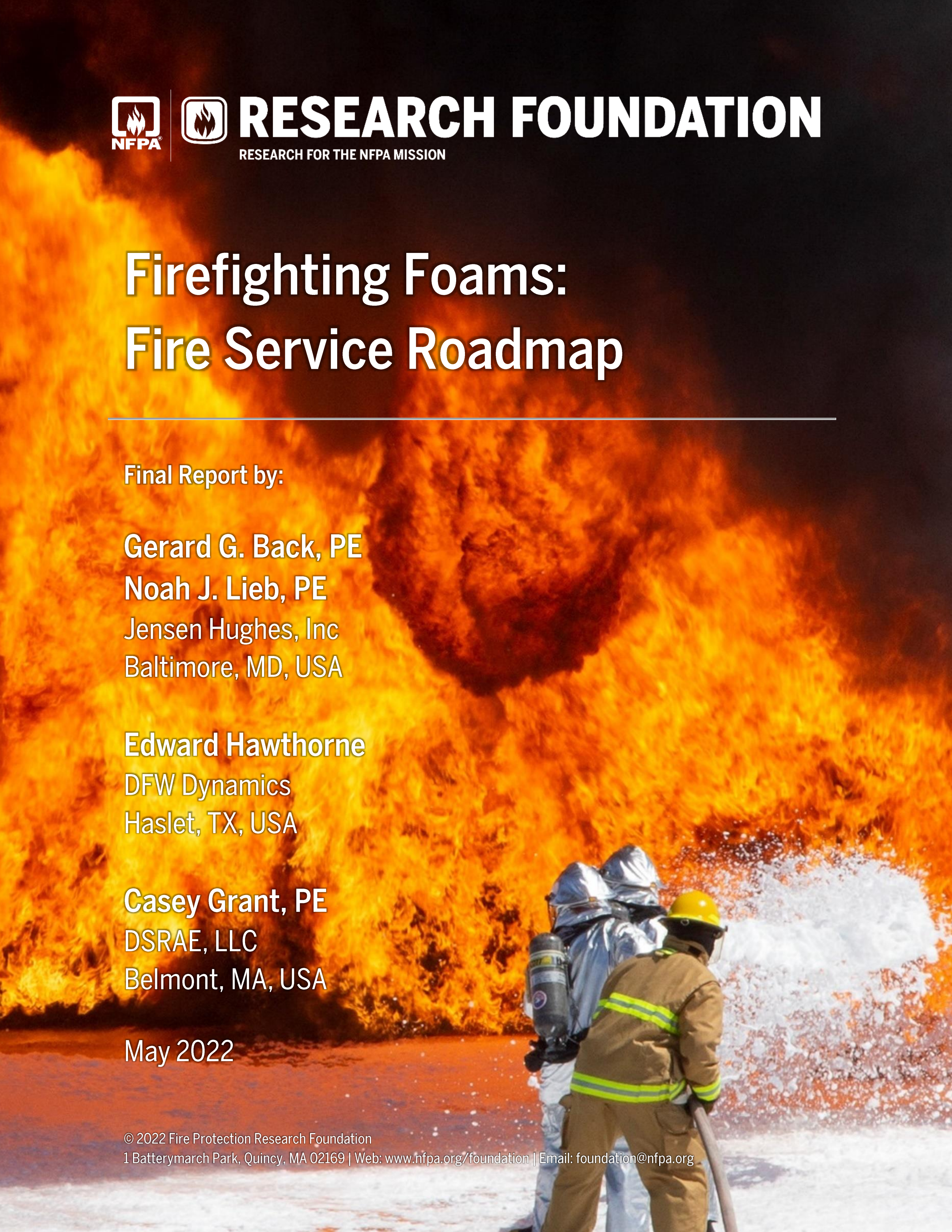

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Firefighting Foams: Fire Service Roadmap

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Report cover picture: Large flammable liquid spill fire test being fought with one of the next generation firefighting foams, October 2021. Picture credit: Gerard G. Back, Jensen Hughes.

Foreword

For decades, Aqueous Film Forming Foams (AFFF) was used as the dominant Class B firefighting foams for the vapor suppression and extinguishment of flammable liquid fires. AFFFs and other possible exposures in the fire ground are a critical concern for long-term firefighter health including possible cancer exposures. Today, fire departments are seeking replacements for AFFFs and other agents containing fluorosurfactants such as per- and polyfluoroalkyl substances (PFAS), and this includes state-based legislations that is phasing out the use of fluorinated foams. The currently available alternatives are not "drop-in" replacement for AFFFs and require additional knowledge and guidance to effectively address the wide range of Class B fires encountered by firefighters. Fire departments desperately need guidance to move these replacements forward. This is a complex problem, with concerns that include fire extinguishing performance, health exposure, environmental contamination, and other concerns. This project aims to proactively educate the fire service on the current and anticipated future issues on firefighting foam operations and handling by developing a strategic roadmap and recommendations of best practices to assist fire departments during this transition period in firefighting foam history.

The overall goal of this project is to develop a roadmap for the fire service while transitioning from fluorinated foam (i.e., AFFF) usage to fluorine free foam technology. The project aims to enhance firefighter safety and health by developing recommendation of best practice for firefighting foam operations and handling, by summarizing currently available information, reporting existing knowledge gaps, including all types of applications of firefighting foam that provide possible exposure pathways to firefighters and others.

The Fire Protection Research Foundation expresses gratitude to the report authors Gerard G. Back, P.E., and Noah J. Lieb, P.E., who are with Jensen Hughes, Inc. located in Baltimore, MD, USA, Edward Hawthorne, who is with DFW Dynamics, located in Haslet, TX, USA, and Casey Grant, P.E., who is with DSRAE, LLC located in Belmont, MA, USA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

Keywords: firefighting foams, fluorine free foams, aqueous film forming foams, AFFF, Class B fires, flammable liquid fires, regulations, roadmap, fire service, firefighting, disposal, NFPA 11, NFPA 30, NFPA 1585

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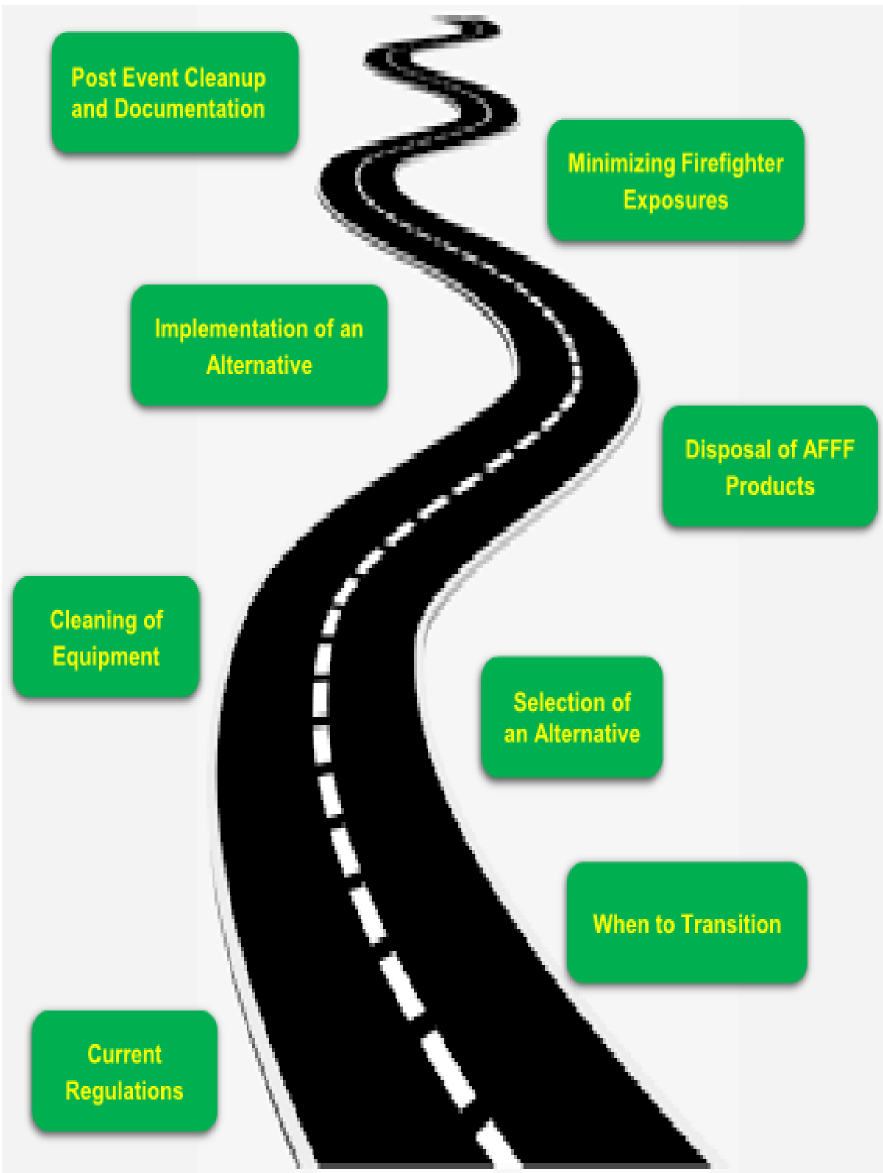

Executive Summary

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1. INTRODUCTION

1.1. BACKGROUND

Aqueous Film Forming Foam (AFFF) has been the industry standard for combatting liquid fuel fires and hazards for almost 50 years. AFFF is a water-based solution that contains a fluorinated, film forming surfactant (per- and poly- fluoroalkyl substances (PFAS)) to seal the fuel surface during suppression/extinguishment.

- PFAS are a family of human-made chemicals in products used by consumers and through various industries.
- Some PFAS are described as forever chemicals that do not naturally breakdown in the environment and/or in the human body.
- Some PFAS have emerged as contaminants of concern.
- Some PFAS have been associated with human health and ecological effects.

As a result, the ability to use AFFF to extinguish Class B fires continues to be greatly restricted and already been banned in numerous States in the United States and in countries across the world such as Australia.

In the early 2000s, the scientific and regulatory communities developed an increased understanding of the potential environmental, safety and occupational health risks associated with continued use of PFAS, which has resulted in evolving, increasingly strict regulations at the federal, state, local and international levels. It was initially believed that the hazards were specific to longer chain (C8) surfactants (i.e., perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)) which were eventually phased out of production in the United States and replaced with shorter C6 chain PFAS. Similar restrictions have occurred in other countries. However, these shorter chain molecules have also emerged as potentially hazardous chemicals to both health and the environment and are also under significant regulatory scrutiny. Exposures to these chemicals are a concern for long-term firefighter health including possible carcinogenic effects. They are also a concern to the general public due to the potential ground water contamination if discharged into the environment.

Recently, Federal and State authorities have implemented health and environmental regulatory actions for PFAS and PFAS-containing AFFF. These regulations will ultimately impact, if not eliminate the production, distribution, and use of legacy AFFF in upcoming years. Finding a suitable, environmentally friendly, non-toxic, and effective AFFF alternative presents one of the greatest challenges the fire protection industry and fire responder community has faced of the past 50 years.

Incidents involving flammable liquids tend to be low frequency, high risk events, which most fire departments seldom experience. The limited actual experience and the lack of firsthand knowledge on the spectrum foam products produces a need for disseminating the most up-to-date information available from multiple sources (foam users, foam manufacturers, foam testing agencies, regulators, etc.) to aid in making decisions on foam replacement and use. This one-year project was funded by a DHS/FEMA Assistance to Firefighters Grant (AFG) Fire Prevention & Safety Program to begin this process. The overall program was led by the Fire Protection Research Foundation (FPRF), the research affiliate of National Fire Protection Association (NFPA), with collaborative support from project partners: Jensen Hughes, Inc., DFW Dynamics, and DSRAE LLC. The initial program is scheduled to be completed by early 2022 with the hope of continual updates over the next few years or until this issue is resolved.

1.2. Goal and Objectives

The overall goal of this project is to enhance firefighter safety and health by developing a strategic fire service roadmap to effectively and efficiently transition from fluorinated foam (i.e., AFFF) usage to a suitable, environmentally friendly, non-toxic, and effective alternative. The overall tasks include:

- Reviewing and summarizing the current level of knowledge on the various aspects associated transitioning to a fluorine-free foam.
- Establishing recommended best practices for acquisition, operations, handling, disposal, and other tasks.
- Coordinating a unified voice to support a fire service national strategy and policies on firefighting foam.
- Facilitating stakeholder and researcher interaction and engagement for all key issues.
- Identifying knowledge gaps and identify future research elements to serve the needs of fire service.
- Stimulating dialogue between ongoing research efforts across all areas of focus (e.g., fire control, health & wellness, environmental, etc.).

1.3. Baseline Introduction

This roadmap program focuses primarily on the application of low-expansion foams (i.e., foam volume to solution volume ratios of ≤20:1) in combating liquid fuel fires (i.e., Class B fires). Some discussion is also provided on products being marketed as “universal agents” that can be used to extinguish both Class A fires (ordinary combustibles) as well as Class B fires (liquid fuel). But in general, since all Class B foam solutions are comprised of over 90% water, they all work well in extinguishing Class A fires.

Firefighting foam consists of air-filled bubbles formed from aqueous solutions. The legacy solutions are created by mixing a foam concentrate with water in the appropriate proportions (typically 1, 3, or 6 percent concentrate to water). The solution is then aerated to form a bubble structure. Because the aerated foam is lighter than flammable or combustible liquids, it floats on the fuel surface. The floating foam produces a layer of aqueous agent, which suppresses and prevents combustion by containing the fuel vapor at the fuel surface and preventing air from reaching the fuel vapor. If the entire surface is covered with an adequate amount of foam, the fuel vapor will be completely separated from air, and the fire will be extinguished. Low-expansion foams are quite effective on two-dimensional (pool) flammable and combustible liquid fires, but not particularly effective on three-dimensional flowing fuel fires. This is particularly true of three-dimensional fires involving low flashpoint fuels. Typically, an auxiliary agent, such as dry chemical, is used with foam where a three-dimensional fire (running fuel or pressurized spray) is anticipated.

Some legacy non-fluorinated foams, notably those that are protein-based, form thick, viscous foam blankets on liquid hydrocarbon fuel surfaces. These foams are typically referred to as mechanical foams. These foams extinguished fires using strong bubble structure to smother the fire as opposed to the film and bubble structure of the AFFF.

The new fluorine-free foams are similar to the legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors to extinguish the fire (i.e., fluorine-free foams do not produce a surfactant film of the fuel surface like AFFF). As a result, air-aspirating discharge devices may be required to optimize the capabilities of these products. Additional information on the capabilities of these products is provided in Annex C.

Many of the commercially available fluorine-free foams have been tested to, and or listed/approved to, the legacy foam test protocols. These include but are not limited to; Underwriters Laboratories (UL), Factory Mutual (FM), European Standards (abbreviated EN), and International Civil Aviation Organization (ICAO) standards.

Foams have been developed almost entirely from experimental work. Although many of the technologies are rather mature, no fundamental explanations of foam extinguishment performance have been developed based on first principles. As a result, the fire protection industry relies heavily on the approval tests for defining the capabilities of the foam as well as the extrapolation of these test results to actual applications by applying factors of safety to the test results. The following sections will provide a review of the important parameters associated with foam agents, test methods used to evaluate foams, and relevant data in the literature that can be used to make informed decisions on fluorine-free selection and system design parameters.

1.4. TERMINOLOGY

Shortly after the transition from long chain C8 AFFFs to shorter chain C6 AFFF formulations, the fire protection industry (i.e., foam manufacturers) began to develop and market new fluorine free formulations. These new foams were labeled by the manufacturers and marketed as Fluorine Free Foams (FFFs). In addition, there are a number of products referred to as “wetting agents” that are being developed and marketed as fluorine free AFFF alternatives. As a point of clarification, it is generally understood that eliminating fluorine in the product ensures that the product is PFAS free. This approach was adopted since the number of PFAS chemicals of concern has been increasing over the past few years and the definition of PFAS is somewhat vague in nature.

During this evolution, various industries have developed their own nomenclature for these products. They were initially referred to by the fire protection industry as “Fluorine-Free Foams” and given the following acronyms: FFF, 3F, F3, and FFreeF. The US DoD refers to them as FFF (F3) as well as “PFAS-Free Foams” (PFF). Underwriters Laboratories (UL) initially grouped these products under “Synthetic Foams”. NFPA 11, Standard for Low, Medium and High Expansion Foam refers to these products as “Synthetic Fluorine Free Foams” (SFFF, and also SF3) which has also been recently adopted by UL. Lastly, NFPA 403 / 460, Standards for Aircraft Rescue and Fire-Fighting Services at Airports refer to these products as “Fluorine Free Synthetic Foams” (FFSF). In any case, all of these terms are used to describe the same group of products. During this program, we will refer to these products as Fluorine-Free Foams (FFFs).

As a point worth noting, there is currently no widely accepted definition of what a FFF is. The fire protection industry is trending toward verbiage that includes “no intentionally added PFAS” and “a maximum PFAS content of less than 1 ppm (1 mg/L)”. Both requirements are under scrutiny by regulatory authorities in the U.S.

1.5. PROGRAM OVERVIEW

The overall roadmap program consisted of research/documentation on various pertinent topics and a workshop to present and collect information. The workshop was held in October 2021 and included numerous presentations on various topics for expert in various fields and seven presentations from the Roadmap Team. This gave the Roadmap Team the opportunity to present the information collected to date as well as to refine the information based on the information presented by others in the field as well as information expressed through the working groups assembled at the end of each presentation series.

The roadmap document is based on the information available at the time of the program. The roadmap and associated documentation have been assembled in a systematic path that works through knowing the current regulations and when to make the transition, cleaning of equipment and disposal of effluents and legacy concentrates, foam selection and implementation, minimizing firefighter exposures, and how to handle foam discharged from a cleanup and documentation perspective. The information has been assembled in separate Annexes which are listed below.

Information Annexes:

A. Understanding current regulations and knowing when to make the transition
B. Firefighting foam tutorial
C. Selection of an acceptable AFFF alternative
D. Cleaning of equipment and definition of acceptable levels
E. Disposal of current AFFF products (concentrates and solutions)
F. Implementation of the selected alternative
G. Health concerns and minimizing firefighter exposures
H. Post fire / post discharge cleanup and documentation
I. Workshop summary
J. Project poster
K. References

In addition to this document, the information has been summarized in a poster that can be printed and placed in the fire station for quick access and to serve as a reminder to keep informed on this topic.

The information presented in this document is a snapshot of the current knowledge on the various topics which is currently in flux. As a result, many of the Annexes provide links to websites that are continually updated with the latest information. A summary of each annex is provided in the following sections.

2. UNDERSTANDING CURRENT REGULATIONS AND KNOWING WHEN TO MAKE THE TRANSITION (ANNEX A)

Annex A provides a high-level summary of existing domestic regulation for PFAS and AFFF. This information is basically a snapshot of the current requirements which are changing almost daily. The most up to date information should be available from your local/state environmental protection agency via their websites and/or by contacting the local/state fire marshal's office.

The regulations may apply to the production, use, release, and disposal of AFFF on a variety of levels (i.e., Federal, State and even local). Legacy AFFF contained fluorinated surfactants based on per- and poly-fluoroalkyl substances (PFAS) that are being increasingly regulated, restricted or banned domestically and internationally. Organizations like the Interstate Technology and Regulatory Council (ITRC) are developing a suite of resources to track changing regulation associated with PFAS and AFFF across the U.S. and international regulatory agencies. The issues and regulations associated with AFFF and the changes in the environmental/use landscape are well documented in the following link - https://pfas-1.itrcweb.org/.

Recently, Federal and State authorities have implemented health and environmental regulatory actions for PFAS and PFAS-containing AFFF. These regulations could potentially impact the production, distribution, use and disposal of legacy AFFF. In December 2019, Congress passed the FY20 National Defense Authorization Act (NDAA), which prohibits uncontrolled release of AFFF at military installations except in emergency response or in training or testing if complete containment, capture and proper disposal is in place. This also required the development of a new shore-based foam specification to aid in the phase out of PFAS-containing AFFF at all shore-based military installations by 2024 (with tightly limited extensions totaling up to 2 years).

The Federal Aviation Administration (FAA) previously required that all Certificated Part 139 airports use MIL-PRF-24385 qualified AFFF for firefighting operations. The FAA Reauthorization Act of 2018 stated that the FAA could not require the use of fluorinated surfactants to meet the MIL-PRF-24385 fire performance requirements after Oct 2021. In early October 2021, the FAA released a statement saying that fluorinated surfactants are no longer required but the foams must still meet the performance requirements of the MilSpec (which none can at this time). Airports Council International – North America determined that continued use of PFAS-containing foams will extend past the mandated date pending further evaluation of PFAS-Free/Fluorine-Free Foams (PFF/FFF) and updates to the DoD shore-based foam specification. FAA transition to PFF/FFF will most likely mirror the DoD transition. In January 2022, the draft shore-based foam specification was circulated to a group of end users for initial review and comment, the specification should be completed by early 2023.

There are a number of federal environmental regulations that potentially apply to the production, sale, release, and disposal of PFAS and PFAS-containing products. The primary regulations potentially restricting PFAS or AFFF include the Safe Drinking Water Act (SDWA), Toxic Substances Control Act (TSCA), Resource Conservation and Recovery Act (RCRA), Clean Water Act (CWA), Clean Air Act (CAA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Currently, there are no federal laws that prohibit the use of existing stocks of legacy AFFF. However, the EPA developed a PFAS Strategic Roadmap that will evaluate future designation of specific PFAS (perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA)) as "hazardous substances" for further regulation.

Multiple states have taken a proactive approach to pass their own regulations or health advisories to restrict the use of AFFF and PFAS in other products. At least 15 states (as of the end of 2021) have passed regulations to ban the use of PFAS-containing AFFF (outside of FAA and DoD installations) with more pending legislation. Some states have passed prohibitions on incineration of PFAS-contaminated wastewater/rinsate, including AFFF concentrate. Multiple states are developing or already established legacy AFFF take-back programs to collect and destroy PFAS-containing foams from municipal and city fire departments. The most up-to-date information on individual state regulation is available at https://itrcweb.org/home.

Individual organizations will need to make an informed decision about transitioning to a fluorine-free foam and disposing of legacy AFFF. In some cases, State legislation will set a clear timeline for this transition. In other cases, organizations may consider a preemptive transition ahead of potential Federal or State regulation.

3. FIREFIGHTING FOAM TUTORIAL (ANNEX B)

A high-level tutorial on firefighting foams is provided in Annex B. Since the roadmap program was initiated to aid in the transition away from AFFF to a fluorine-free foam, the focus is placed on foams used to combat liquid fuel fires (i.e., Class B fires). Some discussion is also provided on products being marketed as "universal agents" that can be used to extinguish both Class A fires (ordinary combustibles) as well as Class B fires (liquid fuel). But in general, since all Class B foam solutions are comprised of over 90% water, they all work well in extinguishing Class A fires.

There are three main parameters used to define foam performance against liquid fuel fires. These include control/extinguishment, burnback protection and vapor suppression. As a result, most protocols have three to four basic components that combine to identify the capabilities of the foam for a specific application. These are shown in Figure 3.0-1 below and include a liquid fuel fire in a pan of a specific size and shape. The fuel type and the fire preburn time is defined based on the hazards of the end-use scenario. After the preburn time is complete, foam solution is applied to the fuel surface either through a fixed nozzle system or manually applied by a firefighter. In either case, the discharge device is designed to produce foam with roughly the same characteristics (i.e., level of aspiration/expansion and drainage time) as the actual devices used in the application. Once the fire has been extinguished, some test protocols (i.e., the ones used by the petroleum industry) have a vapor suppression assessment phase where a lit torch is passed a few inches above the foam blanket to ensure the vapors are being contained by the foam. The final phase includes an assessment of the foam's ability to resist burnback by igniting a small area of the fuel surface (by either removing some of the foam or placing a burning pan of liquid fuel into the larger pan) and measuring the time for the fire to grow to a specific size (percentage of the total pan area).

