Per- and Polyfluorinated Substances in Firefighting Foam

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About the IC2

The Interstate Chemicals Clearinghouse (IC2) is an association of state, local, and tribal governments that promotes a clean environment, healthy communities, and a vital economy through the development and use of safer chemicals and products. The goals of the IC2 are to:

- Avoid duplication and enhance efficiency and effectiveness of agency initiatives on chemicals through collaboration and coordination
- Build governmental capacity to identify and promote safer chemicals and products
- Ensure that agencies, businesses, and the public have ready access to high quality and authoritative chemicals data, information, and assessment methods

The functions of the IC2 include:

- Supporting health and environmental agencies with development and implementation of programs to promote use of safer chemicals and products
- Supporting the development of alternatives assessment methods and identification of safer alternatives
- Sharing data and information on use, hazard, exposure, and alternatives
- Sharing strategies and outcomes on chemicals prioritization initiatives
- Building the capacity of agencies by sharing materials, strategies, and trainings
- Assisting agencies in meeting the relevant information needs of businesses, consumers, and the public

The IC2 is a program of the Northeast Waste Management Officials' Association (NEWMOA). For more information visit: http://theic2.org.

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Contents

Tables

Glossary

alternatives assessment: The process for identifying and comparing potential chemical and non-chemical alternatives that could replace chemicals of concern on the basis of their hazards, comparative exposure, performance, and economic viability.[1]

aqueous film-forming foam (AFFF): A synthetic firefighting foam developed for Class B fires consisting of a fluorochemical and hydrocarbon surfactants combined with high boiling point solvents and water. AFFF have low viscosity and spread rapidly across the surface of most hydrocarbon fuels, forming a water film beneath the foam to cool the fuel, smother the fire, and stop the formation of flammable vapors.

C6 foam: Short-chain, fluorinated firefighting foams that contain perfluorocarboxylic acids (PCAs) with carbon chain lengths of seven and lower, which include perfluorohexanoic acid (PFHxA) and perfluorosulfonic acids (PFSAs) with carbon chain lengths of five and lower, as well as perfluorobutanesulfonic acid (PFBS).

C8 foam: Long-chain, fluorinated firefighting foams that contain perfluorocarboxylic acids (PFCAs) with carbon chain lengths of eight and higher, which include perfluorooctanoic acid (PFOA) and perfluorosulfonic acids (PFSAs) with carbon chain lengths of six and higher, as well as perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonate (PFOS).

Class B fires: Any fire involving flammable liquid(s), such as gasoline, solvents, or other fuels, where blanketing and smothering for vapor suppression is needed.

F-34 fuel: Popularly known as "JP-8" or "JP8" (NATO code for "Jet Propellant 8") , F-34 is a jet fuel that is used widely by the U.S. military. It is specified by MIL-DTL-83133 and British Defence Standard 91-87, and is similar to Jet A-1, a commercial aviation fuel, but with the addition of corrosion inhibitor and anti-icing additives.

firefighting foam: A mixture of air, water, and a foam concentrate that fights fires by blanketing burning fuel, smothering the fire, separating flames from the fuel source, cooling the fuel and adjacent surfaces, and suppressing the release of flammable vapors that can mix with air. (See "water additives" entry for more on the use of the term "water additive(s)" in this report.)

fluorine-free foam (F3): A firefighting foam or other water additive that is free of fluorinated surfactants and thereby containing no fluorine. (See "water additives" entry for more on the use of the term "water additive(s)" in this report.)

fluorosurfactant: Synthetic organofluorine chemical compounds that have multiple fluorine atoms and are made up of two parts: a polar hydrophilic head and a highly hydrophobic fluorocarbon tail. As surfactants, they are more effective at lowering the surface tension of water than comparable hydrocarbon surfactants.

fluorotelomer: Fluorocarbon-based oligomers, or telomers, that are synthesized by telomerization. Some fluorotelomers and fluorotelomer-based compounds are a source of environmentally persistent perfluorinated carboxylic acids, such as perfluorooctanoic acid (PFOA).

GreenScreen® for Safer Chemicals: A globally recognized tool that identifies hazardous and safer chemicals through a rigorous benchmarking scoring system. Products and substances can achieve certification through the assessment program, becoming GreenScreen Certified™.

[1] The Association for the Advancement of Alternatives Assessment uses this definition from the U.S. National Research Council, https://www.saferalternatives.org/about

per- and polyfluoroalkyl substances (PFAS): A group of synthetic chemicals used to make fluoropolymer coatings and products that are resistant to heat, water, and oil. PFAS have been used in a variety of industries since the late 1940s and include perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), which have historically been used in aqueous film forming foam (AFFF).

perfluorooctanoic acid (PFOA): A synthetic, fully fluorinated organic acid (where all hydrogens on all carbons have been replaced by fluorines) comprised of chains of eight carbons that is used in a variety of consumer products and in the production of fluoropolymers. The acid is generated as a degradation product of other perfluorinated compounds. Due to strong carbon-fluorine bonds, PFOA remains stable despite metabolic and environmental degradation. PFOA is a member of a large group of perfluoroalkyl substances (PFAS) that are used to make products more resistant to stains, grease, and water. These compounds have been widely found in consumer and industrial products, as well as in food items. Major U.S. manufacturers voluntarily agreed to phase out production of PFOA by the end of 2015.[2]

perfluorooctane sulfonate (PFOS): A synthetic, fully fluorinated organic acid (where all hydrogens on all carbons have been replaced by fluorines) comprised of chains of eight carbons that is used in a variety of consumer products. It occurs as a degradation product of other perfluorinated compounds. Due to strong carbon-fluorine bonds, PFOS remains stable despite metabolic and environmental degradation. PFOS is a member of a large group of perfluoroalkyl substances (PFASs) that are used to make products more resistant to stains, grease, and water. These compounds have been widely found in consumer and industrial products, as well as in food items. In 2002, the only major U.S. manufacturer voluntarily agreed to phase out production of PFOS.[3]

water additives: A liquid—such as foam concentrates, emulsifiers, and hazardous vapor suppression liquids and foaming agents—intended to be added to water for fire control and extinguishment.[4] While the term "water additive(s)" encompasses all types of products (not only foams) intended to be added to water to extinguish fire, the term "firefighting foam" is frequently used in its place. In this report, unless otherwise noted, "firefighting foam," or simply "foam," is used synonymously with "water additive(s)."

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[2] U.S. EPA Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA), 2016, https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final-plain.pdf
[3] U.S. EPA Drinking Water Health Advisory for Perfluorooctane Sulfonate (PFOS), 2016, https://www.epa.gov/sites/production/files/2016-05/documents/pfos_health_advisory_final_508.pdf
[4] NFPA 18 Standard on Wetting Agents

Acronyms

AFFF	aqueous film-forming foam
DoD	U.S. Department of Defense
FAA	U.S. Federal Aviation Administration
F3	Fluorine free foam
IC2	Interstate Chemicals Clearinghouse
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
ISO	International Organization for Standardization
MIL-SPEC	U.S. Military Specification for firefighting foams, MIL-PRF-23485F(SH)
NFPA	U.S. National Fire Protection Association
NYSP2I	New York State Pollution Prevention Institute
OECD	Organisation for Economic Co-operation and Development
PFAS	per- and polyfluoroalkyl substances
PFC	perfluorinated compound
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
UNEP	United Nations Environment Programme
U.S. EPA	U.S. Environmental Protection Agency

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1. Executive Summary

This document summarizes the results of precursory work to assist with scoping an alternatives assessment of the use of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in Class B aqueous film-forming foam (AFFF), also known as "firefighting foam." AFFF are used to fight fuel fires and typically contain per- and polyfluoroalkyl substances (PFAS). They are responsible for many incidents of contamination of groundwater and drinking water. The goal of the project is to a) help define the parameters for performance evaluation of firefighting foams, b) identify foams containing short-chain PFAS and fluorine-free foams, and c) further inform the scope of any future assessment work to develop alternatives to the use of per- and polyfluorinated substances in firefighting foams.

This work was a project of the Interstate Chemicals Clearinghouse (IC2), an association of state, local, and tribal governments that promotes a clean environment, healthy communities, and a vital economy through the development and use of safer chemicals and products. The project team was led by the New York State Pollution Prevention Institute (NYSP2I) and was carried out by a subgroup of the IC2's Alternatives Assessment Workgroup. The project team worked collaboratively and included IC2 members from state agencies, non-governmental organizations (NGOs), and agencies. Working together in this capacity allowed the team to pool resources and information to further the success of the project.

A note on terminology

Water additives are liquids that are intended to be added to water for fire control and extinguishment. Examples include foam concentrates, emulsifiers, and hazardous vapor suppression liquids and foaming agents.

Firefighting foam is a mixture of air, water, and a foam concentrate that fights fires by blanketing burning fuel, smothering the fire, separating flames from the fuel source, cooling the fuel and adjacent surfaces, and suppressing the release of flammable vapors that can mix with air.

Fluorine-free foam is firefighting foam or other water additive free of fluorinated surfactants, therefore containing no fluorine.

While the term "water additive(s)" encompasses all types of products (not only foams) intended to be added to water to extinguish fire, the term "firefighting foam" is frequently used in its place. In this report, unless otherwise noted, "firefighting foam," or simply "foam," is used synonymously with "water additive(s)."

Notable Findings

Performance Specifications. The requirements of seven performance specifications are summarized and compared. These include U.S. MIL-SPEC and international standards, such as ISO and UL 162. The U.S. MIL-SPEC and International Maritime Organization (IMO) standards are the only ones that require PFAS to be included in the foam formulation. U.S. MIL-SPEC is the only standard that limits PFOA and PFOS content.

Current PFAS in firefighting foams restrictions. In January 2018, the Australian state of South Australia became the first government body in the world to ban fluorinated firefighting foams. This followed bans specifically on PFOA and PFOS by Queensland, its neighboring state to the northeast, in 2016 and by the Government of New Zealand in 2006. In the United States, the recent U.S. Federal Aviation Administration (FAA) Reauthorization Act of 2018 will eliminate the requirement that most U.S. airports use fluorinated firefighting foams within three years. Washington is the first U.S. state to pass a law prohibiting the sale of firefighting foams containing

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fluorinated chemicals. The Washington ban will take effect in 2020—military, FAA-certified airports, petroleum refineries and terminals, and certain chemical plants will all be exempt from it.

Alternative Foams. Over 90 fluorine-free water additives from 22 manufacturers have been identified and tabulated with relevant data, including product and manufacturer name, country, performance specifications met, product application, product description, and the Chemical Abstracts Service (CAS) Registry Number, name, and percent of disclosed ingredients in the product. While this report focuses on fluorine-free foams, 14 manufacturers of AFFF containing short-chain PFAS, also referred to as "C6 foams," have been identified. There are many C6 foams available on the market as most manufacturers no longer offer eight-carbon chain AFFF (known as "C8 foams") because the industry has voluntarily abandoned those.

PFAS Research & Alternatives Assessment Work. A number of organizations are currently involved in researching PFAS, researching and synthesizing fluorine-free foams, and conducting alternatives assessments of products currently available on the market. Highlights include:

- The Organisation for Economic Co-operation and Development (OECD) / United Nations Environment Programme (UNEP) Global Perfluorinated Compound (PFC) Group released their updated New Comprehensive Global Database of PFAS and accompanying methodology report in May 2018. See the report here: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/
- The U.S. Department of Defense's (DoD) Strategic Environmental Research and Development Program and Naval Research Laboratory have active research projects to develop and characterize fluorine-free foams.
- A Petroleum Environmental Research Forum (PERF) research project aims to capture the state of knowledge of the fate, transport, and effects of short-chain, PFAS-based firefighting foams and fluorine-free foams, and to identify limitations of—and data gaps in—the current studies and data sets. A contract for this work was put out for bid in May 2018 and includes an alternatives assessment for fluorine-containing and fluorine-free foams. The project may use GreenScreen® assessments and may use the IC2 Alternatives Assessment (AA) methodology. The current plan is to include foam ingredient chemicals (as delivered) and their final degradates in the chemical hazard assessment.
- Clean Production Action (CPA) is collaborating with Toxic-Free Future and King County Local Hazardous Waste Management Program to reduce exposure to PFAS in firefighting foam in the State of Washington. The goals are to ensure PFAS-free products are safer and not regrettable substitutes, and to create a list of preferred PFAS-free products using GreenScreen Certified™.

Firefighting Foam Research Findings. Highlights include:

- A number of fluorine-free surfactants have been developed.
- Performance testing of fluorine-free foams is limited and the results of available tests show the performance of fluorine-free foams is not consistent across types.
- The ecotoxicity and impacts on human health of fluorine-free alternatives have not been adequately characterized or assessed. Many contain generic statements that fluorine-free alternatives are preferable because they do not contain fluorine, while some have aquatic and human-health information available on the product safety data sheet.
- Comprehensive papers expand on performance needs for suppressing Class B fires beyond those included in the Core Performance Standards in this report.

Conclusions, Research Needs, and Actions

From the review of firefighting foam performance standards, current and upcoming regulations, identification of fluorine-free foams, other researchers working in this area, and literature, the following conclusions, research needs, and actions have been identified:

1. **Three main information gaps need to be filled to characterize fluorine-free foams in order to promote them as safer alternatives to fluorinated foams:**
   a. **Performance data is uncertain and/or lacking.**
   Research need: Independent testing of fluorine-free foams to validate existing claims and test against others. The U.S. MIL-SPEC and IMO standards are the only performance specifications that require fluorinated surfactants. Performance testing of fluorine-free foams is needed to understand if the performance specifications can be met without the use of fluorinated surfactants. Some fluorine-free foams identified in this report indicate they meet performance specifications. There is some doubt in the firefighting foam industry that fluorine-free foams do in fact meet the standards. Independent performance testing to validate these claims would be beneficial. If foams cannot meet the specification, the testing process will identify exactly what parameter(s) is not being met. Performance testing fluorine-free foams is critical, as the FAA's Reauthorization Act of 2018 no longer requires major FAA airports to use fluorinated foams.
   b. **The makeup of foams is incomplete as many ingredients are protected as confidential business information. Many researchers and those in the firefighting foam industries have raised a concern about whether foams are truly fluorine-free or not.**
   Research need: Identify all fluorine-free foam ingredients and verify they are truly fluorine-free. Ingredients lists present on the safety data sheets of the fluorine-free foams identified in this study were reviewed. Many foams have incomplete lists, as ingredients are deemed confidential business information and excluded. Listing proprietary ingredients makes it impossible to characterize the fluorine-free alternatives to ensure promoted alternatives do not result in regrettable substitution, where one hazardous or toxic ingredient (in this case, fluorinated surfactants) is replaced with another ingredient possessing different hazard characteristics. There is some doubt within the firefighting foam industry that fluorine-free foams are truly free of fluorine. Analyzing a subset of foams would shed light on this concern and help to understand if the foams are completely free of fluorine or if they contain trace amounts.
   Research need: Achieve transparency of ingredients through credible third-party evaluation. Manufacturers may be amenable to an independent, third party evaluating confidential ingredients and formulations in order to report any hazard information without releasing proprietary ingredients and product formulations. This allows users to make informed decisions without releasing confidential business information.
   c. **The ecotoxicity and impacts on human health of most fluorine-free foams and their ingredients have not been characterized or assessed.**
   Research need: Characterize ecotoxicity and human-health impacts of fluorine-free foams, ingredients, and degradation products through third-party hazard and exposure evaluations. Most fluorine-free foams have generic statements that fluorine-free alternatives are preferable because they do not contain fluorine. Some of the fluorine-free foams identified in this report have aquatic toxicity and human-health information available on their safety data sheet. Safety data sheets could not be obtained for all products. Having complete ingredient lists or formulations disclosed to a third party for analysis is critical to ensure the whole formulation is

assessed. Again, characterizing alternative foams will help to eliminate regrettable substitutions.

2. **The use of performance standards across industries is not well understood and characterized.** Research need: Dig deeper into mapping performance specifications to applications. A cursory list of industries and situations to which each performance standard applies is included in this report. Reaching out to industry stakeholders, firefighters, and foam manufacturers to validate and expand this list would help to build an understanding of the performance needs for specific fire situations, which could then be used to determine the appropriate foam type for that need.

3. **It is unclear if gaps or discrepancies exist in the performance needs for extinguishing Class B fires and existing performance specifications.** Research need: Compare the performance needs and existing performance specifications. It is unclear if performance standards are too strict, not strict enough, or sufficient in all areas of fire suppression. Comparing the needs to standards, such as MIL-SPEC and UL 162, may identify gaps and discrepancies. Working with users knowledgeable about fire suppression needs, foam manufacturers, performance specification authors, and other stakeholders would ensure specifications are appropriate for all.

4. **Organizations are developing fluorine-free foams, characterizing them, and performing alternatives assessments. Washington is the first U.S. state to ban the sale of fluorinated foams.** Action: Monitor work by other organizations. The DoD's research to develop and characterize fluorine-free foams, PERF's alternatives assessment of fluorine-free foams, and CPA's work to develop a list of preferable PFAS-free foams are all notable and currently ongoing. The State of Washington is getting ready to implement their ban on the sale of fluorinated foams in 2020 and is currently working to assess alternatives. Their outcomes may be adopted by others and influence policy and product formulations. The landscape is rapidly changing and there may be other organizations in the near future doing similar work.

5. **There is no regulation preventing the use of fluorine-free foams by non-military users, including firefighting training centers, chemical manufacturers, oil refineries, and others.** Action: Assist training centers and other non-military users in switching to fluorine-free alternatives. Firefighting training centers do not have to follow the same performance standards as other users and typically use foams that are not certified to a performance standard. There is no regulatory roadblock for training centers to use fluorine-free foams.

2. Project Goals & Approach

The New York State Department of Environmental Conservation (NYSDEC) and many members of the IC2 Alternatives Assessment Workgroup are concerned about the potential or real impact of the use of fluorinated firefighting foams on human health and the environment. They are interested in promoting less toxic alternatives. This project brought these interested parties together through an IC2 subgroup that worked collaboratively to gather information necessary for scoping future alternatives assessment work.

PFAS is used routinely in firefighting water additives designed for Class B fires, typically referred to as "firefighting foams" or simply "foams." This project is focused on firefighting water additives designed for Class B fires that are free of long-chain (commonly referred to as C8) fluorosurfactants. Alternatives may include foams containing short-chain (or C6) fluorosurfactants or fluorine-free firefighting water additives.

The performance specifications and requirements for Class B firefighting suppressants are not well understood by the IC2 subgroup. Many state agencies have pulled together their own lists of fluorine-free foams, though a comprehensive worldwide search has not been performed. There is some uncertainty about whether or not fluorine-free foams are able to meet the same performance specifications as fluorinated foams. Therefore, the goals of the project are to

1. understand the performance needs and specifications of firefighting foams and the use of PFAS to meet them;
2. identify and characterize alternatives to long-chain (C8), fluorine-containing firefighting foams, including short-chain (C6), fluorinated foams and fluorine-free foams;
3. and identify agencies and researchers that are focused on the use of alternatives to PFAS in Class B firefighting foams, including short-chain (C6) fluorosurfactants and fluorine-free foams, and gather credible information that can be used in future alternatives assessment work.

This work is a precursor for an alternatives assessment of PFOA and PFOS in firefighting foam. The goal of an alternatives assessment is to replace chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment. The National Academies of Sciences, Engineering, and Medicine's *A Framework to Guide Selection of Chemical Alternatives* [5] and the IC2's *Alternatives Assessment Guide,* [6] provide structured frameworks for completing an alternatives assessment. After the chemical of concern is identified (in this case, per- and polyfluorinated chemicals in firefighting foam), the next steps are scoping and problem formulation followed by identifying potential alternatives. The information gathered in this paper intends to help scope and formulate the problem by understanding the performance needs of firefighting foam. It provides ecotoxicity and human-health information to help determine which lifecycle stages should be included in an assessment. The C6 and fluorine-free firefighting foams identified in this paper serve as the potential alternatives identified in the frameworks. The intent is that this formation will be used by other practitioners to develop a robust alternatives assessment.

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[5] National Academies Press, A Framework to Guide Selection of Chemical Alternatives, 2014, http://nap.edu/18872
[6] Interstate Chemicals Clearinghouse, Alternatives Assessment Guide, Version 1.1, 2017, http://www.theic2.org/article/download-pdf/file_name/IC2_AA_Guide_Version_1.1.pdf

3. History of PFAS in Firefighting Foam

PFAS are a group of synthetic chemicals that have been used in a variety of industries since the 1940s. The most well-known PFAS are PFOA and PFOS, and both were widely used to make carpets, clothing, furniture fabrics, and paper food packaging resistant to water and grease. PFOA and PFOS are very persistent in the environment and the human body and studies have indicated that they can cause reproductive and developmental, liver, kidney, and immunological effects as well as tumors in laboratory animals.[7] While the U.S. Environmental Protection Agency's (EPA) PFOA Stewardship Program successfully eliminated the manufacture of PFOA and PFOS in the United States, PFOA and PFOS are still produced internationally and can be imported.

