.

Methods: Participants were 4476 workers aged ≥ 20 years with PFAS analyte results available who participated in the National Health and Nutrition Examination Survey (NHANES), 2005–2014. Geometric mean serum levels of PFAS (ng/mL) were obtained across industry and occupation groups using the PFAS subsample weight in SAS-callable SUDAAN V11.

Results: Among 21 industry groups, the highest geometric mean PFAS levels (ng/mL) were observed in Construction (PFOS = 12.61 ng/mL, PFOA = 3.76, PFHxS = 2.10, PFNA = 1.23, and PFDA = 0.33), followed by Utilities (PFOS = 12.46), and Real Estate/Rental/Leasing (PFOS = 12.15). The lowest geometric mean PFAS levels were seen in Private Households (PFOS = 6.34, PFOA = 2.12, PFHxS = 0.75, PFNA = 0.86, and PFDA = 0.25). Among 22 occupation groups, the highest geometric mean PFAS levels were observed in Life/Physical/Social Science occupations (PFOS = 13.19, PFOA = 3.54, PFHxS = 1.69, PFNA = 1.23, and PFDA = 0.33), followed by Installation/Maintenance/Repair occupations (PFOS = 12.75), and Construction/Extraction occupations (PFOS = 12.15). The lowest geometric mean PFAS levels were found in Personal Care/Service occupations (PFOS = 7.25, PFOA = 2.43, PFHxS = 1.07, PFNA = 0.94, and PFDA = 0.25).

Conclusions: Some industry and occupation groups had higher geometric mean levels of PFAS in serum compared to others. Further investigation of these industries and occupations may result in a better understanding of the sources and degree of occupational exposure to PFAS.

Keywords

Industry; NHANES; occupation; PFAS; US workers

1 | Introduction

Research on the prevalence of per- and polyfluoroalkyl substances (PFAS) exposure and its health effects has dramatically increased over the past two decades. However, PFAS has been present in our environment since the 1950s and exposure to humans has been known to occur through a variety of consumer products, ingestion of food and water, and inhalation of indoor dust [1]. PFAS include many different substances but those that have been commonly studied include perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA).

Epidemiologic and experimental studies have established associations between increased levels of PFAS (usually analyzed from whole blood or serum specimens) and adverse health effects. Exposure to several PFAS have been shown to be associated with pregnancy-induced hypertension and preeclampsia, increased serum hepatic enzymes, detrimental changes in serum lipids, decreased antibody response to vaccines, and decreased birth weight [2]. Some studies have shown that PFOA exposure is associated with ulcerative colitis and rheumatoid arthritis [3] and PFOS exposure has been linked to increased deaths from bladder cancer [4]. Results from a meta-analysis conducted by Yao et al. [5] suggest that prenatal exposure to high levels of PFOA may be positively associated with attention deficit hyperactivity disorder (ADHD), and prenatal exposure to PFOS and PFNA may be negatively associated with autism spectrum disorder (ASD).

PFAS have many applications in diverse industries, including waxing materials, textiles, firefighting foam, medical devices, paints, personal care products, construction materials, and industrial processing aids [6]. PFAS are widely used in the textile and leather industries as waterproof membranes and surface finishes to impart water, oil, and stain resistance [7, 8]. They are prevalent in food processing and handling for their non-stick properties and grease, oil, and water resistance [9]. They can also be found in construction for weatherproofing, corrosion prevention, and stain resistance in carpets and rugs, tiles and concrete sealers, roofing, flooring, sealants, glass, wires and cables, tape, and paints [10-12].

Among workers who handle PFAS-treated products, inhalation is the most likely route of occupational exposure with dermal exposure also a potential route [2]. Recently published review studies showed that workers in ski waxing had the highest exposure to PFOA and PFNA airborne concentrations, while workers in textiles had the highest exposure to PFOA [13-15]. Professional ski wax technicians exhibit high exposure to PFAS from glide wax used on skis [13]. A study conducted on textile workers in China found that PFAS exposure was five times higher than that of the general Western population [16].

Firefighters' PFAS (PFOS, PFOA, PFNA, and PFHxS) serum concentrations were much higher than that of the general population [13-15, 17, 18] due to the use of Class B firefighting foam for suppression of liquid fuel fires and use in protective equipment [19-22]. Graber and colleagues [19] found that serum concentrations of PFDA, PFNA, and perfluorododecanoic acid (PFDoA) were higher among active firefighters in New Jersey than in the US general population. Firefighters exposed to aqueous film forming foam (AFFF) had high serum levels of PFOS and PFHxS [20-22]. The first responders to the World Trade Center collapse in September 2001, exposed to dust and smoke, had high serum concentrations of PFAS [23]. A recent study revealed that the interaction of PFAS and occupation was associated with elevated allostatic load, indicating the effects of accumulated stress [24].

The chemical composition of PFAS makes them very stable [25]. The half-life estimates of PFAS in humans vary widely according to reports in observational studies. The US Agency for Toxic Substances and Disease Registry [2] reported estimated half-lives of 3.3–27.0 years for PFOS, 2.1–10.1 years for PFOA, 4.7–35.0 years for PFHxS, 2.5–4.3 years for PFNA. A recent review study by Rosato and colleagues estimated the half-life in humans ranged from 3.4 to 5.7 years for PFOS, 1.5–5.1 years for PFOA, and 2.8–8.5 years for PFHxS [26]. Mean PFOA levels ranged from 1.54 to 15.2 pg/m³ in urban air samples in the United States, Norway, and Japan [2]. PFOS levels in ambient air are generally < 5 pg/m³ [2].

Despite the widespread use of PFAS in textile, food processing, and construction industries, there are limited reports on PFAS serum concentrations among workers. It is important to identify the industries or occupational groups that have higher levels of PFAS exposure. Such knowledge would allow employers to devise and implement protective measures to reduce exposures in the workplace and thereby protect the health of their workers. This study aims to provide valuable insights into serum PFAS levels across different industries and occupations. Therefore, the current study examined the mean concentrations of five

PFAS (PFOS, PFOA, PFNA, PFHxS, and PFDA) by demographic characteristics (sex, age, race/ethnicity, country of birth), and educational level and by 21 industry and 22 occupation groups among US workers in the National Health and Nutrition Examination Survey (NHANES) 2005–2014.

2 | Materials and Methods

2.1 | Data Source and Study Design

This is a descriptive study. Information on the PFAS variables was obtained from NHANES, 2005–2014. The NHANES has been designed as a nationally representative and complex cross-sectional survey conducted in 2-year cycles utilizing questionnaires, physiological examination, and laboratory tests. Detailed information on the questionnaires, methodologies, data, and documentation is available on the NHANES website <https://wwwn.cdc.gov/nchs/nhanes/AnalyticGuidelines.aspx> (accessed March 20, 2024).