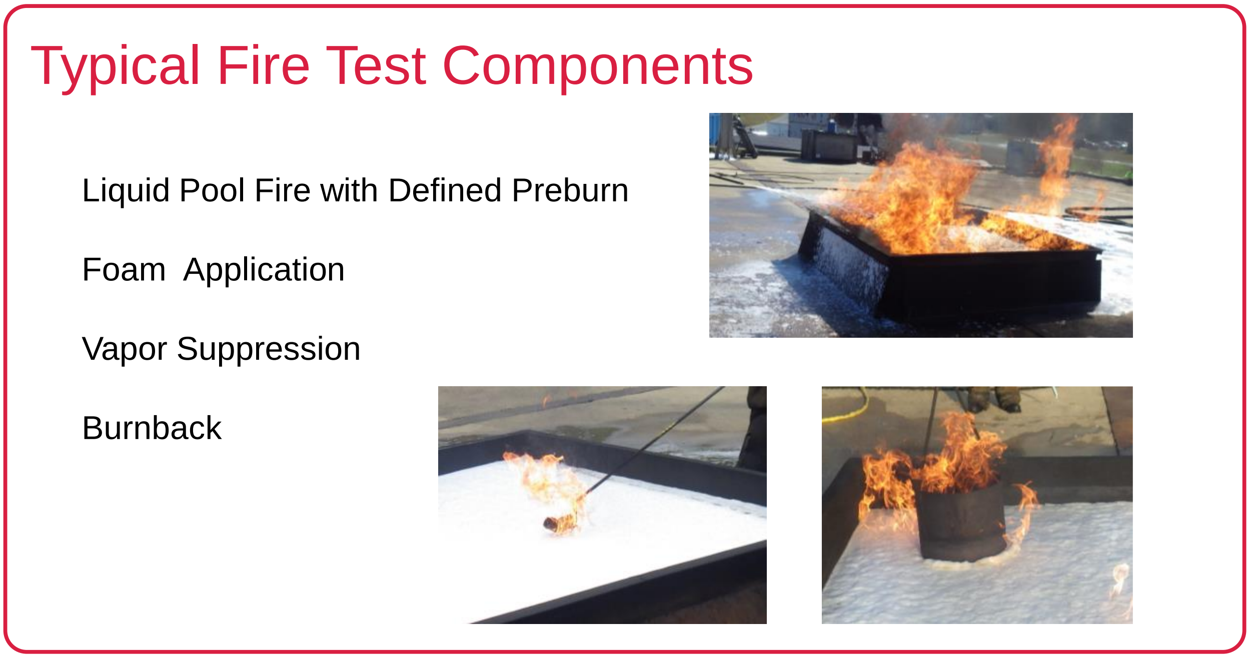


Figure 3.0-1 Typical Foam Approval Test Components

Although the test protocols for the various user segments (described below) have similar components, the test parameters tend to vary depending on the industry and the hazards being protected (i.e., “designer foams”). In other words, the protocols are designed to verify specific capabilities and vary in difficulty depending on the scenario in which it was intended to mitigate. As a result, a foam designed and approved for DoD/Aviation applications may not perform well against a large petroleum industry fire (and vise-a-versa). In addition, fuel type is a significant variable and needs to be considered during testing and foam selection. It needs to be noted that these approval tests are not designed to simulate actual full-scale fire scenarios but rather to provide a means to assess the capabilities of these products on an affordable and reproducible scale using many of the parameters/conditions that makeup the industries’ Maximum Credible Event (MCE).

There are four general user segments of the fire service community that use foam firefighting products: Military, Aviation, Petroleum Industry and Municipal Fire Departments. The hazards and required foam product performance are in most respects, specific to the user segments. Specifically, the foam performance requirements are defined based on an agreed-upon/selected Design Fire (DF) or Maximum Credible Event (MCE).

For the DoD, the design fire includes an aircraft rescue and firefighting (ARFF) scenario that includes a fuel spill under the aircraft that exposes the weapons to fire. This fire needs to be quickly controlled and extinguished to prevent ordnance cookoff. The aviation industry has a similar scenario except the hazards are associated with the burn-through of the fuselage that jeopardizes the occupants of the aircraft. Both the DoD and aviation industry scenarios have well defined fire scenarios (i.e., fuel types and minimal depth spill fires). The primary hazard for the petroleum industry is a large tank fire that contains thousands of gallons of liquid fuel (sometimes referred to as “fuel in depth”). In most scenarios, these are hydrocarbon-based fuels but there are limited scenarios where polar solvents and/or other types of products may be present. Due to this potential range of fuels/hazards, specific foam types may be required to protect specific hazards (e.g., Alcohol Resistant (AR) foams will be required to protect against polar solvents). The "primary" hazards for a municipal fire department are less defined and cover a wider range but smaller versions of the scenarios mentioned previously. Transportation hazards tend to be the most frequent type of hydrocarbon event that occurs with some frequency. All of the other types of events could occur if within the fire departments response area such as an aircraft crash or a terminal storage tank fire, but they are much less likely in most small to medium size departments. An example MCE would include an overturned tractor trailer carrying gasoline that is leaking from the truck and catches fire. Photographs of these four MCEs are shown in Figure 3.0-2 below.

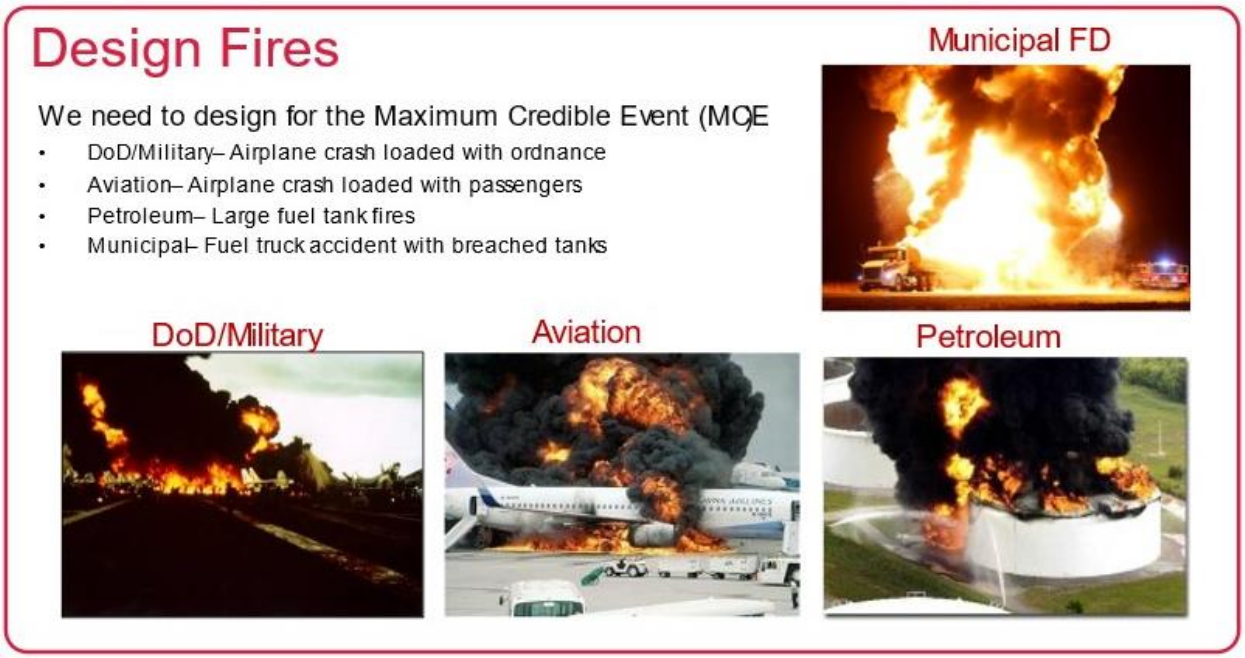


Figure 3.0-2 Industry Segment MCEs

The primary hazards, performance objectives, and the test methods/protocols for the four user segments are summarized in Table 3.0-1 below. The test methods used by the military and the aviation industry were developed around fuel spill scenarios with minimal fuel depth and shorter preburn times and focus more on rapid extinguishment versus burnback protection. Conversely, test methods used by the petroleum industry were developed around fuel storage tanks with significant fuel depths with potentially longer preburn times and focus more on the development of a robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces but allow for longer extinguishment times as a trade-off. Since there are no test methods that apply strictly to municipal fire departments, the selection of a foam needs to be based on the anticipated needs/hazards being protected.

Table 3.0-1 User Segment Test Method/Protocols

User Segment	Primary Hazard (MCE)	Performance	Test Protocol
Military/DoD	Spill fire (mostly kerosene based), short preburn, weapon exposures / cookoff	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F
Aviation Industry	Spill fire (kerosene based), short preburn, passenger exposures / fuselage burn-through	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F ICAO A, B & C NFPA 403/1900
Petroleum Industry	Tank fire (various fuels), long preburn	Decent control and extinguishment, robust foam blanket, good burnback protection	UL 162, EN 1568, NFPA 11, LASTFIRE (tank scenarios)
Municipal Fire Departments	Industrial, Tanker trucks, fuel handling stations, (various fuels), long preburn	Any/all of the above	Not Specified / all of the above

As a high-level overview of the state of the industry, a recent literature search identified between 60-70 commercially available products that were being marketed as “environmentally friendly” AFFF alternatives. A deeper dive into this information revealed that about one-half of these products did not have legitimate approvals and/or listings and were being marketed strictly on limited ad-hoc testing and associated videos. The remaining products have been tested to, and/or listed/approved to the legacy test protocols shown in Table 3.0-1. Many of which have been successfully fielded and are in use today for a range of applications. The use of products tested and approved by credible testing and approval authorities is highly recommended (i.e., be skeptical of products being marketed solely on adhoc testing and videos).

Most, if not all, of the National Fire Protection Association (NFPA) Standards that include the use of foams in the protection schemes are being revised to include fluorine-free foams and/or other environmentally acceptable alternatives/approaches. A significant amount of environmental and toxicology research as well as fire-fighting performance assessments is being conducted under programs funded by the US Department of Defense (DOD) environmental oversite organizations: the Environmental Security Technology Certification Program (ESTCP); and Strategic Environmental Research and Development Program (SERDP). The FAA, NFPA Fire Protection Research Foundation, LASTFIRE and a wide range of commercial entities are also actively investigating the capabilities and limitation of these new products for specific applications. A deeper dive into this research is provided in Annex C which covers foam selection.

There are many very effective FFFs on the market and in use today. However, it is incorrect to assume that these new FFFs are a “drop in” replacement for AFFF even though they may have a specific listing or approval. At this time, there is too much difference between specific FFF's in properties and performance to suggest that the class can be a drop in replacement for the AFFF class of foams. Specific FFF foams maybe used in place of existing specific AFFF foams in fixed systems or portable application, but a detailed evaluation must be completed prior to making that transition as described in this document. Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. This applies to both the discharge devices and proportioning system.

Even though there are a limited number of products that are being marketed as "film-forming" FFFs, all these products are basically mechanical foams and rely almost entirely on the foam blanket to smother the fire. As a result, the degree of foam aspiration/aeration is critical and may eliminate the use of some non-air-aspirated nozzles. In addition, some of the approved FFFs are highly viscous which may require modification and or replacement of a legacy proportion system.

In closing, it needs to be noted that these products continue to evolve, and the firefighting capabilities continue to improve. These trends were also observed for AFFF when it was deployed almost 50 years ago.

4. SELECTION OF AN ACCEPTABLE AFFF ALTERNATIVE (ANNEX C)

The foam selection framework described in Annex C provides a couple of different approaches for identifying and selecting a fluorine-free foam. In short, the first focuses on compatibility with current hardware and/or a comfort level associated with a specific foam manufacturer and the second which revisits the basics and hazards and focuses on best performers independent of previous experience. The framework is outlined in Figure 4.0-1 below.

Selection of an AFFF Alternative

- Application / Use
  - Application may require specific standard/approval
  - Match hazard to test standard
  - Beware of Ad-hoc testing and videos
  - Credible test lab
- Current System/Product (proportioning system and discharge devices)
  - Minimize hardware modifications
  - Talk to foam and/or equipment manufacturers
- Concentrate viscosity (Newtonian vs Non-Newtonian)
- Fire Performance / Design Parameters
  - Approvals and listed parameters
  - R&D Data – SERDP/ESTCP, FAA, LASTFire, RISE, etc.
- Environmental and Health Concerns
  - SDS/Safer Choice/Green Screen

Figure 4.0-1 Foam Selection Framework

Ultimately, there are a range of potential products that should be considered and researched prior to final selection. The end users will need to do their homework to ensure the selection of an appropriate AFFF replacement, to minimize the potential for transition regret (i.e., to avoid multiple repeated replacements over time). Table 4.0-1 below provides a list of the products (and their associated websites) that appear most frequently throughout the literature as described in Annex C. This table is not an endorsement of any of these products but rather is one source of information for additional research. Most of the "Foam" products shown in the table have either

UL-162 or EN 1568-3 listings/approvals or have completed some ICAO Level B or C. Most of the "Wetting" agents have been tested to the requirements defined in NFPA 18.

Table 4.0-1 Frequently Researched Fluorine Free Foams and Agents

Manufacturer	Type	Website	Multi-scale Research Conducted by:
3F – Freedol	Foam	https://www.3fff.co.uk/chemistry/smart-foam/	Pet
Angus	Foam	https://angusfire.co.uk/products/foam-concentrates/product-range/fluorine-free-foam/	AV, DoD, Pet
Ansul	Foam	https://www.ansul.com/en/us/DocMedia/F-2021111.pdf	DoD
Auxquimia	Foam	http://auxquimia.com/synthetic-multiexpansion-foam-concentrates/	
Bio-Ex	Foam	https://www.bio-ex.com/en/our-products/compositions/fluorine-free-foam/	AV, DoD, Pet
Bristol – EkoSol	Foam	http://www.bristol-fire.com/	
Dr. Sthamer	Foam	https://sthamer.com/en/fluorine-free/index.php	AV, Pet
Eau et Feu	Foam	https://eauetfeu.fr/produits/emulseurs/liste-des-emulseurs/airfoam/	AV, Pet
FireBull PFF	Foam	https://enforcerone.com/products/firebull-fluorine-free-foam/	
Fomtec	Foam	https://www.fomtec.com/fluorine-free/category38.html	AV, DoD, Pet
GreenFire	Both	https://gogreenfire.com/greenfire-fire-protection/	
National	Foam	https://nationalfoam.com/foam-concentrates/sfff-fluorine-free-foam/	AV, DoD, Pet
Orchidee	Foam	https://orchidee-fire.com/products-solutions/?_sft_product_cat=fluorine-free-foams	
Phos-Chek	Foam	https://www.perimeter-solutions.com/en/class-a-foam/	
Solberg	Foam	https://www.perimeter-solutions.com/en/class-b-foam/solberg-avigard-fluorine-free/	AV, DoD, Pet
vs FOCUM	Foam	https://vsfocum.com/foams/types/1-fluorine-free-newtonian/	
Amiran	Wetting	https://www.jmesales.com/content/docs/AmiranBioChemicals/FlameOut_DataSheet.pdf	
Coldfire	Wetting	https://firefreeze.com/cold-fire/	
F500	Wetting	https://hct-world.com/products/chemical-agents/f-500-encapsulator-agent/	
Geltech	Wetting	https://geltechsolutions.com/fireice/	
Novacool	Wetting	http://novacoolfoam.com/	
Pyrocool	Wetting	https://www.pyrocooltech.com/pyrocool-fef/	

Research Areas: AV-Aviation / DoD-US Department of Defense / Pet – Petroleum Industry

There are numerous available resources to help with this transition and reduce the learning curve impact. Most, if not all, of the National Fire Protection Association (NFPA) Standards that include the use of foams in the protection schemes are being revised to include fluorine-free foams and/or other environmentally acceptable alternatives/approaches. These standards may provide information on both the selection and use of these new products. In addition, there are numerous research programs that have either been completed or are on-going which may help provide information of product capabilities. With that said, be weary of relying on adhoc testing and focus more on approvals and listings from accredited laboratories and organizations. Adhoc testing might not be representative of an actual fire scenario and/or not recognized by any accredited laboratories.

In addition to fire performance, the selection of a next-generation foam also needs to include an assessment of environmental and health concerns. It needs to be understood that the elimination of PFAS and/or fluorine from the product does not address all the potential health and environmental hazards (only one family of chemicals). The fire protection industry is working with environmental and health groups to develop some approaches for assessing these concerns for firefighting foams. Unfortunately, the development of such a standardized approach is still in its infancy.

Most assessments and approaches developed to date consist of comparing the list of chemicals in the foam concentrate to standard databases of chemicals that are known to be health hazards and/or are known to have ecotoxicity issues. These assessments are typically based on composition data provided by the manufacturer which is, in only a limited number of scenarios, ever empirically/analytically verified. Two such assessments are GreenScreen and the US EPA's Safer Choice. The links to these organization/assessments are provided in the Annex.

Since there are not any widely enforced specific requirements on the health and environmental hazards of FFFs (other than possibly PFAS or Fluorine content), it is typically left to the foam manufacturer to have the product assessed. In future, this may change, and a list of the various certified products may become available. Until then, the end user should consider asking the manufacturer(s) for evidence of independent health and environmental assessments.

The main takeaway of this section is that doing your homework to become better informed should ease the selection and transition burden. Learning from others in your industry that have already made the transition is highly recommended. With that said, talk to at least two organizations that have already made the transition to potentially provide different viewpoints on specific topics/issues.

5. CLEANING OF EQUIPMENT AND DEFINITION OF ACCEPTABLE LEVELS (ANNEX D)

Annex D provides updated information on the cleaning of equipment prior to implementing a selected, fluorine-free foam. This equipment includes foam and concentrate storage tanks, proportioning systems, pipe networks, and fire trucks/Aircraft Rescue and Firefighting (ARFF) vehicles. Multiple studies have shown that PFAS persists in the tanks, piping, gaskets and other "soft" or "porous" components of the firefighting equipment. These contaminants can leach-out over time producing very low levels of PFAS in previously cleaned equipment.

The most common method of cleaning AFFF from firefighting equipment is water rinsing. This method requires the draining and collection of AFFF concentrate/solution followed by a triple-rinse with water to significantly reduce any remaining residual concentrate/PFAS chemicals. This has been identified as a best practice during a number of successful transitions and through US DoD research. Some states and facilities require the use of deionized water, while others allow the use of municipal water. The three-rinse process typically produces a significant amount of wastewater with relatively low concentrations of PFAS that will need to be collected and properly disposed by a reputable environmental waste management company.

Cleaning solutions and/or reagents have been shown to remove PFAS from system components and have been successfully used to decontaminate fixed and mobile fire suppression equipment. Additional Information on these products and links are provided in Annex D. There are also companies that are providing onsite cleaning services that can be identified by searching the web.

To date, there is no clear guidance for how clean final rinsate water must be to satisfy local regulators (i.e., it is currently not mentioned or is undefined). Discussion has been centered around trying to meet either the EPA drinking water advisory level for PFAS (70 ppt), the 1 ppb total PFAS requirement in the NDAA for DoD foams, or the 1 ppm PFAS that has become adopted by other industry standards (UL-162) and throughout Europe (ECHA). Specifically, these industries/countries have defined acceptable limits for PFAS as products containing less than 1 mg/L (1 ppm) of organic fluorine. In the U.S., the EPA plans to publish revised disposal/destruction guidance but not until in 2023. As a point worth noting, it has been difficult to reliably measure concentrations of PFAS and/or organic fluorine below 1 ppm with the available technologies.

It is recommended (but currently not required) that the end-users collect samples prior to rinsing and after the final rinse and have them analyzed for Total Organic Fluorine to provide the percent reduction (i.e., many orders of magnitude reduction) that was achieved during the cleaning process. In closing, it is understood that this entire cleaning process takes time and minimizing the “out of service” time is essential and needs to be considered/accounted during the transition process.

6. DISPOSAL OF CURRENT AFFF PRODUCTS (CONCENTRATES AND SOLUTIONS) (ANNEX E)

As a starting point, it needs to be emphasized that the previously recommended practices of dilution of foams and release of rinsate water to the environment and/or wastewater treatment systems are obsolete and unacceptable for fluorinated foams going forward. AFFF must now be disposed of according to Federal, State, and local regulations. Several states have implemented take-back programs for PFAS-containing foams. Consult with your local state environmental protection agency to obtain more details on available take-back programs. Effective programs may be completely free of charge for pick-up, transport and safe disposal of all forms of legacy AFFF. Most of these regulations can be found by search your State EPA on your browser. An example of such a search is provided in Figure 6.0-1 below.

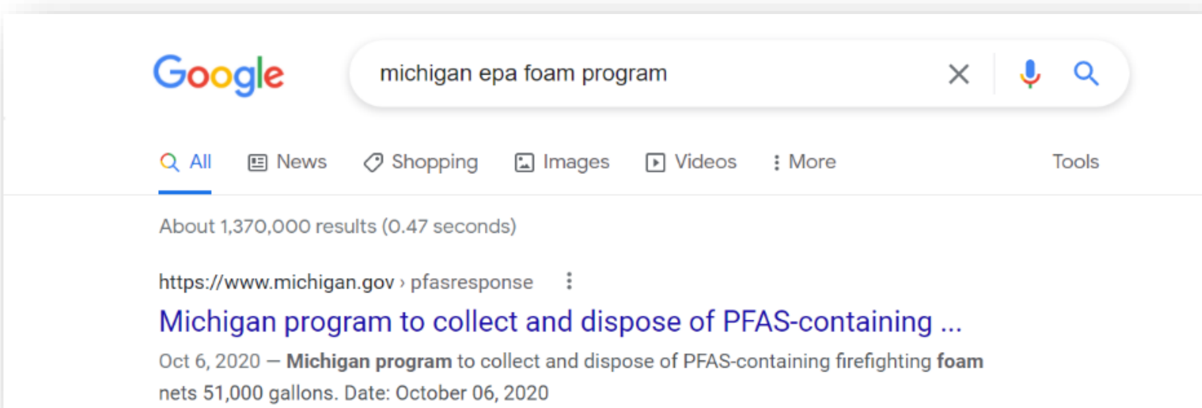


Figure 6.0-1 Example Browser Search

The Interstate Technology Regulatory Council (ITRC) website (https://pfas-1.itrcweb.org/) is also a good source for this type of information.

As a general practice, AFFF waste (i.e., concentrate, foam solution discharge, and rinsate water) should be properly contained and stored to local/state and federal guideline prior to disposal or treatment. AFFF and PFAS constituents can either be destroyed through high energy process or safely stored in a highly contained long-term waste facility. There are also technologies in development to potentially destroy PFAS in place in ground water or soil that has been contaminated by PFAS; however, they are limited in application. In Dec 2020, the U.S. EPA released interim guidance on destruction and disposal of PFAS (and AFFF). Destruction was defined as thermal treatment and disposal was defined as landfilling and underground injection. Additional detail on PFAS destruction best practices and ongoing research is provided in Annex E.

In any case, the first responder community will need to rely on Local/State assistance or pay to have the waste removed and destroyed by a reputable environmental waste management company.

7. IMPLEMENTATION OF THE SELECTED ALTERNATIVE (ANNEX F)

Annex F provides the guidance for implementing the fluorine-free foam product from a functionality and performance standpoint. Prior to starting the process, reviewing one of the case studies documented during this program is highly recommended. Reaching out to an organization that has completed the transition may reduce the learning curve and expedite the transition.

To start, there are a number of documents that need to be reviewed to ensure that the product is deployed withing its tested/approved parameters. These include: any applicable fire codes (i.e., NFPA, ICAO, etc.) and the approval test / UL listing parameters. Most of the NFPA and international standards have been or are being updated to allow these new fluorine-free products. With that said, the legacy test and design requirements have not changed significantly allowing many of these products to be used with currently installed systems (with some minor adjustments). The exception to this may be sprinkler applications which is discussed later in this annex.

The implementation process will require assistance/consulting from both the proportioning system hardware manufacturer as well as the fluorine-free foam manufacturer. This is predominantly true for the first responder community since their applications are typically not governed by specific codes and standards.

One of the considerations identified during the selection of the fluorine-free foam (ANNEX C) included hardware compatibility. For many applications, the foam concentrate is listed for use with a specific set of hardware (i.e., proportioning system and discharged devices). Most of the industry leading AFFF manufacturers are developing FFFs and there is a good chance that this product has been tested with legacy system hardware which would minimize potential future modifications.

In general, the primary concern associated with accurately proportioning FFFs is the concentrate viscosity. Current FFFs cover a wide range of viscosities from products that flow like water to products that are semi-solids and have the consistency of jelly/jam. The fire protection industry tends to refer to these thicker products as either non-Newtonian or pseudo-plastic concentrates. As general a statement, it appears that concentrates that have maximum viscosities (i.e., the viscosity at the lowest use temperature) of 200 mm^2/s (as determined using EN ISO 3104), can be proportioned with legacy AFFF hardware with little to no modification or adjustments. Independent of the concentrate viscosity, contacting the hardware manufacturer is highly recommended, if not required.