PFAS chemicals are found in AFFF—a synthetic foam consisting of fluorochemical and hydrocarbon surfactants combined with high-boiling-point solvents and water—that was developed for use on Class B fires (e.g. flammable liquids or gases, such as gasoline or other fuels). Firefighting foam is made up of water, air, and a foam concentrate. The foam concentrate is available off the shelf and is mixed with water and air by firefighters during use. When the ingredients are mixed together, a foam blanket is formed that covers the burning fuel, smothers the fire, separates the flames from the fuel source, cools the fuel and adjacent metal surfaces, and suppresses the release of flammable vapors that can mix with air.[8]

The MIL-SPEC for firefighting foams dictates that fluorinated surfactants must be included in Class B foams. Therefore, a fluorine-free water additive cannot meet the MIL-SPEC performance requirements by definition, as it does not contain fluorinated surfactants. All branches of the U.S. military must use fluorinated firefighting foams on bases located in the United States and abroad. Prior to 2018, the FAA incorporated the military specification, requiring major U.S. airports to use fluorinated firefighting foams onsite. Local municipalities may also use and store AFFF onsite. In the U.S., 75% of all AFFF are used by the military, while the remaining 25% are used by municipal airports, refineries, fuel tank farms, and other industries.[9]

There are approximately 190 sites in 40 U.S. states currently known to be contaminated with PFAS[10] with more testing and analysis underway.[11] Training and emergency responses are major sources of groundwater PFAS contamination on military bases. There are concerns that PFAS-contaminated ground water on military bases may be affecting water quality in the surrounding areas, with the water in and around 126 military installations containing potentially harmful levels of PFAS.[12] The U.S. DoD is

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[7] U.S. EPA, Basic Information on PFAS, https://www.epa.gov/pfas/basic-information-pfas

[8] Chemguard, General Foam Information, https://www.chemguard.com/about-us/documents-library/foam-info/general.htm

[9] FAQs Regarding PFASs Associated with AFFF Use at US Military Sites, August 2017, http://www.dtic.mil/dtic/tr/fulltext/u2/1044126.pdf

[10] Northeastern University, Per- and Polyfluoroalkyl Substances, https://pfasproject.com/pfas-contamination-site-tracker/, accessed October 2018

[11] Michigan (https://www.michigan.gov/pfasresponse/), New Jersey (https://www.nj.gov/dep/dsr/publications/Investigation%20of%20Levels%20of%20Perfluorinated%20Compounds%20in%20New%20Jersey%20Fish,%20Surface%20Water,%20and%20Sediment.pdf), New York (https://www.dec.ny.gov/chemical/108831.html), Washington State (https://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PFAS), and Vermont (http://dec.vermont.gov/sites/dec/files/documents/PFAS%20Sampling%20Report%207.10.18%20FINAL.pdf), and are all actively monitoring for PFAS.

[12] DoD: At least 126 bases report water contaminants linked to cancer, birth defects, April 2018, https://www.militarytimes.com/news/your-military/2018/04/26/dod-126-bases-report-water-contaminants-harmful-to-infant-development-tied-to-cancers/

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continuing to investigate the extent of PFAS contamination on military bases and surrounding communities.[13]

Historically, foams contained perfluorinated carbon chains that are eight carbons long (C8 foams). Under the 2015 EPA PFOA Stewardship Program, all U.S. foam manufacturers voluntarily reformulated their foams to contain perfluorinated carbon chains six or fewer carbons long (C6 foams) by the end of 2015. C8 fluorosurfactants are persistent, bioaccumulative, and toxic. While C6 fluorosurfactants are persistent, they are thought to be less bioaccumulative and toxic, even though less is known about these compounds and characteristics vary among the class. The toxicity of many C6 fluorosurfactants remains uncharacterized. There is no scientific consensus to conclude that C6 surfactants are preferable to their C8 counterparts.

A number of manufacturers have formulated firefighting foams to be fluorine free. Many of these alternative foams claim to perform as well as fluorinated ones while being completely free of fluorinated surfactants. To date, no independent testing has been performed to validate these claims of fluorine free.

[13] US Department of Veterans Affairs, Public Health, PFAS, https://www.publichealth.va.gov/exposures/pfas.asp, accessed October 2018

4. Firefighting-Foam and Water-Additive Performance Specifications

There are a number of performance specifications for firefighting foam with varying requirements. The standards in this section were compiled from internet searches and from those mentioned in foam product technical specifications. The initial list of about thirty standards was divided into two groups: 1) core standards, those that many products meet and many governments require, and 2) other standards, those to which products may conform but are not specifically related to firefighting performance or are difficult to find and not widely used. Comparisons and details of the core standards follow in this section and the other standards are described in "Appendix A: Additional Performance Standards" of this report.[14]

Table 1 below summarizes the core performance standards, including typical application(s), scope, and noteworthy attributes. More details, including specific performance requirements, are included in "Appendix B: Core Performance Standards Details."

Table 1. Summary of Core Film-Forming Foam Performance Standards

Standard	Application(s)	Scope	Noteworthy
Australian Government DEF (AUST) 5706 Guidelines for testing fixed Aqueous Film Forming Foam (AFFF) suppression systems Updated 2018	Australian military	• Offers general guidance in relation to testing, guidance for the commissioning tests, and requirements for storage, collection, treatment, and disposal of AFFF and AFFF wastewater. • These guidelines endorse and supplement the general testing provisions included in NFPA 11 (below).	• Criteria are similar to ISO 7203. • Guidelines endorse and supplement the general testing provisions included in NFPA 11.
European Standard EN 1568 Parts 1-4 Updated 2018 Available for purchase https://www.en-standard.eu/	The general-use standard developed by the European Union to replace the individual standards that each country had possessed.	• Includes foam extinguishment and burnback performance, expansion, and drainage. • Covers concentrate storage, use of sea water, aging and heat stability, and physical properties.	• Concentrates are given performance grades (Grade 1-4) for extinguishing performance and Grades A-D for burnback resistance. Grade 1A is the highest achievable grade. • Approved products are not conformance monitored after accreditation.
ICAO The International Civil Aviation Organization (ICAO) Airport Services Manual Updated 2014	International airports	• Includes foam extinguishment and burnback performance. • Covers concentrate physical properties.	• Manual developed by the aviation industry with a focus on rapid extinguishment. • It is primarily used in airports and developed to minimize potential danger to those on flights.

[14] A good review of foam, foam types, and specification standards can be found in a white paper from Solberg. This paper is from 2002 and is useful to help understand the lay of the land. Many or all of the specifications likely have since been updated. Dlugogorski, B., Kennedy, E., Schaefer, T., & Vitali, J. (n.d.). *What Properties Matter in Fire-Fighting Foams?* (Solberg). See: http://www.solbergfoam.com/getattachment/3fe1d44d-3b44-4714-89f4-4af37e381b5b/WP-WHAT-PROPERTIES-MATTER-IN-FIRE-FIGHTING-FOAMS.aspx

Standard	Application(s)	Scope	Noteworthy
			• It does not explicitly mention the need for foams to be fluorinated.
IMO International Maritime Organization (IMO) Guidelines for the Performance and Testing Criteria and Surveys of Foam Concentrates for Fixed Fire-Extinguishing Systems Updated 2009	foam concentrates for fixed fire-extinguishing systems onboard tankers and chemical tankers	• Includes foam extinguishment and burnback performance. • Covers concentrate storage, use of sea water, and physical properties.	• Guidelines focus on merchant ships. • They are required by many maritime administrations and classification bodies for foam concentrates to be used on board ships in international waters. It arose as part of the implementation of the SOLAS Convention (Safety of Life at Sea), 174 member states comply with the standard. • Criteria are similar to ISO 7203, largely focus on how to perform the tests, and explicitly calls out aqueous film forming concentrate as having fluorinated surfactants.
ISO 7203 Fire Extinguishing Media (Foam Concentrates) Updated 2011	A general-use standard with respect to foam performance; often required by maritime administrators and classification bodies for use on board ships.	• Includes foam extinguishment and burnback performance, expansion, and drainage. • Covers concentrate storage, use of sea water, aging and heat stability, and physical properties. • Criteria are similar to DEF (AUST) 5706.	• Standard has an international focus. • It was not developed with a singular, specific purpose.
LASTFIRE Hydrocarbon Storage Tanks Updated 2015	Used in general and light industry, it dictates foam concentrate procurement specifications by major international oil companies.	• Includes a "best practices" guide. • Has a focus on how foams will behave and degrade over a long period of time and less with rapid extinguishment.	• Standard was developed by a consortium of oil industry leaders. • Its ratings are based on a scale of 100% effectiveness.
NFPA 11 Standard for Low-, Medium-, and High-Expansion Foam Updated 2016	focus on fire fighting systems and atmospheric tank fires	• Focuses on suppression system components, system types, design, installation requirements, and acceptance. • Includes foam expansion and drainage. • Covers concentrate concentration determination.	• NFPA is a very different style of test. Foam is applied to the fuel surface and it is expected to travel across the fuel. NFPA is focused on the transit time of the foam, making it more ideal for tank fires.

Standard	Application(s)	Scope	Noteworthy
US MIL-SPEC US Military Specification MIL-PRF-23485F(SH) with Amendment 2, 7 Sept 2017 Updated 2017	Applies to all branches of the U.S. military and has been incorporated into FAA specification for major airports.	• Includes foam extinguishment and burnback performance, expansion, and drainage. • Covers concentrate storage, physical properties, corrosion, environmental impact, and fluorine content.	• Specification has focus on rapid extinguishment. • It was developed with the prevention of weapons discharge aboard U.S. Navy ships as the primary focus. • It was approved for use by all U.S. DoD departments and agencies. • It includes maximum PFOA and PFOS content, and requires foam concentrates to contain fluorocarbon surfactants. • There are eight MIL-SPEC-qualified foams.
UL 162 Standard for Foam Equipment and Liquid Concentrates Updated 2018	tank fires	• Requirements are based on the premise that foam equipment and specified types of foam liquid concentrates with which they are intended to be used are to be investigated for use with each other. • Focus on suppression system foam producing equipment, material compatibility, performance • Includes foam extinguishment and burnback performance. • Covers concentrate storage, physical properties, and concentration.	• Standard evaluates specific combinations of foam concentrates and foam equipment together. • It is a pass/fail test. • UL-listed products are monitored with samples sent to UL every three months for conformance testing.
US FAA The US Federal Aviation Administration Updated 2004	major U.S. airports	• States that AFFF agents must meet the requirements of MIL-PRF-24385F.	• Requires compliance with MIL-SPEC.

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5. PFAS in Firefighting Foam Regulatory Overview

There has been significant regulatory activity regarding the use of fluorinated chemicals in firefighting foam over the last year. In January 2018, the Australian state of South Australia became the first government body in the world to ban fluorinated firefighting foams. This followed bans specifically on PFOA and PFOS by Queensland, its neighboring state to the northeast, in 2016 and by the Government of New Zealand in 2006. The U.S. FAA Reauthorization Act of 2018 eliminated the need for the majority of U.S. airports to use firefighting foams containing fluorinated chemicals. The first U.S. state to ban Class B fluorinated firefighting foams is Washington, where the sale of the foams will be prohibited as of July 2020. While the information presented here is up to date at the time of publication, the regulatory climate is changing quickly. The reader is advised that the content of this paper may be outdated by new developments as they occur.

5.1 Australia

South Australia was the first Australian state to ban fluorinated firefighting foams in January 2018. Clause 13A(4) of the Environment Protection (Water Quality) Policy 2015 states: "A person must not supply a firefighting foam product unless the producer's certification of its fluorine content is clearly displayed on a label or document provided with the product.[15]"

South Australia's Environment Protection Authority (EPA) provided guidance that further clarifies the requirement:

> The EPA will consider a certification from the producer to be a statement as follows (either clearly displayed on a label or document provided with the product):
>
> - This firefighting foam product does not contain fluorinated organic compounds.
> - Fluorine or fluorinated substances were not used in the manufacture of this firefighting foam product.
> - Equipment used to manufacture this firefighting foam product was either (a) not previously used to contain or manufacture fluorinated organic compounds; or (b) thoroughly cleaned to prevent residual fluorinated organic compounds from being included as contaminants in this firefighting foam product.[16]

Clause 13A(4) also states that "'prohibited firefighting foam product' means a firefighting foam product that contains a fluorinated organic compound or compounds, but does not include a firefighting foam product that is fluorine free."

The State of Queensland banned the use of PFOA and PFOS in firefighting foam in July 2016. The requirements that the state put into place are outlined in the 2016 publication *Operational Policy: Environmental Management of Firefighting*. It reads:

> 6.2.1 Foams containing PFOS (see Explanatory Notes §3, 3.1, 7.2, 7.4, 9.1) Use of foams that contain the fluorinated organic compound PFOS (perfluoro octane sulphonic acid) as well as its salts or any compound that degrades or converts to PFOS at a concentration of greater than that listed in Table

[15] South Australia Environmental Protection Authority (2018). *Environment Protection (Water Quality) Amendment Policy 2018, Clause 13A(4)*. Retrieved from https://www.legislation.sa.gov.au/LZ/V/POL/2018/ENVIRONMENT%20PROTECTION%20(WATER%20QUALITY)%20AMENDMENT%20POLICY%202018_30.1.2018%20P%20521/30.1.2018%20P%20521.UN.PDF

[16] Ibid. (2018). *Per- and Poly-fluoroalkyl substances (PFAS)*. Retrieved from https://www.epa.sa.gov.au/environmental_info/perfluorinated-compounds

6.2.2 A in foam concentrate must be withdrawn from service and replaced as soon as possible (taking into account related obligations under the Work Health and Safety Act 2011) and no longer used in any situation where they might be released to the environment, including legacy stocks.

6.2.2 Foams containing PFOA & PFOA precursors to be withdrawn (see EN §3.2, 7.2, 7.4) Firefighting foams that contain PFOA, PFOA precursor compounds or their higher homologues, where the total organic fluorine content equivalent to PFOA and higher homologues exceeds that listed in Table 6.2.2 A in foam concentrate must be withdrawn from service as soon as practicable and any held stocks (and any other related wastes) must be secured pending disposal. These materials are to be managed and disposed of as regulated waste.

Table 6.2.2 A – Fluorinated organic compounds limits in concentrates

Compound(s)	Limit (mg/kg)
PFOS (Perfluoro-octane sulfonic acid) and PFHxS (perfluorohexane sulfonate).	10 (sum)
PFOA (Perfluoro-octanoic acid) and higher homologues, PFOA precursors and higher homologous PFCs as the sum of the total oxidisable precursor assay for C7 to C14 compounds (TOPA C7-C14).	50 (as fluorine)

PFOA precursor compounds and their higher homologues include any compounds that potentially degrade or convert to PFOA, such as 8:2 fluorotelomer derivatives, or the higher homologous perfluoroalkyl carboxylic acids (PFCAs) as well as precursors, such as C7 to C14 carbon-chain or similar fluorotelomer derivatives.

6.2.4 Foams containing short-chain fluorotelomers (see Explanatory Notes §7, 7.1–7.5) Foam containing short-chain fluorotelomers (C6 or shorter perfluorinated moieties) can be used if it is found to be the only viable option, after firefighting effectiveness, short and long-term health, safety and environmental risks and property protection characteristics have all been appropriately considered, however, the following requirements must be met:

- The foam must be C6 purity compliant foam (see Definitions).
- No releases directly to the environment (e.g. to unsealed ground, soakage pits, waterways or uncontrolled drains).
- All releases must be fully contained on site.
- Containment measures such as bunds and ponds must be controlled, impervious and must not allow firewater, wastewater, runoff and other wastes to be released to the environment (e.g. to soils, groundwater, waterways stormwater, etc.).
- All firewater, wastewater, runoff and other wastes must be disposed of as regulated waste to a facility authorised to accept such wastes.

5.2 New Zealand

PFOS and PFOA are banned from firefighting foam in New Zealand. They were excluded from the Firefighting Chemicals Group Standard in 2006, effectively banning their import, manufacture, and use in firefighting foams. For more information, visit New Zealand's Ministry of the Environment at http://www.mfe.govt.nz/land/pfas-and-poly-fluoroalkyl-substances

5.3 U.S. Airports

Current FAA regulations require major U.S. airports to use MIL-SPEC-qualified fluorinated firefighting foams. The FAA outlines in *Title 14, Code of Federal Regulations (CFR)* [Part 139] that, in order to issue airport-operating certificates, an airport must

- serve scheduled and unscheduled air-carrier aircraft with more than 30 seats, or

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- serve scheduled air-carrier operations in aircraft with more than nine seats but fewer than 31 seats;

Operators of Part 139 airports must also provide aircraft rescue and firefighting (ARFF) services during air-carrier operations that require a Part 139 certificate. Performance requirements for Aircraft Fire Extinguishing Agents includes the following statement:

> AFFF agents must meet the requirements of Mil-F-24385F. It is important to note that if one vendor's foam is mixed with another vendor's foam in the re-servicing process, there must be compatibility between foams to prevent gelling of the concentrate.

The FAA Reauthorization Act of 2018 will no longer require the use of fluorinated chemicals to meet performance standards.[17] Specifically, the legislation states:

> SEC. 332. AIRPORT RESCUE AND FIREFIGHTING.
>
> (a) Firefighting Foam.—Not later than 3 years after the date of enactment of this Act, the Administrator, using the latest version of National Fire Protection Association 403, "Standard for Aircraft Rescue and Fire-Fighting Services at Airports", and in coordination with the Administrator of the Environmental Protection Agency, aircraft manufacturers and airports, shall not require the use of fluorinated chemicals to meet the performance standards referenced in chapter 6 of AC No: 150/5210–6D and acceptable under 139.319(l) of title 14, Code of Federal Regulations.

5.4 Washington State

Washington is the first U.S. state to ban certain firefighting foams containing perfluorinated compounds. A state law, RCW 70.75A,[18] was passed there in early 2018. Highlights include:

- It prohibits the use of PFAS containing Class B firefighting foam for training purposes starting July 1, 2018;
- It prohibits the manufacture, sale, and distribution of PFAS-containing Class B firefighting foam starting July 1, 2020. Military, FAA-certified airports, petroleum refineries and terminals, and certain chemical plants are all exempt from this requirement.
- Manufacturers and sellers of firefighting personal protective equipment have had to notify purchasers in writing if their products contain PFAS and the reasons for using the chemicals as of July 1, 2018.

[17] The FAA Reauthorization Act of 2018 [H.R.302] became public law in October 2018. It is available online here: https://www.congress.gov/bill/115th-congress/house-bill/302/

[18] See RCW 70.75A here: http://app.leg.wa.gov/RCW/default.aspx?cite=70.75A&full=true

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6. Fluorine-Free Firefighting Water Additives and Short-Chain PFAS Foams

A key purpose of this report is to identify firefighting water additives that do not contain PFOA and PFOS—including products that contain short-chain (C6) PFAS and those that are fluorine free. In the U.S. and Europe, there are firefighting water additives for Class B fires that are free of PFOA and PFOS, including those made with short-chain PFAS currently on the market. While some organizations have identified alternative products or chemistries, there is a need for a comprehensive, up-to-date list to help identify alternatives for specific foam applications. To meet this need, a worldwide search for alternative fluorine-free and C6 products/chemistries was done. The results of this research were then organized in one accessible location. The outcome of this work, a list of available short-chain (C6) foams and fluorine-free foams, is below.[19]

Information on fluorine-free and short-chain (C6) foams was compiled from a number of sources, including:

1. **IC2 Alternatives Assessment Workgroup members**. Many workgroup members had compiled their own lists of fluorine-free foams. Members provided these lists and they were reconciled. Throughout the project duration, workgroup members regularly added to the list of alternatives.
2. **NYSP2I's previous work to identify fluorine-free foams**. In *Supply Chain Assessment of Class B Firefighting Foams for New York State Dept. of Environmental Conservation* (January 2018), NYSP2I identified a number of fluorine-free and C6 foams, as well as foam manufacturers.
3. **Organizations working to develop and research fluorine-free foams**. Many organizations have identified fluorine-free or C6 foams; they are listed in "Research Groups & Agencies involved in Firefighting Foam Work" [Section 7] of this report.
4. **An online search for patents was done to identify fluorine-free firefighting foams and surfactants.** Findings are included in "Firefighting Foam Research" [Section 8] of this report.
5. **Online searches for fluorine-free foam products.**
6. **The U.S. DoD Qualified Products Database** was used to identify products qualified under MIL-PRF-24385. All of the products are short-chain (C6) fluorochemicals, since fluorine is required to meet the MIL-SPEC requirements.[20]

6.1 Fluorine-Free Class B Firefighting Water Additives

Over 90 products from 22 manufacturers have been identified. Pertinent information on the products are tabulated and include product and manufacturer name, country, performance specifications met, product application, product description, and the CAS, name, and percent of disclosed ingredients in the product. The main source of product information was manufacturer websites. Ingredient information is collected from product safety data sheets (SDSs), commonly available on manufacturer websites. Where SDSs were not accessible online, they were requested from the manufacturer. All SDSs found online, made available to NYSP2I staff, and other information, including technical data sheets and/or results of performance tests, were reviewed.

A list of fluorine-free foams is found in Table 2 on the following page. A spreadsheet containing links to product information on manufacturer websites, product application and description, SDSs (where available), and ingredients (where available) is available for download on the IC2 website at http://www.theic2.org.

[19] The list is also available for download from the IC2's website (http://www.theic2.org).
[20] Access the database here: http://qpldocs.dla.mil/

Table 2. Fluorine-Free Class B Firefighting Water Additives [Note: Product information was collected in August 2018. The main source of product information is manufacturer websites and ingredient information is sourced from product Safety Data Sheets (SDSs). It is recommended that readers confirm product information directly with manufacturers as it may have changed since publication. "Product name" is per the manufacturer and does not necessarily match nomenclature used by chemists.]