In this study, we included participants aged 20 years and older who underwent blood tests for PFAS, reported their industry and occupation information, and were currently employed ($N = 4476$). Analyses for this study are based on data collected from the five NHANES survey cycles from 2005–2006 to 2013–2014. The selection of cycles was determined by the availability of industry and occupation data. The recent NHANES 2015–2016 and 2017–March 2020 (Pre-Pandemic) public-released data files do not include the industry and occupation codes. A flowchart outlining the inclusion and exclusion criteria of this study is presented in Supporting Information S1: Figure I. Detailed sample sizes by demographics and industry/occupation groups are provided in the first column of each table. The ethics approval for the NHANES was obtained from the Ethics Review Board of the National Center for Health Statistics (NCHS) [27], and all adult participants provided written informed consent.

2.2 | PFAS Measurement

Serum PFAS concentrations were obtained from blood samples collected during the health examination. PFAS concentrations were measured among a random subsample comprising approximately one-third of individuals aged 12 years and older in each NHANES cycle. We used the NHANES-provided sample weight that accounts for this subsampling to appropriately calculate nationally representative estimates.

We assessed the distribution of five major serum PFAS compounds, including PFOS, PFOA, PFHxS, PFNA, and PFDA. The five PFAS were measured in NHANES cycles from 2005–2006 to 2011–2012. In the 2013–2014 cycle, the concentrations of linear PFOA (n-PFOA) and the sum of branched isomers of PFOA (Sb-PFOA) for PFOA, and those of linear PFOS (n-PFOS) and the sum of perfluoromethylheptane sulfonate isomers (Sm-PFOS) for PFOS were summed to estimate the total concentrations of PFOA and PFOS for each participant [28].

Serum specimens are processed, stored, and shipped to the Division of Environmental Health Laboratory Sciences, National Center for Environmental Health, CDC, for analysis. PFAS quantitation in serum used solid phase extraction coupled with High Performance

Liquid Chromatography-isotope dilution-tandem Mass Spectrometry [29]. The limits of detection for the serum PFAS varied from 0.08 to 0.20 ng/mL over the cycles as shown in Supporting Information S1: Table I. If the value of one isomer was less than the limit of detection (LOD), then the imputed value was used. The imputed value was calculated as the LOD divided by the square root of 2 [28]. The detailed specimen collection and laboratory methods are reported in the NHANES MEC Procedures Manual and Laboratory Procedure Manual [30, 31].

2.3 | Demographics and Industry/Occupation

Demographic data were obtained from the NHANES household questionnaire. The data included sex (male, female), age (20–34, 35–49, 50–64, 65+ years), race and Hispanic ethnicity (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic other races or multiple races, and Hispanic), and country of birth (United States, other countries including US territories). At the time of these analyses, the most recent data available from the NHANES occupational questionnaire was for 2005–2006 through 2013–2014. The data were coded into occupation and industry groups based on 4-digit US Census Bureau codes that are consistent with the Standard Occupational Classification (SOC) system and the North American Industry Classification System (NAICS). The public-use data files provided 22 broad industry groups and 23 broad occupational groups. We included all industry and occupation groups in this study with the exception of ‘Armed Forces’.

2.4 | Statistical Analysis

Descriptive statistics are provided for the participants’ demographic characteristics and for mean levels of serum PFAS by these characteristics. The geometric mean was used to assess the PFAS serum concentration. The geometric mean is commonly used to estimate central tendency for data that are distributed with a long tail. The geometric mean estimates and 95% confidence intervals were generated using NHANES survey subsample weights for US nationally representative estimates, considering the complex survey design and adjusted for age and survey cycle. Unreliable estimates, characterized by sample sizes less than 30 or relative standard errors exceeding 0.3, are marked with a symbol (P) in the analysis tables [32]. All data analyses were performed using SAS-callable SUDAAN v12 software provided Research Triangle Institute, Research Triangle Park, North Carolina.

3 | Results

The distribution of demographic characteristics and the geometric means of the five PFAS by selected demographic variables among US workers ages 20 years and older shown in Table 1. During 2005 to 2014, the overall geometric means of serum level of PFAS among US workers were as follows: PFOS, 9.72 ng/mL (95%CI: 9.30–10.16); PFOA, 3.07 (2.97–3.18); PFHxS, 1.58 (1.49–1.67); PFNA, 1.06 (1.01–1.11); and PFDA, 0.27 (0.26–0.29). Male workers, persons aged ≥ 50 years, Non-Hispanic Whites and Blacks, and those born in the US had higher serum levels of PFAS during this period compared to other workers in their respective groups. There was a notable decrease in PFAS concentrations in the 2013–2014 cycle compared to the 2005–2006 cycle. For example, the geometric mean of

serum PFOS concentration significantly dropped from 17.53 ng/mL in the 2005–06 cycle to 5.31 ng/mL in the 2013–2014 cycle (p -value for trend < 0.0001).

Geometric means of PFAS levels for industry groups among US adult workers are presented in Table 2. Among the 21 industry groups, the highest geometric mean serum PFOS concentration was observed in Construction (12.46 ng/mL; 95% CI: 11.43–13.58) and Real Estate/Rental/Leasing (12.51; 9.71–16.12) followed by Utilities (11.18; 8.56–14.61) and Agriculture/Forestry/Fishing (11.59; 9.32–14.41). The lowest geometric mean serum PFOS concentration was found in Private Households (7.39; 6.14–8.88) followed by Health Care/Social Assistance (8.12, CI: 7.49–8.81) and Accommodation/Food Services (7.99; 7.23–8.84). Similarly, the highest geometric mean serum PFOA concentration was observed in Construction (3.80; 3.55–4.06) followed by Transportation/Warehousing (3.54; 3.25–3.87) and Real Estate/Rental/Leasing (3.59; 3.13–4.11). The lowest geometric mean serum PFOA concentration was found in Private Households (2.53; 2.22–2.89), followed by Accommodation/Food Services (2.62; 2.40–2.86) and Health Care/Social Assistance (2.55; 2.35–2.76). The serum concentrations of PFHxS, PFNA, and PFDA were notably lower than those of PFOS and PFOA across all industry groups. Construction exhibited the highest geometric mean concentrations of PFHxS (2.11; 1.89–2.35), PFNA (1.22; 1.10–1.34), and PFDA (0.33; 0.29–0.36), while Private Households had the lowest geometric mean concentrations across these three PFAS compounds.