The new fluorine-free foams are similar to the basic legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors and prevent them from mixing with oxygen/air above the fuel surface resulting in fire extinguishment (i.e., fluorine-free foams typically do not produce a surfactant film on the fuel surface like AFFF). There are a few fluorine-free foams that are advertised as film formers, but the degree of film formation is inadequate to significantly increase the capabilities of the product. Due to the reliance on the foam blanket, air-aspirating discharge devices may be required to optimize the capabilities of these products. With that said, it needs to be noted that these new products are “foamier” than the legacy products (including AFFF) and that the expansion ratios are usually about 1-2 points (and sometime even more) higher for FFFs than AFFFs over a wide range of discharge devises and typically have significantly longer drainage times than AFFF. This is a general observation of the technology, but the foamability of some products may vary.

The research conducted to date suggests that FFFs tend to lose effectiveness when discharged through non-air-aspirating nozzles that produce lower aspirated/aerated foam with expansion ratios less that 4-5 (generally speaking). However, it needs to be noted that the extinguishment capabilities are a function of application rate, foam quality (i.e., aspiration/expansion), and application technique. Specifically, reduced foam quality can be compensated for by increased application rate and vice versa.

The burnback and vapor suppression capabilities have also been shown to increase with increased aspiration. These trends suggest that after a fire is extinguished and/or there is a fuel spill of a flammable liquid requiring vapor suppression, higher aspirated foam would be more effective. Specifically, aspirated/aerated foam with expansion ratios of 7-8 or greater have been shown to be highly effective for vapor suppression and/or for preventing burnback. As a closing note, drainage time of the foam is also a variable, FFFs that drain slower tend to provide longer burnback protection and greater vapor suppression capabilities.

The following paragraphs provide a high-level discussion on manual firefighting application techniques and tactics. Most of this information was collected during two recent SERDP-ESTCP programs (WP21-3461 & WP21-3465). The tests were conducted to validate the capabilities of five higher performance, commercially available FFFs against two large scale fire scenarios (i.e., running fuel/debris pile and fuel spill fire scenarios) representative of ARFF type incidents. The results were baseline against a legacy MilSpec AFFF.

The following discussion focuses on the lessons learned from the fuel spill fires combated with the 125-gpm hose line. The fuel spill fires were produced by discharging 400 gallons of F-24 onto a concrete surface which produced a spill area of about 2500 ft^2. The 2500 ft^2 fuel spill fires were combatted with three hose line nozzle configurations: the standard nozzle without attachments, the standard nozzle with a long (lower aspiration) foam tube, and the standard nozzle with a short (higher aspiration foam tube). The optimal standard nozzle setting was a narrow angle fog pattern (approximately 10-degree spray angle). At this setting, the standard nozzle provided a 75 ft effective reach of foam solution with an expansion ratio in the range of 4-6. The longer foam tube provided a 65 ft effective reach of foam solution with an expansion ratio in the range of 7-9. The shorter foam tube provided a 45 ft effective reach of foam solution with an expansion ratio in the range of 12-23.

To summarize the results of the program, the MilSpec AFFF outperformed the five FFFs in both scenarios and under all conditions (i.e., discharge devices). However, the FFFs demonstrated the ability to control and extinguish all the test fires conducted during this series with application rates well below those fielded in the ARFF industry. The AFFF was able to extinguish the fuel spill fires in about 30 seconds, independent of the discharge nozzle. All five FFFs were also able to extinguish the spill scenarios but the extinguishment times were typically about 1.5-2 times longer than the AFFF (but typically in less than a minute).

With respect to the discharge device, there are trade-offs associated with using standard nozzles versus foam tubes. The standard nozzle provides more reach and pattern control but with limited foam aspiration. This provides the firefighters with flexibility with respect to how they fight the fire. The foam tubes produce higher aspirated foams but are limited to a set spray pattern and reduced reach. However, the higher aspirated foam produced by the foam tubes by nature, is applied more gently to the fuel surface, had better extinguishment and vapor sealing capabilities but required more technique and faster advancement (i.e., the firefighting party had to advance through the spill in order to reach the other side/completely extinguish the fire). Optimized discharge devices and or the use of Compressed Air Foam Systems (CAFS) have the potential to reduce the performance gap between AFFF and the FFFs.

There were a few main take-aways from the two programs that apply to manual firefighting. First, the FFFs are not as forgiving as AFFF with respect to application technique. Specifically, the first hose stream pass with the FFFs provided good knockdown and control, but it typically took two passes to extinguish all the fires as opposed to one for AFFF. In addition, the FFFs required better application techniques and a little more finesse to be effective. As a result, pre-fire planning and training will be key to successful implementation/deployment of these products going forward. With that said, the current approach of using propane burners for training will not simulate these fire conditions and will not allow the development of optimal application techniques (i.e., no fuel pickup due to plunging and no burning at the stream impact location in the foam blanket). Large water-filled burn pits are also potentially problematic for the same reasons.

Going forward, training and education will be the key to success. Although these new foams are being developed and implemented as environmentally friendly AFFF alternatives, the industry trends will require collection and disposal of these products in the same manner as AFFF is being handled today. So unfortunately, the ability to train with these foams will have the same cost burden as the legacy AFFFs requiring special facilities and waste containment/collection. As a result, innovative training approaches (e.g., immersive reality approaches) should be considered/developed to more effectively and efficiently address the increased challenges of transitioning to these new products. Additional training resources will be required to address new foam alternatives (e.g., model procedures, model strategies or tactics with new foams, training facilities, equipment transition, etc.). Special education and training are needed for foam stewardship (e.g., why the transition is needed, why environmental contamination is important, how to dispose of foam concentrates and/or rinse water, etc.).

8. FIREFIGHTER EXPOSURES & HEALTH CONCERNS (ANNEX G)

AFFF contains fluorinated, film forming surfactants (per- and poly- fluoroalkyl substances (PFAS)) to seal the fuel surface during suppression/extinguishment. All AFFFs (a well as all other fluorinated firefighting foams) contain PFAS.

- PFAS are a family of human-made chemicals in products used throughout various industries in addition to firefighting foams.
- Some PFAS are described as forever chemicals that do not naturally breakdown in the environment and/or in the human body.
- Some PFAS have emerged as contaminants of concern.
- Some PFAS have been associated with human health and ecological effects.

PFAS exposures are not unique to firefighters. In fact, it is estimated that only about 3% of fluorochemical production was used for making AFFF. The general public is exposed to PFAS through a variety of media, including ground and drinking water, stain and water repellant textiles, food packaging or even consumption of meat/produce exposed to PFAS (e.g., fish from contaminated groundwater). Firefighters face additional PFAS exposure risks due to extensive use of legacy PFAS-containing AFFF in training and firefighting foam applications. Handling, training and emergency use of AFFF exposes emergency personnel to PFAS through ingestion, inhalation or dermal absorption. Firefighters can also be exposed to PFAS through the combustion of PFAS-containing products (e.g., carpets, upholstery, etc.). Additionally, firefighters can be exposed to PFAS via turnout gear. PFAS have been used in water-repellent fabrics in all layers of gear to provide water-resistance and to protect firefighters from steam. Some States have passed additional regulation for PFAS in firefighting PPE and there is ongoing research to determine the risks of PFAS exposure through turnout gear.

PFAS exposure can have both short and long-term effects on the human body. Exposure to AFFF and PFAS can cause short-term effects such as irritation of the skin, throat, nose and eye and mucous membranes, rashes, dizziness, headaches, and drowsiness. Research also ties leukemia, lymphoma, and neuroendocrine tumors to prolonged exposure to some PFAS.

Firefighters are shown to have disproportionately high rates of cancer in comparison to the public. Additional data is being collected through the FEMA-funded Firefighter Cancer Cohort Study to provide an epidemiological survey of PFAS exposure and cancer. There is only limited information quantifying the long-term (i.e., carcinogenic) effects of foam exposures on firefighters. A summary of the international and national regulations, advisories, and guidelines is available at: https://www.atsdr.cdc.gov/toxprofiles/tp200-c7.pdf. The Centers for Disease Control and Prevention (CDC) have also conducted research on exposures and ailments and have posted a significant amount of information and guidance on their website: https://www.cdc.gov/biomonitoring/PFAS_FactSheet.html. The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) table is outdated and contains only limited information on PFAS exposures (if any). However, the OSHA webpage that discusses these permissible exposure limits (https://www.osha.gov/annotated-pels) provides links to state specific OSHA websites, the National Institute for Occupational Safety and Health (NIOSH) website and American Conference of Governmental Industrial Hygienists (ACGIH) website.

When reviewing PFAS exposure thresholds, PFAS Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs) can be considered. These are health-based values published by ACGIH and are not intended to be used as legal standards. ACGIH is a private, not-for-profit, nongovernmental corporation that develops recommendations or guidelines to assist in the control of occupational health hazards. TLVs refer to airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse effects. BEIs are guidance values for assessing biological monitoring results – concentrations of chemicals in biological media (e.g., blood, urine). BEIs® represent the levels of determinants that are most likely to be observed in specimens collected from healthy workers who have been exposed to chemicals in the same extent as workers with inhalation exposure at the TLV. The ACGIH TLVs are widely recognized as authoritative and are required to be included on safety data sheets by the OSHA Hazard Communication Standard.

Most of this health hazard information is explained in detail under the "Health Effects Tab" on the Interstate Technology and Regulatory Council (ITRC) website: https://pfas-1.itrcweb.org/ - https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas/.

During the roadmap workshop conducted in October, Shalene Thomas, of Wood provided an exceptional overview of the risks of PFAS exposures. The presentation titled "Science of PFAS Environmental and Health and Safety Risks Overview" provided a systematic approach for identifying the hazard, the exposure pathways, dosage and resulting risk. The presentation is available at the following link: www.nfpa.org/foamroadmap

Firefighters should attempt to minimize all types of PFAS exposures using proper safety equipment (for exposure prevention). In addition, if exposure, immediate action should be taken to minimize the dosage and remediate the continued exposures. A high-level summary of the exposure type, prevention and first aid are shown in Figure 8.0-1 below.

Exposures / Prevention / First Aid

Exposure	Prevention	First Aid
Dermal / Skin	Protective gloves when handling concentrate Firefighter PPE when in use	Wash skin with soap and water. Get medical attention if irritation develops and persists.
Eye	Safety glasses when handling concentrate Eye Protection in combination with breathing protection when in use (Firefighter PPE).	Rinse thoroughly with plenty of water for at least 15 minutes, lifting lower and upper eyelids.
Inhalation	Respirators when handling Eye Protection in combination with breathing protection when in use (Firefighter PPE).	Remove to fresh air. If breathing is difficult, give oxygen. (Get medical attention immediately if symptoms occur.).
Ingestion	Do not eat, drink, or smoke while working with concentrate or solution. Wash hands when complete.	Rinse mouth. Do not induce vomiting without medical advice. If swallowed, call a poison control center or physician immediately.

Figure 8.0-1 Exposures / Prevention / First Aid

It is recommended that firefighters (and other emergency response personal) wear proper personal protective equipment (PPE) when there is a risk of exposure to AFFF. This equipment should be properly fitted, worn, maintained and ultimately decontaminated after exposure to AFFF. Personnel should use self-contained breathing apparatus of positive pressure-supplied air respirators during handling, mixing, application or immediate clean-up of AFFF. In addition, skin should be covered with proper water-resistant clothing and gloves to avoid dermal contact with AFFF. AFFF can be a skin irritant on exposure. During standard fire operations, firefighters should wear turnout gear per specific department requirements. First responders should also follow best hygiene practices to reduce PFAS exposure. Firefighters should wash hands or other exposed skin after using AFFF reduce irritation. Firefighters should also wash hands prior to eating or smoking to prevent accidental ingestion of PFAS.

After exposure to AFFF, PPE should be decontaminated to reduce potential exposures to PFAS. PPE should be removed and safely stored before being cleaned or laundered after AFFF exposure. Additional guidance for PPE decontamination is provided in NFPA 1851: Selection, Care and Maintenance of Protective Ensembles for Structural Firefighting and Proximity Firefighting.

There may also be potential environmental and health concerns associated with the new fluorine free products (i.e., FFFs). As a starting point, it needs to be understood that the elimination of PFAS and/or fluorine from the product/foam does not address all the potential health and environmental hazards (only one family of chemicals). In the past, most environmental and health assessments were very high-level and only based on the information provided in the MSDS/SDS which has been shown to be inadequate. However, although the information on the MSDS/SDS is limited in nature, they still provide some pertinent information and should be kept available for the foam products on hand.

The fire protection industry is working with environmental and health groups to develop a quasi-standard approach for assessing environmental and health concerns associated with the new FF products (i.e., FFFs). Unfortunately, the development of such a standardized approach is still in its infancy. Most assessments and approaches developed to date consist of comparing the list of chemicals in the foam concentrate to standard databases of chemicals that are known to be health hazards (i.e., carcinogens) and/or are known to have ecotoxicity issues. These assessments are typically based on composition data provided by the manufacturer which is, in only a limited number of scenarios, ever empirically/analytically verified. Two such assessments are GreenScreen (https://www.greenscreenchemicals.org/) and the US EPA's Safer Choice (https://www.epa.gov/saferchoice).

GreenScreen has become a standard for evaluating these products (i.e., FFFs). GreenScreen is comprised of three main steps: assess and classify hazards, assign a benchmark score, and make informed decisions. Ultimately, the product will receive a rating of gold, silver or bronze. Most FFFs that have been assessed by GreenScreen have received bronze ratings. It is understood that the "foamability" of these products (which is the characteristic that makes them effective) creates a hazard to aquatic life which explains the lower rating.

The EPA's Safer Choice is gaining traction and will most likely become the default standard for FFFs here in the United States. Safer Choice is like the GreenScreen analysis. Each chemical ingredient in a formulation is evaluated against a Master and Functional-Class Criteria document, as appropriate. These documents define the characteristics and toxicity thresholds for ingredients that are acceptable in Safer Choice products. The criteria are based on EPA expertise in evaluating the physical and toxicological properties of chemicals, and while they incorporate authoritative lists of chemicals of concern, they go far beyond these lists. Safer Choice applies the criteria using EPA research and analytical methods to ensure that Safer Choice products contain only the safest possible ingredients. All criteria documents are part of the Safer Choice Standard.

Since there are not any widely enforced specific requirements on the health and environmental hazards of FFFs (other than possibly PFAS or Fluorine content), it is typically left to the foam manufacturer to have the product assessed. In future, this may change, and a list of the various certified products may become available. Until then, the end user will need to ask the manufacturer(s) for these types of certifications.

9. POST FIRE / POST DISCHARGE CLEANUP AND DOCUMENTATION (ANNEX H)

Annex H addresses the short-term actions to manage, contain and collect foam products (i.e., AFFF) and fuel from recent discharge events. After a live fire or discharge scenario, cleanup should start as soon as possible after the incident and the site is safe to enter to reduce potential ground contamination from PFAS-containing wastes. It is important to note that the previous recommended practice of dilution and release to the environment and/or wastewater treatment systems are obsolete and unacceptable for fluorinated foams (as well as for these new FFFs until determined elsewise).

The annex does not provide guidance for cleanup and remediation of contaminated water, soil or other environmental media. Individual State environmental agencies set required cleanup goals across a variety of scenarios. Multiple removal and destruction processes are available with varying efficacy, with more in development through multiple Department of Defense partners and is outside the scope of responsibilities for the first responder community.

With respect to the first responders, in an emergency fire event, foam solution and fuel should be contained within the area of origin as soon as conditions permit. Best practices are to block sewer drains and divert the foam and fuel to an area for containment, set up portable dikes for land-based applications and use portable booms for temporary containment in marine-based operations. It is also recommended that users document their foam usage to help establish the potential extent of release or contamination in the environment. First responders should collect information regarding the emergency event itself (size, fuel type, duration, etc.), as well as information about the foam product used. This should include volume of AFFF discharged, its concentration, product information (and potentially SDS/ingredient lists if available) and discharge location information. This can be used to inform State regulators, environmental remediation managers or even insurance companies about the nature of the release.

Due to AFFF's increasing restrictions and regulations, documentation is often required for military and state applications of foam discharge, which includes both accidental and intentional usage. See local and statewide regulation to determine required reporting for any release of AFFF. This is primarily reporting to State environmental agencies with details specific to release (intentional or through a spill) for any AFFF. Additional guidance is being developed for DoD for reporting release of AFFF.

10. WORKSHOP SUMMARY (ANNEX I)

A three-day virtual workshop was held on October 12-14 (2021). The purpose of the workshop was to:

- Review the current information/knowledge level on various pertinent topics;
- Stimulate cross dialogue between ongoing research efforts;
- Facilitate discussion to receive commentary from fire service representatives and industrial fire brigade subject matter experts to improve project deliverables;
- Gather information to help develop the strategic roadmap for fire service during this foam technology transition; and
- Identify knowledge gaps and future research required to assist first responders going forward.

The workshop included 27 presentations and had 509 individuals registered from 49 countries. Each day of the workshop focused on a specific topic and included a morning of presentations followed by afternoon discussion group sessions. The various presentations given during the workshop can be viewed by clicking on the link provided on the program's website: www.nfpa.org/foamroadmap.

A PDF of the workshop proceedings and the slides for each presentation are available at the following link:

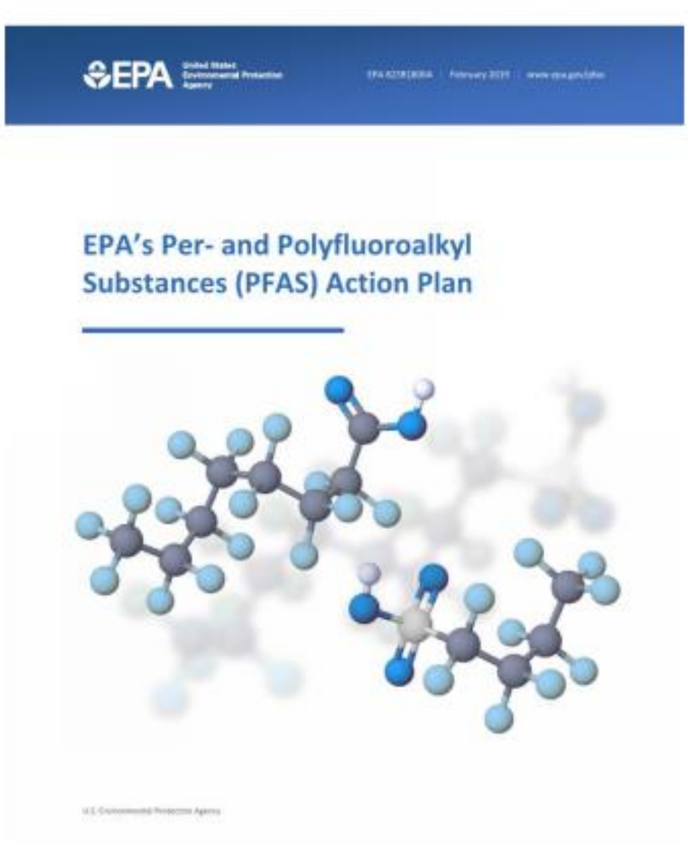
https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Current-projects/Foams/FoamWorkshopProceedingsAppendixA.ashx.

Additional information on the workshop is provided in Annex I.

11. POSTER AND PAMPHLET (ANNEX J)

Project Website: www.nfpa.org/foamroadmap

Firefighting Foams: Fire Service Roadmap



Reference: US Environmental Protection Agency.

Annex A Regulatory Landscape

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A.1. INTRODUCTION TO THE REGULATORY LANDSCAPE

The production, use, release, and disposal of AFFF is regulated by several Federal, State and local environmental and safety regulations. Legacy AFFF required fluorinated surfactants based on per- and poly-fluoroalkyl substances (PFAS) that are being increasingly regulated, restricted or banned domestically and internationally. Regulations can restrict PFAS chemicals in commerce, limit PFAS released to the environment or in drinking water or ban the use of PFAS-containing AFFF. Regulations are changing at a rapid pace and are not consistent from state to state; however, it is not necessary for individuals to track all these changes on their own. Organizations like the Interstate Technology and Regulatory Council (ITRC) are developing a suite of resources to track changing regulation associated with PFAS and AFFF across the U.S. and international regulatory agencies. The issues and regulations associated with AFFF and the changes in the environmental/use landscape are well documented in the following link - https://pfas-1.itrcweb.org/. The U.S. Fire Administration has also established a website/blog with the most up to date information: https://www.usfa.fema.gov/blog/ig-090221-2.html

This annex will provide a high-level summary of existing domestic regulation for PFAS and AFFF. For the most up to date information, contact your local environmental protection agency and/or by contacting the local/state fire marshal's office.

A.2. FEDERAL AGENCY POLICY

In recent years, Federal and State authorities have implemented health and environmental regulatory actions for PFAS and PFAS-containing AFFF. These regulations could potentially impact the production, distribution, use and disposal of legacy AFFF. In December 2019, Congress passed the FY20 National Defense Authorization Act (NDAA), which prohibits uncontrolled release of AFFF at military installations except in emergency response or in training or testing if complete containment, capture and proper disposal is in place. This also required DoD to phase out the use of PFAS-containing AFFF at military installations by 2024 (with tightly limited extensions totaling up to 2 years) for all shore-based applications. This specifically provided an exemption for shipboard use solely onboard ocean-going vessels. The Department of Defense (DoD) is required to publish a revised specification for AFFF (e.g., updates to MIL-PRF-24385, which is the predominant AFFF specification used by DoD, the Federal Aviation Administration (FAA) and multiple industry partners). Changes to MIL-PRF-24385, or publication of an alternate fluorine-free foam specification, will have wide-reaching impacts on the firefighting community. The Congressionally mandated schedule for transition is outlined below.

- January 31, 2023: Navy will publish a specification for fluorine-free fire-fighting agent
- October 1, 2023: DoD will ensure that the agent is available for use by qualifying FFF and populating the Qualified Product List
- October 1, 2023: DoD will ensure that no funding is authorized to procure foams that contain in excess of 1 part per billion ppb PFAS
- October 1, 2024: Fluorinated AFFF will be prohibited for use at any military installation

Subsequent NDAAs have continued this proposed restriction on PFAS-containing AFFF, while also requiring that EPA take action to regulate specific PFAS and increase reporting requirements for AFFF releases. It is anticipated that the EPA could use a variety of mandates to severely restrict the continued production and use of PFAS-containing AFFF outside of the military specification. The FY22 NDAA also set a temporary moratorium on incineration of AFFF, and other materials contaminated with PFAS pending additional EPA guidance.

The FAA previously required that all Certificated Part 139 airports use MIL-PRF-24385 qualified AFFF for firefighting operations. The FAA Reauthorization Act of 2018 stated that the FAA could not require the use of fluorinated surfactants to meet the MIL-PRF-24385 fire performance requirements after Oct 2021. Airports Council International – North America determined that continued use of PFAS-containing foams will extend past the mandated date pending further evaluation of PFFs and updates to the DoD PFAS-free specification. FAA transition to PFF will most likely mirror DoD transition.

A.3. FEDERAL ENVIRONMENTAL REGULATION

There are a number of federal environmental regulations that potentially apply to the production, sale, release and disposal of PFAS and PFAS-containing products. The primary regulations potentially restricting PFAS or AFFF include the Safe Drinking Water Act (SDWA), Toxic Substances Control Act (TSCA), Resource Conservation and Recovery Act (RCRA), Clean Water Act (CWA), Clean Air Act (CAA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Most of these can be downloaded from the EPA's website: https://www.epa.gov/laws-regulations.

Currently, there are no federal laws that prohibit the use of existing stocks of legacy AFFF. However, the EPA developed a PFAS Action Plan that will evaluate future designation of specific PFAS (perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA)) as "hazardous substances" for further regulation.

The SDWA is used to establish Maximum Contaminant Levels (MCLs) in the public water system. The EPA has not established formal MCLs for PFAS but has established non-enforceable drinking water health advisory levels for PFOS and PFOA to be 70 parts per trillion. They are taking action to set actionable MCLs for PFOS and PFOA based on release of final regulatory determinations. This final determination will enable the EPA to implement a National Primary Drinking Water Regulation (NPDWR) for these two PFAS chemicals. EPA is considering the regulation of additional PFAS chemicals, including an additional 29 new PFAS substances in the fifth SDWA-directed review under the Unregulated Contaminant Monitoring Rule (UCMR 5). If this rule is formally passed, public water systems exceeding a certain size will be required to collect and provide data that will serve potential SDWA actions and regulations.