Manufacturer	Location	No.	Product Name	Type
3F Company	United Kingdom	1	FREEDOL SF	F3[a]
		2	FREEFOR SF 1	F3
		3	FREEFOR SF 2	F3
		4	HYFEX SF 1	F3, Hi-Ex[b]
		5	HYFEX SF 3	F3, Hi-Ex
		6	HYFEX SF 6	F3, Hi-Ex
Aberdeen Foam (Oil Technics Fire Fighting Products)	Scotland, United Kingdom	7	Aberdeen Foam 1% F3	F3
		8	Aberdeen Foam 1% F3-LF	F3, LT[c]
		9	Aberdeen Foam 3% F3	F3
		10	Aberdeen Foam 3% F3-LF	F3, LT
		11	Aberdeen Foam 6% F3	F3
		12	Aberdeen Foam 2% HI-EX	F3, Hi-Ex
		13	Aberdeen Foam 3x3% AR-F3	F3, AR[d]
		14	Aberdeen Foam 3x6% AR-F3	F3, AR
		15	Aberdeen Foam 1x3% F3	F3, AR
Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.)	United Kingdom	16	Expandol (a.k.a. Expandol 1-3)	F3, Hi-Ex
		17	Expandol LT (a.k.a. Expandol 1-3LT)	F3, Hi-Ex, LT
		18	Syndura (6% fluorine-free foam)	F3
		19	HiCombat A	F3
		20	Jetfoam 1%	F3
		21	Jetfoam 3%	F3
		22	Jetfoam 6%	F3
		23	Respondol ATF 3-3%	F3
		24	Respondol ATF 3-6%	F3
Auxquimia (ICL Performance Products)(Phos-Chek Fire Retardant)	Spain	25	Phos-Chek 1% Fluorine free	F3
		26	Phos-Chek 3×6 Fluorine free (a.k.a. UNIPOL-FF 3/6)	F3, AR
		27	H-930 synthetic multiexpansion foam concentrates	F3
		28	SF-60L synthetic multiexpansion foam concentrates	F3
Bio-ex	France	29	BIO FOAM 5	F3
		30	BIO FOAM 15	F3, LT
		31	ECOPOL	F3, Hi-Ex
		32	ECOPOL F3 HC	F3
		33	ECOPOL PREMIUM	F3, AR
		34	ECOPOL A 3%/6%	F3
Buckeye Fire Equipment Company	NC, United States	35	Buckeye High Expansion Foam (BFC-HX) (a.k.a. Hi-Ex 2.2)	F3
Dafo Fomtec AB	Sweden	36	Enviro 3% ICAO	F3
		37	Enviro 3x3 Plus	F3, AR
		38	Enviro 3x3 Ultra	F3, AR
		39	Enviro 3x6 Plus	F3, AR
		40	Enviro 6x6 Plus	F3, AR
		41	Enviro USP	F3
		42	LS xMax	F3
		43	LS aMax	F3

Manufacturer	Location	No.	Product Name	Type
		44	MB -20	F3, LT
		45	P 3%	F3
		46	P 6%	F3
Denko	NY, United States	47	6% AFFF	F3
		48	3% AFFF	F3, LT
		49	1% AFFF	F3, LT
		50	Alcohol AFFF 3%-6% Single or Double Strength	F3, LT, AR
		51	High Expansion Foam, Class A or B	F3, Hi-Ex
Fire Safety Devices Pvt. Ltd.	NY, United States	52	Fluorine-free Foam, 1%, 3%, 6%	F3
Fire Suppression Products	MI, United States	53	FIRE CAP PLUS AR-AFFF 1% x 3%	F3, AR
		54	FIRE CAP PLUS	F3
FireFreeze Worldwide, Inc.	NJ, United States	55	Coldfire	F3
FireRein	Canada	56	Eco-Gel	F3
Genius Group	Germany	57	PyroBubbles	F3
Hazard Control Technologies, Inc.	GA, United States	58	F-500	F3
Orchidee Fire	Belgium	59	Orchidex BlueFoam 1x3	F3
		60	Orchidex BlueFoam 3x3	F3
		61	Orchidex BlueFoam 3x6	F3
		62	Orchidex BlueFoam 6x6	F3
Pyrocool Technologies	VA, United States	63	Pyrocool FEF 0.4% Multiclass Foam Concentrate	F3
R. Nickeson Enterprises	MA, United States	64	Novacool UEF Foam	F3
Sthamer	Germany	65	FOAMOUSSE 3% F-15 #5301	F3
		66	vaPUREx LV 1% F-10 #7141	F3
		67	STHAMEX-SV/HT 1% F-5 #9142	F3, LT
		68	MOUSSOL®–FF 3/6 F-15 #7941	F3, AR
		69	MOUSSOL®–FF 3/6 F-5 #7942	F3, AR
		70	STHAMEX® 2% F6 Multi-purpose detergent foam	F3
		71	STHAMEX® K 1% F-15 #9143	F3
		72	STHAMEX® 3% F6 Multi-purpose detergent foam	F3
The Solberg Company (an Amerex Corporation company)	WI, United States	73	RE-HEALING RF1, 1% FOAM CONCENTRATE	F3
		74	RE-HEALING RF1-AG, 1% FOAM CONCENTRATE	F3
		75	RE-HEALING RF1-S, 1% FOAM CONCENTRATE	F3
		76	RE-HEALING RF3, 3% FOAM CONCENTRATE	F3
		77	RE-HEALING RF3-LV, 3% LOW VISCOSITY FOAM CONCENTRATE	F3, LV
		78	RE-HEALING RF3x3% FREEZE PROTECTED ATC FOAM CONCENTRATE	F3, LT
		79	RE-HEALING RF3x6% ATC FOAM CONCENTRATE	F3
		80	RE-HEALING RF3x6% FREEZE PROTECTED ATC FOAM CONCENTRATE	F3, LT
		81	RE-HEALING RF6, 6% FOAM CONCENTRATE	F3
		82	RE-HEALING RF6, 6% FOAM CONCENTRATE	F3

Manufacturer	Location	No.	Product Name	Type
The Solberg Company (Amerex Corporation)	WI, United States	83	RE-HEALING RF-MB FOAM CONCENTRATE	F3
Verde Environmental, Inc. (Micro Blaze)	TX, United States	84	Micro-Blaze Out	F3
vs FOCUM	Spain	85	Silvara 1 (1%)	F3, LV[e]
		86	Silvara APC 3x3	F3
		87	Silvara APC 3x6	F3
		88	Silvara ZFK (0.5%)	F3
		89	Silvara T3	F3
		90	Silvara APC 1	F3, AR
National Foam	PA, United States	91	Universal Green 3%-3%	F3, AR

[a] F3 = Fluorine-free foam or firefighting wetting agent that is advertised to be free of fluorinated surfactants, and therefore free of fluorine.

[b] Hi-Ex = High-expansion foams that have an expansion ratio greater than or equal to 200. They are used when an enclosed space, such as a basement or hangar, must be quickly filled.

[c] LT = Low-temperature foams, sometimes labeled as “freeze free” or “freeze protected,” that are specifically formulated to be used at lower temperatures.

[d] AR = Alcohol-resistant foams that are used as a conventional AFFF on hydrocarbon fuels. They form an aqueous film on the surface of the hydrocarbon fuel. When used on polar solvents (or water miscible fuels), the polysaccharide polymer forms a tough membrane that separates the foam from the fuel and prevents the destruction of the foam blanket. Fifteen AR foams are especially effective for extinguishing and securing flammable hydrocarbon and polar solvent fires. High-risk facilities, such as refineries, pharmaceutical plants, and process areas, often require AR foams.

[e] LV = Low-viscosity foams that are formulated to be thinner than typical foams, thus flowing at a faster rate during application.

6.2 Fluorine-Free Training Foams

Firefighting foam manufacturers typically formulate one or more products specifically for training purposes. These foams do not typically meet performance specifications, as their use in training does not dictate the same level of performance. Similarly, manufacturers have formulated fluorine-free training foams for use at fire academies and other locations for training purposes. Table 3 contains fluorine-free training foams currently available on the market.

Table 3. Fluorine-Free Training Foams [Note: Product information was collected in August 2018. The main source of product information is manufacturer websites and ingredient information is sourced from product Safety Data Sheets (SDSs). It is recommended that readers confirm product information directly with manufacturers as it may have changed since publication.]

Manufacturer	Country	No.	Product Name	Type
3F Company	United Kingdom	T1	T-FOAM SF 3	F3, T
		T2	T-FOAM SF 6	F3, T
Aberdeen Foam (Oil Technics Firefighting Products)	Scotland, United Kingdom	T3	Aberdeen Foam 1% Training Foam (synthetic)	F3, T
		T4	Aberdeen Foam 3% Training Foam (synthetic)	F3, T
Angus Fire	United Kingdom	T5	TF3/TF6 (3%/6% Training Foam Concentrate	F3, T
		T6	Trainol (3% Fluorine-free Training Foam Concentrate)	F3, T
Auxquimia (ICL Performance Products)(Phos-Chek Fire Retardant)	Spain	T7	Phos-Chek Training Foam 136	F3, T
		T8	Phos-Chek Training Foam EE-3	F3, T
Bio-ex	France	T9	BIO T3 (1-3%)	F3, T
Dafo Fomtec AB	Sweden	T10	Trainer E-lite	F3, T
Fire Services Plus	GA, United States	T11	FireAde Training	F3, T
Sthamer	Germany	T12	TRAINING FOAM-N 1% F-0 #9141	F3, T
The Solberg Company (Amerex Corporation)	WI, United States	T13	RE-HEALING TF, TRAINING FOAM CONCENTRATE	F3, T

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6.3 Short-Chain (C6) Foams

Most manufacturers no longer offer long-chain (C8) firefighting foams, as the industry has voluntarily switched over to C6 foams. As a result, the universe of C6 products is vast. The project workgroup focused its efforts on identifying and collecting information on fluorine-free alternatives; the manufacturers in Table 4 are those that offer C6 foams. Please visit each manufacturer's accompanying link to learn about the C6 products they offer.

Table 4. Manufacturers of C6 foams [Note: Product information was collected in August 2018. The main source of product information is manufacturer websites and ingredient information is sourced from product Safety Data Sheets (SDSs). It is recommended that readers confirm product information directly with manufacturers as it may have changed since publication.]

Manufacturer	Country	Link
3F Company	United Kingdom	http://www.3fff.co.uk/index.php/en/chemistry-3f-foams-extinguishers-specialities/smart-foams-industryprotection-3f-england-singapore-morocco-2
Aberdeen Foam (Oil Technics Firefighting Products)	United Kingdom	http://www.firefightingfoam.com/fire-fighting-foam/products-a-z/
Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.)	United States / United Kingdom	http://angusfire.com/foam-concentrates/
Auxquimia (ICL Performance Products)	Spain	https://phoschek.com/brand/auxquimia-s-a/
BIOex	United Kingdom	http://www.bio-ex.com/products/types-of-risk/class-b-liquid-fires-hydrocarbons/product/biofilm-fluorosynthetic-afff-foam-concentrate-effective-on-hydrocarbon-fires-9
Buckeye Fire Company	NC, United States	http://www.buckeyefire.com/foam-equipment-concentrates/
Chemguard	WI, United States	http://www.chemguard.com/fire-suppression/catalog/foam-concentrates
Dr. Sthamer	Germany	https://sthamer.com/en/AFFF_foam_concentrate.php
Fire Safety Devices Pvt. Ltd.	India	http://fcfsd.com/fire-fighting-foams.html
FireAde	GA, United States	http://pro.fireade.com/products/fireade-climate-control/
Fomtec (Dafo Fomtec AB)	Sweden	https://www.fomtec.com/foam/category33.html
National Foam	PA, United States	http://nationalfoam.com/foam-concentrates/
Orchidee	Belgium	http://www.orchidee-fire.com/foams/
Solberg	WI, United States	http://www.solbergfoam.com/Foam-Concentrates/ARCTIC-Foam.aspx

7. Research Groups and Agencies Involved in Firefighting Foam Work

This section highlights the activities from the many organizations in the U.S. and abroad that are actively engaged in work in fluorine-free foams for Class B fires. It is recommended that readers follow up directly with the organizations listed as their work progresses and new information emerges. More information on the work of the research groups and agencies can be found in "Appendix E: Research Groups and Agencies Involved in AFFF Work."

7.1 Intergovernmental Organizations

1. The OECD/UNEP Global PFC Group released the updated "New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances (PFAS)" and an accompanying methodology report in May 2018. The group's informational portal serves to facilitate the exchange of information on per- and polyfluorinated chemicals, focusing specifically on PFAS, in order to support a global transition towards safer alternatives. The portal can be accessed at http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/
2. The Interstate Technology and Regulatory Council (ITRC) has developed a series of fact sheets to summarize the latest science and emerging technologies for remediating PFAS-contaminated sites. The fact sheets are tailored to the needs of state regulatory program personnel who are tasked with making informed and timely decisions regarding PFAS-impacted sites. The content is also useful to consultants and parties responsible for the release of these contaminants, as well as community stakeholders. The fact sheets are available at https://pfas-1.itrcweb.org/fact-sheets/

7.2 Government

3. The U.S. DoD's Strategic Environmental Research and Development Program has active projects under its Environmental Research Programs: Per- and Polyfluoroalkyl Substances (PFASs) subsection. These projects focus on the research and development of fluorine-free AFFF for use by the U.S. military.
4. The U.S. Naval Research Laboratory (NRL) has current projects in fluorine-free foam development and remediation of PFAS-contaminated sites, though details of those projects are not available. A number of presentations and papers have been authored by NRL staff and focus on the performance of fluorine-free foams and the role of surfactants in AFFF.
5. The U.S. Environmental Protection Agency (EPA) has initiated the following:
   i. A request for application (RFA) titled "National Priorities: Per- and Polyfluoroalkyl Substances (PFAS)" closed in June 2018. The RFA solicited applications to generate new information for nationally assessing PFAS fate and transport, exposure, and toxicity.
   ii. On January 21, 2015, EPA proposed a Significant New Use Rule (SNUR) under the Toxic Substances Control Act. It required manufacturers, importers, and processers of PFOA and PFOA-related chemicals (including as part of articles) to notify EPA at least 90 days before starting or resuming new uses of these chemicals in any products. This notification would allow EPA the opportunity to evaluate the new use and, if necessary, take action to prohibit or limit the activity. This SNUR is not currently in effect.
   iii. EPA's New Chemicals Program reviews alternatives for PFOA and related chemicals before they enter the marketplace to identify whether the range of toxicity, fate, and bioaccumulation issues that have caused past concerns with perfluorinated substances may be present. This is done in order to ensure that the new chemicals may not present an unreasonable risk to health or the environment.

Funding Provided by the NYS Department of Environmental Conservation

iv. Since 2000, EPA has worked to review substitutes to PFOA, PFOS, and long-chain PFAS. The focus is on whether the reviewed substances have similar properties to PFOA, PFOS, or long-chain PFAS, and to then try and determine if the reviewed compound raises any new concerns.

6. EPA has done a lot of work in characterizing and detecting PFAS, as well as characterizing fate and transport, researching ecological risk, exposure, toxicity research with animals, and research with computational modeling of PFAS.
7. The State of Washington was the first U.S. state to ban certain firefighting foams containing perfluorinated compounds. A new law, RCW 70.75A, prohibits (1) the use of PFAS containing Class B firefighting foam for training purposes as of July 1, 2018, and (2) the manufacture, sale, and distribution of PFAS containing Class B firefighting foam starting on July 1, 2020. Military, FAA-certified airports, petroleum refineries and terminals, and certain chemical plants are all exempt from this requirement.
8. Other U.S. states are actively involved in PFAS work to varying degrees. This list is not comprehensive. New Jersey found PFAS substances in surface water, sediment, and fish tissue in 2018. New York surveyed potential users of firefighting foam in the state to determine which facilities may be using PFOA/PFOS foams in order to target them for potential contamination and response. New York had a collection and disposal program for firefighting foam containing perfluorinated compounds. Vermont has identified a number of potential sources of PFAS water contamination. Michigan has established a PFAS response team to investigate sources and locations of PFAS contamination in the state, take actions to protect drinking water, and keep the public informed.
9. The Australian Government is currently investigating the use of PFAS contamination in and around military bases. An Expert Health Panel for PFAS was established to advise on the potential health impacts associated with PFAS exposure and to identify priority areas for further research in 2018. South Australia was the first Australian state to ban fluorinated foams in 2018.

7.3 Industry

10. The Petroleum Environmental Research Forum (PERF) is a non-profit organization created to provide a stimulus to and a forum for the collection, exchange, and analysis of research information relating to the development of technology for health, environment and safety, waste reduction, and system security in the petroleum industry. In May 2018, a project was contracted with an aim to capture the state of knowledge of the fate, transport, and effects of short-chain PFAS-based AFFFs and fluorine-free firefighting foams in order to identify limitations of and data gaps in the current studies or data sets. The project may use GreenScreen® assessments and may use the IC2 Alternatives Assessment methodology. The current plan is to include foam ingredient chemicals (as delivered) and their final degradates in the chemical hazard assessment.
11. The LASTFIRE ("LAST" stands for "Large Atmospheric Storage Tanks") Project was initiated to review the risks associated with large-diameter, open-top, floating-roof storage tanks. LASTFIRE has developed their own performance standard (see "Firefighting Foam and Water Additive Performance Specifications" [Section 4] of this report for more info) and holds regular foam industry summits.
12. The Dallas/Fort Worth Fire Training Research Center has presented results on the performance of fluorine-free foams and may be a good resource for performance testing. More information is available here: https://www.dfwairport.com/firetraining/#slide-1[21]

[21] LASTFIRE's 2018 International Fire Fighting Foam Summit and Fire Extinguishment Tests were held at Dallas/Fort Worth Airport.

7.4 Independent Organizations

13. Clean Production Action is collaborating closely with Toxic-Free Future and King County Local Hazardous Waste Management Program in the State of Washington to reduce exposure to PFAS in firefighting foam by identifying safer alternatives.

8. Firefighting Foam Research

The following section includes information to assist with identifying chemical alternatives for fluorinated compounds in firefighting foam and to characterize their impact on the environment and human health. Understanding the performance needs for suppressing Class B fires, beyond those included in the Core Performance Standards in "Firefighting Foam and Water Additive Performance Specifications" [Section 4] of this report, is also part of this task.

This research is performed to support a future alternatives assessment of firefighting water additives. *A Framework to Guide Selection of Chemical Alternatives*, a 2014 publication from the National Academies of Sciences, Engineering, and Medicine, was consulted to determine the point in the alternatives assessment process at which the research papers included here are most useful. Summaries of the research papers are included in "Appendix F: Firefighting Foam Research Detailed Summaries." A summary of key findings follows.

Key findings

1. **A number of fluorine-free surfactants have been developed**. These include patents issued for foams consisting of water and a high-molecular-weight acidic polymer (HMWAP), a siloxane-containing foam, and over 250 foams synthesized (these include carbohydrate siloxane surfactants, siloxane and carbosiloxane surfactants, silica-based foam, and a foam concentrate consisting of an acid group and/or a deprotonated acid group and an oliganosilane unit and/or oligosoloxane unit). The Swedish Chemicals Agency survey of foam manufacturers and their products with their ingredients may be helpful to further identify potential alternative surfactants.

2. **The amount of performance testing of fluorine-free foams is limited and the results of available tests show the performance of fluorine-free foams is not consistent across types**. In some cases, fluorine-free foams perform as well as fluorinated foams, and in other cases, fluorine-free foams do not.

    - Some performance tests show that fluorine-free foams perform as well as fluorinated foams.
        - Siloxane-based foam is tested against the German military performance standard and performs as well as fluorinated foams and better than fluorine-free foams on F-34 fuel fires.
        - Performance tests show that siloxane-based foams perform better on F-34 fuel fires than nonaqueous film-forming Class B foam.
        - In fire extinguishment and burnback tests of two fluorinated MIL-SPEC foams and one fluorine-free foam on four low-flash-point fuels, the fluorine-free foams perform more consistently than fluorinated foams and the fluorinated foams did not outperform the fluorine-free foams when film formation was not possible.
    - Some performance tests show that fluorine-free foams do not perform as well as fluorinated foams.
        - In a comparison of a fluorine-free foam (Solberg's RF6) to a fluorinated foam (Buckeye Fire Equipment's 3%), the RF6 forms larger bubbles and has a longer drainage time. This may contribute to fuel flux and ignition. RF6 had higher fuel flux across different fuels, and this may be due to RF6 not containing oleophobic surfactants, which are found in fluorinated foams and reject fuel as it transfers through the barriers.
        - In a different, independent test of Solberg's RF6 fluorine-free foam, it struggled to contain vapors well as it does not form a film. Two additional fluorine-free foams (composition confidential and not reported) had erratic performance and placed last in all tested

performance parameters, compared to a fluorinated foam and RF6. The paper noted that in actual practice, foams are reapplied frequently. Performance of both fluorinated and RF6 increased dramatically when reapplied. Therefore, it is suggested that in a practical scenario, rather than under the current testing parameters, RF6 would perform adequately.

3. **The ecotoxicity and impacts on human health of fluorine-free alternatives have not been well characterized or assessed**. Many fluorine-free firefighting water additives contain generic statements that they are preferable to fluorinated foams because they do not contain fluorine. Some of the fluorine-free firefighting wetting agents identified in Section 6 of this report have aquatic toxicity and human health information on the safety data sheet. Safety data sheets for about a quarter of the fluorine-free firefighting water additives could not be obtained. Furthermore, the safety data sheet contains aquatic toxicity information for the formulation and it is unknown how the surfactant itself contributes to human health and ecotoxicity effects. This is a significant gap and identifies a clear research need.

4. **Comprehensive papers exist that expand on performance needs for suppressing Class B fires beyond those included in the Core Performance Standards in this report.**
   - One paper, "The Future of Aqueous Film Forming Foam: Performance Parameters and Requirements," details the reasoning behind the MIL-SPEC performance requirements. Rich with information, this work is highly recommended reading for anyone seeking a deeper investigation into research in this field.
   - "What Properties Matter in Fire-Fighting Foams?" is a resource that provides a list of various properties, why standards have chosen to address them, the reason behind certain values, and the physical properties of concern with foams.