The geometric mean serum PFAS concentration by occupation groups shown in Table 3. Among the 22 occupation groups, the geometric mean serum PFOS concentrations ranged from 7.03 ng/mL (95% CI: 5.75–8.55) in Farming/Fishing/Forestry Occupations to 12.98 (11.62–14.49) in Installation/Maintenance/Repair Occupations. Other occupations with high serum PFOS concentration included Construction/Extraction occupations (11.83; 10.90–12.83). Similarly, the highest geometric mean serum PFOA and PFHxS concentrations were observed in Installation/Maintenance/Repair occupations (3.97; 3.64–4.33 for PFOA and 2.17; 1.80–2.61 for PFHxS), followed by Construction/Extraction occupations (3.69; 3.44–3.96 for PFOA and 2.07; 1.83–2.33 for PFHxS). The lowest geometric mean serum PFOA concentration was found in Farming/Fishing/Forestry occupations (1.58; 1.29–1.94), followed by Healthcare Support occupations (2.38; 2.08–2.73) and Food Preparation/Serving occupations (2.51; 2.27–2.79). Similarly, the lowest geometric mean serum PFHxS concentration was found in Farming/Fishing/Forestry occupations (0.95; 0.67–1.35), followed by Personal Care/Service occupations (1.12; 0.93–1.34) and Food Preparation/Serving occupations (1.23; 1.07–1.40). Again, since the small sample size, the estimate for Farming/Fishing/Forestry occupations should be cautiously interpreted. Furthermore, workers in Business/Financial Operations occupations had the highest geometric mean level of serum PFNA, while those in four occupational groups (Construction/Extraction, Community/Social Service, Life/Physical/Social Science, and Business/Financial occupations) had the highest level of serum PFDA concentration.

4 | Discussion

The findings of this study highlight the variations in serum PFAS concentrations among US workers across different demographic, occupational, and industry groups. The observed

disparities in PFAS concentrations across industries and occupations suggest that certain environments may pose a higher risk of exposure, that may warrant further investigation. Additionally, the overall decline in PFAS levels over the study period aligns with previous research and may reflect industry-wide phase-outs of certain PFAS compounds. However, the persistence of these chemicals in some worker groups may benefit from continued monitoring and preventive measures. The following sections explore these findings in greater detail, focusing on differences by demographic characteristics, industry affiliations, and occupational roles.

4.1 | PFAS by Demographics

This study used pooled NHANES Lab data from 2005–2014 to estimate the serum PFAS concentrations of US adult workers across selected demographic characteristics, occupations, and industries. Our findings show that women, Hispanics, and non-US-born workers had lower mean serum concentrations of PFAS. These results are consistent with previous studies conducted on the US adult population [33, 34]. Additionally, we observed a dramatic decrease in PFAS concentrations among workers from 2005–2006 to 2013–2014 cycle, consistent with findings reported by Sonnenberg and colleagues [34]. This decline is likely influenced by the reduction in the use of PFAS chemicals in the United States since 2000 and may continue to decline as additional PFAS products are phased out through 2025 [35, 36]. Moreover, many manufacturers have developed non-fluorinated alternatives to PFAS-based finishing agents in response to increasing demand for more environmentally friendly options [37, 38]. Additionally, both federal and state governments in the US have implemented regulations on the sale and distribution of products containing PFAS [39–41].

4.2 | PFAS by Industry Groups

The primary findings of this study show that there are wide variations in the mean serum PFAS concentrations across the 21 industries and 22 occupation groups. Among industry groups, the workers in Construction and Real Estate/Rental/Leasing sectors exhibited the highest mean serum PFAS concentration, followed by Utilities, while those in Private Households had the lowest mean serum PFAS concentration, followed by Health Care/Social Assistance and Accommodation/Food Services sectors.

This study found that those who were employed in Construction sector had one of the highest serum PFAS concentrations. PFAS chemicals are widely used in various building materials due to their resistance to heat, stains, oils, and water. These materials include roofing shingles (such as metal and asphalt shingles), weatherproofing membranes for flat and low-slope roofs, gutters, concrete, glass panels, ceramic fixtures, paints, carpets, caulking sealants, electric wires and cables, tapes, and composite wood products like plywood and wood fiber insulation [10, 42]. An Australian study has demonstrated that effective management practices (including enforcement and policing) and new treatment methods can address PFAS contamination in the construction industry [43].

We also found elevated serum PFAS concentrations among workers in the Utility sector. Within the energy industry, including renewable or alternative energy sectors, PFAS chemicals are extensively used in various materials or equipment, including sheathing for

power cables, coatings for electrical wires, wind turbines, hydrogen fuel cells, high-capacity batteries, and solar panels [44]. It is possible that workers in energy-related fields may be exposed to PFAS [45]. This issue could warrant further study. Workers in Real Estate/Rental/Leasing sector had highest exposure to PFOS and PFOA. There are no reports as to how those in Real Estate may be exposed to PFAS. However, workers in ski rental and leasing, especially professional ski waxers, had up to 25 times higher PFOS serum concentration than the general population due to workroom aerosols and ski waxes in a Norwegian study [46]. These workers may represent those with high PFAS concentration in the "Leasing" area of the Real Estate/Rental/Leasing sector.

Despite the widespread use of PFAS chemicals in various industries, we found that workers in the Agriculture/Fishing/Forestry sectors had high serum PFOS concentrations. PFAS have also found application in the agriculture industry. Certain pesticides contain PFAS to enhance wetting and penetration of insecticides. Lasee and colleagues found PFOS in 6 out of 10 tested insecticide formulae. Residual PFAS from these applications may remain in soil and be absorbed by crops in areas where insecticides are sprayed [47]. Given the broad range of activities within Agriculture, Fishing, and Forestry, future studies could analyze these industry sectors separately to better understand occupational exposure patterns.

4.3 | PFAS by Occupational Groups

For occupational groups, Installation/Maintenance/Repair occupations showed the highest mean serum PFAS concentration, followed by Construction/Extraction occupations. Food Preparation/Serving occupations had the lowest mean serum PFAS concentration, followed by Health Care Support/Service occupations and Personal Care/Service occupations. These findings underscore the importance of considering industry- and occupation-specific exposures when assessing serum PFAS concentrations in workers.

This study found that workers in Construction/Extraction occupations had the highest serum PFAS concentrations. Construction materials use PFAS for weatherproofing, corrosion prevention, and friction reduction, leading to higher exposure among workers in construction, maintenance, and manufacturing plants involved in producing these materials [11]. Additionally, due to their flame-retardant properties, chemical inertness, hydrophobicity, and dielectric strength, PFAS are intentionally incorporated into production in the electronics industry, including electronic devices, manufacturing processes, and semiconductor production [48].

Additionally, our study identified workers in Installation/Maintenance/Repair Occupations as having elevated serum PFAS concentrations. Fluoropolymers, a subset of PFAS, are extensively employed in the automotive industry for various applications. Fluoropolymers, a subset of PFAS, are used for various applications which include fuel lines, hoses (such as those for turbochargers and hydraulic systems), ABS brake lines, fuel containment and injection systems, lubricants, cylinder head gaskets, emissions reduction systems, and fuel cells and batteries in electric vehicles [49, 50]. Individuals working in auto repair shops, including workers and owners, are probably also exposed to occupational hazards associated with PFAS.

4.4 | Limitations and Strengths

Limitations of this study should be noted alongside its strengths. While we compared serum PFAS concentrations among workers by industry and occupation groups, we are aware that individual serum PFAS concentrations would not result solely from occupational activities. Factors like individual lifestyles, including dietary habits and drinking habits at home, and exposure to materials in the living environment can also influence serum concentrations [2].