The EPA uses the TSCA to restrict materials in commerce and conduct risk assessments for individual compounds. EPA published multiple Significant New Use Rules (SNURs) to require reporting, monitoring, testing of PFAS. The first SNUR, published in 2002, involved 13 PFAS chemicals that were identified and included in the voluntary phase-out of PFOS by 3M. Any uses of these chemicals, either from future manufacturing or importation, require prior notice and review by the EPA unless allowed specifically by the SNUR for limited, and highly technical uses with no available alternatives. An EPA-proposed SNUR from 2015 would require manufactures and importers of PFOS- and PFOA-containing products to notify the EPA at least 90 days prior to manufacturing, processing or importing of such products for evaluation. A final rule was passed in 2020 that finalized amendments to the 2015 SNUR; an amendment for perfluoroalkyl sulfonate chemical substances and an amendment to no longer allow the import of LCPFAC chemical substances to the United States without EPA review. In 2021, EPA released a final guidance document that clarifies which imported articles are covered by the 2020 final SNUR. In total, over 300 PFAS chemicals have been reported to EPA and listed in the public interim report.

The CWA regulates the discharge of pollutants to the waters of the U.S. This establishes permitting for point sources through the National Pollution Discharge Elimination System (NPDES) and Spill Prevention, Control and Countermeasure (SPCC) to set spill prevention and mitigation plans. CWA had been used to restrict PFAS and/or AFFF released to the environment.

CERCLA, also known as Superfund, provides a broad Federal authority to respond to releases or potential releases of hazardous substances that pose a threat to public or environmental health. Any discharge of foam containing PFAS to public waters can be considered a release of a “pollutant or contaminant” under CERCLA and therefore subject to remediation requirements. CERCLA does not regulate any chemical-specific cleanup standards but does requires response actions to protect public health and the environment as well as complying with applicable federal laws and regulations. In December 2019, the EPA released Interim Recommendations for addressing groundwater contaminated with PFOA and PFOS to be used at sites under federal cleanup programs. The Recommendations list a screening level of 40 ppt to determine if PFOS/PFOA are present and require further remediation and set an advisory level of 70 ppt as the preliminary remediation goal for contaminated groundwater. In January 2021, the EPA issued an early draft of an advance notice of proposed rulemaking that is seeking comment on future regulations for PFOA and PFOS under CERCLA and the Resource Conservation and Recovery Act (RCRA). This advance notice seeks comment on whether the EPA should designate PFOA and PFOS as hazardous substances under CERCLA, and hazardous wastes under RCRA. Currently, no PFAS are designated as hazardous substances.

The Resource Conservation and Recovery Act (RCRA) is utilized by the EPA to regulate hazardous waste throughout its lifecycle, from generation through disposal. No PFAS have been formally listed as hazardous waste under RCRA, but the January 2021 advance notice seeks to recognize PFOA and PFOS as hazardous waste. If designated, the EPA would be able to regulate generation, transportation, treatment, storage, and disposal of PFAS-containing substances. RCRA can require clean-up of existing facilities in the event of a release.

The Clean Air Act (CAA) is used to regulate toxic air pollutants. The CAA does not currently regulate PFAS, but the EPA has been evaluating requiring phase-outs of PFAS if feasible and effective alternatives exist.

The EPA’s Strategic Roadmap: EPA’s Commitment to Action 2021-2024 is available at the following website:

https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

A.4. STATE REGULATIONS

Multiple states have taken a proactive approach to pass their own regulations or health advisories to restrict the use of AFFF and PFAS in other products. This is a rapidly changing situation, with hundreds of proposed regulations being published across the country over the last few years. These will vary from state to state, but as a general trend, they are requiring additional reporting or restrictions for training with and use of PFAS containing AFFF, strict MCLs for individual PFAS, disposal requirements and clean-up of existing PFAS contamination. At least 15 states (as of the end of 2021) have passed regulations to ban the use of PFAS-containing AFFF (outside of FAA and DoD installations) with more pending legislation. States have passed additional regulation for PFAS in firefighting PPE as well. Some states have also passed prohibitions on incineration of PFAS-contaminated wastewater/rinsate, including AFFF concentrate. Multiple states are developing or already established legacy AFFF take-back programs to collect and destroy PFAS-containing foams from municipal and city fire departments. The most up-to-date information on individual state regulations is available on the ITRC website: https://pfas-1.itrcweb.org/ and/or on the State's EPA website.

A.5. PRE-EMPTIVE TRANSITION /REQUIRED TRANSITION

Individual organizations will need to make an informed decision about transitioning to FFF and disposing of legacy AFFF. In some cases, State legislation will set a clear timeline for this transition (e.g., California regulations went into effect on January 1, 2022). In other cases, organizations may consider a preemptive transition ahead of potential Federal or State regulation. For agencies that require "MilSpec" foams (MIL-PRF-24385), they will have to decide if they can accept different foam qualifications or wait for final publication of the revised specification.

Firefighting Foams: Fire Service Roadmap

Annex B
Foam Tutorial

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B.1. INTRODUCTION TO FIREFIGHTING FOAMS

This roadmap program focuses primarily on the application of low expansion foams (i.e., foam volume to solution volume ratios of ≤20:1, but normally <10:1) in combating liquid fuel fires (i.e., Class B fires). Some discussion is also provided on products being marketed as “universal agents” that can be used to extinguish both Class A fires (ordinary combustibles) as well as Class B fires (liquid fuel).

Firefighting foam consists of air-filled bubbles formed from aqueous solutions. The solutions are created by mixing a foam concentrate with water in the appropriate proportions (typically 1, 3, or 6 percent concentrate to water). The solution is then aerated to form a bubble structure. Because the aerated foam is lighter than flammable or combustible liquids, it floats on the fuel surface. The floating foam produces a layer of aqueous agent, which suppresses and prevents combustion by containing the fuel vapor at the fuel surface and preventing air from mixing with it. If the entire surface is covered with an adequate amount of foam, the fuel vapor will be completely separated from air, and the fire will be extinguished. Low-expansion foams are quite effective on two-dimensional (pool) flammable and combustible liquid fires, but not particularly effective on three-dimensional flowing fuel fires. This is particularly true of three-dimensional fires involving low flashpoint fuels. Typically, an auxiliary agent, such as dry chemical, is used with foam where a three-dimensional fire (running fuel or pressurized spray) is anticipated.

Some legacy foams, notably those that are protein-based, form thick, viscous foam blankets on liquid hydrocarbon fuel surfaces. Other foams, such as AFFF form both a bubble blanket and a film on the fuel surface providing two mechanisms to contain the fuel vapors. These film-formers are much less viscous and spread rapidly on the fuel surface.

The new fluorine-free foams are similar to the basic legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors to extinguish the fire (i.e., fluorine-free foams typically do not produce a surfactant film on the fuel surface like AFFF). As a result, air-aspirating discharge devices may be required to optimize the capabilities of these products. There are a few fluorine-free foams that are advertised as film formers, but the degree of film formation is inadequate to increase the capabilities of the product. There have also been several studies conducted recently looking at Compressed Air Foam Systems (CAFSs) to enhance the capabilities of these products. As a short explanation, a CAFS incorporates a mixing/aspiration chamber in the pipe network, where air is injected and mixed into the solution prior to the discharge device. Additional information on the capabilities of these products is provided in Annex C.

Many of the commercially available fluorine-free foams have been tested to, and or listed/approved to, the legacy foam test protocols. These include but are not limited to; Underwriters Laboratories (UL), Factory Mutual (FM), European Standards (abbreviated EN), LASTFIRE and International Civil Aviation Organization (ICAO) standards.

Foams have been developed almost entirely from experimental work. Although many of the technologies are rather mature, no fundamental explanations of foam extinguishment performance have been developed based on first principles. As a result, the fire protection industry relies heavily on the approval tests for defining the capabilities of the foam as well as the extrapolation of these test results to actual applications by applying factors of safety to the test results. The following sections will provide a review of the important parameters associated with foam agents, test methods used to evaluate foams, and relevant data in the literature that can be used to make informed decisions on fluorine-free foam selection and system design parameters. Both the NFPA and SFPE Handbook chapters on foams are also good references and provide additional detail on many of the following topics.

NFPA Handbook (Foam Chapter) – https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/Handbooks.

SFPE Handbook (Foam Chapter) - https://www.sfpe.org/standards-guides/sfpehandbook

B.1.1. TERMINOLOGY

AFFF contains a fluorinated, film forming surfactant (per- and poly- fluoroalkyl substances (PFAS)) to seal the fuel surface during suppression/extinguishment. In the early 2000s, the scientific and regulatory communities developed an increased understanding of the potential environment, safety and occupational health risks associated with continued use of certain PFAS, which has resulted in evolving, increasingly strict regulations at the federal, state, local and international levels. The historic longer chain (C8) surfactants (i.e., perfluoro octane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)) were phased out of production in 2002 and replaced with shorter C6 chain PFAS. However, these shorter chain molecules are now the focus of rapidly evolving regulations.

During this timeframe, the fire protection industry (i.e., foam manufacturers) began to develop and market new fluorine-free formulations. These new foams were labeled by the manufacturers and marketed as Fluorine-Free Foams (FFFs). In addition, there are a number of products referred to as “wetting agents” that are being developed and marketed as fluorine-free AFFF alternatives. As a point of clarification, it is generally understood that fluorine-free is synonymous with the term PFAS-free.

During this evolution, various industries have developed their own nomenclature for these products. They were initially referred to by the fire protection industry as “Fluorine-Free Foams” and given the following acronyms: FFF, 3F, F3, and FFreeF. The US DoD refers to them as FFF (F3) as well as “PFAS-Free Foams” (PFF). Underwriters Laboratories groups these alternatives under “Synthetic Foams”. NFPA 11, Standard for Low, Medium and High Expansion Foam refers to these products as “Synthetic Fluorine Free Foams” (SFFF, and also SF3). Lastly, NFPA 403 / 460, Standards for Aircraft Rescue and Fire-Fighting Services at Airports refer to these products as “Fluorine Free Synthetic Foams” (FFSF). In any case, all of these terms are used to describe the same group of products.

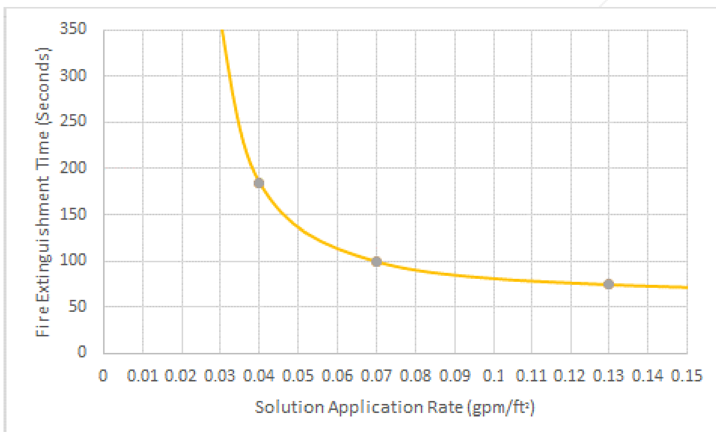
B.2. PERFORMANCE PARAMETERS AND TYPICAL TEST COMPONENTS

There are three main parameters used to define foam performance. These include control and extinguishment, burnback protection and vapor suppression.

The firefighting capabilities (i.e., control and extinguishment times) of foam extinguishing agents typically follow the trends described by an "L Curve". The "L Curve" is a plot of the extinguishment time (seconds) on the Y-axis and the foam application rate (gpm/ft^2) on the X-axis. An example L curve for AFFF is shown in Figure B.2.0-1.

The shape of the curve is directly associated with the extinguishment mechanisms. As a simple explanation of the curve (moving from right to left on the figure), when the foam is applied at a high rate, the fire is quickly controlled and extinguished. This is illustrated by the right side of the plot where the performance levels off even though the foam is being applied at higher rates. As the application rate is reduced, the times tend to increase as the rate approaches a critical value. Specifically, the times asymptotically approach the rate where the foam is being consumed by the fire as fast as it is being applied. In Figure B.2.0-1, this asymptotic value is approximately 0.03 gpm/ft^2. Below this rate, the foam has virtually no effect on the fire.

Terms & Data



Application Rate: Foam solution flow rate per unit area – gpm/ft^2

Extinguishment Application Density: Foam solution quantity required to extinguish the fire – gal/ft^2

Figure B.2.0-1 General Capabilities and Associated Terms

Foams are typically tested and approved at application rates around the "knee" of the curve (i.e., 0.04 gpm/ft^2 for AFFF). The design and deployment values are typically much higher and lie in the flat region to the right side of the curve (i.e., 0.10-0.16 gpm/ft^2 for AFFF). Most factors of safety between the test and deployment values are in the 2-4 range but are never less than 1.67. The term extinguishment application density is often used to describe the capabilities of a specific product or the results of a test. This value is the foam application rate in gallons per minute per square foot of fire area (gpm/ft^2) multiplied by the extinguishment time in minutes. The units of extinguishment application density are in gallons per square foot (gal/ft^2).

In addition to the firefighting capabilities, foam performance is also expressed in terms of burnback protection and vapor suppression. These terms are somewhat synonymous and provide an indication of the robustness of the foam blanket which is highly desired in petroleum industry type applications as well as fuel spill scenarios where the foam is used to contain the fuel vapors and prevent ignition. Burnback protection is also desirable (but to a lesser degree) in Aircraft Rescue and Fire-Fighting (ARFF) applications where fire responders and passenger evacuation can disrupt the blanket during rescue operations.

Most burnback assessments include both vapor suppression (i.e., a burning torch is passed a few inches above the foam blanket) as well as a limit on the time required from sustained burning in the pan after the test until the fire has spread to a specified size (e.g., typ. 20-25%).

Most of the burnback protection and vapor suppression capabilities provided by AFFF are related to the film formation. As a result, most AFFFs are formulated with faster drainage times (relatively speaking) than other foam types. Since the fluorine-free foams rely solely on the foam blanket, they are “foamier” and drain significantly slower that other foam types.

B.2.1. General Test Protocol Components

Most protocols have three to four basic components that combine to identify the capabilities of the foam in a specific application. These are shown in Figure B.2.1-1 and include a liquid fuel fire in a pan of a specific size and shape. The fuel and the fire preburn time is defined based on the hazards of the end-use scenario. After the preburn time is complete, foam solution is applied to the fuel surface either through a fixed nozzle system or manually applied by a firefighter. In either case, the discharge device is designed to produce foam with roughly the same characteristics (i.e., level of aspiration/expansion and drainage time) as the actual devices used in the application. Once the fire has been extinguished, some test protocols (i.e., the ones used by the petroleum industry) have a vapor suppression assessment phase where a lit torch is passed a few inches above the foam blanket to ensure the vapors are being contained by the foam. The final phase includes an assessment of the foam’s ability to resist burnback by igniting a small area of the fuel surface (by either removing some of the foam or placing a burning pan of liquid fuel into the larger pan) and measuring the time for the fire to grow to a specific size (percentage of the total pan area).

Typical Fire Test Components

Liquid Pool Fire with Defined Preburn

Foam Application

Vapor Suppression

Burnback

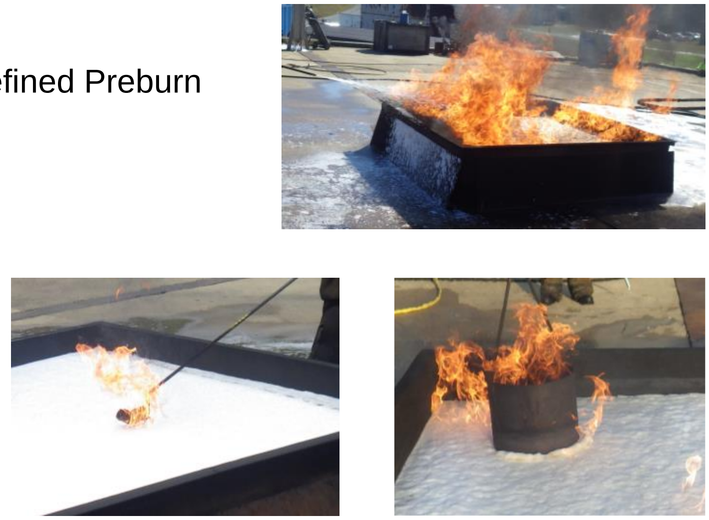


Figure B.2.1-1 Typical Foam Approval Test Components

Although the test protocols have similar components, the test parameters tend to vary depending on the industry and the hazards being protected as shown in Figure B.2.1-2. This may explain some of the differences between the approval test parameters (but not all) which some refer to as “designer foams.”

Typical Fire Test Components & Procedures

Pan/Pool Fires (round or square pans / various free-boards)
Fuel Types (gasoline, heptane, kerosene based, other (i.e., polar solvents))
Preburn Times (10 seconds to 3 minutes)
Agent Application (fixed system or manual application)
Application Rates (0.04 to 0.2 gpm/ft^2)
Extinguishment (30 seconds to 5 minutes)
Vapor Suppression (0-30 minutes – most in the 10-15 minute range)
Burnback (5-6 minutes for between 20-25% of pan area)

Firefighting foam requirements and design parameters are somewhat confusing

Figure B.2.1-2 Industry Segment MCEs

As an example of the differences, some of the fire pans are square while others are round. Some have 4-6 in. sides while others have up to 36 in. sides. The test fuels vary between the industries with the most predominant test fuel being Heptane which is meant to serve as a surrogate for all hydrocarbon fuels and is a specific chemical rather than a less defined mixture of chemicals such as “gasoline” or “kerosene”. Preburn times vary from 10 seconds to as long as 3 minutes. Foam is applied using a fixed system for some protocols but manually fought for others. Foam application rates vary from 0.04 gpm/ft^2 to as high as 0.2 gpm/ft^2. Extinguishment time requirements vary from 30 seconds to up to 5 minutes and burnback scenario requirements vary significantly between protocols.

In closing-out this discussion of test parameters, most of these variations are directly relate to the hazards of the industry in which the protocol was developed for. With that said, it needs to be noted that these approval tests are not designed to simulate actual full-scale fire scenarios but rather to provide a means to assess the capabilities of these products on an affordable and reproducible scale using many of the parameters/conditions that makeup the industries’ Maximum Credible Event (MCE). This is illustrated in Figure B.2.1-3

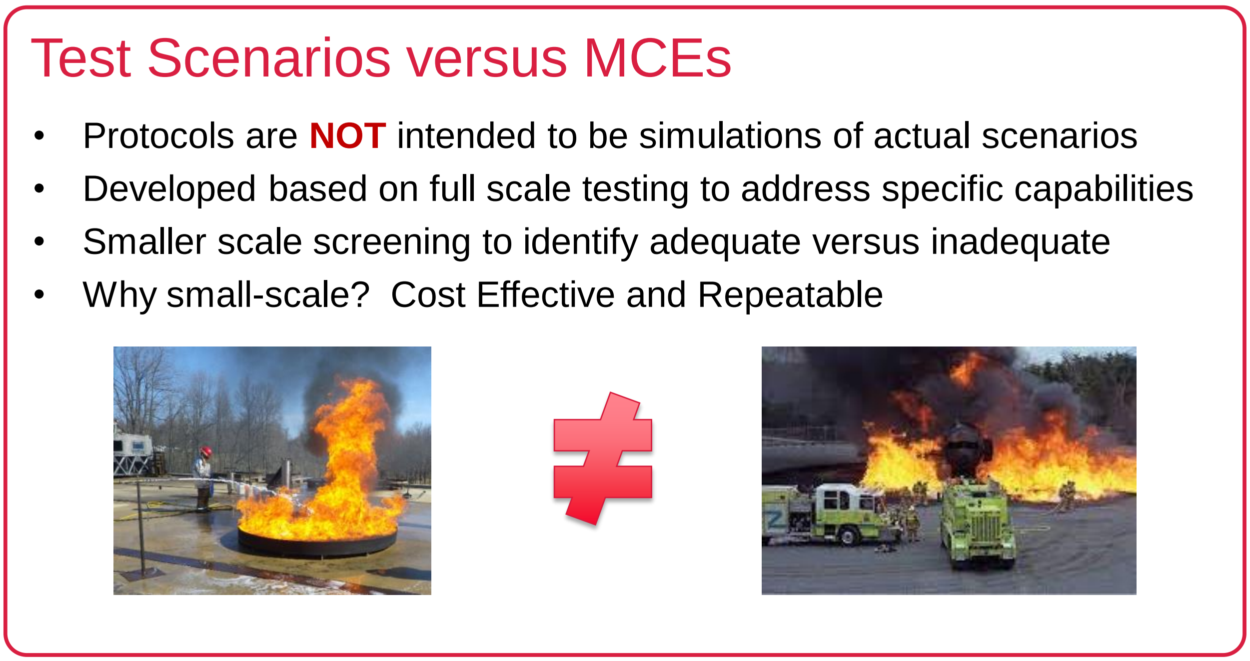


Figure B.2.1-3 Industry Segment MCEs

B.3. FIREFIGHTING FOAM USER SEGMENTS/NEEDS

There are four general user segments of the fire service community that use foam firefighting products: Military, Aviation, Petroleum Industry and Municipal Fire Departments. The hazards and required foam product performance are in most respects, specific to the user segments. Specifically, the foam performance requirements are defined based on an agreed-upon/selected Design Fire (DF) or Maximum Credible Event (MCE).

For the DoD, the design fire includes an aircraft rescue and firefighting (ARFF) scenario that includes a fuel spill under the aircraft that exposes the weapons to fire. This fire needs to be quickly controlled and extinguished to prevent ordnance cookoff. The aviation industry has a similar scenario except the hazards are associated with the burn-through of the fuselage that jeopardizes the occupants of the aircraft. Both the DoD and aviation industry scenarios have well defined fuel types (i.e., kerosene-based aviation fuels) allow foams to be designed specifically for hydrocarbon-based hazards. The primary hazard for the petroleum industry is a large tank fire that contains thousands of gallons of liquid fuel (sometimes referred to as "fuel in depth"). In most scenarios, these are hydrocarbon-based fuels but there are limited scenarios where polar solvents and/or other types of products may be present. Due to this potential range of fuels/hazards, specific foam types may be required to protect specific hazards (e.g., Alcohol Resistant (AR) foams will be required to protect against polar solvents). The "primary" hazards for a municipal fire department are less defined and cover a wider range but smaller versions of the scenarios mentioned previously. One MCE would include an overturned tractor trailer carrying gasoline that is leaking from the truck and catches fire. Photographs of these four MCE are shown in Figure B.3.0-1 and will be discussed in detail in the following sections.

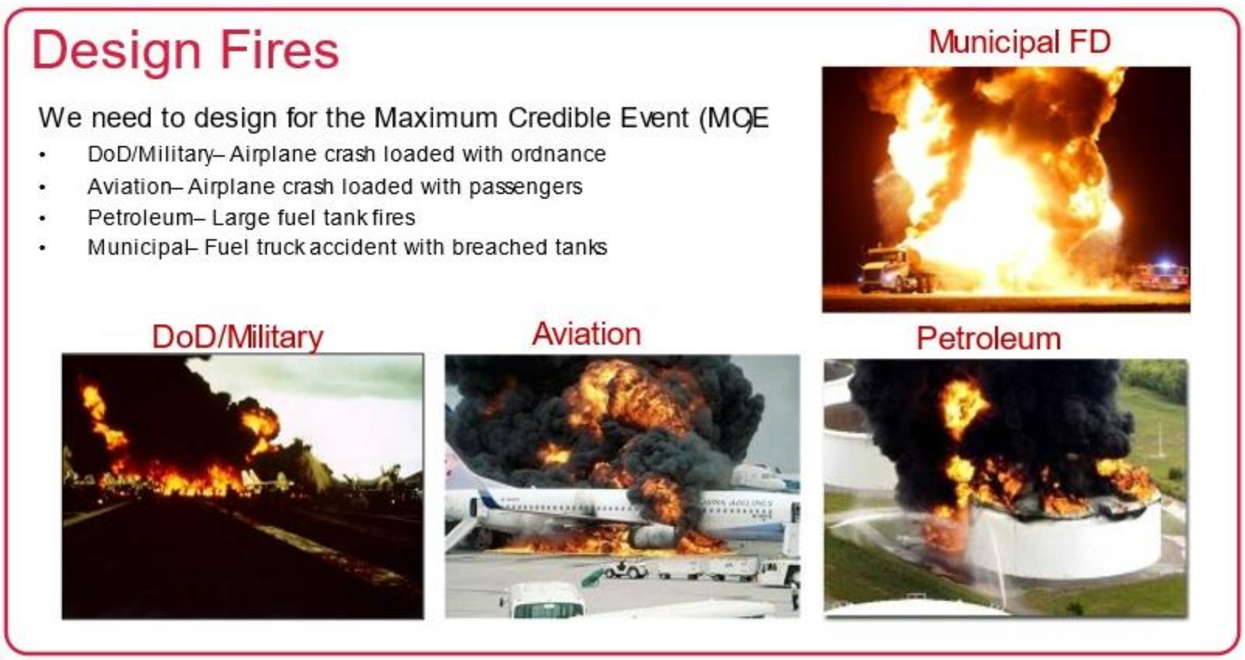


Figure B.3.0-1 Industry Segment MCEs

B.3.1. MILITARY APPLICATIONS

Military personnel (i.e., damage control parties, ARFF and base fire departments) need to respond to aircraft incidents (on land and at sea) that could become catastrophic due to the potential for fuel spill fire exposure to munitions/ordnance. The fire scenario involves thin layers of potentially flowing fuel and short preburn times (i.e., measured in minutes). The initial attack on these fires needs to be made within less than a minute of the start of the incident due to the potential for ordnance cookoff. Desired foam characteristics include very fast knockdown/extinguishment and enough burnback protection to rescue the pilot. In general, most foams used by the military have the fastest extinguishment times of all the available foam products. These departments/organizations have large quantities of foam concentrates and a wide variety discharge equipment and devices.

