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Use of Aqueous Film-Forming Foams and Knowledge of Perfluorinated Compounds Among Florida Firefighters

To the Editor:

The US Navy developed aqueous film-forming foam (AFFF) in the 1960s containing per- and polyfluoroalkyl substances (PFAS) and synthetic foaming surfactants that allowed for improved firefighter safety, particularly for firefighters involved in liquid fuel and crash fire rescue operations and those using nozzles during structural firefighting.¹ PFAS are also commonly used to water and stain-proof specific textiles such as the materials used to construct firefighter turnout gear.^{2,3} AFFFs have evolved to include a number of different formulations (including AFFFs that meet Military Specifications

[MILSPEC], alcohol-resistant aqueous film-forming foam [AR-AFFF], etc.) that often, but not always, rely on PFAS compounds for proper foam performance. AFFFs used to fight class B petroleum fires have historically contained longer chain PFAS such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS)⁴⁻⁶ that are associated with adverse health outcomes.^{7,8} PFOS use in new AFFFs and other products were banned in the European Union in 2011 and Canada in 2013, and major US manufacturers of AFFF indicated they would no longer produce PFOA-based fluorosurfactant foams after 2015.^{9,10} However, AFFFs typically have a long shelf life of up to 25 years.¹¹ In addition, current fluorinated AFFFs contain shorter chain PFAS chemicals with less information on potential toxicity. Little is known about AFFF use and knowledge of legacy and current PFOA and PFOS chemicals among firefighters.

Some PFAS are associated with cancer, such that in 2016 the International Agency for Research on Cancer (IARC) classified PFOA as Group 2B indicating they are possibly carcinogenic to humans, based on limited evidence in humans that it can cause testicular and kidney cancer, and limited evidence in laboratory animals.^{7,12,13} Since the IARC designation, some additional cancer studies have suggested an increased risk of testicular cancer with increased PFOA exposure, whereas others have suggested possible links to thyroid cancer and kidney cancer.¹⁴⁻¹⁶ Epidemiologic studies have associated firefighting with an increased risk for a variety of cancers, including testicular and kidney cancer, among others, but the exposures responsible for these increased rates have not been identified.^{17,18} To date there is limited knowledge about the use of PFOA/PFOS containing foams within the US fire service. This is of greater concern in airport facilities where AFFFs that meet the MILSPEC are required for use on Federal Aviation Administration (FAA)-regulated airports and military airports.

Concerns about AFFF use and PFOA/PFOS chemical exposure center around the potential negative impact on firefighter health as well as on the environment from the discharge of foam solutions generated from the combination of water and foam concentrate. When PFOA/PFOS-containing AFFF are repeatedly used in one location over an extended period of time (such as in firefighter training facilities), the PFOA/PFOS can move from the foam

substance into soil and then into groundwater.¹⁹⁻²¹ The amount of PFOA/PFOS that enter the groundwater depends on the type and amount of AFFF used, where it was used, and the type of soil and other factors. At firefighter training facilities, where AFFF is often repeatedly discharged onto concrete training areas, long-term release of PFAS into the surrounding soil and water from the concrete is anticipated to occur on the order of decades.²² As an initial first step to study the concern about AFFF use and PFOA/PFOS knowledge, we assess the awareness and knowledge of perfluorinated chemicals and AFFF use among Florida fire departments.

MATERIALS AND METHODS

Study Design and Participant Recruitment

A cross-sectional study design was used to collect health and safety survey information from 142 firefighters attending the Florida Fire Chiefs' Association Health and Safety Conference held on December 10 to 12, 2018, in Orlando, FL. Our research team distributed paper surveys during the conference initially by placing a blank survey at each seat in the main conference ballroom, and through distribution at a dedicated exhibitor table located in the immediate entry/egress of the main conference meeting room. The annual Florida fire chiefs meeting is open to all Florida firefighters and is largely composed of attendees from senior-level positions within Florida fire services, including fire chiefs, assistant chiefs, fire prevention officers, shift officers, individual firefighters/paramedics, health and safety officers, and fire investigators. To encourage completion of the survey, conference organizers made an announcement to attendees on the main conference stage twice a day. A t-shirt with the research team's Firefighter Cancer Initiative logo was provided to each firefighter that completed the survey. A verbal consent process was used given the anonymous nature of the survey, where the first page of the survey contained the consent information; firefighters were provided a copy upon request. A total of 11 surveys were removed from the final analytic dataset used in this study given three surveys were from firefighters outside the State of Florida and eight survey respondents indicated they did not know if their department used AFFF, the main study outcome variable.