Second, the classification of 21 industries and 22 occupation groups used in this study is very broad, which may limit our ability to explore specific areas where high PFAS are used. For instance, a review article reported that workers in fluorochemical production plants had the highest serum concentrations (ranging from 120 to 11,000 ng/mL) [15]. As we mentioned in the Methods section, many PFAS have been phased out and replaced since 2000, and the current findings do not take into account these replacements. Data on occupation and industry from 2015–2016 and 2017–2018 have not been coded into Census industry and occupation groups, and industry and occupation were not collected in subsequent cycles. Additionally, classification codes were based on current work status, which may lead to misclassification, especially for workers who have changed jobs before or during the study period. Another limitation concerns the duration (i.e., half-life) of PFAS in the body. We do not have specific information on the excretion rates of each PFAS. However, research has shown that the estimated half-lives of PFAS vary widely due to several environmental and biological factors [2, 26, 33, 51], and thus readers could interpret our results keeping this limitation in mind.

Despite these limitations, a significant strength of this study lies in its utilization of a nationally representative database to obtain blood sample measurements and its adherence to a standardized classification system for occupational and industry groups.

4.5 | Conclusion

In conclusion, our study reveals that workers in the construction, utilities, and installation/repair industry sectors exhibit elevated serum PFAS concentrations. These findings may contribute to the identification of worker groups with higher PFAS exposure for future studies investigating potential health impacts of occupational PFAS exposure. Future studies on PFAS exposure in the working population could consider more detailed occupational and industry groups, as PFAS levels can vary significantly within specific industry settings. By delving deeper into these variations, we can better understand the effects of PFAS on worker health and develop targeted interventions to mitigate potential risks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Abbreviations:

NAICS	North America Industry Classification System
NHANES	National Health and Nutrition Examination Survey
PFAS	per- and polyfluoroalkyl substances (includes PFDA, PFHxS, PFNA, PFOA, PFOS)
PFDA	perfluorodecanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid

References

1. "The Family Tree of Per- and Polyfluoroalkyl Substance (PFAS) for Environmental Health Professionals Names and Abbreviations, NCEH Fact Sheet," Agency for Toxic Substances and Disease Registry (ATSDR), 2017, <https://www.atsdr.cdc.gov/pfas/docs/PFAS-FamilyTree-Community.pdf>.
2. Agency for Toxic Substances and Disease Registry (ATSDR), Toxicological Profile for Perfluoroalkyls (US Department of Health and Human Services, Public Health Service, 2021), 10.15620/cdc:59198, <https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=1117&tid=237>.
3. Steenland K, Zhao L, and Winquist A, "A Cohort Incidence Study of Workers Exposed to Perfluorooctanoic Acid (PFOA)," *Occupational and Environmental Medicine* 72, no. 5 (May 2015): 373–380, 10.1136/oemed-2014-102364. [PubMed: 25601914]
4. Alexander BH, Olsen GW, Burris JM, Mandel JH, and Mandel JS, "Mortality of Employees of a Perfluorooctanesulphonyl Fluoride Manufacturing Facility," *Occupational and Environmental Medicine* 60, no. 10 (October 2003): 722–729, 10.1136/oem.60.10.722. [PubMed: 14504359]
5. Yao H, Fu Y, Weng X, et al. , "The Association Between Prenatal Per- and Polyfluoroalkyl Substances Exposure and Neurobehavioral Problems in Offspring: A Meta-Analysis," *International Journal of Environmental Research and Public Health* 20, no. 3 (2023): 1668, 10.3390/ijerph20031668. [PubMed: 36767045]
6. National Institute of Occupational Safety and Health (NIOSH), Per- and Polyfluoroalkyl Substance (PFAS) (PFAS and Worker Health, PFAS, CDC, 2022).
7. "PFAS in the Textile and Leather Industries," Minnesota Pollution Control Agency (MPCA), May 2023, <https://www.pca.state.mn.us/sites/default/files/gp3-06.pdf>.
8. Whiting R, Nicol L, Keyte I, et al. "The Use of PFAS and Fluorine-Free Alternatives in Textiles, Upholstery, Carpets, Leather and Apparel," Wood, 2020, https://echa.europa.eu/documents/10162/13641/pfas_in_textiles_final_report_en.pdf/0a3b1c60-3427-5327-4a19-4d98ee06f041.