The U.S. Military Specification (MilSpec), "Military Specification – Performance Specification, Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water (MIL-PRF-24385F) - https://quicksearch.dla.mil", has been the AFFF procurement specification for the U.S. military and federal government for almost 50 years. It is important to recognize that MIL-PRF-24385F is unique in that it is a procurement specification as well as a performance specification and is, at present, the only document that governs AFFF used throughout the U.S. Military.

The U.S. Department of Defense (DoD) is under a congressional mandate to publish a new land-based fluorine-free foam military specification by January 31st, 2023, and to begin the transition to these new products later that year (i.e., October 1, 2023). This mandate is published in the FY20 National Defense Authorization Act (NDAA) – https://www.congress.gov/bill/116th-congress/senate-bill/1790/text. There is a significant amount of research being conducted by the U.S. DoD environmental groups (i.e., ESTCP and SERDP). Most of this research is available to the public at their website: https://www.serdp-estcp.org/.

B.3.2. AVIATION APPLICATIONS

Aircraft Rescue and Fire Fighting (ARFF) departments need to respond to aircraft incidents that could potentially involve large fuel spills under damaged aircraft loaded with passengers. The fire scenario involves thin layers of potentially flowing fuel and short preburn times (i.e., measured in minutes). The initial attack on these fires needs to be made within minutes of the start of the incident due to the potential for loss of life. Desired foam characteristics include fast knockdown/extinguishment and enough burnback protection to evacuate the aircraft. These departments/organizations have large quantities of foam concentrates and specialized discharge equipment including crash trucks that contain turrets, hose reels / hand lines, and potentially other agents like dry powder or gaseous streaming agents.

The aviation industry relies on a number of standards to ensure adequate response capabilities at municipal airports. These include NFPA 403/460/1900 as well as International Civil Aviation Organization (ICAO) documents/requirements. The FAA previously required that all Certificated Part 139 airports use MIL-PRF-24385 qualified AFFF for firefighting operations. The FAA Reauthorization Act of 2018 stated that the FAA could not require the use of fluorinated surfactants to meet the MIL-PRF-24385 fire performance requirements after Oct 2021. In October, the FAA released a statement saying that fluorinated surfactants are no longer required but the foams must still meet the performance requirements of the MilSpec (which none can at this time). The details of this release are available at the following site: - https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-21-01-AFFF.pdf

In addition to MilSpec foams, NFPA 403 recognizes ICAO test methods which have significantly different test parameters, including test fuel, application rate, and extinguishment density - https://www.icao.int. These test standards will be discussed later in this document. It needs to be noted that the FAA has recently completed an in-house assessment of the capabilities and limitations of FFFs to aid in developing a path forward. This research should eventually be published on their website: https://www.faa.gov/.

B.3.3. PETROLEUM INDUSTRY APPLICATIONS

Worst case industrial fire hazards/scenarios include very large fires with significant fuel depth such as storage tank fires. The fire scenario involves significant fuel quantities (i.e., fuel depths) and longer preburn times (i.e., it can hours and in any cases, days, to initiate an adequate response/turn-out). At the time of the attack, the fuel surface is likely to be boiling significantly increasing the difficulty to extinguish the fire. Many of these incidents can burn for days. Desired foam characteristics include a balance between cooling, a robust foam banket and rapid extinguishment. In general, Industrial foams tend to have slower extinguishment times but much better burnback characteristics than Aviation and Military foams. These departments/organizations have large quantities of foam concentrates and a wide variety discharge equipment and devices that are centered around medium to high flow rate master streams.

Two NFPA standards govern most of the petroleum industry hazards: NFPA 11 and NFPA 30. Both require the foams to be listed and/or approved for the use application. The two commercial standards used to obtain this listing/approval include Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates - https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL162, which is the principal test standard for the listing of foam concentrates and equipment in the United States, the European equivalent, EN 1568 "Fire Extinguishing Media – Foam Concentrates"- https://www.en-standard.eu and LASTFIRE Test Specification Rev D-APR 2015 - http://www.lastfire.co.uk. These standards are described later in this document. In addition to the listing process, the petroleum industry funds research conducted by LASTFIRE (Large Atmospheric Storage Tank (LAST) Fire) to validate the capabilities of many of these products against representative, real scale fire scenarios.

B.3.4. MUNICIPAL FIRE DEPARTMENT APPLICATIONS

The fire hazards that are mitigated by municipal fire departments are less defined and can cover a wider variety of unknown scenarios that can include a smaller subset of the hazards mentioned above. Specifically, these fires can range from small to moderate liquid fuel fires that occur at facilities, during fuel transportation mishaps and even unlikely aviation incidents. The fire scenarios typically involve smaller quantities of fuel and moderated preburn times (i.e., a typical response may be on the order of 10-15 minutes). A good quality, general purpose foam concentrate that provides decent extinguishment capabilities and burnback resistance is desired. Depending on the potential fuel types, alcohol resistant foams may be the best choice (i.e., if there is a potential fires involving polar solvents including gasoline with alcohol contents greater than 10% (E10)). These departments have limited foam supplies with primarily hand line application tools or lower volume master streams.

Foams used by municipal fire departments are not governed by a specific NFPA standard(s). The foam selection needs to be based on the anticipated needs/hazards being protected. For example, a UL 162 or EN 1568-3 listed products are more than adequate to cover the typical, smaller scale flammable liquid fire events encountered by municipal fire departments. Since many municipal fire departments provide protection of a broad spectrum of hazards, many departments select “wetting agents” or “water additives” that are designed for a range of fire types e.g., Class A, B, C and D. These types of agents are tested and approved/listed to NFPA 18, Standard on Wetting Agents and NFPA 18A, Standard on Water Additives for Fire Control and Vapor Mitigation. The advantages and disadvantages of these various products will be discussed later in this document.

B.4. FIREFIGHTING FOAM TEST METHODS / PROTOCOLS

Because a fundamental understanding of foam fire suppression has not been developed, performance of foams is measured using fire tests. The test methods used to approve foams for the user segments vary significantly with respect to fuel type, application method, application rate and performance criteria to name a few. Most of these variations are in some way attributed to the intent of the test method (i.e., the hazard being protected). As stated previously, test methods used by the military and the aviation industry typically focus more on rapid extinguishment versus burnback protection. Conversely, test methods used by the petroleum industry focus more on the development of a robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces and allow for longer extinguishment times. To achieve the desired performance objectives, different formulations are typically required for the various user segments. As a result, foams formulated to provide rapid extinguishment may have reduced burnback capabilities and vise-a-versa (foam formulated for burnback protection may have longer extinguishment times). Details of specific approval-scale tests are described in the following sections.

B.4.1. DEPARTMENT OF DEFENSE / MILITARY

The MilSpec (MIL-PRF-24385F) has been the AFFF procurement specification for the U.S. military and federal government for almost 50 years. In general, the fire performance requirements were developed around the need for extremely fast extinguishment to prevent munitions exposed to the fire from exploding. In other words, the Design Fire (DF) or Maximum Credible Event (MCE) is a large fuel spill fire that engulfs an aircraft loaded with munitions such as events that occurred on the USS Forestall in the 60’s or on the USS Nimitz in the 80’s.

The MilSpec has been the “gold standard” for approving legacy AFFF in DoD and ARFF applications and is by far, the most extensive protocol in use today. However, none of the commercially available FFFs can meet these requirements leading to the development of a new land-based specification mentioned earlier. Although the MilSpec is currently not directly applicable to FFFs a summary of the requirements is provided in the following paragraphs.

It is important to recognize that the MilSpec is unique in that it is a procurement specification as well as a performance specification. Hence, there are requirements for packaging, initial qualification inspection, and quality conformance inspection, in addition to fire performance criteria. Equipment designs unique to the military, in particular U.S. Navy ships, have impacted the development of these specification requirements (e.g., use of seawater solutions and mis-proportioning-related fire tests).

Figure B.4.1-1 summarizes the fire extinguishment and burnback resistance requirements for full-strength solutions in the MilSpec. The fire tests are conducted using 28 ft^2 and 50 ft^2 circular fire test pans with 4-inch sides using unleaded alcohol-free gasoline as the fuel.

MIL-PRF-24385F (Fed. Spec. almost 50yrs)

Procurement (fire performance, physical and chemical property requirements, environmental impact, aging, compatibility, packaging and quality control)

Summary of the U.S. Military AFFF Specification (MIL-PRF-24385F)
Key Performance Requirements

Test Parameter	Revision F
Fire extinguishment	
28 ft² fire test	
Application rate	0.071 gpm/ft²
Maximum extinguishment time	30 sec
Maximum extinguishment density	0.036 gal/ft²
50 ft² fire test	
Application rate	0.04 gpm/ft²
Minimum 40 s summation	320 sec
Maximum extinguishment time	50 sec
Maximum extinguishment density	0.033 gal/ft²
Burnback resistance	
28 ft² and 50 ft² fire tests	25% maximum at 360 sec

Figure B.4.1-1 MilSpec Fire Test Summary (Full-strength solutions)

In addition to these fire tests, there are specific requirements to conduct fire tests of the agent after it has been subjected to an accelerated aging process (simulating prolonged storage) and after intentionally mis-proportioning the concentrate with water (i.e., half-strength and quintuple-strength). There are also requirements for the foam to be compatible with dry chemical agents. Dry chemical agents are likely to be used as "secondary" agents in aviation and shipboard machinery space fires to combat three-dimensional fuel fires, where AFFF alone may have limited effectiveness. The MilSpec requires that an agent's compatibility with potassium bicarbonate dry chemical agent (PKP) be demonstrated for both extinguishment and burnback. There are also requirements for foam concentrate compatibility which is specifically unique to this protocol. These requirements were developed to allow the "topping-off" of AFFF concentrate tanks with other products on the Qualified Products List (QPL). All-in-all, there are 42 fire tests that need to be conducted to complete the qualification process.

In addition to fire performance, there are a number of physical and chemical properties evaluated during the qualification process. These include, refractive index, concentrate viscosity, pH, corrosivity, total halides/chlorides, and environmental impact. Every product that has successfully complete the MilSpec requirements is listed on the Qualified Products List QPL No. 24385. An online copy of QPL is available the Qualified Products Database (QPD) at https://assist.dla.mil.

The new land-based MilSpec (MIL-PRF-XX727) is currently being developed by the US Navy (i.e., Naval Research Laboratory (NRL) and Naval Sea Systems Command (NAVSEA)). The development is on schedule for an early 2023 release. As with the legacy MilSpec, MIL-PRF-XX727 will be owned by NAVSEA and will be conducted by NRL. The initial requirements in MIL-

PRF-XX727 will be a subset of the requirements in the legacy specification adjusted to the land-based hazards and to the capabilities of a limited number of the top performing commercially available FFFs. As an example, the new requirements will not include seawater/saltwater compatibility, nor will they include compatibility between foam concentrates. It is intended that the fire performance requirements (as well as other requirements) will evolve (become more challenging) as the FFF technology advances and becomes more mature.

B.4.2. AIRCRAFT RESCUE AND FIREFIGHTING (ARFF)

The underlying principle in aviation fire protection is to temporarily maintain the integrity of an aircraft fuselage after a mishap to allow time for the occupants (i.e., passengers and crew) to escape and/or to be rescued. As a result, the DF or MCE for the ARFF community is a large fuel spill fire that engulfs an aircraft loaded with passengers.

When an aircraft is involved in a fuel spill fire, the aluminum skin will burn through in about 1 minute. If the fuselage is intact, the sidewall insulation will maintain a survivable temperature inside the cabin until the windows melt out in approximately 3 minutes. At that time, the cabin temperature rapidly increases beyond survivable levels.

It was originally intended that aircraft rescue and firefighting (ARFF) vehicles have a goal of reaching an incident scene on the airport property in two minutes. Having reached the scene in this time frame, the agent must be applied to control a fire in 1 minute or less. The three-minute critical time for passenger safety is achieved under these circumstances. This was the basis of the original criteria in NFPA 403 Standard for Aircraft Rescue and Fire-Fighting Services at Airports. In the 2014 revision, NFPA 403 changed its ARFF response time criteria from two to three minutes, which correlates with Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) criteria. The two-minute response time is still an operational objective. As part of the NFPA consolidation effort, NFPA 403, NFPA 405, and NFPA 412 are combined in NFPA 460: Standard for Aircraft Rescue and Fire-fighting Services at Airports, Recurring Proficiency of Airport Fire Fighters, and Evaluating Aircraft Rescue and Fire-fighting Foam Equipment.

The minimum agent requirements on ARFF vehicles are established using the 1-minute critical control time plus the anticipated spill area for the largest aircraft using the airport. A "theoretical critical fire area" has been developed, based on tests, and is defined as the area adjacent to the fuselage, extending in all directions to the point beyond which a large fuel fire would not melt an aluminum fuselage regardless of the duration of the exposure. A function of the size of an aircraft, the theoretical critical fire area was amended to a "practical critical fire area" after evaluation of actual aircraft fire incidents. The practical critical area, two-thirds the size of the theoretical critical area, is widely recognized by the aviation fire safety community, including FAA, NFPA, and ICAO. The response capacity of the airport (i.e., number of vehicles, total agent capacity, total discharge rate) must be adequate to control a fire in the practical critical area within 1 minute. Vehicles must also be equipped with a secondary agent (potassium-based dry chemical or halogenated agent) for use in combating three-dimensional fuel fires.

Over the past 50 years, significant research has been conducted to identify the critical application rates required to meet the 60-second control time for various types of foam products. These rates are 0.13 gpm/ft^2 for AFFF, 0.18 gpm/ft^2 for fluoroprotein foam, and 0.20 gpm/ft^2 for protein foam. Using these rates, the practical critical fire area and the 60-second control time criteria, minimum agent quantities are established for airports serving different size aircraft. These criteria were contained in NFPA 403 (2014 edition and earlier) and the FAA Advisory Circular 150/5210-6C, “Aircraft Fire and Rescue Facilities and Extinguishing Agents – Version D.” During the 2018 revision of NFPA 403, the call-outs for fluoroprotein foam and protein foam in the requirements table were replaced with ICAO Levels B and C respectively. ICAO Level C requirements were also lumped-in with the requirements for MilSpec AFFF.

Since the MilSpec protocol was discussed previously, the following paragraphs will focus on the ICAO requirements.

The ICAO test methods have significantly different test parameters, including test fuel, application rate, and extinguishment application density as compared to the MilSpec and ranks foams based on three levels of performance: Level A, B and C. The firefight capabilities of these products increase in alphabetical order with A being the lowest performers and C being the highest performers. The test protocol is in Doc-9137-Airport Services Manual Part1 Rescue and Fire-Fighting.

Figure B.4.2-1 summarizes the ICAO test parameters for the three level of performance. The fire tests are conducted using 30 ft^2, 48 ft^2 and 79 ft^2 circular fire test pans with 8-inch sides using kerosene as the test fuel. All tests are conducted using a Uni-86, 3 gpm aspirating foam nozzle that is installed in a fixed position during the test (i.e., no manual firefighting). This nozzle flow rate corresponds to application rates of 0.10 gal/ft^2, 0.061 gal/ft^2, and 0.043 gal/ft^2 for Levels A, B and C respectively. The fires are required to be extinguished within one minute of foam discharge but fingers of flames are allowed to persist around the pan edges as long as they are extinguished by the end of the two minute discharge. There are no surface-tension, interfacial-tension, and spreading coefficient requirements in the protocol.

International Civil Aviation Organization (ICAO)

ICAO Foam Test Requirements

Fire Test Parameters/Levels	Level A	Level B	Level C
Application rate	0.10 gpm/ft^2	0.06 gpm/ft^2	0.043 gpm/ft^2
Discharge rate	3.0 gpm	3.0 gpm	3.0 gpm
Fire size (circular)	30 ft^2	48 ft^2	78 ft^2
Fuel	Kerosene	Kerosene	Kerosene
Preburn time	60 sec	60 sec	60 sec
Fire performance			
Extinguishing time *	60 sec	60 sec	60 sec
Total application time	120 sec	120 sec	120 sec
25% reignition time	≥5 min	≥5 min	≥5 min
Ext. Application Density*	0.10 gal/ft^2	0.06 gal/ft^2	0.043 gal/ft^2
Ext. Application Density (actual)	0.20 gal/ft^2	0.12 gal/ft^2	0.086 gal/ft^2

* Flickers are allowed around edges until end of discharge

Figure B.4.2-1 ICAO Foam Test Requirements

The ICAO Airport Services Guide, Part 1, “Rescue and Fire-fighting,” which tends to be the governing document for most airports outside of the US, describes the turnout requirements for protecting airports based on these performance levels like NFPA 403. Minimum usable amounts of extinguishing agents are defined based on application rates of 0.20 gpm/ft^2 for Level A, 0.13 gpm/ft^2 for Level B and 0.10 gpm/ft^2 for Level C. Consequently, the use of higher performing foams reduces the application rate and agent/water requirements for the airport. There is no publicly available database on ICAO tested and approved foams.

B.4.3. PETROLEUM INDUSTRY

The petroleum industry relies on two main commercial standards for approving foam concentrates as well as research conducted by a LASTFIRE (Large Atmospheric Storage Tank (LAST) Fire). The two commercial standards include Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates, which is the principal test standard for the listing of foam concentrates and equipment in the United States, and the European equivalent EN 1568 “Fire Extinguishing Media – Foam Concentrates”.

For tank fires, the LASTFIRE standard test specification is used by a number of oil companies as part of a detailed performance-based procurement specification. This test was developed in the1990s, originally by Mobil Research and Development Center (MRDC) recognizing that none of the available standards truly represented the special conditions of a tank fire. MRDC handed the protocol over to LASTFIRE for completion and adoption. These standards are described in the following sections.

B.4.3.1. Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates

Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates, is the principal test standard for the listing of foam concentrates and equipment in the United States -https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL162. UL 162 is unique in the fact that it effectively lists the foam as a "system" versus just a concentrate as compared to the other test standards. Test procedures outlined in this standard have been developed to evaluate specific agent/proportioner/discharge device combinations. When a foam concentrate is submitted for testing, it must be accompanied by the discharge device(s) and proportioning equipment with which it is to be listed. As a result, the listing includes all three component groups which are documented and described in the UL Fire Protection Equipment Directory now referred to as the UL Prodcut iQ™ available at the following web address: https://productiq.ulprospector.com/en.

The discharge devices included in the listings are classified as Type II, or III. Type II discharge devices gently deliver the foam onto the liquid surface resulting in minimal submergence and agitation of the fuel surface. Examples include tank wall–mounted foam chambers, and applications where foam is bounced off the wall of a tank. Type III discharge devices such as handheld nozzles provide a more forceful application of the foam onto the fuel surface. In addition to the general categories of Type II and Type III, UL 162 also include methods for sprinklers, subsurface injection, and topside discharge devices, including nozzles. Class B fire test requirements for Types II and III discharge devices and sprinklers are summarized in Figure B.4.3-1.

UL 162 Foam Equipment and Liquid Concentrates

Table 12.1
Foam application and duration to burnback ignition

Application	Foam concentrate	Fuel group	Test application density, gpm/ft²	Time of foam application, minutes	Duration until burnback ignition, minutes	Minimum design application density, gpm/ft²
1. Type III Discharge Outlets	P, FP, S, FFFP[a]	Hydrocarbon	0.06	5	15	0.16
	AFFF, FFFP[a],	Hydrocarbon	0.04	3	9	0.10
2. Type II Discharge Outlets	P, FP, S, FFFP[a]	Hydrocarbon	0.06	5	15	0.10
	AFFF, FFFP[a]	Hydrocarbon	0.04	3	9	0.10
	All	Polar	b	5	15	c
3. Foam Water Sprinklers	P, FP, S	Hydrocarbon	0.16	5	15	0.16
4. Standard Orifice Sprinkler	AFFF, FFFP	Hydrocarbon	0.10	5	15	0.16
		Polar	b	5	15	d
5. Large, nominal 17/32 in, Orifice Sprinkler	AFFF, FFFP	Hydrocarbon	0.14	5	15	0.22
		Polar	b	5	15	d

P – Protein
FP – Fluoroprotein
FFFP – Film Forming Fluoroprotein
AFFF – Aqueous Film Forming Foam
S – Synthetic

[a] Film-forming fluoroprotein is to be tested at application densities of 0.06 and 0.04 gallons per minute per square foot
[b] Application rate may vary among polar groups, as specified by the manufacturer.
[c] 0.10 or 1.67 times Test Application Rate, whichever is greater.
[d] 0.16 or 1.6 times test application rate, whichever is greater.

Source: UL 162, *Standard for Foam Equipment and Liquid Concentrates*, Feb 23, 2018. Reprinted with permission. Copyright © ULS.

Square pan 50ft²
Application rate(s) 0.04 & 0.06 gpm/ft²
Extinguishment time(s) 3 & 5 minutes
Heptane and others
Type II (gentle) Type III (forceful)
Test and design parameters
Concentrate, proportioner and discharge devices
Fire tests conducted over a range of foam qualities / aspirations
https://iq.ulprospector.com
Component performance and material tests

Type II Configuration

Type III Configuration

Figure B.4.3-1 UL 162 Fire Test Summary

The test protocol can be used to list any “type” of low expansion foam including, Aqueous Film Forming foam (AFFF), Fluoroprotein Foam (FP), Film Forming Fluoroprotein Foam (FFFP), Protein Foam (PF) and Synthetic Foams (S). The new FFFs fall under the definition of synthetic foams.

The hydrocarbon tests are conducted using commercial grade n-heptane and a 50 ft^2 square test pan with 11-inch-high sides. During the Type II tests, the nozzle is fixed in a position to spray onto a backboard located on the opposite side of the pan. During the Type III tests, the nozzle is held still spraying onto the fuel in the center of the pan until the fire is “controlled” (i.e., 90% extinguished), at which point, the firefighter is allowed to move around two side of the pan directing the foam at the burning areas.

With respect to timing, the fuel is ignited and allowed to burn for 60 seconds. Foam is then discharged for the duration specified in the figure. The foam blanket resulting from the foam discharge must spread over and completely cover the fuel surface, and the fire must be completely extinguished before the end of the foam discharge period (i.e., 3 minutes for AFFF and 5 minutes for other types of foams).

After all the foam is discharged, the foam blanket formed on top of the fuel is left undisturbed for the period specified in the figure. During this period, a lighted torch is passed approximately 1-inch above the entire foam blanket in an attempt to reignite the fuel. If the fuel reignites and continues to burn for more than 30 seconds, the test is considered to be a failure.

After the attempts to reignite the fuel with the lighted torch are completed, a 12-in. diameter section of stovepipe is lowered into the foam blanket. The portion of the foam blanket that is enclosed by the stovepipe is removed, using a ladle with as little disturbance as possible to the remaining blanket outside the stovepipe. The cleared fuel area inside the stovepipe is ignited and allowed to burn for 1 minute. The stovepipe is then slowly removed from the pan while the fuel continues to burn. After the stovepipe is removed, the foam blanket must either restrict the spread of fire for 5 minutes to an area not larger than 10 ft^2 (i.e., 20% of the pan area) or flow over and reclose the burning area. The test is conducted at the extremes of the foam quality (aspiration) produced by the listed discharge devices (i.e., the highest and lowest expansion ratios measured with the discharge devices).

As stated previously, the UL 162 listing includes the foam concentrate, proportioning device, and discharge device. The UL Fire Protection Equipment Directory must be referenced to determine with what equipment the concentrate has been tested and approved. Furthermore, UL 162 is not an agent specification; therefore, there are no requirements for physical properties, such as film formation and sealability and corrosion resistance. However, there are requirements for a positive spreading coefficient (greater than zero using cyclohexane) for film-forming foams in the standard.