Authors' contributions: AJCM, NSS, PLF, KG, KS, MC, JB, and EK conceived the study, participated in its design and coordination, performed statistical analyses, and codrafted the manuscript. AJCM, NSS, PLF, KG, and KS collected field data, entered study data, and assisted in data analysis and interpretation of study results. AJCM, NSS, PLF, KG, KS, DJL, SD, SKD, KF, MC, JB, and EK performed statistical analysis, interpreted study results, and helped with the manuscript draft. All authors read, revised, and approved the final manuscript.

Institution and Ethics approval and informed consent: This study research protocol was reviewed and approved by the University's Institutional Review Board (#20170787).

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Survey Instrument and Study Measures

We designed a 97-item survey instrument, Firefighter Assessment of Strategies Trumping Cancer (FAST-C), with the goal of documenting fire department and individual firefighter-level decontamination practices among Florida firefighters. Survey measures were adapted from previously validated or administered surveys of occupational safety and health and worksite health promotion.^{23–25} New measures assessing awareness and knowledge of PFOA/PFOS and AFFF use were adapted from other occupational health and safety measures^{26,27} and assessed for content and face validity with Florida firefighters before survey administration.

AFFFs Use and Knowledge Measures

We asked survey respondents “Does your fire service department use AFFFs?” with response options “Yes, No, or Don’t Know.” We assessed the frequency of AFFF use with the question “Approximately how many times each year does your fire department answer calls in which you need to use AFFFs?” with response options “0 to 1, 2 to 5, 6 to 10, 11 to 15, 16 to 20, 20+, or Don’t Know.” Measures assessing AFFF brand, formulation, PFOA/PFOS components, and decontamination post-AFFF fire suppression use were assessed with the following questions all with “Yes, No, or Don’t Know” response options: “Do you know the brand or manufacturer of the AFFF that your fire department currently uses?”; “If your department uses/stores AFFF, are you aware if it is the original formulation or the newest formulation?”; “Do you know if the AFFF, which you currently use, has PFOA or PFOS as a main component?”; and “After incidents where AFFFs are employed, do you and others in your fire department exchange or wash your gear?” Lastly, we assessed the firefighter’s interest in the following current trade profession discussion on AFFF and PFOA on turnout gear with the two questions: “Do you follow the current discussion about AFFF” and “Do you follow the current discussion about PFOA and turnout gear?” with response options “Yes, No, or Don’t Know.”

Organizational Characteristics

We evaluated four organizational characteristics of the fire department: workforce size, total health and safety officers, fire department geographic location, and employment type. Workforce size was defined as the number of active firefighters (nonadministrative positions) employed within the fire department. Total health

and safety officers were defined as the total number of health and safety officers employed within the fire department, where the officer is a firefighter whose job function includes the health and safety of their fire department workforce. The geographic location where the fire department is located within Florida was operationalized as rural area only, urban area only, suburban area only, and mixed area (ie, urban, suburban, and rural). Employment type was a measure assessing if the fire department was composed of career firefighters only, volunteer only, or mixed career/volunteer.

Data Analysis

Descriptives, Bivariates, and Correlations

We conducted exploratory statistical data analyses for continuous variables, expressed as mean with its standard error, and for categorical variables, represented as frequency and percent of the sample. We examined the main outcome of use of AFFF stratified by workforce size, total health and safety officers, fire department geographic location, and employment type. For categorical data, we conducted chi-square analyses to compare groups, and used *t* tests for continuous data. We used a Levene test of homogeneity of variance across groups for each variable.²⁸ We used Spearman product-moment correlation to examine the relationship between workforce size, number of health and safety officers and frequency of AFFF use. The significance level was set at 5%. All statistical analyses were done on SPSS v21 (IBM Corp., Armonk, NY). This study research protocol was reviewed and approved by the University’s Institutional Review Board.