9. "Authorized Uses of PFAS in Food Contact Applications," Food and Drug Administration (FDA), <https://www.fda.gov/food/process-contaminants-food/authorized-uses-pfas-food-contact-applications#:~:text=Some%20PFAS%20are%20used%20in,are%20authorized%20for%20the%20market>.
10. "Per- and Polyfluoroalkyl Substances and Alternatives in Coatings, Paints and Varnishes (CPVs)," Organization for Economic Co-operation and Development (OECD), Report on the Commercial Availability and Current Uses, OECD Series on Risk Management, No. 70, Environment, Health and Safety, Environment Directorate, OECD, 2022, [https://one.oecd.org/document/ENV/CBC/MONO\(2022\)4/en/pdf](https://one.oecd.org/document/ENV/CBC/MONO(2022)4/en/pdf).
11. Fernández SR, Kwiatkowski C, and Bruton T, BUILDING A BETTER WORLD: Eliminating Unnecessary PFAS in Building Materials (Green Science Policy Institute (GSPI), 2021), <https://greensciencepolicy.org/docs/pfas-building-materials-2021.pdf>.
12. "The Use of PFAS and Fluorine-Free Alternatives in Textiles, Upholstery, Carpets, Leather and Apparel," European Commission (EC), Published in Wood, 2020, Doc Ref. 42054-WOOD-XX-XX-RP-OP-0004_S4_P01.3, https://saicmknowledge.org/sites/default/files/resources/pfas_in_textiles_final_report_en.pdf.
13. Lucas K, Gaines LGT, Paris-Davila T, and Nylander-French LA, "Occupational Exposure and Serum Levels of Per- and Polyfluoroalkyl Substances (PFAS): A Review," American Journal of Industrial Medicine 66, no. 5 (2023): 379–392, 10.1002/ajim.23454. [PubMed: 36573587]
14. Paris-Davila T, Gaines LGT, Lucas K, and Nylander-French LA, "Occupational Exposures to Airborne Per- and Polyfluoroalkyl Substances (PFAS)—A Review," American Journal of Industrial Medicine 66, no. 5 (2023): 393–410, 10.1002/ajim.23461. [PubMed: 36719301]
15. Christensen BT and Calkins MM, "Occupational Exposure to Per- and Polyfluoroalkyl Substances: A Scope Review of the Literature From 1980–2021," Journal of Exposure Science & Environmental Epidemiology 33 (2023): 673–686. [PubMed: 36977833]
16. Heydebreck F, Tang J, Xie Z, and Ebinghaus R, "Emissions of Per- and Polyfluoroalkyl Substances in a Textile Manufacturing Plant in China and Their Relevance for Workers' Exposure," Environmental Science & Technology 50, no. 19 (2016): 10386–10396. [PubMed: 27617679]
17. Dobraca D, Israel L, McNeel S, et al. , "Biomonitoring in California Firefighters: Metals and Perfluorinated Chemicals," Journal of Occupational & Environmental Medicine 57, no. 1 (January 2015): 88–97, 10.1097/JOM.0000000000000307. [PubMed: 25563545]
18. Burgess JL, Fisher JM, Nematollahi A, et al. , "Serum Per- and Polyfluoroalkyl Substance Concentrations in Four Municipal US Fire Departments," American Journal of Industrial Medicine 66, no. 5 (May 2023): 411–423, 10.1002/ajim.23413. [PubMed: 35864570]
19. 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," International Journal of Environmental Research and Public Health 18, no. 7 (2021): 3730, 10.3390/ijerph18073730. [PubMed: 33918459]
20. Rotander A, Toms LML, Aylward L, Kay M, and Mueller JF, "Elevated Levels of PFOS and PFHxS in Firefighters Exposed to Aqueous Film Forming Foam (AFFF)," Environment International 82 (2015): 28–34, 10.1016/j.envint.2015.05.005. [PubMed: 26001497]
21. Laitinen JA, Koponen J, Koikkalainen J, and Kiviranta H, "Firefighters' Exposure to Perfluoroalkyl Acids and 2-Butoxyethanol Present in Firefighting Foams," Toxicology Letters 231, no. 2 (2014): 227–232, 10.1016/j.toxlet.2014.09.007. [PubMed: 25447453]
22. Jin C, Sun Y, Islam A, Qian Y, and Ducatman A, "Perfluoroalkyl Acids Including Perfluorooctane Sulfonate and Perfluorohexane Sulfonate in Firefighters," Journal of Occupational & Environmental Medicine 53, no. 3 (2011): 324–328, 10.1097/JOM.0b013e31820d1314. [PubMed: 21346631]
23. Tao L, Kannan K, Aldous KM, Mauer MP, and Eadon GA, "Biomonitoring of Perfluorochemicals in Plasma of New York State Personnel Responding to the World Trade Center Disaster," Environmental Science & Technology 42, no. 9 (2008): 3472–3478, 10.1021/es8000079. [PubMed: 18522136]
24. Bashir T and Obeng-Gyasi E, "Interaction of Per- and Polyfluoroalkyl Substances and Allostatic Load Among Adults in Various Occupations," Diseases 10, no. 2 (2022): 26, 10.3390/diseases10020026. [PubMed: 35645247]

25. Cousins IT, DeWitt JC, Glüge J, et al. , “Strategies for Grouping Per- and Polyfluoroalkyl Substances (PFAS) to Protect Human and Environmental Health,” *Environmental Science: Processes & Impacts* 22 (2020): 1444–1460. [PubMed: 32495786]
26. Rosato I, Bonato T, Fletcher T, Batzella E, and Canova C, “Estimation of Per- and Polyfluoroalkyl Substances (PFAS) Half-Lives in Human Studies: A Systematic Review and Meta-Analysis,” *Environmental Research* 242 (2024): 117743, 10.1016/j.envres.2023.117743. [PubMed: 38008199]
27. “NCHS Ethics Review Board Approval,” Centers for Disease Control and Prevention (CDC), National Center for Health Statistics, 2022, <https://www.cdc.gov/nchs/nhanes/irba98.htm#print>.
28. “NHANES 2013-2014 Data Documentation Codebook and Frequencies, Perfluoroalkyl and Polyfluoroalkyl Substances—Linear and Branched PFOS and PFOA Isomers (Surplus),” Centers for Disease Control and Prevention (CDC), National Center for Health Statistics, 2022, https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/SSPFAS_H.htm.
29. “NHANES 2005-2006 Data Documentation Codebook and Frequencies, Polyfluoroalkyl Chemicals,” Centers for Disease Control and Prevention (CDC), National Center for Health Statistics, 2012, https://wwwn.cdc.gov/Nchs/Nhanes/2005-2006/PFC_D.htm.
30. “NHANES MEC Procedures Manual,” Centers for Disease Control and Prevention (CDC), National Center for Health Statistics, 2013, https://wwwn.cdc.gov/nchs/data/nhanes/2013-2014/manuals/2013_MEC_Laboratory_Procedures_Manual.pdf.
31. “NHANES Laboratory Procedure Manual,” Centers for Disease Control and Prevention (CDC), National Center for Health Statistics, 2014, https://wwwn.cdc.gov/nchs/data/nhanes/2013-2014/labmethods/PFAS_H_MET.pdf.
32. Klein RJ, Proctor SE, and Boudreault MA, “Healthy People 2010 Criteria for Data Suppression,” *Statistical Note Number* 24, 2004;July (24):1–12.
33. Jain RB and Ducatman A, “Serum Concentrations of Selected Perfluoroalkyl Substances for US Females Compared to Males as They Age,” *Science of the Total Environment* 842 (2022): 156891, 10.1016/j.scitotenv.2022.156891. [PubMed: 35753482]
34. Sonnenberg NK, Ojewole AE, Ojewole CO, Lucky OP, and Kusi J, “Trends in Serum Per- and Polyfluoroalkyl Substance (PFAS) Concentrations n Teenagers and Adults, 1999–2018 NHANES,” *International Journal of Environmental Research and Public Health* 20 (2023): 6984. [PubMed: 37947542]
35. “History and Use of Per- and Polyfluoroalkyl Substances (PFAS) Found in the Environment,” Interstate Technology Regulatory Council (ITRC), 2017, https://pfas-1.itrcweb.org/wp-content/uploads/2020/10/history_and_use_508_2020Aug_Final.pdf.
36. Chemical & Engineering News (C&EN), “3M Says It Will End PFAS Production by 2025,” ISSN 0009-2347, 2022, American Chemical Society, 10.1021/cen-10101-leadcon.
37. “Alternatives to Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) in Textiles,” Danish Environmental Protection Agency (DEPA), 2025, <https://legislature.vermont.gov/Documents/2020/WorkGroups/House%20Human%20Services/Bills/S.295/Witness%20Testimony/S.295~Elena%20Mihaly~DK-PFAS-AlternativesTextiles15~6-24-2020.pdf>.
38. Drage DS, Sharkey M, Berresheim H, Coggins M, and Harrad S, “Rapid Determination of Selected PFAS in Textiles Entering the Waste Stream,” *Toxics* 11, no. 1 (2023): 55, 10.3390/toxics11010055. [PubMed: 36668781]
39. “PFAS Strategic Roadmap: EPA’s Commitments to Action 2021–2024,” October 2021, Environmental Protection Agency (EPA), EPA-1---K-21-002, https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf.
40. “PFAS Strategic Roadmap: DOE Commitments to Action 2022–2025,” Department of Energy (DOE), August 2022, <https://www.energy.gov/sites/default/files/2022-08/DOE%20PFAS%20Roadmap%20August%202022.pdf>.
41. “Analysis of State Legislation Addressing Toxic Chemicals and Plastics,” Safer States, 2024, <https://www.saferstates.org/wp-content/uploads/Safer-States-2024-Multistate-Analysis.pdf>.
42. “PFAS in Building Materials,” Green Science Policy Institute (GSPI), <https://greensciencepolicy.org/our-work/building-materials/pfas-in-building-materials/>.