9. Conclusions, Research Needs, and Actions

From the review of firefighting foam performance standards, current and upcoming regulations, identification of fluorine-free foams, other researchers working in this area, and literature, the following conclusions, research needs, and actions have been identified:

1. **Three main information gaps need to be filled to characterize fluorine-free foams in order to promote them as safer alternatives to fluorinated foams:**
    a. **Performance data is uncertain and/or lacking.**
    Research need: Independent testing of fluorine-free foams to validate existing claims and test against others. The U.S. MIL-SPEC and IMO standards are the only performance specifications that require fluorinated surfactants. Performance testing of fluorine-free foams is needed to understand if the performance specifications can be met without the use of fluorinated surfactants. Some fluorine-free foams identified in this report indicate they meet performance specifications. There is some doubt in the firefighting foam industry that fluorine-free foams do in fact meet the standards. Independent performance testing to validate these claims would be beneficial. If foams cannot meet the specification, the testing process will identify exactly what parameter(s) is not being met. Performance testing fluorine-free foams is critical, as the FAA's Reauthorization Act of 2018 no longer requires major FAA airports to use fluorinated foams.
    b. **The makeup of foams is incomplete as many ingredients are protected as confidential business information. Many researchers and those in the firefighting foam industries have raised a concern about whether foams are truly fluorine-free or not.**
    Research need: Identify all fluorine-free foam ingredients and verify they are truly fluorine-free. Ingredients lists present on the safety data sheets of the fluorine-free foams identified in this study were reviewed. Many foams have incomplete lists, as ingredients are deemed confidential business information and excluded. Listing proprietary ingredients makes it impossible to characterize the fluorine-free alternatives to ensure promoted alternatives do not result in regrettable substitution, where one hazardous or toxic ingredient (in this case, fluorinated surfactants) is replaced with another ingredient possessing different hazard characteristics. There is some doubt within the firefighting foam industry that fluorine-free foams are truly free of fluorine. Analyzing a subset of foams would shed light on this concern and help to understand if the foams are completely free of fluorine or if they contain trace amounts.
    Research need: Achieve transparency of ingredients through credible third-party evaluation. Manufacturers may be amenable to an independent, third party evaluating confidential ingredients and formulations in order to report any hazard information without releasing proprietary ingredients and product formulations. This allows users to make informed decisions without releasing confidential business information.
    c. **The ecotoxicity and impacts on human health of most fluorine-free foams and their ingredients have not been characterized or assessed.**
    Research need: Characterize ecotoxicity and human-health impacts of fluorine-free foams, ingredients, and degradation products through third-party hazard and exposure evaluations. Most fluorine-free foams have generic statements that fluorine-free alternatives are preferable because they do not contain fluorine. Some of the fluorine-free foams identified in this report have aquatic toxicity and human-health information available on their safety data sheet. Safety data sheets could not be obtained for all products. Having complete ingredient lists or

formulations disclosed to a third party for analysis is critical to ensure the whole formulation is assessed. Again, characterizing alternative foams will help to eliminate regrettable substitutions.

2. **The use of performance standards across industries is not well understood and characterized.**
   Research need: Dig deeper into mapping performance specifications to applications. A cursory list of industries and situations to which each performance standard applies is included in this report. Reaching out to industry stakeholders, firefighters, and foam manufacturers to validate and expand this list would help to build an understanding of the performance needs for specific fire situations, which could then be used to determine the appropriate foam type for that need.

3. **It is unclear if gaps or discrepancies exist in the performance needs for extinguishing Class B fires and existing performance specifications.**
   Research need: Compare the performance needs and existing performance specifications. It is unclear if performance standards are too strict, not strict enough, or sufficient in all areas of fire suppression. Comparing the needs to standards, such as MIL-SPEC and UL 162, may identify gaps and discrepancies. Working with users knowledgeable about fire suppression needs, foam manufacturers, performance specification authors, and other stakeholders would ensure specifications are appropriate for all.

4. **Organizations are developing fluorine-free foams, characterizing them, and performing alternatives assessments. Washington is the first U.S. state to ban the sale of fluorinated foams.**
   Action: Monitor work by other organizations. The DoD's research to develop and characterize fluorine-free foams, PERF's alternatives assessment of fluorine-free foams, and CPA's work to develop a list of preferable PFAS-free foams are all notable and currently ongoing. The State of Washington is getting ready to implement their ban on the sale of fluorinated foams in 2020 and is currently working to assess alternatives. Their outcomes may be adopted by others and influence policy and product formulations. The landscape is rapidly changing and there may be other organizations in the near future doing similar work.

5. **There is no regulation preventing the use of fluorine-free foams by non-military users, including firefighting training centers, chemical manufacturers, oil refineries, and others.**
   Action: Assist training centers and other non-military users in switching to fluorine-free alternatives. Firefighting training centers do not have to follow the same performance standards as other users and typically use foams that are not certified to a performance standard. There is no regulatory roadblock for training centers to use fluorine-free foams.

Appendix A: Additional Performance Standards

APSAD R12. France. APSAD R12 is concerned with automatic high-expansion foam extinguishing installations. The rule stipulates the design, construction, commissioning, periodical checking, and maintenance requirements of fixed, automatic, high-expansion foam extinguishing systems installed in buildings in the industrial, commercial, agricultural, or tertiary sectors. English version of the standard is not available. Only one mention of this standard was found during the project, so it has very limited application. Learn more: http://www.cyrus-industrie.com/non-classe-en/apsad-r12-4447

CAN/ULC-S564 Standard for Categories 1 and 2 Foam Liquid Concentrates. Canadian standard: https://www.scc.ca/en/standardsdb/standards/23093

CAP168 Licensing of Aerodromes. UK standard: https://www.folkestone-hythe.gov.uk/webapp/lydd-airport/CORE%20DOCS/CD16/CD16.1.pdf

Class A: Ceren Certificate. Forest fire standard: http://www.valabre-ceren.org/

Draves Test AATCC 17-2005. Efficiency of ordinary commercial wetting agents. Learn more: https://members.aatcc.org/store/tm17/484/

FM 5130 Foam Extinguishing Systems. Complex standard covering foams in their entirety from suppression system to concentrate. Referenced once throughout project duration. Learn more: https://www.fmapprovals.com/approval-standards

GB15308-94: General specification for Foam Extinguishing Agents. Standards Administration of China. Referenced once throughout project duration. See standard: https://standards.globalspec.com/std/143880/sac-gb-15308-94

GESIP. Based in France with a French website, this standard was developed by an oil and chemical industry safety research group that shares feedback, and provides training and information. It has been difficult to glean information; appears they certify companies to standards with respect to the oil industry. It is similar to LASTFIRE. Learn more: http://gesip.com/

IMO MSC.1/Circ 1312. Provides some standard information with respect to foams utilized by boats. It seems that, if this standard is met, then the foam is acceptable for ship use, though it does not include other standards associated with suppression systems. Learn more:
http://www.imo.org/blast/blastDataHelper.asp?data_id=25955&filename=1312.pdf.

IMO MSC/Circ.670: Guidelines for the Performance and Testing Criteria and Surveys of High-Expansion Foam Concentrates for Fixed Fire Extinguishing Systems. While it is unclear if this is an outdated version of the IMO MSC.1/Circ 1312 or just very similar to it, it is not necessary to consider it individually. Learn more: http://imo.udhb.gov.tr/dosyam/EKLER/MSC-Circ.670.pdf

LASTFIRE. Standard focused on fires with respect to hydrocarbon fuels. Developed by petrochemical companies and designed with constraints less focused on emergency (life-threatening) situations. Learn more: http://www.lastfire.co.uk/

Lloyd's Register. Independent organization that certifies to ISO standards. Learn more: https://www.lr.org/en/

Marine: Veritas/BV. Independent organization that certifies products/companies to ISO/IMO standards. It appears certification by this company means that the vessel is following all standards necessary for the use of foam on a ship. Learn more: https://www.bureauveritas.com/marine-and-offshore

MED Wheelmark. Independent organization that certifies European Union maritime vessels. Learn more: http://www.ecosafene.com/EN/firetesting/marine/262.html

NFPA 1145 Guide for the Use of Class A Foam in Firefighting. This guide assists fire departments and wildland fire agencies in the safe and effective use of Class A foams for manual structural firefighting and protection. Foam application is outside the scope of this project. Learn more: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1145

NFPA 1150 Standard on Foam Chemicals for Fires in Class A Fuels. This standard defines the acceptance requirements and test methods for fire-fighting foam chemicals that are used to control, suppress, or prevent fires in Class A fuels. May be a fluorine-free standard. Learn more: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1150

NFPA 18 Standard on Wetting Agents. Provides requirements for the performance and use of wetting agents as related to fire control and extinguishment. It is intended for the guidance of the fire services, authorities having jurisdiction (AHJs), and others concerned with judging the acceptability and use of any wetting agent offered for such a purpose. It could be applied to film-forming foams, but it may not be ideal since it is very broad in scope. Learn more: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=18

NFPA 298 Standard for Foam Chemicals for Wildland Fire Control. Specifies requirements and test procedures for foam chemicals used in wildland firefighting. The standard is most likely concerned with Class A fires, so fluorosurfactants would not be as vital to its assessment. It may be a fluorine-free standard. Learn more: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=298

UK 42-42. UK Military spec firefighting foam that was replaced by EN 1568.

U.S. Department of Agriculture Forest Service Specification 5100-307a Specification for Fire Suppressant Foam for Wildland Firefighting (Class A Foam). This standard outlines requirements for foams utilized for Class A fires. It contains biodegradability requirements, which means that foams meeting this standard are not likely to contain fluorosurfactants. It may inadvertently be a fluorine-free standard. Learn more: https://www.fs.fed.us/rm/fire/wfcs/documents/307a.pdf

USC/CNC; USL/CNL. Unable to find information on these standards. The foam manufacturer FireAde lists them on their website: http://pro.fireade.com/products/fireade/

Appendix B: Core Performance Standards Details

This section includes a summary of each core performance standards along with key text and table excerpts from the standards.

B.1 Australian Government DEF (AUST) 5706

Guidelines for testing fixed Aqueous Film Forming Foam (AFFF) suppression systems

*Australia military standard. Criteria similar to ISO. Updated in 2018. Accessible here: http://www.defence.gov.au/EstateManagement/Governance/Policy/EngineeringMaintenance/FireProtection/Guidelines/GuidelinesForTestingFixedAqueousFilmFormingFoam(AFFF)SuppressionSystems.*pdf

These guidelines are for testing fixed Aqueous Film Forming Foam (AFFF) monitor, overhead deluge, and pop-up sprinkler fire suppression systems in Australian Defense hangars. They include general guidance in relation to testing, commissioning tests, and requirements for storage, collection, treatment, and disposal of AFFF and AFFF wastewater.

The National Fire Protection Association (NFPA) 11—Standard for Low-, Medium-, and High-Expansion Foam is the internationally and locally acknowledged relevant standard. These guidelines endorse and supplement the general testing provisions included in NFPA 11. In the event of conflict between the requirements of NFPA 11 and the guidelines set out in DEF (AUST) 5706, the latter prevails.

B.2 European Standard EN 1568, Parts 1–4

A general-use standard developed by the European Union to replace the individual standards that each country had possessed. Updated in 2018. Available for purchase here: https://www.en-standard.eu/

- Not a pass or fail standard: Concentrates are given performance grades (in other words, Grades 1-4 for extinguishing performance and Grades A-D for burnback resistance). **Grade 1A is the highest achievable grade**.
- EN 1568-approved products are not conformance monitored after accreditation.
- **Part 1** applies to medium-expansion foam for use on water-immiscible liquids.
- **Part 2** applies to high-expansion foam for use on water-immiscible liquids.
- **Part 3** applies to low-expansion foam for use on water-immiscible liquids.
- Requires a 4.52 m^2 heptane fire with a pre-burn of 60 s to be extinguished at an application rate of 2.52 L/min/m^2 using foam with potable and sea water.
- **Part 4** applies to low-expansion foam for use on water-miscible liquids.
- Requires a 1.72 m^2 acetone fire with a preburn of 120 s to be extinguished at an application rate of 6.6 L/min/m^2 using foam with potable and sea water.

EN 1568-1	
Sediment Before/After Ageing	0.25%/1%
Viscosity:	
Newtonian	>200 mm^2/s
Psuedo Plastic	120 mPa*s
pH	6.0-9.5
Extinction Time	>120 s
1% Burnback	<30 s

EN 1568-2	
Sediment Before/After Ageing	0.25%/1%
Viscosity:	
Newtonian	>200 mm^2/s
Psuedo Plastic	120 mPa*s
pH	6.0-9.5
Extinction Time	>150 s

EN 1568-3					
Extinguishing Performance Class	**Burnback Resistance Level**	**Gentle Application Test**		**Forceful Application Test**	
		Extinction Time Not More Than	**25% Burnback Time Not Less Than** (min)	**Extinction Time Not More Than**	**25% Burnback Time Not Less Than** (min)
I+	A			1.5	10
	B		15	1.5	
	C		10	1.5	
	D		5	1.5	
I	A			3	10
	B		15	3	
	C		10	3	
	D		5	3	
II	A			4	10
	B		15	4	
	C		10	4	
	D		5	4	
III	B	5	15		
	C	5	10		
	D	5	5		

EN 1568-4			
Extinguishing Performance Class	**25% Burnback Resistance Level**	**Extinction Time Not More Than** (min)	**25% Burnback Time Not Less Than** (min)
I	A	3	15
	B	3	10
	C	3	5
II	A	5	15
	B	5	10
	C	5	5

B.3 ICAO: The International Civil Aviation Organization Airport Services Manual

The standard that the aviation industry developed with a focus on rapid extinguishment. It is primarily used in airports and was developed to minimize potential danger to those on flights. It provides recommendations and classifications A-C for firefighting foams as well as other best practices for airports. It is internationally applied, though the Federal Aviation Administration (FAA) is U.S. centric. It was last updated in 2014. Available here: https://www.docdroid.net/13f3i/icao-airport-services-manual-part-1-rescue-and-fire-fighting.pdf.

- International Civil Aviation Organization (ICAO)-approved products are not conformance monitored after accreditation.
- ICAO Level A requires a 2.8 m^2 fire to be extinguished at an application rate of 4.1 L/min/m^2.
- ICAO Level B requires a 4.5 m^2 fire to be extinguished at an application rate of 2.5 L/min/m^2.
- ICAO Level C requires a 7.32 m^2 fire to be extinguished at an application rate of 1.75 L/min/m^2.
- All levels require a heptane fire with a 60 s preburn and use of potable water.
- Chapter 8 (p. 43) of the manual is of the most interest as it discusses firefighting foams, detailing procedures for storage, transport, application, standard testing, testing conditions, etc.
- **It does not explicitly mention the need for foams to be fluorinated.**
- It includes best practices for airports with respect to firefighting and general safety.
- The following quote outlines the manual's specific requirements for foam-concentrate performance:

  For each performance level, a foam concentrate is acceptable

  > a) if the time to extinguish the fire from the overall surface of the tray is equal or less than 60 s, and b) the re-ignition of 25% of the tray surface is equal to or longer than five minutes. (Note for testing authorities: At the 60 s time, minute flames (flickers) visible between the foam blanket and the inner edge of the tray are acceptable.)
  >
  > a) if they [flickers] don't spread in a cumulative length exceeding 25% of the circumference of the inner edge of the tray, and b) they [flickers] are totally extinguished during the second minute of foam application.

ICAO Performance Specifications			
Fire Tests	Performance Level A	Performance Level B	Performance Level C
Nozzle (Air Aspirated)			
Branch Pipe	"Uni 86" Foam Nozzle	"Uni 86" Foam Nozzle	"Uni 86" Foam Nozzle
Nozzle Pressure	700 kPa	700 kPa	700 kPa
Application Rate	4.1 L/min/m2	2.5 L/min/m2	1.56 L/min/m2
Nozzle Discharge Rate	11.4 L/min	11.4 L/min	11.4 L/min
Fire Size	2.8 m2 circular	4.5 m2 circular	7.32 m2 circular
Fuel (on Water Substrate)	Kerosene	Kerosene	Kerosene
Preburn Time	60 s	60 s	60 s
Fire Performance			
Extinguishing Time	≤ 60 s	≤ 60 s	≤ 60 s
Total Application Time	120 s	120 s	120 s
25% Reignition Time	≥ 5 min	≥ 5 min	≥ 5 min

B.4 IMO: International Maritime Organization

Guidelines for the Performance and Testing Criteria and Surveys of Foam Concentrates for Fixed Fire-Extinguishing Systems

Follows similar criteria to ISO and largely focuses on how to perform the tests. Updated in 2009.

The IMO standards are focused on merchant ships and are required by many maritime administrations and classification bodies for foam concentrates to be used on board ships in international waters. They arose as part of the implementation of the Safety of Life at Sea (SOLAS) Convention.[22] There are 174 member states that follow IMO.

- **Explicitly calls out aqueous film-forming concentrate as having fluorinated surfactants**
- **IMO MSC Circ.670** sets out the testing protocols and acceptance criteria for the testing of high-expansion foam concentrates. Find further information here: http://imo.udhb.gov.tr/dosyam/EKLER/MSC-Circ.670.pdf
- The standards are now required by many maritime administrations and classification bodies for foam concentrates to be used on board ships in international waters and have arisen as part of the implementation of the SOLAS Convention.

IMO Specifications	
Sedimentation	≤ 0.25% by volume
Kinematic Viscosity	Max: 200 mm^2/s
pH	6 < pH < 9.5 at 20 °C
Spreading Coeffcient	> 0 N/m
Expansion Ratio Parameters:	
Flow Rate	11.4 L/in
Nozzle Pressure	6.3 ± 0.3 bar
Extinction Time	≤ 5 min
Burnback Time	> 15 min for 25% of the surface
Mass Density	ASTM D 1298-85 (reference)

[22] Read the International Convention for the Safety of Life at Sea (SOLAS), 1974 here: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

B.5 ISO-7203

Fire Extinguishing Media: Foam Concentrates

International focus. Updated in 2011.

The International Standards organization developed a general use standard with respect to foam performance. These were not developed with a singular specific purpose and the multitude of classes provide variety in how well the foam will perform so that buyers will know exactly what they are getting. Below are the ISO's specifications in detail.

ISO 7203-1 Specification for low-expansion foam concentrates for top application to water-immiscible liquids (Full document: http://iso-iran.ir/standards/iso/ISO_7203_1_2011_,_Fire_Extinguishing.pdf)

ISO Max Extinction Times and Min Burnback Times (min)					
Extinguishing Performance Class	Burnback Resistance Level	Gentle Application Test		Forceful Application Test	
		Extinction Time Not More Than	25% Burnback Time Not Less Than (min)	Extinction Time Not More Than	25% Burnback Time Not Less Than (min)
I	A	Not applicable		3	10
	B		15	3	Not applicable
	C		10	3	
	D		5	3	
II	A	Not applicable		4	10
	B		15	4	Not applicable
	C		10	4	
	D		5	4	
III	B		15	Not applicable	
	C		10		
	D		5		

ISO 7203-2 Specification for medium- and high-expansion foam concentrates for top application to water-immiscible liquids (Full document: http://iso-iran.ir/standards/iso/ISO_7203_2_2011_,_Fire_Extinguishing.pdf)

Types of Expansion Foam	Medium Expansion Foam	High Expansion Foam
Extinction Time (s)	Not more than 120	Not more than 150
1% burnback Time (s)	Not less than 30	Not applicable

ISO 7203-3 Specification for low-expansion foam concentrates for top application to water-miscible liquids (Full document: (Full document: http://iso-iran.ir/standards/iso/ISO_7203_3_2011_,_Fire_Extinguishing.pdf)

Extinguishing Performance Class	Burnback Resistance Level	Extinction Time Not More Than (min)	25% Burnback Time Not Less Than (min)
I	A	3	15
	B	3	10
	C	3	5
II	A	5	15
	B	5	10
	C	5	5

B.6 LASTFIRE Hydrocarbon Storage Tanks

Updated in 2015. Accessible here: http://www.lastfire.org.uk/uploads/LFTestSpecRevD-APR2015.pdf

The LASTFIRE standard emerged when a consortium of oil industry leaders came together to provide accurate information on firefighting foams. ("LAST" is an acronym for Large Atmospheric Storage Tank.) More of a "best practices" guide than a set of standards, it ranks foams from 0–100. It is focused on atmospheric tank fires and, as a result, is more concerned with how foams will behave and degrade over a long period of time than with rapid extinguishment.

- The project was initiated due to the oil and petrochemical industries' recognition that the fire hazards associated with large-diameter, open-top, floating-roof tanks were insufficiently understood to be able to develop fully justified site-specific fire-response and risk-reduction policies.
- Part of this project was to develop a foam-testing protocol in order to assess a foam's capability to achieve the special performance characteristics relevant to large storage tank firefighting.
- The LASTFIRE test was rapidly established as a standard for this severe application and has been included as a requirement in foam concentrate procurement specifications by major international oil companies.
- Applications are focused on putting out fires in open-top fuel tanks
- Ratings are based on a scale of 100% effectiveness (p. 13)
    - Fire control: 5%
    - Extinguishment capability: 65%
    - Post-extinguishment vapor suppression: 15% (2 trials of 7.5% each)
    - Burnback resistance: 15%
    - These values were based on polls of experienced operators and what they felt was important in the foams.
- 100–80% is considered "Good Fire Performance."
- 79.5–50% is considered "Acceptable Fire Performance."
- 49.5–25% is considered "Reduced Fire Performance."
- 24.5–0% is considered "Poor Fire Performance" (p. 21).

LASTFIRE Criteria	Minutes from ignition	Score	Remarks
Fire Control	0-5	5	
	>5-8	2	
	8-10	0	
	>10	FAIL	Overall Fail
	Maximum score	***5***	***5% of total***
Extinguishment	0-6	65	
	>6-10	55	
	>10-12	45	
	>12-20	25	
	20-30	15	
	>30	FAIL	Overall Fail
	Maximum score	***65***	***65% of total***
Vapor Suppression	**Test One**		
		7.5	*No reignition*
		5	*Minor edge ignition only*
		2.5	*Full circumference ignition or single ghosting over surface*
		0	*Full flash and prolonged ghosting over surface*

LASTFIRE Criteria	Minutes from ignition	Score	Remarks
	Maximum score	***7.5***	***7.5% of total***
	Test two - scoring as test one		
		7.5	*No reignition*
		5	*Minor edge ignition only*
		2.5	*Full circumference ignition or single ghosting over surface*
		0	*Full flash and prolonged ghosting over surface*
		OVERALL FAIL	*Significant prolonged flaming 25-50%, flames>pan*
	Maximum score	***7.5***	***7.5% of total***
Burnback Resistance		15	*<25%, minor flaming*
		10	*<25% flash/<65% circ.*
		5	*Flash 25-50%/<65% circ.*
		0	*Full flash/continued ghosting 25-50%*
		OVERALL FAIL	*Full flash/sustained flaming or ghosting >50%/exposed fuel >10%, iceberging*
	Maximum score	***15***	***15% of total***
	Total	**100**	

Below are extracts from LASTFIRE regarding specific topics.