The foams listed by Underwriters Laboratories (UL 162 – Standard for Foam Equipment and Liquid Concentrates) can be found on their website by searching the listed products directory using the UL Category Code – GFGV. As stated previously, FFFs would be provided on the manufacturer’s listing page as “Synthetic (S)” foams using the 2018 edition of UL 162. The next edition 2022 will list these products as Synthetic Fluorine Free Foams (SFFF), consistent with the terminology defined in NFPA 11.

In addition, prior to 2020, UL did not verify the composition claims made by the manufacturers (i.e., did not assess the fluorine content of the product) but has recently included the chemical analysis as an option for the manufacturer during the listing process.

There have been several recent studies that have shown that various blends of gasoline were extremely challenging to extinguish using these new fluorine-free formulations and that heptane was not an adequate surrogate for all hydrocarbon fuels. In fact, many of the original new formulations are listed at higher application rates for gasoline hazards than shown in the table for "hydrocarbons". As a result, a UL 162 listing, in itself, does not provide adequate information for using these products to protect gasoline hazards. Fortunately, many of the foam manufacturers are having tests conducted by UL with E15 gasoline to provide the required information.

B.4.3.2. EN 1568 Fire Extinguishing Media – Foam Concentrates

The European equivalent of UL 162 is EN 1568-3, Fire-extinguishing-media-foam-concentrates-specification-for-low-expansion-foam-concentrates-for-surface-application-to-water-immiscible-liquids - https://www.en-standard.eu. The specification includes definitions for protein, fluoroprotein, synthetic, alcohol resistant, AFFF, and FFFP concentrates. A positive spreading coefficient is required for film-forming foams when cyclohexane is used as the test fuel. There are also toxicity, corrosion, sedimentation, viscosity, expansion, and drainage criteria included in the standard. The fire performance test consists of a 8-ft diameter circular pan with heptane as the fuel. The UNI 86 foam nozzle is used for either a "forceful" or "gentle" application method at a flow rate of 3 gpm. The application rate is 0.06 gpm/ft^2. For the greatest performance level, a 3 minute extinguishment time is required. This extinguishment time results in an extinguishment application density of 0.19 gal/ft^2.

The ISO/EN requirements for extinguishing and burnback are summarized in Figure B.4.3-2 (Table 1). There are three levels of extinguishment performance and four levels of burnback performance. For extinguishing performance, Class I is the highest class and Class III the lowest class. For burnback resistance, Level A is the highest level and Level D is the lowest level. The typical performance classes and levels for the various concentrates is provided in Annex A of the standard and are also shown in Figure B.4.3-2 (Table A.1).

EN 1568-3 Extinguishing Media – Foam Concentrates

Circular pan $50 ft^2$
Heptane
Type II (gentle) and/or Type III (forceful)
Application rate $0.06 gpm/ft^2$
Vapor suppression and burnback
Rating scale for performance
Physical and chemical properties
Toxicity and corrosion

Table A.1 — Typical performance for various grades of foam concentrate

Grade	Extinguishing performance class	Burn-back resistance level	Film formation
AFFF (not AR)	I	C	Yes
AFFF (AR)	I	A or B	Yes
FFFP (not AR)	I	B	Yes
FFFP (AR)	I	A or B	Yes
FP (not AR)	II	A or B	No
FP (AR)	II	A or B	No
P (not AR)	III	B	No
P (AR)	III	B	No
S (not AR)	III	C	No
S (AR)	III	C	No

Table 1 — Maximum extinction times and minimum burn-back times

Times in minutes

Extinguishing performance class	Burn-back resistance level	Gentle application test (See H.2)		Forceful application test (See H.3)	
		Extinction time not more than	Burn-back time not less than	Extinction time not more than	Burn-back time not less than
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	5	15	Not Applicable	
	C	5	10		
	D	5	5		

NOTE 1 There is no burn-back resistance level A for class III.

NOTE 2 Typical extinguishing performance classes and burn-back resistance levels for different types of foam concentrate are given in Annex A.

Figure B.4.3-2 EN 1568-3 Fire Test Summary and Performance Levels

B.4.3.3. NFPA 11 / CFR / IMO

In addition to the two main approval test protocols mentioned previously, there is also an Annex (Annex F) in NFPA 11 that addresses maritime applications with a focus on tank-top protection for large cargo ships/freighters. The annex is based on the US Coast Guard regulations documented in the Code of Federal Regulations (CFR) and the International Maritime Organizations (IMOs) requirements. The test protocol provided in the annex includes a $100 ft^2$ gasoline fire that is conducted in a square pan (10 ft by 10 ft) with 3-foot-high sides. The fire is allowed to free-burn for one minute prior to foam application. The foam is applied to the pan at a rate of 6 gpm ($0.06 gpm/ft^2$ application rate) for a period of five minutes. The foam solution is indirectly applied to the fuel by bouncing it off the pan wall on the opposite side of the pan from the nozzle (similar to the UL 162 Type II application). The fire must be extinguished by the end of the five-minute discharge. Fourteen minutes after foam discharge is complete, a burning torch is then passed across the top of the foam blanket for a one-minute period. After the torch pass, a burnback assess is conducted to identify the 25% burnback time.

B.4.3.4. Large Atmospheric Station Tank Fire (LASTFIRE)

In addition to the UL and EN Standards, and Annex F of NFPA 11, the petroleum industry also relies on an industry focused organization known as LASTFIRE - http://www.lastfire.co.uk. LASTFIRE is an industry group of international oil companies developing best practices in storage tank fire hazard management. It was started in the early 1990s by 16 oil companies. Current focus is the transition to FFF.

Recognizing that none of the standard foam fire tests at the time simulated the special conditions of a tank fire, Mobil Research and Development Center (MRDC) started defining such attest and handed it over to the LASTFIRE Group for completion and implementation

It modified the features of the commercial test protocols to be more representative of large tank conditions. As example, the side heights of the fire pans have been increased to a height of 2 ft and the preburn times have been increased from one minute to 3 minutes to be more representative and more challenging than the commercial protocols. The fires are conducted with heptane as the default fuel but gasoline is available upon request. The foam is applied to the pan through a fixed-nozzle system (i.e., no manual firefighting) that is capable of simulating three representative discharge devices: semi-aspirated nozzles, aspirated nozzles, and foam pourers. The application rates are typically representative of NFPA design requirements but reduced to include a factor of safety. The requires include extinguishment, vapor suppression (i.e., torch passes above the foam blanket) and burnback resistance. This information is summarized in Figure B.4.3-3 below.

Figure B.4.3-3 LASTFIRE Tank-Top Specific Approval Tests

B.4.3.5. Petroleum Industry Summary

Historically, the petroleum industry has incorporated a combination of approvals consisting of either UL or EN tested foams as well as supplemental data from LASTFIRE. They have also defaulted to using alcohol resistant foams that can cover the spectrum of typical petroleum industry hazards/scenarios. Going forward, this may not be the best approach since the study conducted by the NFPA Fire Protection Research Foundation demonstrated that FFFs approved solely for hydrocarbon-based fuels are superior to AR-FFFs lower flashpoint fuels with higher vapor pressures such as gasoline, but more research is required on this with longer preburns, longer flow distances and obstructions to validate the results.

B.4.4. Municipal Fire Departments

The selection of foams by municipal fire departments is not governed by a specific NFPA standard or test protocol. The selection needs to be based on the anticipated needs/hazards being protected. As an example, if the hazards are primary flammable liquid fuel based, the UL 162 or EN 1568-3 would be a good choice. However, since many municipal fire departments provide protection of a broad-spectrum hazards, many departments select “wetting agents” or “water additives” that are designed for a range of fire types e.g., Class A, B, C and D. These types of agents are tested and approved/listed to NFPA 18, Standard on Wetting Agents and NFPA 18A, Standard on Water Additives for Fire Control and Vapor Mitigation.

NFPA 18 contains two fire tests, one for Class A fires (ordinary combustibles) and one for Class B fires (liquid fuel fires). It also contains a limited number of physical and chemical parameter requirements including viscosity, pH, corrosion, and environmental and health considerations.

Expanding more on the liquid fuel fire tests, the fire tests are conducted using the same setup as UL 162. Specifically, the tests are conducted using commercial grade n-heptane and a 50 ft^2 square test pan with 11-inch sides. However, during the NFPA 18 tests, wetting agents are applied at a much higher rate (i.e., wetting agents are applied at 10 gpm versus foams that are applied at 3 gpm). These flow rates correspond to an application rate of 0.2 gpm/ft^2 for wetting agents versus 0.06 gpm/ft^2 for foams. This suggests that foams approved per UL 162 or EN 1568-3 are 3-4 times better than the wetting agents approved per NFPA 18 for extinguishing liquid fuel fires. This is shown in Figure B.4.4-1 below.

NFPA 18 Wetting Agents

Genesis is wildland fires (sticky water) and deep-seated Class A (slippery water)

Both Class A & Class B Fire Tests

Square pan 50ft^2
Heptane
Either Type II (gentle) or Type III (forceful)
Application rate 0.2 gpm/ft^2
10 gpm Wetting vs 2 or 3 gpm for foams
Extinguishment time 5 minutes
Corrosion tests
Toxicity and Biodegradability

Figure B.4.4-1 Wetting Industry Segment MCEs

Circling back to the use of these products to combat Class A fires (i.e., fires involving ordinary combustibles), many legacy foam products (i.e., AFFFs) and well as many of the new fluorine free products can be used as wetting agents at lower concentrations (i.e., 0.5%) to enhance the capabilities of water against Class A fires. All of these products are surfactant based and tend to reduce the surface tension of water, even at very low concentrations. As a result, selecting a foam product for use as a “universal agent” provides comparable performance against Class A fires but significantly superior capabilities against Class B fires. As a final thought, with the environmental landscape becoming more restrictive, first responders are urged to use water to combat Class A fires and only use foam products we necessary (i.e., to combat liquid fuel fires).

B.4.5. SUMMARY

The design fires, performance objectives, and the test methods/protocols for the four user segments are summarized in Table 4.5-1 below. The fire performance objectives for the user segments are based on an agreed-upon/selected Design Fire (DF) or Maximum Credible Event (MCE). Specifically, test methods used by the military and the aviation industry were developed around fuel spill scenarios with minimal fuel depth and shorter preburn times and focus more on rapid extinguishment versus burnback protection. Conversely, test methods used by the petroleum industry were developed around fuel storage tanks with significant fuel depths with potentially longer preburn times and focus more on the development of a robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces but allow for longer extinguishment times as a trade-off. Since there are no test methods that apply strictly to municipal fire departments, The selection of a foam needs to be based on the anticipated needs/hazards being protected.

Table 4.5-1 User Segment Test Method/Protocols

User Segment	Primary Hazard (MCE)	Performance	Test Protocol
Military/DoD	Spill fire (mostly kerosene based), short preburn, weapon exposures / cookoff	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F
Aviation Industry	Spill fire (kerosene based), short preburn, passenger exposures / fuselage burn-through	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F ICAO A,B & C NFPA 403/1900
Petroleum Industry	Tank fire (various fuels), long preburn	Decent control and extinguishment, robust foam blanket, good burnback protection	UL 162, EN 1568, NFPA 11, LASTFIRE (tank scenarios)
Municipal Fire Departments	Industrial, Tanker trucks, fuel handling stations, (various fuels), long preburn	Any/all of the above	Not Specified / all of the above

The test methods/protocols for DoD/Aviation applications are summarized in Table 4.5-2. In the U.S., all DoD facilities and commercial airports are required to us “MilSpec” AFFF. Most overseas commercial airports tend to default to ICAO Level B approved products.

The desired firefighting capabilities are focused on rapid extinguishment versus burnback protection. Specifically, these protocols require much faster extinguishment times than the protocols used to approve foams for petroleum industry applications. Conversely, while all three DoD/aviation test protocols include burnback assessments, the burnback requirements are much less than the protocols used to approve foams for petroleum industry applications. As a point worth noting, all foam types used in the aviation industry are tested using the same test parameters (i.e., application rates and discharge times) as opposed to the protocols developed for the petroleum industry which hold film-formers (i.e., AFFF) to higher standards than non-film formers (i.e., FFFs).

When comparing the tests shown in Table 4.5-2, there are three parameters that contribute to the difficulty of the test; fuel type, foam application rate and extinguishment application density. With respect to fuel types, the lower flashpoint fuels typically have significantly higher vapor pressures making them much harder to extinguish than higher flashpoint fuels (i.e., gasoline is much harder to extinguish than kerosene-based fuels). The next parameter is application rate (foam solution flow rate per unit area of fire). At very low application rates, the fire tends to consume the foam as fast as it is being applied. Once the application rate exceeds a critical value, a foam blanket begins to develop on the fuel surface and eventually grows to cover and extinguish the burning fuel. The test protocols tend to focus on this critical rate which is then multiplied by a factor of safety (a minimum of 1.67) during system design and/or response planning. The final parameter is the extinguishment application density. This value is the application rate multiplied by the extinguishment time. In general, the lower the extinguishment application density, the better the fire extinguishing capabilities of the product.

Applying this logic to Table B.4.5-2, demonstrates that the MilSpec approved foams would have better extinguishing capabilities than the ICAO approved products. However, NFPA 403/460 and CAP 168 consider MilSpec and ICAO Level C as equivalent when developing emergency response requirements even though the MilSpec tests are conducted with gasoline.

Table B.4.5-2 DoD/Aviation Test Method/Protocols

Test Standard	Fuel	Application Rate (gpm/ft^2)	Pan Size (ft^2)	Nozzle Movement	Ext. Time (sec)	Ext. App. Density (gal/ft^2)
MilSpec	Gasoline	0.04/0.07	50/28	Yes	50/30	0.033
ICAO Level C	Kerosene	0.04	78	No	60/120*	0.04/0.08
ICAO Level B	Kerosene	0.06	50	No	60/120*	0.06/0.12

* small flames at edges OK at 60 seconds and complete extinguishment by 120 seconds

The test methods/protocols used by the petroleum industry are summarized in Table B.4.5-3 below. The tests are intended to identify products that produce a more robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces but tend to allow for longer extinguishment times as a trade-off. Since the vapor suppression and burnback assessments are similar between these standards, the following discussion will focus more on fuel type and pan configuration (i.e., side height) as opposed to extinguishment density.

Table B.4.5-3 Petroleum Industry Test Method/Protocols

Test Standard	Fuel	Application Rate (gpm/ft2)	Pan Size (ft2)	Nozzle Movement	Ext. Time (sec)	Ext. App. Density (gal/ft2)
UL 162 AFFF EN 1568-3	Heptane*	0.04	50	Yes	180	0.12
UL 162 Synthetic EN 1568-3	Heptane*	0.06	50	Yes	300	0.3
NFPA 11 Annex F	gasoline	0.06	100	No	300	0.3
LASTFIRE	Heptane*	50% of design	50	No	Test Specific	Test Specific

* Heptane is the default hydrocarbon surrogate, but the test(s) may be conducted with gasoline and/or other fuels if requested by the foam manufacturer.

Applying the logic described above, both the UL 162 and EN 1568-3 protocols identify good quality foams for broad spectrum petroleum applications but are conducted using heptane and pans with shorter side dimensions. Both the NFPA 11 (Annex F) and the LASTFIRE test protocols focus tank top protection and take these initial listings/approvals to a higher level. Specifically, the use of gasoline in the NFPA 11 test combined with the 3-foot-high sides makes this test significantly more challenging than both the UL 162 and EN 1568-3 tests. The same holds true for the LASTFIRE tests that tend to do a better job simulating the actual tank top conditions and discharge devices. In addition, the longer preburn times used by LASTFIRE also makes these tests significantly more challenging than both the UL 162 and EN 1568-3 tests.

The selection of foams by municipal fire departments needs to be based on the anticipated needs/hazards being protected. As an example, if the hazards are primary flammable liquid fuel spill fires like ignited overturned tractor trailers, foams used by the DoD or the ARFF community may be a good choice. Conversely, if the primary hazards are fuel tanks (i.e., fuels in depth) and/or fuel spills that typically do not ignite (i.e., vapor suppression), the UL 162 listed or EN 1568-3 approved products would be a good choice. Also, fuel type needs to be considered. Specifically, if the likely hazards include polar solvents such as alcohols or alcohol blends, AR (alcohol resistant) foams listed by UL or tested to EN 1568-3 would be the best (and possibly only) choice. With respect to "universal agents", most, if not all foams approved by any of the "foam" standards mentioned above can be diluted to low than their design concentrations (i.e., 0.5% versus 3%) to enhance their penetrating capabilities against deep seated Class A fires.

B.5. GENERAL STATE OF THE ART (CAPABILITIES AND LIMITATIONS)

A recent literature search identified between 60-70 commercially available products that were being marketed as "environmentally friendly" AFFF alternatives. A deeper dive into this information revealed that about one-half of these products did not have legitimate approvals and/or listings and were being marketed strictly on limited ad-hoc testing and associated videos. The remaining products have been tested to, and/or listed/approved to the legacy test protocols described in the previous sections. Many of these products have been successfully fielded and are in use today for a range of applications. There are a number of case studies identified during this roadmap program that can be used as a template for transitioning to a next-generation product.

Most, if not all, of the National Fire Protection Association (NFPA) Standards that include the use of foams in the protection schemes are being revised to include fluorine-free foams and/or other environmentally acceptable alternatives/approaches. The details of these revisions are discussed in the subsequent sections of this chapter. In addition, there is a US congressional mandate to develop a new military specification to allow the use of fluorine-free foams in land-based military applications and installations (as mentioned previously). As a result, a significant amount of the environmental and toxicology research as well as fire-fighting performance assessments are being conducted under programs funded by the US Department of Defense (DOD) environmental oversite organizations: the Environmental Security Technology Certification Program (ESTCP); and Strategic Environmental Research and Development Program (SERDP). The FAA, NFPA Fire Protection Research Foundation, LASTFIRE and a wide range of commercial entities are also actively investigating the capabilities and limitation of these new products for specific applications. A deeper dive into this research is provided in Annex C which cover foam selection.

As of today, it is generally believed that FFFs are not a “drop in” replacement for AFFF. Even though there are a limited number of products that are being marketed as “film-forming” FFFs, all these products are basically mechanical foams and rely almost entirely on the foam blanket to smother the fire. As a result, during almost all side-by-side comparisons that have been made between these products and legacy AFFFs, the FFFs typically require about 1.5-2 times longer to extinguish the fire than AFFF, but the fires DO go out.

With that said, many of these products can be made to perform effectively as AFFF alternatives with proper testing and design. In some situations, higher application rates and/or aspirating nozzles may be required. Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. This applies not only to the discharge devices but also to the proportioning systems as well (due to the highly viscous nature of some of the FFF concentrates).

In closing, it needs to be noted that these products continue to evolve, and the firefighting capabilities continue to improve. These trends were also observed for AFFF when it was deployed almost 50 years ago.

Firefighting Foams: Fire Service Roadmap

Annex C
Foam Selection

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C.1. INTRODUCTION

There are several factors that need to be considered when making the transition to a Fluorine-Free Foam (FFF). The websites identified in Annex A provide the tools to monitor the regulatory requirements on both state and federal levels. These sites may also provide additional information to assist in this transition. The cleaning of the legacy equipment is covered in Annex D and the disposal of the cleaning effluents and AFFF concentrates is covered in Annex E. This Annex provides the framework for the selection of a next-generation foam.

There are numerous available resources to help with this transition and reduce the learning curve impact. As an example, most, if not all, of the National Fire Protection Association (NFPA) Standards that include the use of foams in the protection schemes are being revised to include fluorine-free foams and/or other environmentally acceptable alternatives/approaches. These standards may provide additional information on both the selection and use of these new products. Ultimately, doing your homework to become better informed should ease the transition burden.

Going forward, it is generally believed that FFFs are currently not a “drop in” replacement for AFFF. Even though there are a limited number of products that are being marketed as “film-forming” FFFs, all these products are basically mechanical foams and rely almost entirely on the foam blanket to smother the fire. As a result, during almost all side-by-side comparisons that have been conducted between FFFs and legacy AFFFs over the past five years, the FFFs typically require about 1.5-2 times longer to extinguish the fire than AFFF, but the fires DO go out.

Although FFFs tend to take longer to extinguish most fires, the available empirical data demonstrates that many of these products can be made to perform effectively as AFFF alternatives with proper testing and design. In some situations, higher application rates and/or aspirating nozzles may be required. End users need to ensure robust design and installation practices are followed in accordance with the listed parameters of the foam to ensure adequate protection of the hazard. This applies not only to the discharge devices but also to the proportioning systems as well (due to the highly viscous nature of some of the FFF concentrates). If fact, some of the new FFF concentrates are described as “non-Newtonian” which at this time means that they are extremely thick (e.g., can even have the consistency of jelly or jello) and don’t flow through pipes and orifices like typical liquids. It also needs to be noted that the FFF formulations continue to evolve, in the same manner that AFFF did 50 years ago, and the firefighting capabilities continue to improve.

C.1.1. HAZARD REASSESSMENT

Prior to starting the transition, reassessing the hazard is warranted. Specifically, AFFF has been used to protect a range of hazards for almost 50 years. The hazards may have changed as well as the code requirements. An outline for reassessing the need for using a fluorine-free foam is provided in Figure C.1.1-1.

Re-Assessment of the Hazard

1. Fire Hazard Analysis
   a. Define Conditions / Hazards
   b. Code requirements
   c. Design Fires
   d. Define Performance Objectives
   e. Protection Options
   f. If foam is required, conduct design review below
   g. If foam is not required, select new approach
2. Design Review
   a. Code requirements
   b. Application rates
   c. Duration / Concentrate quantities

Example: NFPA 409 – Standard for Aircraft Hangars – 2022 edition

Figure C.1.1-1 Hazard Reassessment Logic

The process begins with a review of the conditions and the fire hazards that are being protected. Once these are defined, the code requirements for the type of facility and occupancy should be reviewed to identify the protection requirements. If the protection requirements are not well defined for the specific facility/application and/or the use of foam is problematic for any reason, a typical performance-based design approach for protecting the facility should be initiated. This includes defining the likely fire scenarios that make up the hazards, determining the protection objectives (i.e., life safety /egress and/or protection of the structure/equipment), selection of an alternate protection scheme and demonstrating equivalency to current code objectives and/or requirements.

As an example of this logic and/or industry trends, NFPA 409, The Standard for Aircraft Hangars (2022) was just revised to provide flexibility in selecting a protection scheme versus a prescriptive requirement for a foam fire extinguishing system.

C.1.2. FLUORINE FREE PRODUCTS

A recent literature search identified between 60-70 commercially available products that were being marketed as “environmentally friendly” AFFF alternatives. A deeper dive into this information revealed that about one-half of these products did not have legitimate approvals and/or listings and were being marketed strictly on limited ad-hoc testing and associated videos. The remaining products have been tested to, and/or listed/approved to the legacy test protocols described in Annex B. Many of these products have been successfully fielded and are in use today for a range of applications.

To aid in the selection process, Table C.1.2-1 below provides a list of the products (and their associated websites) that appear most frequently throughout the literature. This table is not an endorsement of any of these products but rather is one source of information for additional research. This table includes 15 "foam" manufacturers (i.e., products that have been tested to foam test protocols) and 6 "wetting agent" manufacturers (i.e., products that have been tested to wetting agent test protocols). Most of the "foam" manufacturers have products formulated and approved for specific hazards (e.g., ARFF). Annex B provides a detailed description of the difference in these types of products and is summarized in Section 1.3 below. The capabilities of specific products need to be research using the information provided later in this annex.