RESULTS

A total of 131 Florida firefighters representing 67 Florida fire departments (13.7% of all Florida fire departments) completed the survey. Respondents were predominately in the 36 to 45 years old age group (36.7%), male (85.4%), career firefighters (96.9%), and current rank of chief/battalion chief/division chief (35.4%; Table 1). Over 80% of survey respondents indicated their fire departments use AFFF as part of their fire suppression activities. Fire departments using AFFF were predominantly an all career workforce (93.1% vs 76.9%, $P=0.015$) and had no health and safety officers on staff (7.1% vs 0.0%, $P=0.050$) compared with fire departments not using AFFF.

A third (33.3%) of fire departments using AFFF indicated that they used it on two to five calls per year and almost 17% of departments used it greater than 16 times

per year (Fig. 1). Departments that used AFFF greater than 16 times per year were predominately medium-sized departments (101 to 500 firefighters, 50.0%), had one health and safety officer (60.0%), and were located in an urban area (43.8%). Among fire departments that use AFFF, there were more small- (1 to 100 firefighters, 48.0%) and medium-sized (101 to 500 firefighters, 43.1%) than large-sized fire departments (8.8%). Among all respondents, 24.5% knew the brand or manufacturer of the AFFF, 17.6% were aware of the original or newest formulation, 4.6% were aware that their AFFF brand had PFOA or PFOS as a main component, and 48.0% of firefighters indicated their department members wash their turnout gear after incidents where AFFF was employed. Survey respondents reported that 30.0% of them follow the current professional firefighter trade discussion about AFFF use, and 33.8% follow discussions on the presence of PFOA on turnout gear.

Among firefighters who reported on the brand of AFFF used by their department, the types include Universal Gold 1%/3% AR-AFFF (37.5%), FireAde Class A foam (20.8%), Ansul-A Municipal Class Fire (12.5%), Ansulite 1 × 3 F-601A AR-AFFF (12.5%), CHEMGUARD C3B 3% AFFF (8.3%), Fire Aide/National Gold (4.2%), and FireAde 2000 AR-AFFF (4.2%). The annual frequency of using AFFF for fire suppression had a moderate, positive correlation to the number of active firefighters in the department ($r=0.405$; $P<0.001$). We also found that annual AFFF use has a small/moderate, positive correlation to the total number of health and safety officers employed in the fire department ($r=0.288$; $P=0.003$). A sensitivity analysis to assess agreement between firefighters responding for the same fire department (approximately two firefighters per department) yielded near-perfect agreement ($\kappa=0.98$) in the responses to the AFFF use, knowledge, and organizational characteristics measures.

DISCUSSION

This is the first study to survey frequency and use of AFFF in fire departments. A large proportion of participating Florida fire departments currently use AFFF during fire suppression activities, with the most frequent use of AFFF occurring two to five calls per year for specific fire suppression calls. Fire departments with heavy AFFF use (16 or more times per year) were predominately medium-sized departments (101 to 500 firefighters) with at least one health and safety officer on staff, and located in an urban geographic area. The vast majority of firefighting foam that is currently in stock or in service in the United States is AFFF or AR-AFFF, with many AFFF products containing PFAS.^{10,27,29} We found among

TABLE 1. Florida Firefighter and Fire Department Characteristics Stratified by Aqueous Film-Forming Foams (AFFFs) Use Among Attendees of the 2018 Florida Fire Chiefs' Association Health and Safety Conference