Fire control:

> Marks are awarded for the foam’s ability to achieve 90% control up to a maximum of eight min from ignition (in other words, 5 min [of] foam application). Foams controlling the fire in 8–10 min (5–7 minutes of foam application) are given no marks in this section. Those foams that fail to control the fire once foam application has ceased even after 30 minutes from ignition are deemed to have “failed” the requirements of the LASTFIRE test and given a resultant zero overall score.

Extinguishment:

> Recognising that extinguishment of the fire is the ultimate aim of foam application and, generally speaking, the sooner it is achieved the better, scoring shall be based on a “sliding scale” with full marks given for extinguishment during the first three minutes of foam application (up to 6 min from ignition). If extinguishment is not achieved within the full 30 min test, then the foam is classified as “FAIL” and given an overall zero score.

Vapor suppression:

> Vapor suppression performance shall be assessed in the LASTFIRE test by passing a lighted torch around the full circumference and centre of the foam blanket. This shall be done twice during the test and each test [will be] given a maximum possible 7.5% of the total test marks. The extent of reignition shall be evaluated and scores given for each “torch test” based on the following observations:
>
> - Seven-and-a-half marks for no reignition
> - Five marks for < 65% of the circumference of the pan reignition which then extinguish and are not taller than the pan height.
> - Two-and-a-half marks for > 65% of the circumference of the pan reignition or minor “ghosting” occurs which is short lived and extinguished rapidly.

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- Zero marks for full flashover if flames subside rapidly or > 65% of the circumference ignites with flames greater than the pan height that persist, or ghosting is persistent but not greater than the height of the pan.
- “OVERALL FAIL” shall be deemed if significant, prolonged flaming over a large proportion of the surface (25–50 %) is observed, with flames greater than the test pan height. “OVERALL FAIL” shall be given, even if flaming subsides, and subsequent seal or burn back tests can be conducted.

Burnback resistance:

Different foams are able to resist “burnback” to varying degrees. Upon removal of the burnback pot (and in some cases before removal) foams can exhibit minor or extended reignition of the foam blanket. In some cases, the fuel surface will be exposed as subsequent foam “layers” are burnt and deteriorate. . . . Marks shall be awarded for burnback resistance as follows:

- Fifteen marks for < 25% of reignition at any point during test, no full surface flash, minor flickers no greater than the height of the pan are allowed, <65% of circumference flash with flames no greater than the height of the pan, and no visible fuel is observed.
- Ten marks for < 25% of reignition with a full flash permitted if it subsides slowly and <25% continues to burn, < 65% of circumference burns and flames are less than the pan height, and no exposed fuel is observed.
- Five marks for < 25% of reignition with a full flash permitted if it subsides slowly and <25% continues to burn, < 65% of the circumference burns but the flames are greater than the pan height, and no exposed fuel is observed.
- Zero marks for 25–50% of the fuel flaming at the end of test, ghosting or flaming is persistent over 25–50% of the test bed, fuel exposure is evident as long as it is < 10% of pan area.
- OVERALL FAIL shall be deemed if > 50% of the surface area is caught in a full flash or is burning at the end of the test, prolonged surface flames greater than the height of the pan are observed, > 10% fuel exposure is observed, or significant foam deterioration occurs (iceberging).

B.7 NFPA 11 Standard for Low-, Medium-, and High-Expansion Foam

U.S. standard focused on firefighting systems. Updated in 2016. Available for purchase here: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=11.

This standard was developed with tank fires as the primary concern and is mostly concerned with foam transit time across a hot fuel surface. It covers the design, installation, operation, testing, and maintenance of low-, medium-, and high-expansion foam systems for fire protection. Criteria apply to fixed, semi-fixed, or portable systems for interior and exterior hazards.

B.8 UL 162 Standard for Foam Equipment and Liquid Concentrates

Internationally recognized standard developed and maintained by Underwriters Laboratories Inc. Updated in 2018. Available for purchase here https://standardscatalog.ul.com/standards/en/standard_162.

This is a comprehensive and persistent standard that shows the compatibility of foams and provides firefighting performance specifications. Its requirements cover foam-producing equipment and liquid concentrates employed for the production and discharge of foam that has an expansion ratio of 20:1 or less and is used for fire extinguishment. This standard evaluates specific combinations of foam concentrates and foam equipment together, since performance for a given concentrate may vary depending on equipment-specific factors.

- It is a pass/fail test.
- UL 162 requires a 50 ft^2 heptane fire with a preburn of 60 s to be extinguished at an application rate of 1.63 L/m^2 using a freeze-protected foam with potable and sea water.
- UL-listed products are monitored with samples that are sent to UL every three months for conformance testing. This guarantees the foam being supplied is the same formulation as was originally tested; no other test standard requires this monitoring.

Products that meet the current standard can be found by searching UL category code "GFGV" on the UL Certifications Directory (Access here: http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.html). Each company listing includes the foam products it carries and the equipment that the foams are certified to work with.

B.9 U.S. Federal Aviation Administration (FAA)

The Federal Aviation Administration (FAA) outlines in Title 14, Code of Federal Regulations (CFR) [Part 139] that, in order to issue airport-operating certificates, an airport must

- serve scheduled and unscheduled air-carrier aircraft with more than 30 seats, or
- serve scheduled air-carrier operations in aircraft with more than nine seats but fewer than 31 seats.

Below are resources related to Part 139.

- A list of airports certified under Part 139 can be accessed here: https://www.faa.gov/airports/airport_safety/part139_cert/media/part139-cert-status-table.xls
- Operators of Part 139 airports must provide aircraft rescue and firefighting (ARFF) services during air carrier operations that require a Part 139 certificate. The guidance and resources below address ARFF training, ARFF vehicles, and other aviation fire and rescue requirements.
- General website summarizing ARFF standards: https://www.faa.gov/airports/airport_safety/aircraft_rescue_fire_fighting/
- In Chapter 6 of a 2004 advisory circular outlining performance requirements for Aircraft Fire Extinguishing Agents, the following specifications are outlined:

  > AFFF agents must meet the requirements of Mil-F-24385F. It is important to note that if one vendor's foam is mixed with another vendor's foam in the reservicing process, there must be compatibility between foams to prevent gelling of the concentrate.[23]

- The statement below is from a National Part 139 CertAlert [No. 16-05] issued by the FAA in 2016, titled "Update on Mil-Spec Aqueous Film Forming Foam (AFFF)."[24]

  > 3. Actions.
  >
  > a. Airport operators must ensure any AFFF purchased after July 1, 2006, meets MilSpec standards.
  >
  > i. AFFF meets Mil-Spec standards if the AFFF appears on the DoD QPD web site.
  >
  > ii. If the AFFF is NOT on the QPD, the AFFF is NOT authorized for use at Part139 airports.
  >
  > b. However, if a Part 139 airport operator:
  >
  > i. Purchased the previous AFFF standard of UL 162 prior to July 1, 2006, the airport operator can continue to use the current inventory until depleted or the AFFF reaches the manufacturers' expiration date; or
  >
  > ii. Purchased AFFF listed on the QPD after July 1, 2006, but that AFFF is no longer listed on the current QPD, the airport operator can continue to use the current inventory until depleted or the AFFF reaches the manufacturers' expiration date.

- Further regulatory information can be found in Title 14, CFR [Part 139.137], titled "Aircraft Rescue and Firefighting: Equipment and Agents." It contains specifications for vehicles and extinguishing agents and can be found here: https://www.faa.gov/airports/airport_safety/part139_cert/

[23] Access the advisory circular here: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5210-6D.pdf
[24] See the advisory alert here: https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-16-05-Mil-Spec-AFFF-website-update.pdf

B.10 US Military Specification (MIL-SPEC)

MIL-PRF-23485F(SH) w/Amendment 2, 7 Sept 2017

Focused on rapid extinguishment. Developed with the prevention of weapons discharge aboard Navy ships as the primary focus. Approved for use by all departments and agencies of the U.S. Department of Defense (DoD). Only standard that includes maximum PFOA and PFOS content. Available here http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=17270

The following segments from the standard outlines the requirements it specifies:

3. REQUIREMENTS 3.2 Materials. Concentrates shall consist of fluorocarbon surfactants plus other compounds as required to conform to the requirements specified hereinafter. The material shall have no adverse effect on the health of personnel when used for its intended purpose.

Total fluorine content of the AFFF shall be determined and shall not deviate more than 15 % of the value determined and reported at time of qualification report.

4.7.8 PFOA and PFOS content. The tests for PFOA and PFOS content shall be conducted by a laboratory that is accredited by the DoD Environmental Laboratory Accreditation Program (ELAP) and tests in compliance with the "Per- and Polyfluoroalkyl Substances (PFAS) Using Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS) with Isotope Dilution or Internal Standard Quantification in Matrices Other Than Drinking Water" table of DoD QSM Version 5.1. (A list of ELAP accredited laboratories can be found online at http://www.denix.osd.mil/edqw/accreditation/accreditedlabs. Under the "Method" drop-down list, select "PFAS by LCMSMS Compliant with QSM 5.1 Table B-15.") Test results shall be recorded from the lowest dilution possible while still meeting all of the requirements in the DoD QSM table. This may require results to be recorded from two different dilutions; one for PFOA and one for PFOS.

6.6 PFOA and PFOS content. The DoD's goal is to acquire and use a non-fluorinated AFFF formulation or equivalent firefighting agent to meet the performance requirements for DoD critical firefighting needs. The DoD is funding research to this end, but a viable solution may not be found for several years. In the short term, the DoD intends to acquire and use AFFF with the lowest demonstrable concentrations of two particular PFAS; specifically PFOS and PFOA. The DoD intends to be open and transparent with Congress, the Environmental Protection Agency (EPA), state regulators, and the public at large regarding DoD efforts to address these matters. AFFF manufacturers and vendors are encouraged to determine the levels of PFOS, PFOA, and other PFAS in their products and work to drive these levels toward zero while still meeting all other military specification requirements.

MIL-SPEC Table 1: Chemical and Physical Requirements for Concentrates or Solutions		
Requirement	Values	
	Type 3	Type 6
Minimum Refractive Index	1.3630	1.3580
Viscosity (Centistokes)		
Maximum at 5 °C	20	10
Minimum at °C	2	2
pH	7.0-8.5	7.0-8.5
Minimum Spreading Coefficient	3	3
Foamability:		
Minimum Foam Expansion	5.0	5.0
Minimum Drainage Time, 25 %	2.5	2.5
Corrosion Rate:		

General		
Cold-Rolled Steel, Maximum milli in/yr	1.5	1.5
Copper-Nickel, Maximum milli in/yr	1.0	1.0
Nickel-Copper, Maximum milli in/yr	1.0	1.0
Bronze, Maximum mg	100	100
Localized, Corrosion Resistant Steel	No Pits	No Pits
Perfluorooctanoic Acid (PFOA) Content, Maximum ppb	800	800
Perfluorooctane Sulfonate (PFOS) Content, Maximum ppb	800	800

MIL-SPEC Table 2: Fire Performance			
	AFFF Solutions, percent		
	1.5% of Type 3 3% of Type 6	3% of Type 3 6% of Type 6	15% of Type 3 30% of Type 6
	(Fresh and Sea)	(Fresh and Sea)	(Sea)
$28\ ft^2$ fire:			
Maximum Foam Time to Extinguish	45	30	55
Minimum Burnback Time	300	360	200
$50\ ft^2$ fire:			
Maximum Foam Time to Extinguish		50 (sea only)	
Minimum Burnback Time		360	
Minimum 40 s Summation		320	

MIL-SPEC Qualified Products

There are currently eight MIL-SPEC-qualified products, each available at 3% and 6% concentration. All qualified products contain short-chain (C6) fluorosurfactants. The list of qualified products is available online at http://qpldocs.dla.mil/. Related information is summarized below.

MIL-SPEC Qualified Products	Environmental info, per the manufacturer	Manufacturer
AER-O-WATER 3EM-C6 AFFF AER-O-WATER 6EM-C6 AFFF	C6 Fluorosurfactants National Foam Concentrates do not contain PFOS.	NATIONAL FOAM, INC. 350 E UNION ST WEST CHESTER, PA 193823450 www.NationalFoam.com
TRIDOL-C6 M3 AFFF TRIDOL-C6 M6 AFFF	Angus Fire foam concentrates do not contain PFOS. The C6 surfactants balance high performance and low environmental impact, and are biodegradable.	
ANSULITE AFC-3MS 3% AFFF ANSULITE AFC-6MS 6% AFFF	C6 fluorochemicals manufactured using a telomer-based process that does not produce PFOS. These C-6 materials do not breakdown to yield PFOA compounds.	TYCO FIRE PRODUCTS LP TYCO FIRE PROTECTION PRODUCTS 1 STANTON ST MARINETTE, WI 541432542

MIL-SPEC Qualified Products	Environmental info, per the manufacturer	Manufacturer
CHEMGUARD C306-MS 3% AFFF CHEMGUARD C606-MS 6% AFFF	C6 fluorochemicals are manufactured using a telomer-based process that does not produce PFOS. These C6 materials do not breakdown to yield PFOA compounds. Meets the goals of the UPEPA 2010/15 PFOA Stewardship Program.	
ARCTIC 3% MIL-SPEC AFFF ARCTIC 6% MIL-SPEC AFFF	C6 fluorosurfactants comply with the U.S. EPA 2010/2015 PFOA Product Stewardship Program. Arctic Foam concentrates do not contain PFOS.	AMEREX CORPORATION SOLBERG COMPANY, THE 1520 BROOKFIELD AVE GREEN BAY, WI 543138808 http://www.solbergfoam.com
FIREADE MILSPEC 3 FIREADE MILSPEC 6	Made from 98% organic compounds and zero hazardous chemicals. Encompasses water-based and food-grade ingredients. They are biodegradable and contain no ingredients reportable under the Superfund Amendments and Reauthorization Act (SARA) Title III, Section 313 of 40 CFR-372 or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).	FIRE SERVICE PLUS, INC 180 ETOWAH TRACE FAYETTEVILLE, GA 302145902 http://www.fireade.com
FOMTEC AFFF 3%M "SWE" FOMTEC AFFF 3%M "USA"	Products are biodegradable, formulated with the latest fluorine technology and uses only “All-C6 fluorinated” compounds.	DAFO FOMTEC AB VINDKRAFTSVAGEN 8 STOCKHOLM, 13570 http://www.fomtec.com
PHOS-CHEK 3% AFFF MS PHOS-CHEK 6% MILSPEC AFFF	Made with a mixture of water, hydrocarbon surfactants, solvents, and C6 fluorosurfactants.	ICL PERFORMANCE PRODUCTS LP WILDFIRE CONTROL DIVISION 10667 JERSEY BLVD RANCHO CUCAMONGA, CA 917305110 www.phoschek.com

Appendix C: Core Performance Standards Requirements Comparison

This section contains summary tables of the core requirements of performance standards in order to facilitate easy comparison.

Table C1 contains performance parameters defined in a majority of the standards.

Table C2 contains additional performance parameters that are covered in some, but not all, of the standards.

Table C1. Summary of core performance standards requirements

Standard	Fire Size	Preburn Time	Application Time	Time to Extinguish(s)	25% Reignition Time(s)[a]
DEF (AUST) 5706	4.5 m^2	60	120	50	300
EN 1568-1	1.73 m^2	60	120	120	30 (1% burnback)
EN 1568-2	1.73 m^2	60	120	150	
EN 1568-3 I A	4.52 m^2	60	180	180 (F)	600 (F)
EN 1568-3 I B	4.52 m^2	60	180(F)/300(G)	180 (F)	900 (G)
EN 1568-3 I C	4.52 m^2	60	180(F)/300(G)	180 (F)	600 (G)
EN 1568-3 I D	4.52 m^2	60	180(F)/300(G)	180 (F)	300 (G)
EN 1568-3 I+A	4.52 m^2	60	180	90 (F)	600 (F)
EN 1568-3 I+B	4.52 m^2	60	180(F)/300(G)	90 (F)	900 (G)
EN 1568-3 I+C	4.52 m^2	60	180(F)/300(G)	90 (F)	600 (G)
EN 1568-3 I+D	4.52 m^2	60	180(F)/300(G)	90 (F)	300 (G)
EN 1568-3 II A	4.52 m^2	60	180	240 (F)	600 (F)
EN 1568-3 II B	4.52 m^2	60	180(F)/300(G)	240 (F)	900 (G)
EN 1568-3 II C	4.52 m^2	60	180(F)/300(G)	240 (F)	600 (G)
EN 1568-3 II D	4.52 m^2	60	180(F)/300(G)	240 (F)	300 (G)
EN 1568-3 III B	4.52 m^2	60	300	300 (G)	900 (G)
EN 1568-3 III C	4.52 m^2	60	300	300 (G)	600 (G)
EN 1568-3 III D	4.52 m^2	60	300	300 (G)	300 (G)
EN 1568-4 I A	1.73 m^2	60	180	180	900
EN 1568-4 I B	1.73 m^2	120	180	180	600
EN 1568-4 I C	1.73 m^2	120	180	180	300
EN 1568-4 II A	1.73 m^2	120	300	300	900
EN 1568-4 II B	1.73 m^2	120	300	300	600
EN 1568-4 II C	1.73 m^2	120	300	300	300
ICAO A	2.82 m^2	60	120	60	300
ICAO B	4.5 m^2	60	120	60	300
ICAO C	7.32 m^2	60	120	60	300
IMO	4.5 m^2	60	300	300	900
ISO High Expansion	1.73 m^2	60	120	150	
ISO I A	4.52 m^2	60	180(F)/300(G)	180 (F)	600 (F)
ISO I B	4.52 m^2	60	180(F)/300(G)	180 (F)	900 (G)

Standard	Fire Size	Preburn Time	Application Time	Time to Extinguish(s)	25% Reignition Time(s)[a]
ISO I C	4.52 m^2	60	180(F)/300(G)	180 (F)	600 (G)
ISO I D	4.52 m^2	60	180(F)/300(G)	180 (F)	300 (G)
ISO II A	4.52 m^2	60	180(F)/300(G)	240 (F)	600 (F)
ISO II B	4.52 m^2	60	180(F)/300(G)	240 (F)	900 (G)
ISO II C	4.52 m^2	60	180(F)/300(G)	240 (F)	600 (G)
ISO II D	4.52 m^2	60	180(F)/300(G)	240 (F)	300 (G)
ISO III B	4.52 m^2	60	180(F)/300(G)		900 (G)
ISO III D	4.52 m^2	60	180(F)/300(G)		300 (G)
ISO IIIC	4.52 m^2	60	180(F)/300(G)		600 (G)
ISO Medium Expansion	1.73 m^2	60	120	120	30 (1% burnback)
MIL-SPEC 1.5% Type 3 MIL-SPEC 3% Type 6[b]	28 ft^2	10	90	45	300
MIL-SPEC 15% Type 3 MIL-SPEC 30% Type 6 [b]	28 ft^2	10	90	55	200
MIL-SPEC 3% Type 3 MIL-SPEC 6% Type 6 (SEA) [b]	28 ft^2	10	90	30/50 (SEA)	360/360 (SEA)
NFPA 11	NFPA is a very different style of test. Instead of foam being applied via nozzle, foam is instead applied to the fuel surface and the foam is expected to travel across the fuel. NFPA is focused on transit time of the foam, making it more ideal for tank fires but largely unavailable for reporting here.				

*Notes:

[a] (F) is the forceful application of foam, or direct application to liquid fuel and (G) is the gentle application of foam, or application via backboard or other surface.

[b] MIL-SPEC foams must pass all three iterations. To clarify, Type 3 foams must pass tests at 1.5%, 3%, and 15% concentrations and Type 6 foams must pass tests at 3%, 6%, and 30%.

Table C2. Additional core performance standards requirements

	Minimum Refractive Index	Surface Tension, mN/m	Viscosity, Centistokes (maximum/ minimum)	pH	Sedimentation Potential (maximum)	Minimum Spreading Coefficient	Minimum Foam Expansion Ratio	Minimum Drainage Time, 25%, min	Maximum PFOA Content,	Maximum PFOS Content, ppb	LC_{50} Toxicity mg/L (minimum)	COD, mg/L	BOD/COD
DEF (AUST) 5706[a]		0.5 of acceptance testing value	10% of approved manufacturer value	6.5-9									
EN 1568		Within .95x and 1.05x of sampled foam concentrate	200/120 mPa*s (Pseudo Plastic)	6-9.5	0.25% before aging 1% aged			20% of fresh water value					
ICAO			200	6-8.5	0.50%		6-10 film-forming & fluorine-free 8-12 protein based foam	>3 film forming >5 protein based foam					
IMO			200	6-9.5	0.25%	Must be Positive							
ISO		70	200/120 mPa*s (Pseudo Plastic)	6-8.5	0.25% before aging 1% aged	Must be Positive	+ - 20% or + - 1 of manufacturer stated value	+ - 20% of the manufacturer stated time					
MIL-SPEC Type 3[b]	1.363		20/2	7-8.5		3	5	2.5	800	800	500	1000K	0.65
MIL-SPEC Type 6[b]	1.358		2-Oct	7-8.5		3	5	2.5	800	800	1000	500K	0.65

[a] DEF (AUST) 5706 requires corrosion information in the form of mass change. [b] MilSpec also requires corrosion information.

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Appendix D: Research Groups & Agencies involved in AFFF Work

This section summarizes the activities from the many organizations in the United States and abroad that are actively engaged in fluorine-free AFFF work. It is recommended that readers follow up directly with the organizations listed as their work progresses and new information emerges.

Table of contents

Funding Provided by the NYS Department of Environmental Conservation

D.1 Intergovernmental Organizations

OECD/UNEP Global PFC Group

URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/

The OECD/UNEP Global PFC Group was established in 2012 and brings together experts from OECD-member and non-member countries in academia, governments, industry, and within the NGO sectir, as well as representatives from other international organizations.