Table C.1.2-1 Frequently Researched Fluorine Free Foams and Agents

Manufacturer	Type	Website	Multi-scale Research Conducted by:
3F – Freedol	Foam	https://www.3fff.co.uk/chemistry/smart-foam/	Pet
Angus	Foam	https://angusfire.co.uk/products/foam-concentrates/product-range/fluorine-free-foam/	AV, DoD, Pet
Ansul	Foam	https://www.ansul.com/en/us/DocMedia/F-2021111.pdf	DoD
Auxquimia	Foam	http://auxquimia.com/synthetic-multiexpansion-foam-concentrates/	
Bio-Ex	Foam	https://www.bio-ex.com/en/our-products/compositions/fluorine-free-foam/	AV, DoD, Pet
Bristol – EkoSol	Foam	http://www.bristol-fire.com/	
Dr. Sthamer	Foam	https://sthamer.com/en/fluorine-free/index.php	AV, Pet
Eau et Feu	Foam	https://eauetfeu.fr/produits/emulseurs/liste-des-emulseurs/airfoam/	AV, Pet
FireBull PFF	Foam	https://enforcerone.com/products/firebull-fluorine-free-foam/	
Fomtec	Foam	https://www.fomtec.com/fluorine-free/category38.html	AV, DoD, Pet
GreenFire	Both	https://gogreenfire.com/greenfire-fire-protection/	
National	Foam	https://nationalfoam.com/foam-concentrates/sfff-fluorine-free-foam/	AV, DoD, Pet
Orchidee	Foam	https://orchidee-fire.com/products-solutions/?_sft_product_cat=fluorine-free-foams	
Phos-Chek	Foam	https://www.perimeter-solutions.com/en/class-a-foam/	
Solberg	Foam	https://www.perimeter-solutions.com/en/class-b-foam/solberg-avigard-fluorine-free/	AV, DoD, Pet
vs FOCUM	Foam	https://vsfocum.com/foams/types/1-fluorine-free-newtonian/	
Amiran	Wetting	https://www.jmesales.com/content/docs/AmiranBioChemicals/FlameOut_DataSheet.pdf	
Coldfire	Wetting	https://firefreeze.com/cold-fire/	
F500	Wetting	https://hct-world.com/products/chemical-agents/f-500-encapsulator-agent/	
Geltech	Wetting	https://geltechsolutions.com/fireice/	
Novacool	Wetting	http://novacoolfoam.com/	
Pyrocool	Wetting	https://www.pyrocooltech.com/pyrocool-fef/	

Research Areas: AV-Aviation / DoD-US Department of Defense / Pet – Petroleum Industry

C.1.3. USER SEGMENTS AND PROTOCOLS

There are four general user segments of the fire service community that use foam firefighting products: Military, Aviation, Petroleum Industry and Municipal Fire Departments. The hazards and required foam product performance are in most respects, specific to the user segments. Specifically, the foam performance requirements are defined based on an agreed-upon/selected Design Fire (DF) or Maximum Credible Event (MCE).

The design fires, performance objectives, and the test methods/protocols for the four user segments are summarized in Table C.1.3-1 below. The fire performance objectives for the user segments are based on an agreed-upon/selected Design Fire (DF) or Maximum Credible Event (MCE). Specifically, test methods used by the military and the aviation industry were developed around fuel spill scenarios with minimal fuel depth and shorter preburn times and focus more on rapid extinguishment versus burnback protection. Conversely, test methods used by the petroleum industry were developed around fuel storage tanks with significant fuel depths with potentially longer preburn times and focus more on the development of a robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces but allow for longer extinguishment times as a trade-off. Since there are no test methods that apply strictly to municipal fire departments, The selection of a foam needs to be based on the anticipated needs/hazards being protected.

Table C.1.3-1 User Segment Test Method/Protocols

User Segment	Primary Hazard (MCE)	Performance	Test Protocol
Military/DoD	Spill fire (mostly kerosene based), short preburn, weapon exposures / cookoff	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F
Aviation Industry	Spill fire (kerosene based), short preburn, passenger exposures / fuselage burn-through	Rapid control and extinguishment, decent burnback protection	MIL-PRF-24385F ICAO A,B & C NFPA 403/1900
Petroleum Industry	Tank fire (various fuels), long preburn	Decent control and extinguishment, robust foam blanket, good burnback protection	UL 162, EN 1568, NFPA 11, LASTFIRE (tank scenarios)
Municipal Fire Departments	Industrial, Tanker trucks, fuel handling stations, (various fuels), long preburn	Any/all of the above	Not Specified / all of the above

The test methods/protocols for DoD/Aviation applications are summarized in Table C.4.5-2. In the U.S., all DoD facilities and commercial airports are required to us “MilSpec” AFFF. Most overseas commercial airports tend to default to ICAO Level B approved products.

The desired firefighting capabilities are focused on rapid extinguishment versus burnback protection. Specifically, these protocols require much faster extinguishment times than the protocols used to approve foams for petroleum industry applications. Conversely, while all three DoD/aviation test protocols include burnback assessments, the burnback requirements are much less than the protocols used to approve foams for petroleum industry applications. As a point worth noting, all foam types used in the aviation industry are tested using the same test parameters (i.e., application rates and discharge times) as opposed to the protocols developed for the petroleum industry which hold film-formers (i.e., AFFF) to higher standards than non-film formers (i.e., FFFs).

When comparing the tests shown in Table 4.5-2, there are three parameters that contribute to the difficulty of the test; fuel type, foam application rate and extinguishment application density. With respect to fuel types, the lower flashpoint fuels typically have significantly higher vapor pressures making them much harder to extinguish than higher flashpoint fuels (i.e., gasoline is much harder to extinguish than kerosene-based fuels). The next parameter is application rate (foam solution flow rate per unit area of fire). At very low application rates, the fire tends to consume the foam as fast as it is being applied. Once the application rate exceeds a critical value, a foam blanket begins to develop on the fuel surface and eventually grows to cover and extinguish the burning fuel. The test protocols tend to focus on this critical rate which is then multiplied by a factor of safety (a minimum of 1.67) during system design and/or response planning. The final parameter is the extinguishment application density. This value is the application rate multiplied by the extinguishment time. In general, the lower the extinguishment application density, the better the fire extinguishing capabilities of the product.

Applying this logic to Table C.1.3-2, demonstrates that the MilSpec approved foams would have better extinguishing capabilities than the ICAO approved products. However, NFPA 403/460 and CAP 168 consider MilSpec and ICAO Level C as equivalent when developing emergency response requirements even though the MilSpec tests are conducted with gasoline.

Table C.1.3-2 DoD/Aviation Test Method/Protocols

Test Standard	Fuel	Application Rate (gpm/ft^2)	Pan Size (ft^2)	Nozzle Movement	Ext. Time (sec)	Ext. App. Density (gal/ft^2)
MilSpec	Gasoline	0.04/0.07	50/28	Yes	50/30	0.033
ICAO Level C	Kerosene	0.04	78	No	60/120*	0.04/0.08
ICAO Level B	Kerosene	0.06	50	No	60/120*	0.06/0.12

* small flames at edges OK at 60 seconds and complete extinguishment by 120 seconds

The test methods/protocols used by the petroleum industry are summarized in Table C.1.3-3 below. The tests are intended to identify products that produce a more robust foam blanket to minimize the likelihood of reignition near heated tank walls and surfaces but tend to allow for longer extinguishment times as a trade-off. Since the vapor suppression and burnback assessments are similar between these standards, the following discussion will focus more on fuel type and pan configuration (i.e., side height) as opposed to extinguishment density.

Table C.1.3-3 Petroleum Industry Test Method/Protocols

Test Standard	Fuel	Application Rate (gpm/ft^2)	Pan Size (ft^2)	Nozzle Movement	Ext. Time (sec)	Ext. App. Density (gal/ft^2)
UL 162 AFFF EN 1568-3	Heptane*	0.04	50	Yes	180	0.12
UL 162 Synthetic EN 1568-3	Heptane*	0.06	50	Yes	300	0.3
NFPA 11 Annex F	gasoline	0.06	100	No	300	0.3
LASTFIRE	Heptane*	50% of design	50	No	Test Specific	Test Specific

* Heptane is the default hydrocarbon surrogate, but the test(s) may be conducted with gasoline and/or other fuels if requested by the foam manufacturer.

Applying the logic described above, both the UL 162 and EN 1568-3 protocols identify good quality foams for broad spectrum petroleum applications but are conducted using heptane and pans with shorter side dimensions. Both the NFPA 11 (Annex F) and the LASTFIRE test protocols focus tank top protection and take these initial listings/approvals to a higher level. Specifically, the use of gasoline in the NFPA 11 test combined with the 3-foot-high sides makes this test significantly more challenging than both the UL 162 and EN 1568-3 tests. The same holds true for the LASTFIRE tests that tend to do a better job simulating the actual tank top conditions and discharge devices. In addition, the longer preburn times used by LASTFIRE also makes these tests significantly more challenging than both the UL 162 and EN 1568-3 tests.

The selection of foams by municipal fire departments needs to be based on the anticipated needs/hazards being protected. As an example, if the hazards are primary flammable liquid fuel spill fires like ignited overturned tractor trailers, foams used by the DoD or the ARFF community may be a good choice. Conversely, if the primary hazards are fuel tanks (i.e., fuels in depth) and/or fuel spills that typically do not ignite (i.e., vapor suppression), the UL 162 listed or EN 1568-3 approved products would be a good choice. Also, fuel type needs to be considered. Specifically, if the likely hazards include polar solvents such as alcohols or alcohol blends, AR (alcohol resistant) foams listed by UL or tested to EN 1568-3 would be the best (and possibly only) choice. With respect to "universal agents", most, if not all foams approved by any of the "foam" standards mentioned above can be diluted to lower than their design concentrations (i.e., 0.5% versus 3%) to enhance their penetrating capabilities against deep seated Class A fires. The research has shown that "foams" (products approved to foam test protocols/standards) have significantly better firefight capabilities against liquid fuel fires than "universal" agents (i.e., wetting agents). If for no other reason, wetting agents are tested/approved at flow rates that are 3-4 times greater than foam products.

C.2. FOAM SELECTION FRAMEWORK

The foam selection framework is outlined in Figure C.2.0-1 and is discussed in the following sections. The framework provides a couple of different approaches for identifying and selecting a fluorine-free foam. The order shown in the figure outline may be juggled depending on the end-user specific needs. Ultimately, there are a range of potential products that should be considered and researched prior to final selection. The end users will need to do their homework to ensure the selection of an appropriate AFFF replacement to minimize the potential for transition regret.

Selection of an AFFF Alternative

- Application / Use
  - Application may require specific standard/approval
  - Match hazard to test standard
  - Beware of Ad-hoc testing and videos
  - Credible test lab
- Current System/Product (proportioning system and discharge devices)
  - Minimize hardware modifications
  - Talk to foam and/or equipment manufacturers
- Concentrate viscosity (Newtonian vs Non-Newtonian)
- Fire Performance / Design Parameters
  - Approvals and listed parameters
  - R&D Data – SERDP/ESTCP, FAA, LASTFire, RISE, etc.
- Environmental and Health Concerns
  - SDS/Safer Choice/Green Screen

Figure C.2.0-1 Foam Selection Framework

C.2.1. APPLICATION / USE

Starting from scratch, the application or use of the foam may be governed by building code/fire code requirements which may require that the foam meet a specific test protocol. For example, an airport in Europe may be required to use ICOA Level B foams. This could be advantageous since it would narrow the search parameters when searching the various manufacturers websites. In any case, the selection will entail the identification of a number of foams based on general data (i.e., manufacturer's websites), and then down-selection of a final product by doing a deeper dive into the available information.

C.2.1.1. Match the Hazard to Test Protocol and Performance Objectives

If the application is not governed by a specific set of requirements, the performance objectives of the foam as described for the various user segments and/or their associated approval test protocols could be used as a starting point. For example, if the primary hazard includes alcohols/polar solvents, that automatically places the focus on UL 162 or EN 1568-3 approved products since none of the other protocols are intended for that use. Conversely, if the hazard is primarily gasoline, UL 162 or EN 1568-3 could be options if the foams were tested/listed for this fuel specifically (i.e., the manufacturer's approval/listing specifically has guidance for gasolines such as E15).

C.2.1.2. Manufacturer's Information

The search will ultimately lead to a number of manufacturer's websites to investigate their various product descriptions and approval tests/listings. The websites for many of the product manufacturers are provided in Table C.1.2-1. While on the site, emphasis should be placed on matching the product descriptions and approvals/listings to the end user hazards/conditions. Also, the approval tests/listings need to have been conducted by a credible 3rd-party test lab, and against recognized approval test protocols. There numerous products being marketed based on ad-hoc testing and associated videos that not recognized by most technical authorities. During the final selection process, discuss the product capabilities and current use scenarios with the manufacturers and ask for the approval test letters and/or reports prior to purchase.

C.2.1.3. Product Databases

There are only a limited number of approved/listed product databases that can be searched to aid in your selection. These include products that have been tested to the US military's foam specification (MilSpec) and Underwriter's Laboratory (UL) approved products list. Every product that has successfully complete the MilSpec requirements is listed on the Qualified Products List QPL No. 24385. An online copy of QPL is available the Qualified Products Database (QPD) at https://assist.dla.mil. However, until the new land-based MilSpec (MIL-PRF-XX727) is developed and implemented (2023), the QPL will only contain AFFFs.

The Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates, is the principal test standard for the listing of foam concentrates and equipment in the United States. The UL Fire Protection Equipment Directory (legacy term) now referred to as the UL Product iQTM is available at the following web address: https://productiq.ulprospector.com/en.

Once on the site, foam concentrates can be searched by inputting “GFGV” in the search window. An example of the resulting search screen is shown in Figure C.2.1-1. FFFs are currently shown with “Synthetic” after the product name and will eventually be documented as “Synthetic Fluorine Free Foams (SFFFs)” in the future.

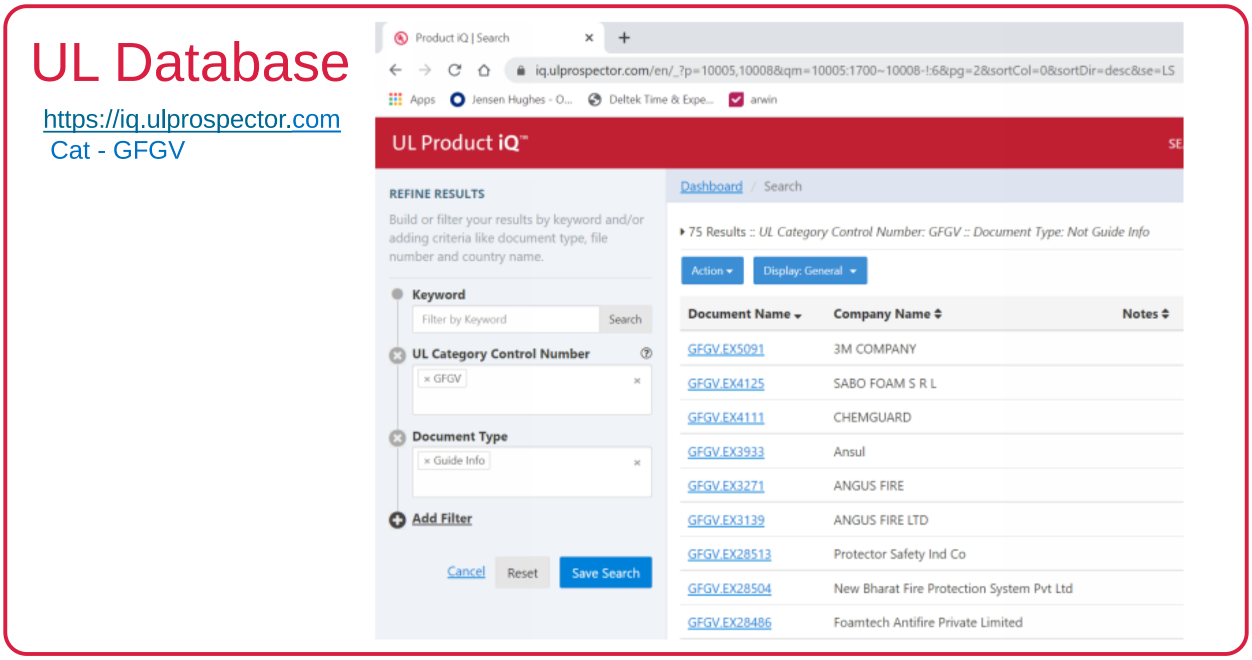

Figure C.2.1-1 UL Product iQTM Website (GFGV search results)

C.3. CURRENT PRODUCT (AFFF) AND HARDWARE

Most of the industry leading AFFF manufacturers are developing FFFs. If the end user has been pleased with the performance and support from a legacy provider, contacting them is good starting point for several reasons. As an example, if the manufacturer has a FFF product, there is a good chance that this product has been tested with the legacy system hardware which would minimize potential future modifications.

If the end user application does not match the proportioning and discharge hardware with a specific foam concentrate (e.g., ARFF vehicles/scenarios), contacting the hardware manufacturer is highly recommended. Many of the FFF manufacturers have been working with equipment manufacturers to verify compatibility between their concentrates and equipment used throughout the industry. If the hardware manufacturers do not have any recommendations, they should be able to provide some of the limits on the physical and chemical characteristics for the foam concentrates that can be used in their equipment. At a minimum, this would require the definition of an acceptable range of concentrate viscosities that can be accurately proportioned by their system and the compatibility (i.e., corrosiveness) of the concentrate with the materials use in the system (storage tank, piping, and nozzle components).

C.4. FIRE PERFORMANCE DATA AND DESIGN PARAMETERS

This section provides information to assist an end user in collecting data on the firefighting capabilities of specific products.

C.4.1. APPROVAL TEST REPORTS AND/OR LISTED PARAMETERS

In many instances, the manufacturer is provided a detailed test report as part of the approval process. Some manufacturers may be willing to share these results to aid in your decision making and for getting acceptance from an approval authority. In addition, many of the larger foam producers have their own test facilities and/or one that is available to them for product development. This could be beneficial if the approval test parameters do not cover your specific hazard. As an example, if the approval test/listing only includes an assessment of capabilities against heptane, and your hazard is gasoline, asking for a manufacturer to perform a validation test may not be out of the question.

As stated previously, the foam concentrates that are UL listed are available at the following web address: https://productiq.ulprospector.com/en by searching "GFGV". In addition to the standard listing information, if the product was tested against other fuels such as E15 gasoline, that information will also be included on the listing page. This can be used to verify the capabilities of the product against gasoline (for instance) and can also be used to compare the capabilities against other concentrates that have also been tested against E15. This is shown in Figure C.4.1-1.

UL Listed Parameters

Foam A - Nozzles

Fuel	Min Application Rate GPM/Sq Ft
Hydrocarbons	0.16
15% Ethanol/85% Gasoline	0.17

Foam B - Nozzles

Fuel	Min Application Rate GPM/Sq Ft
Hydrocarbons	0.16
15% Ethanol/85% Gasoline	0.22

Figure C.4.1-1 Comparison of Two Listed Foam Parameters

The figure shows a comparison of the listed parameters for two "Synthetic" foams that are being marketed as fluorine free. The "fluorine free" claim is not verified in the listing but will be in the future. The values shown in the figure are for 1 ½ inch firefighting nozzles. As can be seen in the figure, the minimum application rate for Foam B for protecting E15 gasoline is about 30% greater than Foam A. This suggests that Foam A has better firefighting capabilities against E15 gasoline than Foam B.

C.4.2. R&D DATA

Ultimately, the end user will need to do their homework in selecting an appropriate fluorine-free foam for their specific application. The following sections summarize some of the research conducted to date and link to pursue additional information. These will be continuously updated as the research and the technology progresses.

C.4.2.1. Fire Protection Research Foundation

The first detailed parametric study of the capabilities and limitations of FFFs was conducted by the Fire Protection Research Foundation (FPRF) in 2019 to provide input to NFPA 11. The full report is available on the FPRF website at: https://www.nfpa.org/News-and-Research/Data-research-and-tools/Suppression/Evaluation-of-the-fire-protection-effectiveness-of-fluorine-free-firefighting-foams. The program was conducted as a blind study to assess the firefighting capabilities (extinguishment and burnback times) of five commercially available, UL listed FFFs. The assessment included: three alcohol resistant FFFs, two hydrocarbon approved FFFs, and one short chain C6 AFFF for a baseline comparison. The final report is available on the FPRF website: https://www.nfpa.org/foundation.

The fire-fighting capabilities were assessed as a function of application rate (gpm/ft^2) and extinguishment application density (gal/ft^2) for a range of test parameters including: foam quality (foam aspiration representative of both air aspirating and non-air-aspirating discharge devices, fuel type (heptane, Isopropyl Alcohol (IPA) and two grades of gasoline (E0 (MIL-PRF-24385F) and E10). Water type (fresh and salt) and ambient fuel temperature were also evaluated.

The assessment was conducted on “approval scale” size fires, UL 162 50 ft^2 pan/pool fires. Two types of application methods were used: Type II with polar solvents and Type III with the hydrocarbon-based fuels. During the Type II tests, the nozzle was fixed and positioned/aimed such that the spray impacted a backboard located on the opposite side of the pan (i.e., indirect/gentle application of foam to the fuel surface). During the Type III tests, the foam was manually applied directly onto the fuel surface (i.e., forceful application with potential plunging).

One hundred sixty-five tests were conducted during this assessment. As a high-level summary, the baseline C6 AR-AFFF demonstrated consistent/superior fire-fighting capabilities through the entire test program under all test conditions and test fuels. The FFFs did well against heptane but struggled against some of the scenarios conducted with IPA and gasoline (both E0 and E10), especially for the lower aspirated foam solutions. From an application rate perspective, the FFFs typically required between 1.5 to 3 times the application rates to produce comparable performance as the baseline AR-AFFF for the range of parameters included in this assessment. From an extinguishment density perspective, the extinguishment densities for the FFFs were typically 2-7 times greater than the baseline AR-AFFF and were determined to be both manufacturer and fuel type dependent.

The three major findings of the study include: (1) foam aspiration has a significant effect on the fire-fighting capabilities of FFFs, (2) there are variations in extinguishment performance associated with the fuel type and (3) there are variations in extinguishment and burnback capabilities between listed FFFs.

With respect to foam aspiration, the lower aspirated foam solutions had 20-50% higher extinguishment densities as compared to the higher aspirated foam solutions. In some cases, higher application rates were required to extinguish the fires using the lower aspirated foam solutions.

With respect to the extinguishment difficulty between test fuels, it appears that E0 gasoline is twice as difficult to extinguish as heptane (the approval/listing test fuel), E10 gasoline is twice as difficult as E0 gasoline (four times as difficult as heptane) and IPA is twice as difficult as E10 gasoline (eight times as hard as heptane), all based on extinguishment densities. It was also observed that IPA could not be extinguished by directly applying the foam onto the fuel surface but rather required an indirect attack (bouncing off the pan sides) to be effective.

For the FFFs in general, the fire-fighting capabilities of the foams varied from manufacturer to manufacturer making it difficult to develop “generic” design requirements. This may also be the case with AFFFs but only one was tested during this program (i.e., no data to assess variability). When comparing capabilities of the types of FFFs (i.e., alcohol resistant versus hydrocarbon use only) against hydrocarbon fuels (i.e., heptane and gasoline), the H-FFFs typically out-performed the AR-FFFs requiring a 30% lower application rate to achieve comparable performance

The study concluded that the FFFs were not a “drop in” replacement for AFFF. However, some can be made to perform effectively as AFFF alternatives with proper testing and design (i.e., with higher application rates and/or aspirating nozzles). Ultimately, end users will need to design and install within the listed parameters in order to ensure a high probability of success during an actual event. This applies not only to the discharge devices but also to the proportioning systems as well (due to the highly viscous nature of some of the FFF concentrates).

The two primary conclusions are: (1) FFFs need to be deployed in strict compliance with the listing or approval, and (2) since FFFs incorporate the same extinguishment mechanisms as protein foams, the design parameters and discharge devices developed for protein foams are a good default/starting point for deploying FFFs for the spectrum of potential applications. Addition research conducted recently suggests that the current design parameters developed for AFFF are adequate for the top performing FFFs due to the traditionally high factors of safety applied to AFFF.

C.4.2.2. U.S. Department of Defense

The U.S. Military Specification (MilSpec), MIL-PRF-24385F, has been the AFFF procurement specification for the U.S. military and federal government for almost 50 years. It is important to recognize that MIL-PRF-24385F is unique in that it is a procurement specification as well as a performance specification and is, at present, the only document that governs AFFF used throughout the U.S. Military.

The U.S. Department of Defense (DoD) is under a congressional mandate to publish a new land-based fluorine-free foam military specification by January 31st, 2023, and to begin the transition to these new products later that year (i.e., October 1, 2023). There is a significant amount of research being conducted by the U.S. DoD environmental groups (i.e., ESTCP and SERDP). Most of this research is available to the public at their website: https://www.serdp-estcp.org/.

A list of programs that assessed the capabilities of some of the commercially available products is provided below. The final reports and out-briefs can be downloaded by typing in the program number in the search box on the main web page. In addition, the contact information for the program managers is also available.