Characteristics	Total sample <i>N</i> (%) [*]	Use of AFFF <i>N</i> (%) [*]	No use of AFFF <i>N</i> (%) [*]	<i>P</i> [†]
Total	131 (100.0)	105 (80.2)	26 (19.8)	
<i>Respondent characteristics</i>				
Age				
26–35 yr olds	16 (12.5)	11 (10.8)	5 (19.2)	0.227
36–45 yr olds	47 (36.7)	41 (40.2)	6 (23.1)	
46–55 yr olds	46 (35.9)	37 (36.3)	9 (34.6)	
55 years and older	19 (14.8)	13 (12.7)	6 (23.1)	
Sex				
Male	111 (85.4)	92 (87.6)	19 (76.0)	0.139
Female	19 (14.6)	13 (12.4)	6 (24.0)	
Firefighter type				
Volunteer	4 (3.1)	2 (1.9)	2 (7.7)	0.125
Career	127 (96.9)	103 (98.1)	24 (92.3)	
Current rank				
Chief/Battalion chief/Division chief	45 (35.4)	34 (33.7)	11 (42.3)	0.676
Fire prevention	8 (6.3)	7 (6.9)	1 (3.8)	
Shift officer	24 (18.9)	19 (18.8)	5 (19.2)	
Firefighter/paramedic	24 (18.9)	18 (17.8)	6 (23.1)	
Health and safety officer	26 (20.5)	23 (22.8)	3 (11.5)	
<i>Department characteristics</i>				
Department workforce size				
Small (1–100 firefighters)	57 (44.5)	49 (48.0)	8 (30.8)	0.233
Medium (101–500 firefighters)	60 (46.9)	44 (43.1)	16 (61.5)	
Large (>500 firefighters)	11 (8.6)	9 (8.8)	2 (7.7)	
Total health and safety officers				
None	7 (5.6)	7 (7.1)	0 (0.0)	0.050
One officer	76 (60.8)	55 (55.6)	21 (80.8)	
Two or more officers	42 (33.6)	37 (37.4)	5 (19.2)	
Department geographic location				
Rural area only	20 (15.7)	12 (11.9)	8 (30.8)	0.107
Urban area only	38 (29.9)	33 (32.7)	5 (19.2)	
Suburban area only	23 (18.1)	19 (18.8)	4 (15.4)	
Mixed area (urban/sub/rural)	46 (36.2)	37 (36.6)	9 (34.6)	
Department employment type				
All career	115 (89.8)	95 (93.1)	20 (76.9)	0.015
Mixed career and volunteer	13 (10.2)	7 (6.9)	6 (23.1)	

^{*}Differences in subtotal population sample due to item nonresponse or missing.

[†]P values are calculated from chi-square test for association for categorical variables.

Florida firefighters, who recalled their department's brand of AFFF, approximately 46% used contemporary AFFF products. AFFF products and other fluorinated foams are of concern because they contain PFAS. This raises the need for further research in conducting national surveillance of the types and frequency of AFFF used by US fire departments, as well as to conduct continuous biomonitoring of PFAS chemical exposures in firefighters.

Firefighter respondents in our study indicated low awareness of AFFF health effects and the relationship to perfluorinated chemicals. Some PFAS pose a risk to groundwater and surface water quality, but they are also highly persistent chemicals, that may be mobile within the work environment and bioaccumulate in organisms.²⁹ Numerous animal and human studies have evaluated both noncancer and cancer health effects related to exposure to a limited

number of PFAS, including PFOA and PFOS.^{30,31} Little to no health-effects data are available for many PFAS. For example, Rotander et al evaluated firefighter blood levels for 11 PFAS compounds and reported elevated concentrations for PFOS and perfluorohexane sulfonic acid and its salts (PFHxS) compared with the general population; however, they did not observe any association with studied health effects.³² One study examining PFOS and PFHxS levels in veteran firefighters working at different fire stations in San Francisco as part of a longitudinal biomonitoring program concluded that firefighters who used personal protective equipment (PPE) have lower levels of PFAS in the serum likely due to PPE use.³

Fire departments that used AFFF in this study were more likely to have no health and safety officers than departments that did not use AFFF. In addition, although

it is currently not known if washing turnout gear removes PFAS compounds from gear, this study found that less than half of the departments that used AFFF in specific fire incident responses reported washing their turnout gear after using AFFF. It may be possible that health and safety officers play a unique role in educating and training their fire department's workforce on AFFF use and possible health effects. In a recent firefighter health promotion intervention, the use of an expert-led sleep program that included health and safety officers had the greatest reach and effectiveness in educating and screening firefighters.³³ Health and safety officers can play a critical role as champions within their fire service to further document the use, exposures, and health effects of AFFF where there is currently limited understanding of AFFF use. Given the low knowledge and awareness of PFOA/PFOS, researchers should consider