It was created in response to the International Conference on Chemicals Management (Resolution II/5) (See details of conferences here: https://old.saicm.org/index.php?option=com_content&view=article&id=218:iccm2-outcomes-and-follow-up&catid=89:iccm-2), calling upon intergovernmental organizations, governments and other stakeholders to:

> …consider the development, facilitation and promotion in an open, transparent and inclusive manner of national and international stewardship programmes and regulatory approaches to reduce emissions and the content of relevant perfluorinated chemicals of concern in products and to work toward global elimination, where appropriate and technically feasible.

The Group's online portal serves to facilitate the exchange of information on per- and polyfluorinated chemicals, focusing specifically on PFAS. It provides information on the following areas:

1. What are PFAS? (URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/aboutpfass/)
2. Risk reduction approaches (URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/riskreduction/)
3. Alternatives (URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/alternatives/)
4. Production and emissions (URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/)
5. Information from countries (URL: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/)

Information provided in the portal comes principally from the work done within the context of the Group.

The OECD released their updated New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances (PFAS) and accompanying methodology report in May 2018. http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/

Interstate Technology Regulatory Council (ITRC)

PFAS Fact Sheets

URL: https://pfas-1.itrcweb.org/fact-sheets/

Fact sheets summarize the latest science and emerging technologies for PFAS and are tailored to the needs of state regulatory program personnel who are tasked with making informed and timely decisions regarding PFAS-impacted sites. Content is also useful to consultants and parties responsible for the release of these contaminants, as well as community stakeholders.

An Introductory document (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2017/11/pfas_fact_sheet_introductory__11_13_17.pdf) has been prepared that briefly describes the contents of each of the fact sheets.

- Naming Conventions and Physical and Chemical Properties (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_naming_conventions__3_16_18.pdf) (updated Mar. 16, 2018)
- Regulations, Guidance, and Advisories (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2018/01/pfas_fact_sheet_regulations__1_4_18.pdf) (updated Jan. 4, 2018)
    - Section 4 Tables Excel file (URL: https://pfas-1.itrcweb.org/tables/ITRCPFASFactSheetSect4TablesNovember17.xlsx) (published Nov. 2017)

    - Table 4-1 presents the available PFAS water values established by the U.S. EPA, each pertinent state, or country (Australia, Canada, and Western European countries)
    - Table 4-2 presents the available PFAS soil values established by the U.S. EPA, each pertinent state, or country (Australia, Canada, and Western European countries)
    - Section 5 Tables Excel file (URL: https://pfas-1.itrcweb.org/tables/ITRCPFASFactSheetSect5TablesNovember17.xlsx) (published Nov. 2017)
    - Table 5-1 summarizes the differences in the PFOA values for drinking water in the United States.
    - Table 5-2 summarizes the differences in the PFOS values for drinking water in the United States.
- History and Use (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2017/11/pfas_fact_sheet_history_and_use__11_13_17.pdf) (published Nov. 13, 2017)
- Environmental Fate and Transport (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_fate_and_transport__3_16_18.pdf) (published Mar. 16, 2018)
    - Table 3-1 Log Koc values for select PFAS Excel file (published Apr. 2018)
- Site Characterization Considerations, Sampling Precautions, and Laboratory Analytical Methods (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_site_characterization_3_15_18.pdf) (published Mar. 15, 2018)
- Remediation Technologies and Methods (URL: https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_remediation_3_15_18.pdf) (published Mar. 15, 2018)
    - Remediation Comparison Tables (published Apr. 2018), Table 1 – Solids Comparison & Table 2 – Liquids Comparison
- Aqueous Film-Forming Foam (expected soon)

D.2 Government

US Department of Defense

Environmental Research Programs on PFAS by the Strategic Environmental Research and Development Program (SERDP)

URL: https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs

Project objectives are identified in annual statements of need. The AFFF formulation projects are in the “Weapons Systems and Platforms” program area (See: https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/(list)/1/). Some projects contain additional information and are organized by “Active Projects” and “Completed Projects” on the program-area web page. No recent AFFF projects were identified among the “Completed Projects” group (accessed May 2018). Projects related to AFFF under the “Active Projects” group are detailed below by start year.

Contact:
Robin A. Nissan, Ph.D.
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“Fluorine-Free Aqueous Film-Forming Foam”
FY 2017 Statement of Need Projects

URL: https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Contaminated-Groundwater-SONs/Film-Forming-Foam-PFAS-WP

The projects listed below were selected to address the objectives of this Statement of Need.

"WP-2737 Novel Fluorine-Free Replacement for Aqueous Film Forming Foam"
The objective of this project is to demonstrate proof-of-concept for the development of the next generation of fluorine-free firefighting foam formulations as a replacement for existing AFFF. The novel foam systems produced in this research are derived from polysaccharide copolymers and nanoparticles (based on chitosan) that are sustainable, non-toxic, water-soluble (or water-dispersible) and will be applied using existing military firefighting equipment. These foam systems will meet or exceed both environmental regulations and firefighting performance defined in military specification (MIL-SPEC) MIL-F-24385F "Military Specification: Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, For Fresh and Seawater" (1994).

Principal Investigator: Dr. Joseph Tsang, NAVAIR, Phone: 760-939-0256, joseph.tsang@navy.mil

Status (April 2018): This project started in January 2017 and reportedly is complete. No report is available at this time (personal communication, Robin Nissan, SERDP). Additional project description is available here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2737

"WP-2738 Fluorine-Free Aqueous Film Forming Foam"
The environmental issue to be addressed in this project is the use of fluorosurfactants and fluoropolymers in AFFF for fire suppression. All foams that meet the requirements of MIL-F 24385 must contain fluorocarbons. Older formulations contain C8; newer products have shorter C6 fluorocarbon chains. C6 fluorocarbons are persistent in the environment, but their toxicology to humans and aquatic species is considered more benign than C8. A fire-fighting foam that genuinely biodegrades in the natural environment would eliminate any future concerns.

The objective of this project is to use scientific methods to increase understanding of the physical and chemical processes that underlie fire-fighting foams and how the components of a foam formulation can deliver the properties required for good fire performance while minimizing environmental burdens. Statistical methods will be employed to develop a fluorine-free surfactant formulation that meets the performance requirements defined in MIL-F 24385.

A life-cycle assessment (LCA) will compare the environmental impact of each foam type and identify routes to improving environmental performance.

Principal Investigator: John Payne, National Foam, john.payne@aisafetygroup.com

Status (April 2018): This project began January 2017 and is expected to continue through 2019. A detailed project plan was provided by the principal investigator (PI) and is available among the IC2 project documents. The project LCA is nearly complete, and the PI provided a poster summary. Formulation work should be complete in mid-to-late 2019. Quick results are expected through the use of existing commercial surfactants rather than new, synthesized formulations. A project summary can be found here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2738

"WP-2739 Fluorine-free Foams with Oleophobic Surfactants and Additives for Effective Pool Fire Suppression"
The objective of this project is to develop a fluorine-free, firefighting surfactant formulation that meets the performance requirements of MIL-F-24385F and is an environmentally friendly, drop-in replacement for the current environmentally hazardous AFFF.

This project will build on U.S. Naval Research Laboratory (NRL) experience and on the toxicology and analytical capabilities of Oregon State University in a dual-track approach to identify and develop fluorine-free surfactants with both fire suppression effectiveness and low environmental impact. The investigators will choose oxyhydrocarbon and siloxane surfactants from commercial sources where available or synthesize at laboratory scale. Investigators employ a tiered-approach, wherein the number of candidate surfactants taken forward will be reduced at each tier based on the results from modeling, measurements of fire suppression efficiency, and environmental acceptability. They will choose and modify surfactant structures to balance oleophobicity and amphiphilicity to improve suppression of fuel transport through foam and foam stability. They will use QSAR, molecular and continuum dynamics models to select, eliminate, and modify surfactant structures based on acute toxicity and fuel transport through a single lamella (bubble's liquid wall). They will perform prescreening measurements of surfactant solution properties and lamella dynamics to down-select promising surfactants. They will evaluate surfactants by quantifying long-term toxicity, biodegradability, and the fire-suppression effectiveness of the foams at laboratory scale. Finally, investigators will perform the 28-ft^2-pool-fire-suppression test and the aquatic toxicity test according to MIL-F- 24385F and the appropriate ASTM, EPA, OECD methods on the down-selected foam formulations.

Principal Investigator: Ramagopal Ananth, U.S. Naval Research Lab, Phone: 202-767-3197, ramagopal.ananth@nrl.navy.mil

Status (April 2018): The project started in January 2017 and is expected to continue through 2019. The PI provided a number of presentations and documents related to NRL work in the AFFF area (available in the IC2 project files). A project summary can be found here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2739

"Innovative Approaches to Fluorine-Free Aqueous Film Forming Foam"
FY 2018 Statement of Need Projects

The objective of this limited-scope Statement of Need is to develop a fluorine-free surfactant formulation for use in AFFF fire-suppression operations.

URL: https://serdp-estcp.org/content/download/45625/425507/file/WPSON-18-L1%20Fluorine-Free%20AFFF.pdf

Several AFFF projects were identified from the SERDP website with start dates in 2018:

"WP18-1638 Fluorine-free Aqueous Film Forming Foams Based on Functional Siloxanes"
AFFF containing PFOA and PFOS have been traditionally used by the DoD in fuel-fire suppression operations. These chemicals have strong chemical bonds and are considered as persistent, bio-accumulative and toxic (PBT) substances. PFOS/PFOS chemicals have been detected around the world in the food chain, drinking water, animals, and human blood. Therefore, EPA is regulating the chemical industry for the complete elimination of PFOA and PFOS chemicals along with certain C6 substances (containing six fluorinated carbons) by 2015. Therefore, the DoD is seeking non-toxic alternatives—preferably fluorine-free compounds—to replace PFOA/PFOS in firefighting foam formulations. In this project, specifically functionalized siloxane-based surfactants will be synthesized, and their physical and fire suppression abilities will be evaluated. The tests will include the evaluation of 28-ft^2-fire performance, spreading coefficient, aquatic toxicity, chemical oxygen demand (COD), and bio-persistency.

Principal Investigator: Kris Rangan, Materials Modification, Inc., Phone: 703-560-1371

Status (May 2018): The project started in March 2018. No attempt was made to contact the PI.
A project summary can be found here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP18-1638

"WP18-1519 Surfactants with Organosilicate Nanostructures for Use as Fire-Fighting Foams (F3)"
The objective of this research project is to explore an innovative approach in using polyhedral oligomeric silsesquioxanes (POSS) as drop-in replacements of perfluoroalkyl surfactants found in current AFFF concentrates used in fire-fighting by the DoD. The new POSS surfactants produced in this research will contain only the elements carbon, silicon, hydrogen, and oxygen. Foams containing the new surfactants will extinguish small-scale, unleaded-gasoline pool fires in 45 seconds or less, as dictated by MIL-F-24385F. In addition, the POSS surfactants will have low, acute toxicity to fish and be biodegradable according to measurements of chemical oxygen demand and biological oxygen demand of microorganisms. Commercially available alkylated POSS compounds will be chemically modified with hydrophilic polyethylene glycol (PEG) units. A range of PEG lengths will be used in the selective modification to

determine the proper size range imparting surfactant properties to the PEGylated POSS. By this approach, the organosilicate cage of the POSS surfactants will be targeted to reside at the air-water boundary layer of the bubble lamella in foams. The new POSS surfactants will be characterized by standard analytical techniques (nuclear magnetic resonance [NMR], gas chromatography mass spectrometry [GCMS]). Key physical properties of the POSS surfactants will be measured such as density, surface and interfacial tensions, foam expansion rate, and spreadability. The POSS surfactants will be formulated into AFFF concentrates similar to commercial varieties used by the DoD. The thickness of POSS surfactant film, alone or in concentrate form, supported by hydrocarbon solvent will be measured. Small-fire extinguishing experiments will be conducted to compare the differences (time to extinguish and burnback) between the POSS-based AFFF and the current technology. The small-scale experiments will be a stepping stone to the large MIL-SPEC test (MIL-F-24385F). A preliminary toxicity screening of the POSS surfactants by the Microtox assay and acute toxicity to fish will be made by fee-for-service laboratories.

Principal Investigator: Dr. Matthew Davis, NAWCWD China Lake, Phone: 760-939-0196, matthew.davis@navy.mil

Status (May 2018): The project started in March 2018. No attempt was made to contact the PI.
A project summary can be found here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP18-1519

"WP18-1592 Stability of Fluorine-Free Foams with Siloxane Surfactants for Improved Pool Fire Suppression"

The research team plans to synthesize siloxane surfactants with a systematic structural variation of the head group and quantify the effects on foam degradation, fire extinction, and environmental impact by quantitative structure-property relationships. This knowledge will be used to achieve full coverage of burning pool surface with a siloxane foam. The researchers have been conducting research to identify and develop fluorine-free surfactants having both high fire-suppression effectiveness and low environmental impact. The evaluation of several commercial fluorine-free siloxane surfactants in the last several months has shown that foams made from several of these surfactants exhibit more rapid degradation relative to AFFF containing fluorocarbon surfactants. The rapid degradation prevents these siloxane-based fluorine-free foams from completely covering the liquid fuel surface; full coverage is necessary but not sufficient to extinguish the fire because the foam layer must also block the diffusion of fuel vapors through the foam. Quantifying the effects of systematic and fundamental variations in surfactant structure on foam stability is essential to achieve foam's full coverage of the fuel pool's surface.

This research will synthesize fluorine-free, siloxane-based surfactants by attaching different head groups (cationic, anionic, non-ionic, zwitterionic) to a fixed tail group because the solubility of surfactant in fuel (versus water phase) and stability of the lamellae (bubble walls) within the foam are affected by the charge or polarity of the surfactant's head group. Researchers will also attach different tail groups (straight chain siloxane, trisiloxane with methyl pendant groups, and a trisiloxane with phenyl pendant groups) to the most promising head group to vary the packing density and stiffness of the tail at the lamella surface. They will quantify the effect of both head group and tail group substitution on foam stability. They will also synthesize a straight-chain siloxane with a sulfonate head group and compare its performance with a hydrocarbon analogue (e.g., sodium dodecyl sulfonate); they will test the basic hypothesis that siloxane-based surfactant tails are more effective than hydrocarbon tails for suppressing fuel transport and thus more effective at fire suppression. The research team will use Quantitative Structure Activity Relationships (QSAR) and EPA models to assess the environmental impact of the promising siloxane-based, fluorine-free surfactants.

Principal Investigator: Ramagopal Ananth, U.S. Naval Research Lab, Phone: 202-767-3197, ramagopal.ananth@nrl.navy.mil

Status (April 2018): The project started in March 2018. The PI provided a number of presentations and documents related to Naval Research Laboratory work in the AFFF area (available in the IC2 project files). A project summary can be found here: https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/WP18-1592.

US Naval Research Laboratory (NRL)

NRL is the home of work in the Navy on AFFF, but there may be other work at other branches of the military. NRL has ongoing funding to improve/develop AFFF. In addition to a standing budget, they can apply for and win SERDP funding for environmental projects. They have current projects in fluorine-free foam development and in remediation of PFAS-contaminated sites.

The Navy is not willing to sacrifice performance of foams. They feel that many lives were lost before the introduction of PFAS foams that would have otherwise been saved. They are strongly committed to the existing firefighting infrastructure on ships. Huge costs would be involved in changing the equipment to meet a different set of foam properties. NRL is always willing to evaluate and test the performance of alternatives. Any foam can apply to join the Qualified Products List; suppliers need to pay the costs of the testing work at NRL.

The Navy has considered whether there should be a change in specifications. For example, it might make sense to have a different standard for ships from what is used for land-based applications.

Presentations and Papers

"Molecular Dynamics Simulations of the Fluorinated and Fluorine-free Surfactant Monolayers at Air-Water and Heptane-Water Interfaces" [presentation], 255th ACS National Meeting, New Orleans, LA (March 18-22, 2018), Xiaohong Zhuang, ASEE Postdoctoral Associate and Katherine Hinnant and Ramagopal Ananth, Chemistry Division, U.S. NRL

"Evaluating Foam Degradation and Fuel Transport Rates Through Novel Surfactant Firefighting Foams for the Purpose of AFFF Perfluorocarbon Replacement," Spring Technical Meeting, Eastern States Section of the Combustion Institute, State College, PA (March 4-7, 2018), Xiao Zhuang, ASEE Postdoctoral Associate and Katherine Hinnant, Art Snow, Spencer Giles, and Ramagopal Ananth, Chemistry Division, U.S. NRL

URL: https://blogs.gwu.edu/houston/2018/02/12/evaluating-foam-degradation-and-fuel-transport-rates-through-novel-surfactant-firefighting-foams-for-the-purpose-of-afff-perfluorocarbon-replacement/

"Liquid-Pool Fire Extinction Characteristics of Aqueous Foams Generated from Fluorine-free Surfactants" [presentation], Spring Technical Meeting, Eastern States Section of the Combustion Institute, State College, PA (March 4-7, 2018), Dr. R. Ananth, S. Giles, K. Hinnant, X. Zhuang, A. Snow, J. Fleming, J. Farley, Chemistry Division, U.S. NRL

"Comparison of Firefighting Performance Between Commercial AFFF and Analytically Defined Reference AFFF Formulations" [paper], Katherine Hinnant, Art Snow, John Farley, Spencer Giles, Ramagopal Ananth, U.S. NRL, Washington, DC

"Comparing Firefighting Performance Between Commercial and Analytically Defined AFFF" [presentation and paper], SupDet 2017, College Park, MD (September 14, 2017), Katherine Hinnant, Art Snow, John Farley, Spencer Giles, and Ramagopal Ananth, Chemistry Division, U.S. NRL

URL: https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2017-SUPDET/SUPDET17-Hinnant-et-al.ashx?la=en&hash=DDE76AC1EC354C8107497344F7DB5309837B5D18

"Development of an Analytical AFFF Formulation" [presentation], 10th US National Combustion Meeting, College Park, MD, April 24, 2017; Katherine Hinnant, Art Snow, John Farley, Spencer Giles and Ramagopal Ananth, Chemistry Division, US Naval Research Laboratory

URL: https://blogs.gwu.edu/houston/2017/04/24/development-of-an-analytical-afff-formulation-for-the-evaluation-of-alternative-surfactants/

"Mechanisms of Fire Suppression with Aqueous Foams and the Role of Surfactants" [presentation], 10th US National Combustion Meeting, College Park, MD, April 24, 2017; Ramagopal Ananth and Katherine Hinnant, Chemistry Division, US Naval Research Laboratory

U.S. Environmental Protection Agency (EPA)

"National Priorities: Per- and Polyfluoroalkyl Substances (PFAS)" Request for Application (RFA)

URL: https://www.epa.gov/research-grants/national-priorities-and-polyfluoroalkyl-substances

Open Date: May 4–June 18, 2018

National Priorities: Per-and polyfluoroalkyl substances

Background: The U.S. EPA released an RFA, "National Priorities: Per- and Polyfluoroalkyl Substances (PFAS)." EPA sought applications that generate new information for nationally assessing PFAS fate and transport, exposure, and toxicity. Per- and polyfluoroalkyl substances (PFASs) are manmade chemicals designed to resist heat, water, and oil. Used in a variety of consumer products and industrial applications, PFASs are moderately-to-highly water soluble, persistent, bioaccumulative, and toxic.

This RFA will inform new strategies that protect public health and the environment from PFAS exposure and adverse outcomes. The EPA anticipates funding approximately two awards under this RFA for a total of $1,984,400. The total project period requested in an application submitted for this RFA may not exceed three years.

For information on eligibility and project specifications, go to https://www.epa.gov/research-grants/national-priorities-and-polyfluoroalkyl-substances

"National Priorities: Per-and Polyfluoroalkyl Substances" is part of EPA's Safe and Sustainable Water Resources (SSWR) Research Program.

"Research on Per- and Polyfluoroalkyl Substances (PFAS)"

URL: https://www.epa.gov/chemical-research/research-and-polyfluoroalkyl-substances-pfas

Provides brief insight into the efforts being supported by EPA, as well as indicating some of the findings and what role they might play. A summary is below.

- Characterizing and detecting Per and Polyfluoroalkyl substances:
    - EPA developed a Stewardship Program to voluntarily stop producing commercial products that could lead to the generation of PFOA. This was requested after discovery that PFOA was toxic to the environment and poses health risks to both aquatic life and humans.
- Characterizing fate and transport of Per and Polyfluoroalkyl substances:
    - EPA has supported research focused on the degradation of fluorotelomer-based polymers (FTP) into PFOA and PFAS. This research suggests that FTP do break down over time, which was not widely known or supported before the publication. This was largely done through mass spectroscopy method development. The analysis methods can then also be applied so that soil, sludge, plants, animal tissue, and water can be tested for contamination. Initial analysis suggests that using sewage sludge and applying it to agricultural land may be a large contributor to human contamination with PFAS.
- Research on ecological risk from Per and Polyfluoroalkyl substances:
    - The link between PFAS and fish health is largely unclear due to the varied nature of the substances. EPA continues to support research into PFAS impact on fish populations so that policies relating to fish consumption might be developed.
- Exposure from Per and Polyfluoroalkyl substances:
    - EPA works to develop methods to detect PFAS, determine breakdown of PFAS, determine levels of PFAS in a product, and evaluate impact of PFAS on fish populations. Methods already exist to minimize PFAS discharge via wastewater treatment, so the current focus of research is to determine whether biosolids with PFAS can be spread on fields.
- Per- and Polyfluoroalkyl toxicity research with animal models:

  - In the 1980s and 1990s, liver toxicity and tumor development were seen in animals exposed to PFAS as well as stillbirth in pregnant rodents that had been exposed. Biomonitoring also reported elevated levels of PFAS in the general population and in waterways, including those in the Arctic. After additional research, EPA determined that a high level of PFOS exposure would likely cause pulmonary failure in rats/mice while moderate levels would cause retardation in growth and development. PFOA did not produce similar results, but the data was difficult to interpret due to differences between male and female rats and humans. These findings will be used by EPA to generate guidelines, support policies, and support rule-making decisions.
- Using computational modeling for Per- and Polyfluoroalkyl substances research:
  - Computational models are used by EPA to predict what biological effects commonly detected compounds might have to attempt to characterize them. Pharmacokinetic studies are focused on chemical fate within a body. These studies help to show how a chemical will travel, be modified by, and be removed by the body. Comparisons between species can be drawn and overall effects predicted. Overall, these studies have indicated that persistence in the body is proportional to chain length, meaning shorter chains, like PFBA, may be acceptable replacements.