43. Chamberlain K, Storey B, Brown J, Rayburg S, Rodwell J, and Neave M, "Cleaning Up Forever Chemicals in Construction: Informing Industry Change," *Sustainability* 14, no. 5 (2022): 2854, 10.3390/su14052854.
44. Ancil A, "Facts About Solar Panels: PFAS Contamination," *Clean Energy in Michigan Series*, Number 12. October 2020, <https://graham.umich.edu/media/pubs/Facts-about-solar-panels-PFAS-contamination-47485.pdf>.
45. Guelfo J, Ferguson P, Beck J, et al., "The Dirty Side of Clean Energy: Lithium Ion Batteries as a Source of PFAS in the Environment," 2023, 10.21203/rs.3.rs-3150504/v1.
46. Freberg BI, Haug LS, Olsen R, et al. , "Occupational Exposure to Airborne Perfluorinated Compounds During Professional Ski Waxing," *Environmental Science & Technology* 44, no. 19 (2010): 7723–7728, 10.1021/es102033k. [PubMed: 20831156]
47. Lasee S, McDermett K, Kumar N, et al. , "Targeted Analysis and Total Oxidizable Precursor Assay of Several Insecticides for PFAS," *Journal of Hazardous Materials Letters* 3 (2022): 1000670, 10.1016/j.hazl.2022.100067.
48. Lay D, Keyte I, Tiscione S, and Kreissig J, "Check Your Tech—A Guide to PFAS in Electronics," ChemSec Funded From the European Union's Horizon, 2020, Project No. SA22171340, https://chemsec.org/app/uploads/2023/04/Check-your-Tech_230420.pdf.
49. Zhu H and Kannan K, "A Pilot Study of Per- and Polyfluoroalkyl Substances in Automotive Lubricant Oils From the United States," *Environmental Technology & Innovation* 9 (2020): 100943.
50. Ebnesajjad S, *Introduction to Fluoropolymers: Materials, Technology, and Applications*, 2nd ed. (Elsevier, 2020).
51. Batzella E, Rosato I, Fitter G, et al. , "Determinants of PFOA Serum Half-Life After End of Exposure: A Longitudinal Study on Highly Exposed Subjects in the Veneto Region," *Environmental Health Perspectives* 132, no. 2 (2024): 27002, 10.1289/EHP13152. [PubMed: 38306197]

TABLE 1 |
Demographics and the geometric mean (ng/mL) of PFAS by demographics in US workers, NHANES 2005–2014.

	Sample size	Estimated US Workers' Population (million)	Weighted % ^a	PFOS	PFOA	PFHxS	PENA	PFDA
All	4476	125.6	100%	9.72 (9.30, 10.16)	3.07 (2.97, 3.18)	1.58 (1.49, 1.67)	1.06 (1.01, 1.11)	0.27 (0.26, 0.29)
Sex								
Male	2411	69.0	54.9	12.04 (11.49, 12.63)	3.59 (3.46, 3.71)	2.12 (2.00, 2.25)	1.16 (1.09, 1.23)	0.29 (0.27, 0.30)
Female	2065	56.6	45.1	7.49 (7.11, 7.88)	2.54 (2.44, 2.66)	1.10 (1.02, 1.18)	0.95 (0.91, 1.00)	0.26 (0.24, 0.27)
<i>p</i> value ^b			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Age (years)								
20–34	1451	40.1	31.9	8.29 (7.84, 8.77)	2.94 (2.80, 3.08)	1.49 (1.39, 1.60)	0.97 (0.91, 1.03)	0.25 (0.24, 0.27)
35–49	1513	45.8	36.5	9.38 (8.83, 9.97)	2.95 (2.81, 3.10)	1.46 (1.35, 1.59)	1.05 (0.99, 1.12)	0.28 (0.26, 0.29)
50–64	1215	33.7	25.1	11.65 (10.99, 12.36)	3.32 (3.14, 3.51)	1.78 (1.63, 1.94)	1.16 (1.08, 1.24)	0.29 (0.26, 0.31)
65+	297	6.0	4.1	13.25 (11.53, 15.22)	3.60 (3.31, 3.92)	2.05 (1.81, 2.33)	1.24 (1.12, 1.38)	0.30 (0.27, 0.33)
<i>p</i> value ^c			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0022
Race/ethnicity								
NH White	1916	85.9	68.4	10.13 (9.64, 10.64)	3.32 (3.18, 3.26)	1.74 (1.62, 1.86)	1.06 (0.99, 1.12)	0.26 (0.25, 0.28)
NH Black	894	12.7	10.2	10.50 (9.49, 11.62)	2.58 (2.36, 2.80)	1.38 (1.25, 1.53)	1.13 (1.04, 1.24)	0.31 (0.28, 0.34)
Hispanic	1212	18.3	14.5	7.54 (7.09, 8.02)	2.53 (2.39, 2.67)	1.21 (1.11, 1.31)	0.99 (0.92, 1.07)	0.25 (0.23, 0.27)
NH Others	454	8.7	6.9	9.82 (8.62, 11.20)	2.77 (2.56, 3.00)	1.26 (1.10, 1.442)	1.14 (1.02, 1.28)	0.37 (0.33, 0.41)
<i>p</i> value ^d			< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.1423	0.2666
Place of birth								
USA	3103	102.3	81.5	10.07 (9.60, 10.56)	3.21 (3.09, 3.33)	1.68 (1.57, 1.78)	1.06 (1.00, 1.12)	0.27 (0.25, 0.28)
Other countries	1370	23.2	18.5	8.34 (7.79, 8.93)	2.54 (2.42, 2.66)	1.20 (1.10, 1.31)	1.05 (0.99, 1.12)	0.30 (0.28, 0.33)
<i>p</i> value ^b			< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.7676	0.0016
Education								
< 12 years	936	17.0	13.5	8.48 (7.90, 9.10)	2.72 (2.54, 2.99)	1.36 (1.24, 1.48)	1.03 (0.95, 1.12)	0.26 (0.24, 0.28)
High graduate	933	26.0	20.7	10.03 (9.16, 10.98)	3.20 (2.99, 3.43)	1.62 (1.46, 1.80)	1.10 (1.01, 1.20)	0.27 (0.25, 0.29)
Some college	1376	40.2	32.0	9.77 (9.27, 10.30)	3.05 (2.92, 3.18)	1.55 (1.43, 1.68)	1.03 (0.96, 1.11)	0.27 (0.25, 0.29)
College graduate	1228	42.4	33.8	10.00 (9.43, 10.61)	3.16 (3.05, 3.28)	1.66 (1.54, 1.80)	1.07 (1.02, 1.12)	0.28 (0.26, 0.30)