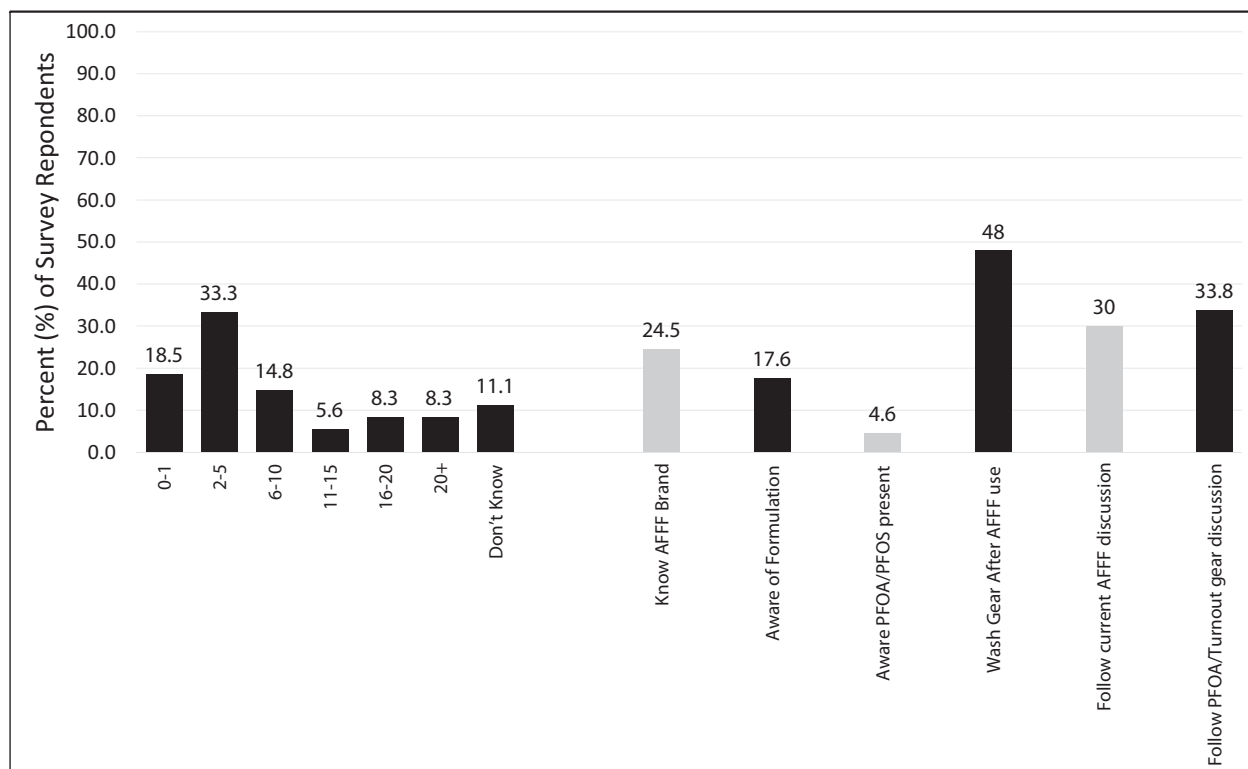


FIGURE 1. Frequency of AFFF use and knowledge/awareness of AFFF/PFOS issues among Florida firefighters.

exploring how health and safety officers in a fire service could educate and train on AFFF use.

Data collected from this study were self-reported and subject to recall bias from respondent firefighters. The sample size is relatively small but included survey respondents from 67 departments that captures close to 14% of the Florida fire departments. In addition, sensitivity analyses of Florida fire departments participating in this survey were similar in geographic location (ie, rural, suburban, urban) compared with those departments that did not participate in the survey. A similar sensitivity analysis of survey response data among firefighters from the same fire department found near-perfect agreement for survey items about AFFF use, knowledge, and organizational characteristics. Despite these limitations, this study sheds new light on the practice and type of AFFFs use in Florida fire departments. It is the first to document awareness of and knowledge in the types of AFFF and PFOA/PFOS chemicals associated with foam use using survey data collected largely from the leadership of various Florida fire departments. This pilot survey project also identifies a potential approach in using fire department health and safety officers as a vehicle to educate, train, and possibly surveil for AFFF use and exposures in fire departments.

This study identified relatively low awareness and knowledge of AFFF use and PFOA/PFOS chemicals in Florida fire departments. There is an urgent need to conduct national surveillance for AFFF use across US fire departments. Surveillance should include point sources of AFFF exposure (ie, fire suppression, training activities, etc.) that may be impacting firefighter health and safety. Biomonitoring activities among fire departments that use AFFF and AR-AFFF could shed further light into any acute or chronic health effects experienced by AFFF exposure. As we found low levels of awareness and knowledge of PFOA/PFOS chemicals in our sample of Florida fighters, further education and training in the proper use of AFFF is needed. Lastly, the number of health and safety officers, regardless of fire department workforce sizes, seems to be associated with AFFF use, suggesting these officers may play a unique role in educating firefighters on AFFF and PFOA/PFOS exposures.

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