"Risk Management for Per- and Polyfluoroalkyl Substances (PFASs) Under TSCA"

URL: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass

EPA has taken a range of regulatory actions to address PFAS substances in manufacturing and consumer products, as noted below. In addition, EPA worked with eight major leading companies in the PFAS industry to develop and implement a global stewardship program with the goal of eliminating these chemicals from emissions and products by 2015.

- Learn more about EPA's 2010/2015 PFOA Stewardship Program: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass#tab-3
- Read background information on PFAS: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass#tab-2
- Current actions
  - On January 21, 2015, EPA proposed a significant new use rule (SNUR) under the Toxic Substances Control Act to require manufacturers, importers, and processors of PFOA and PFOA-related chemicals (including as part of articles) to notify EPA at least 90 days before starting or resuming new uses of these chemicals in any products. This notification would allow EPA the opportunity to evaluate the new use and, if necessary, take action to prohibit or limit the activity. (See SNUR here: https://www.regulations.gov/document?D=EPA-HQ-OPPT-2013-0225-0001)
  - EPA's New Chemicals Program reviews alternatives for PFOA and related chemicals before they enter the marketplace. Its purpose is to identify whether any new chemicals contain the range of toxicity, fate, and bioaccumulation issues that have been associated with perfluorinated substances in order to avoid any unreasonable risk to health or the environment. (See program documentation here: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/new-chemicals-program-review-alternatives-pfoa-and)
- Previous actions
  - On September 30, 2013, EPA issued a rule requiring companies to report all new uses of certain PFOA-related chemicals as part of carpets, a category of potentially harmful chemicals once used on carpets to impart soil, water, and stain resistance. Companies must now report to EPA their intent to manufacture or import these chemical substances use as part of carpets or to treat carpets. This also includes any importation of carpets already containing these chemical substances. (See SNUR: https://www.regulations.gov/#%21documentDetail;D=EPA-HQ-OPPT-2012-0268-0034)
  - On October 9, 2007, EPA finalized a SNUR on 183 PFAS chemicals believed to no longer be manufactured, imported, or used in the United States. Read more information on the 2007 SNUR for 183 chemicals here: https://www.gpo.gov/fdsys/pkg/FR-2007-10-09/pdf/E7-19828.pdf
  - On March 11, 2002, EPA published a SNUR to require notification to EPA before any future manufacture or import of 13 PFAS chemicals specifically included in the voluntary phase-out of

PFOS by 3M that took place between 2000 and 2002. This SNUR allowed the continuation of a few specifically limited, highly technical uses of these chemicals for which no alternatives were available, and which were characterized by very low volume, low exposure, and low releases. Any other uses of these chemicals would require prior notice to and review by EPA. Read more information on the 2002 SNUR for 13 chemicals: https://www.gpo.gov/fdsys/pkg/FR-2002-03-11/pdf/02-5746.pdf

- On December 9, 2002, EPA published a SNUR to require notification to the agency before any future manufacture or import of 75 PFAS chemicals specifically included in the voluntary phase out of PFOS by 3M that took place between 2000 and 2002. This SNUR allowed the continuation of a few specifically limited, highly technical uses of these chemicals for which no alternatives were available, and which were characterized by very low volume, low exposure, and low releases. Any other uses of these chemicals would require prior notice to and review by EPA. Read more information on the 2002 SNUR for 75 chemicals: https://www.gpo.gov/fdsys/pkg/FR-2002-12-09/pdf/02-31011.pdf

"Fact Sheet: 2010/2015 PFOA Stewardship Program"

URL: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

In 2006, eight companies committed to attempt to achieve 95% reduction in per- and polyfluoroalkyl substance and any precursor substance emissions by 2010. Additionally, they would attempt to eliminate these chemicals from emissions and products entirely by 2015. Participating companies submitted baseline data, reported annual progress, and agreed to work with the EPA cooperatively. All public documents, including final reports, can be found in EPA Docket EPA-HW-OPPT-2006-0621. All participating companies met the goals of the program. This was achieved by most companies stopping the manufacture and importation of long-chain PFAS. The PFOA Stewardship Program was developed because of concerns with the impact of PFOA and long-chain PFAS on human health and the environment. These concerns developed due to the chemical's persistence, presence in the environment, long half-life in people, and developmental effects in lab animals. The participating companies were Arkema, Asahi, BASP Corporation, Clariant, Daikin, 3M/Dyneon, DuPont, and Solvey Solexis. All of them provided commitments on March 1, 2006, and are global companies. The baseline for comparison purposes was emission- and product-content data from the year 2000. Largely, PFOS and PFOA are no longer manufactured in or imported into the United States, though stocks may exist and still be in use.

"Significant New Use Rules: Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances"

URL: https://www.regulations.gov/document?D=EPA-HQ-OPPT-2013-0225-0001

The following is an extract from the SNUR titled "Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances."

> Under the Toxic Substances Control Act (TSCA), EPA is proposing to amend a significant new use rule (SNUR) for long-chain perfluoroalkyl carboxylate (LCPFAC) chemical substances by designating as a significant new use manufacturing (including importing) or processing of an identified subset of LCPFAC chemical substances for any use that will not be ongoing after December 31, 2015, and all other LCPFAC chemicals substances for which there are currently no ongoing uses. For this SNUR, EPA is also proposing to make inapplicable the exemption for persons who import LCPFAC chemical substances as part of articles. In addition, EPA is also proposing to amend a SNUR for perfluoroalkyl sulfonate (PFAS) chemical substances that would make inapplicable the exemption for persons who import PFAS chemical substances as part of carpets. Persons subject to these SNURs would be required to notify EPA at least 90 days before commencing such manufacture or processing. The required notifications would provide EPA with the opportunity to evaluate the intended use and, if necessary, an opportunity to protect against potential unreasonable risks from that activity before it occurs….

1. EPA would receive notice of any person's intent to manufacture or process LCPFAC chemical substances, PFOA or its salts, or PFAS chemical substances for the described significant new use before that activity begins.
2. EPA would have an opportunity to review and evaluate data submitted in a SNUN before the notice submitter begins manufacturing or processing these chemical substances for the described significant new use.
3. EPA would be able to regulate prospective manufacturers or processors of these chemical substances before the described significant new use of the chemical substance occurs, provided that regulation is warranted pursuant to TSCA sections 5(e), 5(f), 6, or 7.

This is the most recent version of the SNUR, but there are older versions that indicate that EPA has been concerned with PFAS use and the resulting chemicals for several years. In brief, notices on imports or business concerning selected compounds must be submitted to EPA so that it can place restrictions on the activity, if necessary. Large business notices are expected to cost no more than $8,589 per notice and, for small businesses, the notices are expected to cost no more than $6,189. EPA developed the SNUR due to concerns with how LCPFAC and PFAS may affect human health and the environment. With the Stewardship Program and the halting of importation via carpets, EPA expects that the presence of PFAS will decline over time. The previous SNURs were implemented in 2007 and 2002, while this latest version is from 2013.

"New Chemicals Program Review of Alternatives for PFOA and Related Chemicals"

URL: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/new-chemicals-program-review-alternatives-pfoa-and

Since 2000, EPA is working to review substitutes to PFOA, PFOS, and long-chain PFAS. The agency focuses on whether the reviewed substances have similar properties to PFOA, PFOS, or long-chain PFAS, and try to determine if the reviewed compound raises any new concerns. These concerns could be related to either health or the environment. Testing of short-chain fluorotelomers includes degradation potential to determine bioaccumulation potential, toxicity, and overall fate compared to PFOA. While previously exempt, polymers containing CF3 or longer chain length fluorinated compounds under the Polymer Exemption Rule can no longer be considered to "not present an unreasonable risk to human health or the environment."

"Final Report: Fluorine-Free Hybrid Surfactants for Fire-Fighting Foams"

URL: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.highlight/abstract/5089/report/F

The following is an extract from the EPA report titled "Final Report: Flourine-Free Hybrid Surfactacts for Fire-Fighting Foams."

> **Description:** Aqueous film-forming foams (AFFFs) are among the most popular fire-fighting foams used against fuel and oil fires because of their effectiveness and their ease of application. Unfortunately, recent studies have shown that one key ingredient of AFFFs, the fluorosurfactant perfluorooctyl sulfonate (PFOS), is toxic to aquatic life and is a persistent chemical that accumulates in the blood of humans and other animals. Thus, the production of PFOS was stopped in May 2000. Among the phased-out products are 44 fire-fighting foams and foam components. The fire-fighting industry currently is stocked with materials that have been phased out and that, sooner or later, need to be replaced. New fluorosurfactants have been introduced into the market since 2000, and used to formulate aqueous fire-fighting foam concentrates. The toxicity of the new fluorosurfactants and their persistence in the environment are not well established and still are under investigation. Their presence in the future market is unsure. Therefore, the fire-fighting industry has an urgent need for new, environmentally friendly foaming agents and foam stabilizers to replace fluorosurfactants in aqueous fire-fighting foams.

The State of Washington

The State of Washington's Departments of Ecology and Health are working together to develop a chemical action plan that identifies sources and recommends actions to reduce the use, release, and exposure to PFAS in

Washington. The Interim Chemical Action Plan for Per- and Polyfluorinated Alkyl Substances (April 2018) can be found here https://fortress.wa.gov/ecy/publications/summarypages/1804005.html

Washington will be the first U.S. state to ban certain firefighting foams containing perfluorinated compounds beginning in 2018. RCW 70.75A (See here http://app.leg.wa.gov/RCW/default.aspx?cite=70.75A&full=true) was passed in early 2018.

Local Hazardous Waste Management Program in King County, Washington

The Local Hazardous Waste Management Program in King County, Washington, is collaborating closely with Clean Production Action and Toxic-Free Future to reduce exposure to PFAS in firefighting foam by identifying safer alternatives as part of their Safer Alternatives Strategy. King County is also working on reducing exposures to PFAS from food-contact paper and other sources to protect human health and the environment.

New Jersey

"Investigation of Levels of Perfluorinated Compounds in New Jersey Fish, Surface Water, and Sediment"

A report by the New Jersey Department of Environmental Protection, Division of Science, Research, and Environmental Health, SR15-010 (June 18, 2018)

URL: https://www.nj.gov/dep/dsr/publications/Investigation%20of%20Levels%20of%20Perfluorinated%20Compounds%20in%20New%20Jersey%20Fish,%20Surface%20Water,%20and%20Sediment.pdf

The Division of Science, Research, and Environmental Health (DSREH) within the New Jersey Department of Environmental Protection performed an initial assessment of 13 PFAS, all of which are perfluorinated compounds (PFC), at 11 waterways across the state. Fourteen surface-water and sediment samples and 94 fish-tissue samples were collected at sites along these waterways. The sites were selected based on their proximity to potential sources of PFAS and their likelihood of being used for recreational and fishing purposes.

New York

"Per- and Polyfluorinated Substances (PFAS)"

A web page published by New York State's Department of Environmental Conservation (DEC) on its website.

URL: https://www.dec.ny.gov/chemical/108831.html

Statewide PFAS Survey

DEC surveyed select businesses, fire departments, fire-training centers, bulk-storage facilities, airports, and Department of Defense (DoD) facilities from June to September 2016. The responses to the survey have helped to determine if these entities have used or stored PFOA/PFOS. The results have provided essential information to DEC and to the Water Quality Rapid Response Team so that they can further investigate additional areas for potential contamination. The results of this survey will be updated periodically as additional responses are received.

State Firefighting Foam Collection Efforts

Through funding prioritized by Governor Andrew Cuomo in the Environmental Protection Fund, DEC has worked with the Division of Homeland Security and Emergency Services to launch a collection program for the removal and appropriate disposal of firefighting foam containing perfluorinated compounds. Through the $600,000 investment, DEC is working with municipal fire and emergency response departments across the state to dispose of the contaminated foam. As of the end of 2017, more than 20,000 gallons of contaminated foam have been collected and properly disposed; the collection is ongoing.

Vermont

"Perfluoroalkyl Substances (PFAS) Contamination Status Report" (July 2018)

URL:
http://dec.vermont.gov/sites/dec/files/documents/PFAS%20Sampling%20Report%207.10.18%20FINAL.pdf

In February 2016, Vermont's Department of Environmental Conservation (DEC) discovered a contamination problem in Bennington of perfluoroalkyl substances (PFAS) from a former Teflon-coating factory located in North Bennington. Since that first discovery, the DEC has investigated numerous sources of PFAS using a strategic sampling strategy that is updated and adapted based on the latest scientific research. This report provides an overview of the findings of this work and provides a look into additional work needed in the future.

Michigan

"PFAS Response, Taking Action to Protect the Public's Water"

Michigan PFAS Action Response Team (MPART)

URL: https://www.michigan.gov/pfasresponse/

In 2017, the Michigan PFAS Action Response Team (MPART) pulled together agencies representing health, environment, and other branches of state government to investigate the sources and location of PFAS contamination in the state, take actions to protect drinking water, and keep the public informed. The state is working

1) to better understand how PFAS may affect people's health;

2) to identify locations where PFAS may be present as a contaminant by testing drinking water from all community water supplies and a selection of groundwater, lakes and streams, soil, sediment, wastewater, and PFAS foam that can accumulate at lakes and rivers;

3) to provide a map of confirmed detections of PFOA and PFOS in groundwater;

4) to test deer and fish for PFAS and issue "do not eat" advisories as appropriate;

5) and to work with the fire service community to identify the amount of PFAS foam in use, it's training and emergency storage protocols, and other best-practice procedures in order to develop statewide solutions to dispose of the foam properly and prevent further contamination.

Australia

"Inquiry into the management of per- and polyfluoroalkyl substances (PFAS) contamination in and around Defence bases"

A report from the Joint Standing Committee on Foreign Affairs, Defence and Trade, the Parliament of Australia

URL:
https://www.aph.gov.au/Parliamentary_Business/Committees/Joint/Foreign_Affairs_Defence_and_Trade/InquiryintoPFAS

On 30 May 2018, the Joint Standing Committee on Foreign Affairs, Defence and Trade adopted an inquiry referred by the Australian Senate, asking the committee to inquire into and report on the management of per- and polyfluoroalkyl substances (PFAS) contamination in and around Australian Defence bases.

The following is an extract from the report:

> Terms of Reference
> The Committee shall inquire into the Commonwealth Government's management of per- and polyfluoroalkyl substances (PFAS) contamination in and around Defence bases, with particular reference to:
> a) the extent of contamination in and around Defence bases, including water, soil, other natural assets and built structures;
> b) the response of, and coordination between, agencies of the Commonwealth Government, including, but not limited to, the Department of Prime Minister and Cabinet, the Department of Health, the Department of the Environment and Energy, the Department of Defence and the Australian Defence Force;
> c) communication and coordination with state and territory governments, local councils, affected local communities and businesses, and other interested stakeholders;
> d) the adequacy of health advice and testing of current and former defence and civilian personnel and members of the public exposed in and around Defence bases identified as potentially affected by contamination;
> e) the adequacy of Commonwealth and state and territory government environmental and human health standards and legislation, and any other relevant legislation;
> f) remediation works at the bases; and
> g) what consideration has been given to understanding and addressing any financial impact to affected businesses and individuals.

Australian Government PFAS Website

URL: https://www.pfas.gov.au/

This website provides easy access to information on per- and polyfluoroalkyl substances (PFAS) and PFAS contamination for a wide range of interested audiences. It provides links to PFAS information pages on Commonwealth and State/Territory government agency websites, as well as links to relevant international sites. PFAS-specific guidance materials can also be accessed on this site. Follow the links to search for PFAS information by audience, location, or topic.

"Expert Health Panel for PFAS Report" (April 2018)

URL: http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-expert-panel.htm

The Australian Government established the Expert Health Panel for PFAS to advise on the potential health impacts associated with PFAS exposure and to identify priority areas for further research.

New Zealand

URL: http://www.mfe.govt.nz/land/pfas-and-poly-fluoroalkyl-substances/pfospfoa-nz

According to New Zealand's Ministry for the Environment, no importation, manufacture, or use of PFOS compounds is permitted, with the only exception being when it is for laboratory use. Furthermore, The New Zealand Defence Force has been advised by its suppliers that since 2002 they have not supplied to NZDF any foam products containing PFOS or PFOA above trace levels.

Fire and Emergency NZ (FENZ) has had the bulk of its Class B foam stocks chemically analysed, and has confirmed that none of these products contain any PFOS or PFOA.

FENZ is taking a precautionary approach and instructing its personnel not to use the small amount of type of Class B foams that has not been tested as at this stage they can't be completely assured that they don't contain PFOS or PFOA.

D.3 Industry

PERF (Petroleum Environmental Research Forum)

URL: http://perf.org/projects/

Project 2016-05

Below is an extract from the project documentation:

> A mixture of Per- and Poly-fluorinated Alkylated Substances (PFAS) are found in aqueous film-forming foams (AFFF) used for firefighting. Some of the long-chain PFAS and some of their degradation products are highly persistent in the environment, bioaccumulative in wildlife and humans, and have been linked to environmental and human health impacts. The nature of oil and gas operations necessitates the use of AFFFs to combat liquid hydrocarbon fires and use of AFFFs in drills and incidents may result in input of PFAS into the environment. The costs and feasibility of long-chain AFFF stockpile replacement are unclear and must be balanced with the risk reduction realized from switching to short-chain AFFFs or fluorine-free foam. While scientific studies support that short-chain PFAS AFFFs are less bioaccumulative and toxic, a recent compilation of these data is needed to address uncertainty in how much short-chain PFAS AFFFs or fluorine-free foam reduces H&E risks.
>
> This project aims to capture the state of knowledge of the fate, transport, and effects of short-chain PFAS-based AFFFs and fluorine-free firefighting foams and identify limitations of and data gaps in the current studies or data sets. This project will help to address uncertainties regarding human health and environmental hazards associated with long-chain PFAS foam alternatives, inform future research opportunities, support advocacy for effective fire response tools, and inform risk-based decision-making on foam replacement and management.

Project status (April 2018): A contract for this work was put out for bid in May 2018. The project manager reported that the contract includes an alternatives assessment for fluorine-containing and fluorine-free foams. The project may use GreenScreen® assessments and may use the IC2 Alternatives Assessment methodology. However, the final comparisons will likely be based on risk assessment calculations. The current plan is to include foam ingredient chemicals (as delivered) and their final degradates in the chemical hazard assessment.

LASTFIRE Project, United Kingdom

URL: http://www.lastfire.co.uk/default.aspx?ReturnUrl=%2f

On behalf of a consortium of 16 oil companies, a project was initiated in the late 1990s to review the risks associated with large diameter (greater than 40 m) open-top, floating-roof storage tanks. The project was known as the LASTFIRE Project ("LAST" meaning "Large Atmospheric Storage Tanks"). The project was initiated due to the oil and petrochemical industries recognition that the fire hazards associated with large-diameter, open-top, floating-roof tanks were insufficiently understood to be able to develop fully justified site specific fire response and risk reduction policies

Research Paper: "Foam Concentrate Usage and Options" (October 2016)

URL: http://www.lastfire.co.uk/uploads/Foam%20Position%20Paper%20Issue%202%20Oct%202016%20s.pdf

LASTFIRE Foam Summit: 17-18 October 2017 (Budapest, Hungary)

The LASTFIRE Foam Summit follows the "Cradle-to-Grave" approach used in the recently published LASTFIRE Foam Assurance Guidance and Questionnaire. It included speakers from around the world. Presentations are available here: http://www.lastfire.org.uk/refmatpapers.aspx

Firefighting Foam Summit and Fire Extinguishing Tests: October 2018 (Dallas/Fort Worth Airport, TX)

An international event organized by LASTFIRE, Arcadis, and DFW Airport to review the current situation related to selection, use, and management of firefighting foam.

Dallas/Fort Worth Fire Training Research Center

URL: https://www.dfwairport.com/firetraining/#slide-1

This center has presented results on the performance of fluorine-free foams. They may be a good source of information on performance testing and may have experience with fluorine-free foam performance.

D.4 Independent Organizations

Clean Production Action

Firefighting Foam – Identify, prioritize, and assess alternatives with GreenScreen Certified™

The following is from the Clean Production Action website (https://www.cleanproduction.org/):

> Clean Production Action is collaborating closely with Toxic-Free Future and King County Local Hazardous Waste Management Program to reduce exposure to PFAS in firefighting foam in Washington State. Our focus is to educate and align stakeholders on the need to ensure PFAS-free products are also safer and not regrettable substitutes, to create market pressures for manufacturers of PFAS-free products to use hazard assessment to evaluate ingredients, and to create a list of preferred PFAS-free products using GreenScreen Certified™. For more information, contact Clean Production Action at greenscreen@cleanproduction.org.

Toxic-Free Future, State of Washington

URL: https://toxicfreefuture.org/science/chemicals-of-concern/perfluorinated-chemicals-pfcs/

Toxic-Free Future works to eliminate PFAS in AFFF and food packaging in the State of Washington.

Contact: Erika Schreder | Science Director, eschreder@toxicfreefuture.org, 206-632-1545 x 119 Toxicfreefuture.org

Green Science Policy Institute

The Green Science Policy Institute hosts monthly PFAS conference calls. Below are relevant publications.