	Sample size	Estimated US Workers' Population (million)	Weighted % ^a	PFOS	PFOA	PFHxS	PENA	PFDA
<i>p</i> value ^e				0.0011	0.0001	0.0053	0.1358	0.2996
Survey cycle								
2005–2006	836	26.3	21.0	17.53 (16.30, 18.87)	4.14 (3.74, 4.58)	1.64 (1.40, 1.92)	1.16 (0.98, 1.36)	0.38 (0.31, 0.45)
2007–2008	938	25.7	20.5	13.94 (12.73, 15.26)	4.39 (4.19, 4.60)	1.98 (1.72, 2.28)	1.30 (1.22, 1.39)	0.31 (0.29, 0.34)
2009–2010	1,003	25.2	20.1	9.42 (8.16, 10.88)	3.23 (2.98, 3.49)	1.61 (1.45, 1.78)	1.30 (1.15, 1.45)	0.29 (0.27, 0.31)
2011–2012	815	23.6	18.8	6.62 (6.18, 7.09)	2.18 (2.05, 2.32)	1.30 (1.18, 1.44)	0.93 (0.84, 1.03)	0.21 (0.19, 0.23)
2013–2014	885	24.8	19.8	5.31 (4.81, 5.86)	2.03 (1.87, 2.21)	1.40 (1.25, 1.58)	0.72 (0.66, 0.78)	0.20 (0.18, 0.22)
<i>p</i> value ^c				< 0.0001	< 0.0001	0.0013	< 0.0001	< 0.0001

Note: Geometric means of PFAS with sex, race/ethnicity, place of birth, and education were adjusted for age and survey cycle. Geometric means of PFAS with age were adjusted for survey cycle. Geometric means of PFAS with survey cycle were adjusted for age.

Abbreviations: NH, non-Hispanic; NHANES, National Health and Nutrition Examination Survey; PFAS, per- and poly-fluoroalkyl substances; PFDA, perfluorodecanoic acid; PFHxS, perfluorohexane sulfonic acid; PFNA, perfluorononanoic acid; PFOA, perfluorooctanoic acid; PFOS, perfluorooctane sulfonic acid.

^aThe weighted % was calculated from the estimated US workers population.

^b*p*-value was obtained from the *t*-test.

^c*p*-value was obtained from the linear trend.

^d*p*-value was obtained from the *t*-test (comparing only NH White vs. Hispanic).

^e*p*-value was obtained from the *t*-test (comparing only < 12 years vs. High graduate).

TABLE 2 |
Geometric means^a in the serum concentration (ng/mL) of selected PFAS by Industry Groups, among US adult workers, NHANES 2005–2014.

Industry group	Estimated population size	Sample size	PFOS	PFOA	PFHxS	PFNA	PFDA
Agriculture, forestry, fishing	1,610,107	59	11.59 (9.32, 14.41)	2.43 (2.08, 2.85)	1.71 (1.43, 2.05)	0.95 (0.78, 1.15)	0.26 (0.20, 0.34)
Mining	1,037,376	29	10.77 (8.99, 12.90) ^b	2.94 (2.60, 3.33) ^b	1.17 (0.88, 1.55) ^b	1.10 (0.93, 1.31) ^b	0.27 (0.24, 0.31) ^b
Utilities	1,356,302	41	11.18 (8.56, 14.61)	3.42 (2.91, 4.03)	1.79 (1.33, 2.41)	1.02 (0.86, 1.21)	0.25 (0.20, 0.31)
Construction	9,353,309	332	12.46 (11.43, 13.58)	3.80 (3.55, 4.06)	2.11 (1.89, 2.35)	1.22 (1.10, 1.34)	0.33 (0.29, 0.36)
Manufacturing: Durable goods	9,323,417	315	10.99 (10.08, 11.99)	3.31 (3.02, 3.61)	1.68 (1.50, 1.89)	1.13 (1.02, 1.25)	0.27 (0.24, 0.30)
Manufacturing: Non-durable goods	5,174,117	205	10.38 (8.99, 11.97)	3.14 (2.82, 3.50)	1.53 (1.27, 1.84)	1.05 (0.94, 1.17)	0.26 (0.23, 0.30)
Wholesale trade	3,293,828	115	9.89 (8.56, 11.42)	3.21 (2.66, 3.87)	1.69 (1.31, 2.18)	1.07 (0.94, 1.22)	0.26 (0.22, 0.30)
Retail trade	12,412,563	440	8.84 (7.89, 9.90)	3.01 (2.83, 3.21)	1.43 (1.263, 1.63)	0.98 (0.91, 1.07)	0.25 (0.23, 0.28)
Transportation, warehousing	4,632,493	172	11.27 (10.15, 12.51)	3.54 (3.25, 3.87)	1.87 (1.66, 2.12)	1.16 (1.05, 1.27)	0.28 (0.25, 0.32)
Information	3,354,066	103	10.25 (8.70, 12.07)	3.42 (3.06, 3.87)	1.91 (1.51, 2.42)	1.12 (0.97, 1.35)	0.27 (0.24, 0.30)
Finance, insurance	5,024,338	160	8.73 (7.64, 9.99)	2.96 (2.60, 3.37)	1.55 (1.29, 1.86)	1.04 (0.89, 1.22)	0.27 (0.22, 0.32)
Real estate, rental, leasing	2,710,938	92	12.51 (9.71, 16.12)	3.59 (3.13, 4.11)	1.78 (1.30, 2.44)	1.14 (0.90, 1.44)	0.32 (0.26, 0.40)
Professional, technical services	8,524,922	250	9.40 (8.40, 10.52)	3.23 (3.01, 3.46)	1.63 (1.41, 1.89)	1.07 (0.98, 1.16)	0.27 (0.25, 0.29)
Management, administrative, waste services	5,622,067	264	9.18 (8.00, 10.54)	3.09 (2.71, 3.52)	1.60 (1.36, 1.90)	1.04 (0.93, 1.16)	0.26 (0.23, 0.29)
Education services	11,777,300	384	10.02 (9.40, 10.68)	3.03 (2.85, 3.22)	1.54 (1.40, 1.68)	1.08 (1.01, 1.16)	0.29 (0.27, 0.32)
Health care, social assistance	17,041,787	622	8.12 (7.49, 8.81)	2.55 (2.35, 2.76)	1.24 (1.10, 1.40)	0.99 (0.91, 1.06)	0.26 (0.24, 0.28)
Arts, entertainment, recreation	2,905,017	96	9.68 (8.60, 10.89)	3.21 (2.81, 3.66)	1.79 (1.53, 2.10)	0.99 (0.88, 1.11)	0.28 (0.25, 0.32)
Accommodation, food services	7,356,232	328	7.99 (7.23, 8.84)	2.62 (2.40, 2.86)	1.27 (1.13, 1.42)	0.98 (0.88, 1.08)	0.26 (0.23, 0.29)
Other services	5,957,338	218	10.85 (9.77, 12.05)	3.19 (2.90, 3.52)	1.92 (1.67, 2.20)	1.11 (1.00, 1.23)	0.27 (0.24, 0.30)
Private households ^c	1,086,262	60	7.39 (6.14, 8.88)	2.53 (2.22, 2.89)	0.97 (0.76, 1.25)	0.95 (0.85, 1.06)	0.27 (0.24, 0.31)
Public administration	6,065,695	191	9.91 (8.83, 11.13)	3.19 (2.88, 3.53)	1.74 (1.51, 2.02)	1.09 (0.99, 1.21)	0.27 (0.24, 0.31)

Note: Numbers in parentheses are the 95% confidence intervals of the geometric means.