- "PFAS in Drinking Water: The Need for a Coordinated Strategy" (URL: http://greensciencepolicy.org/pfas-statement/)
- "Consumers' Guide to Highly Fluorinated Chemicals" (URL: http://greensciencepolicy.org/highly-fluorinated-chemicals/)

Appendix F: Detailed Summaries of Firefighting-Foam Research

The National Academies of Sciences publication *A Framework to Guide Selection of Chemical Alternatives* and the IC2's *Alternatives Assessment Guide* were consulted to determine the point in the alternatives assessment process at which the research papers collected below are most useful. A summary of each paper is included. Papers are listed alphabetically by title within the applicable framework step, the title and location where the work took place and/or the authors' affiliations is included, and a link to the paper is provided.

1. Identify Chemical of Concern
"Identification of Novel Fluorochemicals in AFFF Used by the U.S. Military," URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3390017/ Fast-atom-bombardment mass spectrometry (FAB-MS) and high-resolution quadrupole-time-of-flight mass spectrometry (QTOF-MS) were combined to elucidate chemical formulas for the fluorochemicals in AFFF mixtures used by the U.S. military. Structures were assigned along with patent-based information. Sample collection and analysis were focused on AFFF that have been designated as certified for U.S. military use. Ten different fluorochemical classes were identified in the seven military-certified AFFF formulations, and include anionic, cationic, and zwitterionic surfactants with perfluoroalkyl chain lengths ranging from 4 to 12. The environmental implications are discussed and research needs are identified.
2. Scoping and Problem Formulation
"Preliminary Assessment Aqueous Film-Forming Foam Use Portland International Airport Portland," Oregon URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3390017/ Study performed to determine the history of AFFF at an airport and other high-use areas. Provides detailed insight into operations and history at the airport; this may be helpful with identifying stakeholders and understanding performance requirements **"Queensland Firefighting Foam Survey—Results Summary,"** Australia URL: https://environment.des.qld.gov.au/assets/documents/pollution/management/incidents/firefighting-foam-survey-summary.pdf Recent survey of foam uses in the Australian state of Queensland. Type of foam and industry groups are identified. Useful for identifying industry groups for outreach and potential stakeholders. • Industries most likely to use and store foam are bulk fuel and chemical storage. **"Use and Potential Impacts of AFFF Containing PFAS at Airports,"** U.S. Transportation Research Board URL: https://www.nap.edu/read/24800/chapter/6 • Metal-plating operations utilize fluorinated compounds and are considered essential. It is possible they contribute to contamination of areas. • Recommended for future research: Alternatives to AFFF containing PFAS, disposal methods, replacing AFFF in existing systems, environmental standards for AFFF, evaluation of existing separation/treatment facilities for processing wastewater impacted by PFASs, understanding how firefighting can be optimized, broadly applicable analytical methods, environmental and human-health risks associated with short-chain PFAS in AFFF, feasible cost-effective remediation techniques and/or approaches.
3. Identify Potential Alternatives
"Fire Testing a New Fluorine-Free AFFF Based on a Novel Class of Environmentally Sound High-Performance Siloxane Surfactants," Germany URL: http://iafss.org/publications/fss/11/1261/view/fss_11-1261.pdf A new family of carbohydrate siloxane surfactants was synthesized and successfully tested for film-forming capabilities. • May be possible to produce a fluorine-free AFFF for the military—relevant fuels are based on siloxane surfactants.

- A comparison of commercial firefighting foam agents with the experimental siloxane surfactant blend and blind tests proves that the water film significantly promotes the extinguishing performance in terms of extinction times and burnback process. It is particularly noticeable that the extinguishing performance of the experimental siloxane blend is only surpassed by the fluorine-containing AFFF, although its composition is net yet optimized. Conversely, the fluorine-free Class B foams clearly perform worse. For the future, the drainage of the siloxane-containing foam should be adjusted to the behavior of the fluorinated foam to optimize the burnback characteristics of the foam.

"Fire Testing of Experimental Siloxane-Based AFFF: Results From New Experiments," Germany

URL: https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2015-SUPDET/2015-papers/SUPDET2015HetzerAbstract.ashx?la=en

More than 250 siloxane and carbosilane surfactants were synthesized and tested as possible film-formers for fluorine-free foams. The surfactant T-C3-Malt was chosen for a fire test because of its film-forming ability and foaming behavior. Five foam solutions were mixed and four application rates of each foam were tested.

- The series of fire tests shows that the rising of the siloxane surfactant concentration strongly reduces the fire-extinguishing times on F-34 fuel. In comparison with commercially available fluorine-free Class B foams and fluorinated foams, according to the German Armed Forces technical specification TL 4210-0112, the experimental siloxane-based aqueous film-forming foams clearly surpass the fluorine-free Class B foams and reach nearly the extinguishing performance of the fluorinated foams in small-scale fire tests.

- Conducted experiments show the ability of siloxane surfactants to act as an alternative film-forming compound for fluorine-free high-performance firefighting foams for pool fires.

"Fluorine-Free Firefighting Agents and Methods," U.S. Patent Application US2005000119, issued 2006

URL: https://patents.google.com/patent/US20050001197A1/en?q=~patent%2fUS9687686B2&page=1

A foam concentrate comprising water and a high-molecular-weight acidic polymer (HMWAP), and a coordinating salt.

"Fluorine-Free Firefighting Agents and Methods," U.S. Patent Application US20050001197A1, issued 2006

URL: https://patents.google.com/patent/US20050001197A1/en

Kirtland Clark (original assignee: Chemguard, current assignee: Tyco Fire and Security GmbH)

The concentrate is formed from water, a high-molecular-weight acidic polymer (HMWAP), and a salt.

"Silica Foams for Fire Prevention and Fire Fighting," Russia

URL: https://pubs.acs.org/doi/abs/10.1021/acsami.5b08653

Detailed description of the physicochemical processes of silica-foam formation at the molecular level and functional comparison with current fire-extinguishing and firefighting agents.

- As a result of fire-extinguishing tests, it is shown that the extinguishing efficiency exhibited by silica-based sol–gel foams is almost 50 times higher than that for ordinary water, and 15 times better than that for state-of-the-art, firefighting-agent aqueous film-forming foam. The biodegradation index determined by the time of the induction period was only 3 d, while, even for conventional foaming agents, this index is several times higher.

"Silicon-Containing Organic Acid Derivatives as Environmentally Friendly AFFF Extinguishing Agent," U.S. Patent Application US20170259099A1, pending 2015

URL: https://patents.google.com/patent/DE102014112851A1/en

A firefighting foam concentrate with a first surfactant that comprises an acid group and/or a deprotonated acid group and an oligosilane unit and/or oligosiloxane unit.

"Siloxane-Containing Fire Extinguishing Foam," U.S. Patent 9,687,686, issued June 27, 2017, for fluorine-free foam

URL: https://patents.google.com/patent/US9687686B2/en

Professor Dirk Blunk at the University of Cologne (Germany) has multiple patents on alternatives. It is a carbohydrate-containing siloxane surfactant.

"Survey of Fire-Fighting Foam," Swedish Chemicals Agency (KEMI)

URL: https://www.kemi.se/global/pm/2015/pm-5-15-survey-of-fire-fighting-foam.pdf

Summary of foam use in Sweden. Authors reached out to manufacturers for information on their products. List of foams and their ingredients are provided as an appendix.

"The Phase-out of Perfluorooctane Sulfonate (PFOS) and the Global Future of Aqueous Film-Forming Foam," India

URL: http://pubs.sciepub.com/ces/2/1/3/

High-level discussion of the history of fluorinated foams with a brief interlude about where the industry is headed with telomere-based foams.

- Foams are now telomere-based, which has displaced electrochemical fluorination as the primary synthesis method. Telomer surfactants are generated via telomerisation. Telomers are typically shorter in chain length (< C6) and are perfluorinated as opposed to polyfluorinated.

4. Assess Human Health Hazards

"Environmental Management of Firefighting Foam Policy - Explanatory Notes (Revision 2)," Australia

URL: https://www.qld.gov.au/__data/assets/pdf_file/0034/68776/firefighting-foam-policy-notes.pdf

Comprehensive study on the distinctions between different types and aspects of fluorinated foams. Focus on impacts of firefighting foams, including ecotoxicity, and human-health concerns, treatment and disposal of foams, and use issues.

"What Properties Matter in Fire-Fighting Foams?" Australia and the United States

URL: https://www.solbergfoam.com/getattachment/3fe1d44d-3b44-4714-89f4-4af37e381b5b/WP-WHAT-PROPERTIES-MATTER-IN-FIRE-FIGHTING-FOAMS.aspx

Describes important properties in firefighting foams, identifies a number of standards that firefighting foams must follow. Provides a comprehensive list of each foam's various properties, why standards have chosen to address them, the reason behind certain values, and the most concerning physical properties of foams. Additional explanations provide insight into why certain values and properties were chosen. Properties of bubbles are explored and their effect on foams discussed.

- Concerns were raised that all PFAS decompose to perfluorooctanesulphonic acid (PFOSH), which binds to blood and buildup in the gallbladder and liver. This may be due to the body mistaking these compounds for bile acids. No adverse effects have been reported.
- PFOA, specifically ammonium salt, was concluded by EPA to be weakly carcinogenic.

5. Assess Ecotoxicity

"Discovery of 40 Classes of Per- and Polyfluoroalkyl Substances in Historical Aqueous Film-Forming Foams (AFFFs) and AFFF-Impacted Groundwater," United States

URL: https://pubs.acs.org/doi/abs/10.1021/acs.est.6b05843?src=recsys

An in-depth analysis on fluorinated compounds found in contaminated groundwater sites using mass spectroscopy as the primary characterization method.

"Discovery and Implications of C_2 and C_3 Perfluoroalkyl Sulfonates in Aqueous Film-Forming Foams and Groundwater," United States

URL: https://pubs.acs.org/doi/abs/10.1021/acs.estlett.5b00049

Evidence showed that the short chain compounds in 3M's foams have persisted in the environment for about 15 years. Paper recommends PFEtS and PFPrS be included among the PFASs monitored in groundwater potentially impacted by AFFFs and other PFASs sources.

"Environmental Management of Firefighting Foam Policy - Explanatory Notes (Revision 2)," Australia

URL: https://www.qld.gov.au/__data/assets/pdf_file/0034/68776/firefighting-foam-policy-notes.pdf

Comprehensive study on the distinctions between different types and aspects of fluorinated foams. Focuses on impacts of firefighting foams, including ecotoxicity and human-health concerns, treatment and disposal of foams, and use issues.

"Historical Usage of Aqueous Film-Forming Foam: A Case Study of the Widespread Distribution of Perfluoroalkyl Acids From a Military Airport to Groundwater, Lakes, Soils, and Fish," Sweden

URL: https://www.sciencedirect.com/science/article/pii/S0045653514010650?via%3Dihub

Transport of fluorinated compounds from extinguishing sites through concrete to groundwater and fish.

"Foam Concentrate Usage and Options," LASTFIRE Group

URL: http://www.lastfire.co.uk/uploads/Foam%20Position%20Paper%20Issue%202%20Oct%202016%20s.pdf

Practicality and performance of fluorine-free foams as compared to fluorinated counterparts, including anecdotal evidence of performance with fluorine-free foams.

- List of environmental data that should be included when assessing a foam: dissolved oxygen, BOD (biological oxygen demand), persistence in the environment, bioaccumulation, toxicity, COD (chemical oxygen demand), and aquatic toxicity.

"Perfluorinated Surfactants and the Environmental Implications of Their Use in Fire-Fighting Foams," United States

URL: https://pubs.acs.org/doi/abs/10.1021/es991359u

Technical overview of the potential impact of AFFF on the environment. Published in 2000, so while it provides some good points, it may be outdated.

"Perfluoroalkyl Substances in a Firefighting Training Ground, Distribution, and Potential Future Release," Australia

URL: https://www.sciencedirect.com/science/article/pii/S0304389415001958?via%3Dihub

Analysis of long- and short-chain fluorinated compounds traveling through and retaining in concrete washpads in Australia. Shorter chain compounds move more easily through the concrete and were found throughout the vertical column. Long-chain compounds were found exclusively at the surface layer. This may imply that shorter chain compounds are more mobile and can impact groundwater more readily.

"The Search for Alternative Aqueous Film-Forming Foams (AFFF) With a Low Environmental Impact: Physiological and Transcriptomic Effects of Two Forafac® Fluorosurfactants in Turbot," *Aquatic Toxicology* (August 2011)

URL: https://www.sciencedirect.com/science/article/pii/S0166445X1100110X?via%3Dihub

An in-depth study of two specific foams and their toxicity to fish. One foam consists of C6 and C8 fluorochemicals and the other consists of C6, C8, C10, and C12 fluorochemicals.

"Use and Potential Impacts of AFFF Containing PFAS at Airports," U.S. Transportation Research Board

URL: https://www.nap.edu/read/24800/chapter/6

Comprehensive look at foam use in airports. Survey of 167 airports across the US & Canada focused on life cycle of foams and legacy impacts.

- Two-thirds of the responding North American airports indicated that AFFF discharged during testing is disposed of onto the ground. The remaining third of respondents discharge AFFF into an engineered containment system. For the one-third of respondents who used engineered containment systems, the type of system most widely used was a small or non-permanent vessel, and the next most widely used system was testing in a designated area such as a containment basin or training pit.

6. Life-Cycle Thinking

Funding Provided by the NYS Department of Environmental Conservation

"Use and Potential Impacts of AFFF-Containing PFAS at Airports," U.S. Transportation Research Board
URL: https://www.nap.edu/read/24800/chapter/6

Comprehensive look at foam use in airports. Survey of 167 airports across the United States and Canada that is focused on the life cycle of foams and legacy impacts.

7. Performance Assessment

"The Extinguishing Performance of Experimental Siloxane-Based AFFF," Germany
URL:
https://www.researchgate.net/profile/Ralf_Hetzer/publication/305033141_The_Extinguishing_Performance_of_Experimental_Siloxane-Based_AFFF/links/577f7ad108ae9485a43983ca/The-Extinguishing-Performance-of-Experimental-Siloxane-Based-AFFF

Siloxane-based foam is tested against the German military performance standard, and performs as well as fluorinated foams and better than fluorine-free foams on F-34 fires.

- Fluorine-free siloxane based foam can be achieved for military relevant fuels on the base of siloxane surfactant SLB.
- The siloxane-based foams exhibit an extinguishing performance similar to fluorinated foam according to TL 4210-0112 (German military specification) and significantly outperform the fluorine-free foams on fires of the NATO standard fuel F-34.
- Additional laboratory and application tests demonstrate that the experimental siloxane-based foam concentrate is surprisingly near to a commercially viable foam concentrate. Furthermore, it already matches the requirements of the German military technical specification in many aspects.

"Extinguishment and Burnback Tests of Fluorinated and Fluorine-Free Firefighting Foams With and Without Film Formation," U.S. National Fire Protection Association (NFPA)
The fire extinguishment and burnback performance of three foams (two fluorinated MIL-SPEC qualified foams and one fluorine-free foam) were tested on four low-flash-point fuels with different surface tensions. This paper is often cited in articles referring to the limitations of fluorine-free foams.
- AFFFs did not perform any better than fluorine-free foam when film formation was not possible.
- Fluorine-free foams behave more consistently than AFFF.

"The Future of Aqueous Film-Forming Foam (AFFF): Performance Parameters and Requirements," U.S. Navy Technology Center for Safety and Survivability
URL: https://www.nist.gov/sites/default/files/documents/el/fire_research/R0201327.pdf

Provides insight into the reasoning behind MIL-F-24385F. Specifically, it explains how AFFF operates and it establishes the role of fluorinated carbons in AFFF. It also describes the challenges of MIL-SPEC, outlines the surface tension requirements of MIL-SPEC, and summarizes the issues many have raised concerning MIL-SPEC's use of equilibrium surface tension values.

"Influence of Fuel on Foam Degradation for Fluorinated and Fluorine-Free Foams," U.S. Naval Research Laboratory
URL: https://www.sciencedirect.com/science/article/pii/S0927775717302169

Theoretical discussion on how foam is influenced by various parameters like heat and bubble size.
- Mixed surfactants are better at slowing degradation than individual surfactants.
    - Smaller chain hydrocarbons also contribute to faster degradation.
    - Heat can also contribute due to increased evaporation and expansion of gas inside of bubbles causing ruptures and liquid drainage.
    - Foam lifetime decreases as temperature of the fuel increases. Severe enough to change the scale of degradation from hours at room temperature to minutes at elevated (50 °C) temperatures. This is due to increased fuel vapors at the interface.
        - At 50 ° C, RF6 degrades in three minutes. Buckey degrades in 35 minutes.

"LASTFIRE Large Atmospheric Storage Tank Fires, Foam Concentrate Usage, and Options," LASTFIRE Group
URL: http://www.lastfire.co.uk/uploads/Foam%20Position%20Paper%20Issue%202%20Oct%202016%20s.pdf

Practicality and performance of fluorine-free foams as compared to fluorinated counterparts, including anecdotal evidence of performance with fluorine-free foams.

- Performance testing shows that C6 products have not performed as well as C8. One manufacturer reported that changing to a C6 formulation will result in reduced performance or higher cost, and concludes no "C6-based or FF formulations have been able to achieve the same levels of extinguishing performance demonstrated by previously proven high-quality concentrates for tank-fire application."

"Measuring Fuel Transport Through Fluorocarbon and Fluorine-Free Firefighting Foams," U.S. Naval Research Laboratory
URL: https://www.sciencedirect.com/science/article/pii/S0379711217301352?via%3Dihub

Focuses on the major factors affecting fuel transfer in firefighting foams. Provides good insight into characteristics of interest when it comes to suppressing fuel transfer and, therefore, potential flash fires.

- Fluorine-free RF6 (Solberg) forms larger bubbles than Buckeye 3% (Buckeye Fire Equipment) and has a longer drainage time. May contribute to fuel flux and ignition.
- Fluorinated foams had lower fuel fluxes consistently across several different fuels as compared to RF6.
  - Fluorosurfactants are likely the cause, as they contain highly oleophobic aspects that attempt to reject the fuel as it attempts to transfer through the barriers, which slows down flux. RF6 does not contain oleophobic surfactants and therefore has less discouraging power.
- Experiments with iso-octane indicate that the foam layer may be more important than the aqueous film to fuel flux. This is likely due to the many bubbles present in the foam and how difficult it would be for fuel to transfer through so many mediums and surfaces.

"Preliminary Assessment: Aqueous Film-Forming Foam Use Portland International Airport," Portland, Oregon
URL: https://www.deq.state.or.us/Webdocs/Controls/Output/PdfHandler.ashx?p=4079b1d7-f8b6-4343-b701-e739287b8357.pdf&s=Preliminary%20Assessment%20Aqueous%20Film-Forming%20Foam%20Use%20PDX%2020170803.pdf

Summarizes the history of AFFF at an airport and other high-use areas. Provides detailed insight into operations and history at the airport. It may be a helpful resource for identifying stakeholders and building an understanding of performance requirements.

"Sealability Properties of Fluorine-Free Fire-Fighting Foams," *Fire Technology* (September 2008)
URL: https://link.springer.com/article/10.1007/s10694-007-0030-8

Comparison of three synthetic foams without fluorine and AFFF-vapor sealability performance utilizing Australian Defense Force Specification (DEF(AUST)) 5706. Provides strong insight into concerns with vapor suppression and briefly discusses tests with respect to actual practices. Useful for discussing vapor suppression in foams and their purpose to firefighting foams.

- In performance testing, Fluorine-free RF6 (Solberg) struggled to contain vapors well as it does not form a film. AFFF consistently outperformed all other foams in all areas. RF6 consistently came in second in all areas. Formulations A and B (both fluorine free) were erratic and always came in third/fourth in all areas.
  - Actual practices in firefighting have foam reapplied frequently and the performance of both the AFFF and RF6 increased dramatically when following these guidelines. It is suggested that in a practical scenario, RF6 would perform adequately.

"Siloxane-Based AFFF: Testing of Experimental Foam Concentrates," Bundeswehr Research Institute for Protective Technologies and NBC-Protection (WIS), Germany
URL: https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2016-SUPDET/2016-Papers/SUPDET2016Hetzer.ashx?la=en

- Performance and toxicological parameters of a siloxane-based foam (consisting of 180 g/kg Glucopon 215 CS UP, 150 g/kg siloxane surfactant 1, 500 g/kg 2-[2-Butoxyethoxy] ethanol and 170 g/kg solvent) compared to fluorinated foam.
- Performance and toxicological parameters of a siloxane-based foam (consisting of 180 g/kg Glucopon 215 CS UP, 150 g/kg siloxane surfactant 1, 500 g/kg 2-(2-Butoxyethoxy)ethanol) show:
    - An extinguishing performance that significantly surpasses the commercial fluorine-free foams and nearly meets the performance of the fluorinated foams in the fire suppression tests with the NATO standard fuel F-34.
    - The viscosity and density of the 1% siloxane-based foam concentrate are acceptable in a temperature range between -15 °C and 60 °C
    - The toxicological behavior of the siloxane-based experimental foam concentrate is acceptable.
    - Siloxane-based fluorine-free foams are easily manufactured and perform significantly better on F-34 than the non-aqueous film form class-B-foam without persistent ingredients.

"What Properties Matter in Fire-Fighting Foams?" National Research Institute of Fire and Disaster

URL: https://www.solbergfoam.com/getattachment/3fe1d44d-3b44-4714-89f4-4af37e381b5b/WP-WHAT-PROPERTIES-MATTER-IN-FIRE-FIGHTING-FOAMS.aspx

Describes important properties in firefighting foams. Identifies a number of standards firefighting foams must follow. Also provides a list that outlines the properties of foams, why specific standards were chosen, the reasoning behind certain values, and the physical properties of foams that cause the most concern. Additional explanations provide further insight into why certain values and properties are included when creating standards. Properties of bubbles are explored and their effect on foams discussed.

- Fluorosurfactants are useful because they exhibit hydrophilic heads and hydrophobic tails. This is a unique property that makes forming a film possible.

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