^aThe geometric mean estimates are weighted and adjusted for age and survey cycle.

^bThe geometric mean estimate in Mining is not reliable due to the small sample size [32].

^cPrivate households: workers include cooks, maids, nannies, butlers, and outside workers, such as gardeners, caretakers, and other maintenance workers.

TABLE 3 |
Geometric means^a (ng/mL) in serum of selected PFAS by occupational groups, among US adult workers, NHANES 2005–2014.

Occupational group	Population size	Sample size	PFOS	PFOA	PFHxS	PFNA	PFDA
Management occupations	15,754,756	423	10.83 (9.95, 11.78)	3.37 (3.16, 3.58)	1.90 (1.72, 2.09)	1.14 (1.06, 1.22)	0.27 (0.25, 0.30)
Business, financial operations occupations	4,807,962	157	10.32 (8.97, 11.86)	3.40 (3.08, 3.75)	1.54 (1.26, 1.89)	1.18 (1.07, 1.31)	0.31 (0.28, 0.36)
Computer, mathematical occupations	3,656,532	109	8.50 (7.01, 10.38)	3.01 (2.66, 3.42)	1.71 (1.34, 2.20)	0.89 (0.76, 1.05)	0.24 (0.22, 0.27)
Architecture, engineering occupations	2,825,868	70	10.85 (9.19, 12.81)	3.52 (3.07, 4.05)	1.88 (1.53, 2.32)	1.12 (1.00, 1.26)	0.30 (0.24, 0.36)
Life, physical, social science occupations	1,574,829	60	11.26 (9.42, 13.47)	3.35 (2.98, 3.75)	1.48 (1.25, 1.99)	1.15 (1.00, 1.31)	0.31 (0.27, 0.36)
Community, social services occupations	1,640,857	63	9.03 (7.70, 10.58)	3.16 (2.71, 3.68)	1.21 (0.95, 1.53)	1.09 (0.95, 1.26)	0.31 (0.27, 0.37)
Legal occupations	1,472,101	41	9.39 (7.63, 11.56)	2.78 (2.28, 3.38)	1.38 (1.12, 1.71)	1.05 (0.81, 1.36)	0.29 (0.24, 0.36)
Education, training, library occupations	7,755,968	234	9.31 (8.64, 10.03)	2.88 (2.65, 3.13)	1.43 (1.29, 1.59)	1.03 (0.94, 1.13)	0.28 (0.25, 0.30)
Arts, design, entertainment, sports, media occupations	2,567,167	79	10.28 (8.66, 12.20)	3.23 (2.81, 3.72)	1.73 (1.43, 2.09)	1.00 (0.83, 1.19)	0.26 (0.22, 0.31)
Healthcare practitioner, technical occupations	7,109,192	203	8.76 (7.82, 9.81)	2.53 (2.26, 2.84)	1.28 (1.04, 1.57)	1.07 (0.97, 1.19)	0.27 (0.24, 0.30)
Healthcare support occupations	2,938,168	128	7.60 (6.51, 8.86)	2.38 (2.08, 2.73)	1.24 (1.07, 1.43)	0.95 (0.85, 1.06)	0.26 (0.21, 0.28)
Protective service occupations	2,866,532	105	10.62 (9.06, 12.45)	2.97 (2.59, 3.40)	1.74 (1.40, 2.16)	1.09 (0.98, 1.21)	0.29 (0.25, 0.33)
Food preparation, serving occupations	5,720,740	254	7.46 (6.56, 8.49)	2.51 (2.27, 2.79)	1.23 (1.07, 1.40)	0.97 (0.87, 1.08)	0.25 (0.22, 0.28)
Building and grounds cleaning, maintenance occupations	5,969,957	320	10.06 (9.06, 11.18)	3.04 (2.76, 3.36)	1.55 (1.34, 1.79)	1.10 (1.00, 1.21)	0.28 (0.26, 0.31)
Personal care, service occupations	4,377,043	192	7.84 (6.82, 9.01)	2.59 (2.26, 2.97)	1.12 (0.93, 1.34)	0.96 (0.87, 1.07)	0.26 (0.23, 0.29)
Sales and related occupations	12,672,208	425	9.30 (8.44, 10.25)	3.06 (2.87, 3.26)	1.57 (1.40, 1.75)	1.04 (0.96, 1.13)	0.27 (0.24, 0.29)
Office, administrative support occupations	14,069,630	512	8.33 (7.80, 8.90)	2.90 (2.71, 3.11)	1.33 (1.22, 1.45)	0.95 (0.88, 1.02)	0.25 (0.23, 0.27)
Farming, fishing, forestry occupations ^b	572,673	25	7.03 (5.75, 8.55) ^b	1.58 (1.29, 1.94) ^b	0.95 (0.67, 1.35) ^b	0.65 (0.56, 0.75) ^b	0.19 (0.16, 0.22) ^b
Construction, extraction occupations	7,907,363	284	11.83 (10.90, 12.83)	3.69 (3.44, 3.96)	2.07 (1.83, 2.33)	1.17 (1.05, 1.30)	0.31 (0.28, 0.36)
Installation, maintenance, repair occupations	4,508,115	144	12.98 (11.62, 14.49)	3.97 (3.64, 4.33)	2.17 (1.80, 2.61)	1.15 (1.03, 1.28)	0.29 (0.25, 0.33)
Production occupations	7,581,443	321	10.78 (9.46, 12.27)	3.17 (2.92, 3.45)	1.65 (1.48, 1.84)	1.12 (1.00, 1.26)	0.27 (0.24, 0.30)
Transportation, material moving occupations	7,325,633	329	11.24 (10.39, 12.17)	3.35 (3.08, 3.64)	1.87 (1.65, 2.13)	1.11 (1.01, 1.23)	0.28 (0.25, 0.32)

Note: Numbers in parentheses are the 95% confidence intervals of the geometric means.

^aThe geometric mean estimates are weighted and adjusted for age and survey cycle.

^bThe geometric mean estimate in Farming, Fishing, Forestry Occupations is not reliable due to the small sample size [32].