- WP19-5299 & WP20-5335: Validation of Fluorine Free Foams (PFFs) against Military Specification Performance Criteria
- WP19-5324: Capabilities Assessment of Commercially Available Fluorine-Free Foams / PFAS-Free Foams
- WP19-5332: Screening Tests for Fluorine-Free Firefighting Foams
- WP19-5374: Foam Quality Effects on PFAS Free Foam Firefighting Capabilities: A Demonstration of the Link Between Foam Quality and Extinguishment Capabilities and What's Being Produced by DoD Hardware
- WP20-3048 Identification of Critical Properties and Features of Surfactant Solutions for Firefighting Foams
- WP20-5334: PFAS-Free Foam / Compressed Air Foam, Fire Suppression Alternative
- WP21-3461 & WP21-3465: Validation Testing of the Leading Commercially Available PFAS-Free Foams

In addition, the website includes on number of programs on equipment cleaning and remediation. These can be found searching “PFAS” on the main page as well.

Most of the SERDP and ESTCP research programs have focused on commercial products made by Angus, National, Bio-Ex, Fomtec and Soldberg products. The previous information was not an endorsement or recommendation of a specific product but rather to inform the reader of products currently being researched during SERDP and ESTCP programs.

C.4.2.3. Aviation R&D

The aviation industry relies on a number of standards to ensure adequate response capabilities at municipal airports. These include NFPA 403/460/1900 as well as International Civil Aviation Organization (ICAO) documents/requirements. Currently, all certified airports in the United States are required to use MilSpec approved foams. As of October 2021, the FAA no longer requires the use of fluorinated surfactants to meet the MilSpec requirements. However, none of the commercially available fluorine-free products can meet these performance requirements (at least at this time). In addition to MilSpec foams, NFPA 403 recognizes ICAO test methods which have significantly different test parameters, including test fuel, application rate, and extinguishment density. To aid in the response to the mandate and to provide information for any future decision making, the FAA has recently completed an in-house assessment of the capabilities and limitations of FFFs to aid in developing a path forward. This research should eventually be published (early 2022) on their website: https://www.faa.gov/. During this assessment, the FAA tested over 20 of the top commercially available products against both the MilSpec and ICAO test standards.

In addition to the FAA research, the DoD research is also focused on ARFF scenarios. Also, many airports throughout the world have already made the transition to FFFs. There are case studies included in both the Wood report and the IPEN report. Most of the Australia airports including military bases has recently made the transition. The Department of Transportation - Canada has published guidance for the transition with most Canadian airports, currently making the transition.

In general, most Australia ARFF transitions have been to Solberg or Bio-Ex, the Scandinavian countries tend to use Dr. Sthamer, the UK and Ireland tend toward Angus and Dr. Sthamer, France uses Bio-Ex and Eau et Feu, and Canada seems to be trending towards National. The previous information was not an endorsement or recommendation of a specific product but rather to inform the reader of products currently being used in the aviation industry.

C.4.2.4. Petroleum Industry R&D

In addition to the UL and EN Standards, and Annex F of NFPA 11, the petroleum industry also relies on an industry focused organization known as LASTFIRE to conduct a significant amount of their research. The LASTFIRE standard test specification is used by a number of oil companies as part of a detailed performance-based procurement specification. This test was developed in the1990s, originally by Mobil Research and Development Center (MRDC) recognizing that none of the available standards truly represented the special conditions of a tank fire. MRDC handed the protocol over to LASTFIRE for completion and adoption. Generally speaking, the LASTFIRE test protocols are commercial standards that have modified to be more representative of large tank conditions. These modifications include pan side heights and application devices to name a few.

LASTFIRE has been supporting/leading the petroleum industry in assessing FFFs by conducting research, workshops and conferences. The LASTFIRE website (http://www.lastfire.co.uk) provides a significant amount of this information including tabs to the workshops conducted in Dallas TX (DFW Airport) in 2018 & 2019, and more recent conferences conducted in Rotterdam in April of 2020 and France in September of 2021. Typically, the workshops and conferences are attended by and include presentations from end users, foam manufacturers, equipment manufacturers and research organizations.

With the understanding that the characteristics of the foam blanket (i.e., degree of aspiration provided by the discharge system/device) are key performance parameters for FFFs, there have been several studies conducted recently looking at Compressed Air Foam Systems (CAFSs) to enhance the capabilities of these products. Several of the studies have been conducted for US DoD via SERDP and ESTCP programs. As a short explanation, a CAFS incorporates a mixing/aspiration chamber in the pipe network, where air is injected and mixed into the solution prior to the discharge device. CAFSs have been shown to produce more uniform foam structures with higher densities of smaller bubbles. Relating this to fire performance, CAFSs have been shown to increase the capabilities of most FFFs in many applications (i.e., reduce the extinguishment times and increase the burnback resistance) and tends to produce similar results between many of the FFFs (i.e., tends to level the playing field with respect to product performance). There are however tradeoffs associated with the system. Specifically, the system adds additional components to legacy type foams systems which may increase the maintenance requirements and reduce reliability. In addition, there may be significant space, weight and cost penalties associated with the storage of the compressed air and/or compressed air system.

A number of products have been tested over a range of scales including Solberg (Perimeter), Angus/National Foam, Eau et Feu, BioEx, Dr Sthamer, and 3F, with a variety of CAF, fixed system and monitor application techniques. One Scandinavian oil company (Equinor) has made a total transition whereas others, including global organizations, have made the commitment to do so and have started the process using fluorine free in first strike apparatus. Australian companies in the State of Queensland and elsewhere are making the transition based on new legislation and have worked with the regulator to develop pragmatic timescales and a risk-based approach to clean up of application systems and hardware. The need to consider the combination of equipment characteristics and foam concentrate to optimize performance has been highlighted in this work. The previous information was not an endorsement or recommendation of a specific product but rather to inform the reader of products currently being used in the petroleum industry.

C.4.2.5. International Test Labs, Interest Group Reports and Conferences

Many of the international test labs are also actively researching AFFF alternatives. The labs currently active in foam research, but are limited to include:

- NIST (United States) - https://www.nist.gov/el/fire-research-division-73300
- RISE (Sweden) - https://www.ri.se/en)
- VTT (Finland) - https://www.vttresearch.com/en
- SINTEF (Norway) - https://www.sintef.no/en/
- VDS - https://vds.de/en/
- BRE Group (United Kingdom) - https://www.bre.co.uk/page.jsp?id=1721

Most of the recent research can be found on their websites by reaching “fluorine free” or “PFAS Free” firefighting foams. Some of the more predominant research papers written over the last few years are summarized below.

Wood Environment and Infrastructure Solutions Report

In 2018, Wood Environment and Infrastructure Solutions in the UK started a two-year effort to investigate “The use of PFAS and fluorine-free alternatives in fire-fighting foams”. The initial report was published in mid-2019 and the final a year later (mid-2020). The report was conducted for the European Commission DG Environment / European Chemicals Agency (ECHA) and is available at the following website:

https://echa.europa.eu/documents/10162/28801697/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

The overall aim of the report is to collect information to support the assessment of potential regulatory management options to address the human health and environmental risks associated with the use of PFAS in fire-fighting foams in the EU, as well as providing that information in the format of a REACH Annex XV dossier.

The report includes a significant amount of data on the types and market shares of the various types of PFAS and fluorine free alternatives, an assessment of the emissions and hazards of these new products, perceived capabilities of these products based on a literature and survey of end users (i.e., no testing was conducted during this effort), a review of remediation costs and technologies and the socio-economic impact of substituting one of these products for legacy AFFF. In addition, there are detailed case studies of transitions that have already been made by both the ARFF and Petroleum Industries.

International Pollutants Elimination Network (IPEN)

The International Pollutants Elimination Network (IPEN) is a committee of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals. One of the most extensive panel studies on FFFs was published during the Stockholm Convention POPRC-14 in Rome (September 2018). The report "Fluorine-Free Fire Fighting Foams (3F) – Viable Alternatives to Fluorinated Aqueous Film-Forming Foams (AFFF)" is available at:

https://ipen.org/sites/default/files/documents/IPEN_F3_Position_Paper_POPRC-14_12September2018d.pdf

The 74-page report includes case studies on previous transitions in both the petroleum and aviation industries as well as testimonials and contact information for the various panel experts.

NRC Construction Research Centre - Canada

In October 2020, the NRC completed a program titled "Assessment of Non-Fluorinated Firefighting Foams: Foam Performance and Ecotoxicity" The study included a review of available fire performance data on twelve commercially available products (no testing was conducted by NRC) as well as an ecotoxicity analysis. The fire performance assessment was consistent with most other studies stating that the new FFF products were not as good as AFFF. The study also concluded that the ecotoxicity of the FFFs depended on the chemical ingredients used in the product, but overall, the FFFs did not pose a clear advantage over the fluorinated surfactants used in AFFFs. In general, many of the FFFs were found to have high concentrations of hazardous ingredients, which resulted in rankings between Acute 1 (very toxic) and Acute 3 (harmful) when analyzed with the highest concentration values in their safety data sheets (SDS).

Groups arguing for keeping legacy AFFFs

There are a group of organizations and consultants that are arguing against the ban on AFFFs (namely AFFFs that contain short chain fluorinated surfactants (i.e., C6 products)). The consortium continues to write reports and present technical data stating inadequacy of the current FFFs as well as health and environmental data stating C6 AFFFs are safe for use. The information prepared by these organizations is always worth reviewing, however, this group represents only a small percentage of the fire protection and regulatory community. In other words, the vast majority of the fire protection industry and regulators, believe these products to be hazardous driving the need to make this transition. From a first responder or fire protection engineering perspective, the regulatory environment is out of our control and we need to follow best practices going forward. An example is a recent report published by the Fire Protection Association - Australia available at the following link: http://www.fpaa.com.au/advocacy-technical/technical-documents/information-bulletins/ib-06-v11-selection-and-use-of-firefighting-foams.aspx.

C.5. ENVIRONMENTAL AND HEALTH CONCERNS

The selection criteria described previously was based solely on fire performance. With that said, the selection of a next-generation foam also needs to include an assessment of the environmental and health concerns. It needs to be understood that the elimination of PFAS and/or fluorine from the product does not address all the potential health and environmental hazards (only one family of chemicals).

The fire protection industry is working with environmental and health groups to develop some approaches for assessing these concerns for firefighting foams. Unfortunately, the development of such a standardized approach is still in its infancy.

On a regulatory level, most assessments and approaches developed to date consist of comparing the list of chemicals in the foam concentrate to standard databases of chemicals that are known to be health hazards and/or are known to have ecotoxicity issues. These assessments are typically based on composition data provided by the manufacturer which is, in only a limited number of scenarios, ever empirically/analytically verified. Two such assessments are GreenScreen (https://www.greenscreenchemicals.org/) and the US EPA's Safer Choice (https://www.epa.gov/saferchoice).

Overseas, GreenScreen has become the industry standard for evaluating these products (i.e., FFFs). GreenScreen is comprised of three main steps: assess and classify hazards, assign a benchmark score, and make informed decisions. Ultimately, the product will receive a rating of gold, silver or bronze. Most FFFs that have been assessed by GreenScreen have received bronze ratings. It is my understanding that the "foamability" of these products (which is the characteristic that makes them effective) creates a hazard to aquatic life which explains and/or is related to the lower rating.

The EPA's Safer Choice is gaining traction and will most likely become the default standard for FFFs here in the United States. Safer Choice is like the GreenScreen analysis. Each chemical ingredient in a formulation is evaluated against a Master and Functional-Class Criteria document, as appropriate. These documents define the characteristics and toxicity thresholds for ingredients that are acceptable in Safer Choice products. The criteria are based on EPA expertise in evaluating the physical and toxicological properties of chemicals, and while they incorporate authoritative lists of chemicals of concern, they go far beyond these lists. Safer Choice applies the criteria using EPA research and analytical methods to ensure that Safer Choice products contain only the safest possible ingredients. All criteria documents are part of the Safer Choice Standard.

Since there are not any widely enforced specific requirements on the health and environmental hazards of FFFs (other than possibly PFAS or Fluorine content), it is typically left to the foam manufacturer to have the product assessed. The information provided in most of the AFFF and FFF Safety Data Sheets is general in nature and may not provide enough information about health and safety precautions to be able to develop proper precautions to protect firefighters when using these firefighting agents. The Fire Department management should consider asking foam manufacturers to get specific detailed health and safety information to develop appropriate health and safety guidelines.

C.6. SUMMARY

This Annex provides the framework for the selection of a next-generation foam. The regulatory landscape is changing almost daily and needs to be monitored to determine when the transition to a next-generation foam needs to be completed. The websites identified in Annex A provide the tools to monitor these requirements of various state and federal levels.

There are numerous available resources to help with this transition and reduce the learning curve impact. Most, if not all, of the National Fire Protection Association (NFPA) Standards that include the use of foams in the protection schemes are being revised to include fluorine-free foams and/or other environmentally acceptable alternatives/approaches. These standards may provide information on both the selection and use of these new products.

The foam selection framework described in this annex provides a couple of different approaches for identifying and selecting a fluorine-free foam. In short, one focuses on compatibility with current hardware and/or a comfort level associated with a specific foam manufacturer and a second which revisits the basics and hazards and focus on best performers independent of previous experience. Ultimately, there are a range of potential products that should be considered and researched prior to final selection. A list of the products (and their associated websites) that appear most frequently throughout the literature was provided in Section C.1.2. The main take of this section is that doing your homework to become better informed should ease the selection and transition burden and reduce the likelihood for transition regret (i.e., to avoid multiple repeated replacements over time). Learning from others in your industry that have already made the transition is highly recommended. With that said, talk to at least two organizations that have already made the transition to potentially provide different viewpoints on specific issues.

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Firefighting Foams: Fire Service Roadmap

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Environmentally Sustainable Methods Demonstrations to Clean Firefighting Delivery Systems

09/30/2020

The Department of Defense's (DoD's) goal to use per- and polyfluoroalkyl substance (PFAS)-free firefighting formulations requires that existing firefighting systems that have previously contained PFAS-based agents be cleaned prior to use with PFAS-free formulations. With a large amount of foam delivery systems in aircraft hangars and on firefighting vehicles, replacing or cleaning this equipment would be very costly. Development of a method to remove all trace elements of the current firefighting agent from its existing systems, thereby eliminating the need to replace equipment, would be a substantial cost savings for the DoD.

In 2020, ESTCP began funding a group of projects that will demonstrate and validate environmentally sustainable methods for cleaning firefighting delivery systems in aircraft hangars or on firefighting vehicles as well as any rinsate or residue derived from the cleaning process. Described below are the six projects that were selected for funding.

- At Duke University, Dr. Marc Deshusses and his team will demonstrate the use of supercritical water oxidation (SCWO) for the complete destruction of PFAS in a variety of relevant waste streams. The PFAS destruction efficacy will be quantified and optimized under a range of operating conditions. The results of this demonstration will provide a cost-effective, scalable treatment option that has the ability to co-treat all types of wastes. (Project Overview)
- Dr. Selma Mededovic at DMAX Plasma, LLC and her team will demonstrate the operation of a mobile plasma treatment system for the treatment of AFFF rinsate from firefighting delivery systems. This technology does not need chemical additions and produces no residual waste that will limit future liability. (Project Overview)
- At Colorado School of Mines, Dr. Chris Bellona and his team will demonstrate the use of propylene glycol as a co-solvent to remove residual AFFF constituents from tanks and lines of firefighting delivery systems. In addition, they will optimize a nanofiltration process for separating the PFAS and co-solvent mixtures. This demonstration will provide a cost-effective approach for cleaning out older firefighting equipment for use with new, PFAS-free firefighting agents. (Project Overview)
- Mr. Ian Ross from Arcadis and his team will demonstrate the use of a biodegradable cleaning reagent as an effective cleaning option to remove entrained PFAS from fire suppression systems and associated infrastructure. The results of this demonstration will provide an optimized, standardized cleaning method to remove PFAS from existing infrastructure across DoD. (Project Overview)
- At CDM Smith, Inc., Dr. Kent Sorenson and his project team will demonstrate the use of the treatment solution, PerfluorAd®, as a functional precipitate to enhance the cleanout of firefighting delivery systems and the resulting rinsate. This demonstration will provide a low-cost, sustainable process for cleaning firefighting delivery systems with little waste production. (Project Overview)
- Dr. Matthew Magnuson from the U.S. Environmental Protection Agency (USEPA) and his team will provide data, information, and best practices on the efficacies of decontamination techniques for firefighting systems and how to manage the decontamination solutions containing PFAS. The project results will include a standardized decontamination framework based on a toolbox of options utilized across the DoD aviation firefighting community. (Project Overview)

Summaries of these demonstration projects are available on the SERDP and ESTCP website and all reports originating from these efforts will be available from the project webpages.

Blog Posts
- SERDP and ESTCP (46)
- Installation Energy and Water (52)
- Environmental Restoration (66)
- Munitions Response (61)
- Resource Conservation and Resiliency (67)
- Weapons Systems and Platforms (64)

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Schedule of events, solicitation deadlines, and training opportunities.
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Annex D Cleaning of Equipment

Prepared By:

Noah J. Lieb
Jensen Hughes
Baltimore, MD USA

Reference: SERDP ESTCP DOD's Environmental Research Programs. https://www.serdp-estcp.org/News-and-Events/Blog/Environmentally-Sustainable-Methods-Demonstrations-to-Clean-Firefighting-Delivery-Systems

D.1. CLEANING OF AFFF CONTAMINATED EQUIPMENT

Equipment containing legacy AFFF needs to be cleaned prior to transitioning to a new foam or when it is being decommissioned. This can include storage tanks, fixed installation piping, fire trucks or other Aircraft Rescue and Firefighting (ARFF) equipment. Multiple studies have shown that PFAS persists in the tanks, piping, gaskets, and other components of the firefighting equipment, with potentially more risk for residual contamination in "soft" components like gaskets and hoses. Entrained PFAS forms scale on the surfaces that make it difficult to remove with a simple water rinse. If the equipment is not thoroughly cleaned, PFAS will continue to pollute the equipment and subsequent FFF will be contaminated with PFAS. Initial analysis has shown that PFAS concentrations rebound in the weeks that follow a cleaning (i.e., concentration of PFAS will continue to rise as it is solvated into the new solution).

The most common method of cleaning AFFF from firefighting equipment is water rinsing. This method requires the draining and collection of AFFF solution followed by a triple-rinse with PFAS-free water to ensure no foam concentrate remains. This was identified as a best practice during numerous successful transitions and by US DOD research. Some states and facilities require the use of deionized water, while others allow the use of municipal water that does not contain PFAS. Tanks and similar foam housing equipment are required to be visually inspected for residual foam, while hoses are required to be flushed thoroughly until the water discharge is clear and free of foam. Runoff water, anecdotally at least 3-4 times the volume of the system, needs to be contained and stored in proper containment until it can be sent for further disposal. This produces an excessive amount of wastewater with relatively low concentrations of PFAS. It may be preferable to concentrate the PFAS through physical separation or water evaporation to reduce the amount of waste that must be treated. PFAS can be separated from the wastewater through a variety of separation technologies, including granular activated carbon or ion exchange resin treatments.

Cleaning solutions or reagents can also be used to remove AFFF solutions from existing system components. International partners have already started the process of transitioning to FFF. Addition of a cleaning agent has been shown to remove PFAS from the walls of the equipment. Subsequently it has been used to decontaminate fixed and mobile fire suppression equipment successfully. The Office of the Secretary of Defense Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program (SERDP/ESTCP) is funding research into PFAS treatment and destruction technologies, including ARFF equipment clean-out. New clean-out technologies are currently at various stages of maturity and are being demonstrated at DoD facilities. More information is available at: https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs.

D.2. HOW CLEAN IS CLEAN ENOUGH?

To date, there is no clear guidance for how clean final rinsate water must be to satisfy local regulators (i.e., it is currently not mentioned or is undefined). All rinsate should be stored and disposed of per all required local, State and Federal regulation. Discussion has been centered around trying to meet either the EPA drinking water advisory level for PFAS (70 ppt), the 1 ppb total PFAS requirement in the NDAA for DoD foams, or the 1 ppm PFAS that has become adopted by other industry standards (e.g., GreenScreen and UL-162). Specifically, these industries/countries have defined acceptable limits for PFAS as products containing less than 1 mg/L (1 ppm) of organic fluorine. It has been difficult to reliably measure concentrations of PFAS and/or organic fluorine below 1 ppm with the available technologies.

The EPA plans to publish revised disposal/destruction guidance in 2023. It is recommended that organizations collect samples prior to rinsing and after the final rinse to provide a percent reduction in the final system until there is further guidance from the EPA, DoD or other end users for the best practice for equipment cleanout. Samples can be analyzed for Total Organic Fluorine, Total Organic Precursor Assay or select PFAS compounds if the composition of the foam is known. Additional guidance should become available on the EPA's website: https://www.epa.gov/laws-regulations.

The European Chemicals Agency (ECHA) will provide requirements aimed at regulating the EU export, production, and use of PFAS in firefighting foams. The final requirements are being reviewed by ECHA's scientific Committees for Risk (RAC) and Socio-Economic Analysis (SEAC) and should be implemented in the March/April 2022 timeframe.

In closing, it is understood that this entire cleaning process takes time and minimizing the "out of service" time is essential and needs to be considered/accounted during the transition process.

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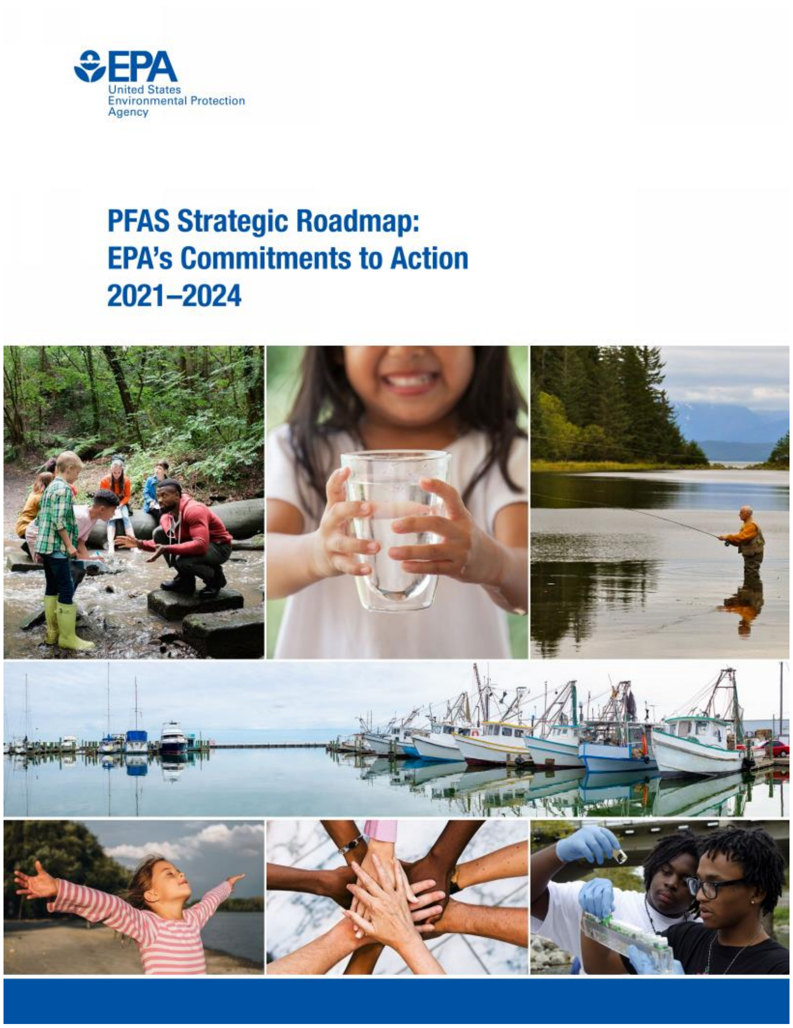
Firefighting Foams: Fire Service Roadmap

Annex E
Disposal of AFFF Products



Reference: US Environmental Protection Agency. https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

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E.1. BEST PRACTICES FOR DISPOSAL AND DESTRUCTION

Legacy AFFF must be disposed of according to Federal, State, and local regulations. As a result, the legacy practices of diluting with copious quantities of water and dumping into sewer drains is no longer acceptable. As a general practice, AFFF waste (i.e., concentrate, foam solution discharge, and rinsate water) should be contained and stored prior to disposal. AFFF and PFAS constituents can either be destroyed through high energy process or safely stored in a highly contained long-term waste facility. There are also technologies in development to potentially destroy PFAS in place in ground water or soil that has been contaminated by PFAS; however, they are limited in application. In Dec 2020, EPA released interim guidance on destruction and disposal of PFAS (and AFFF). Destruction was defined as thermal treatment and disposal was defined as landfilling and underground injection. The EPA prescribed the best options based on current data. They recommend the following:

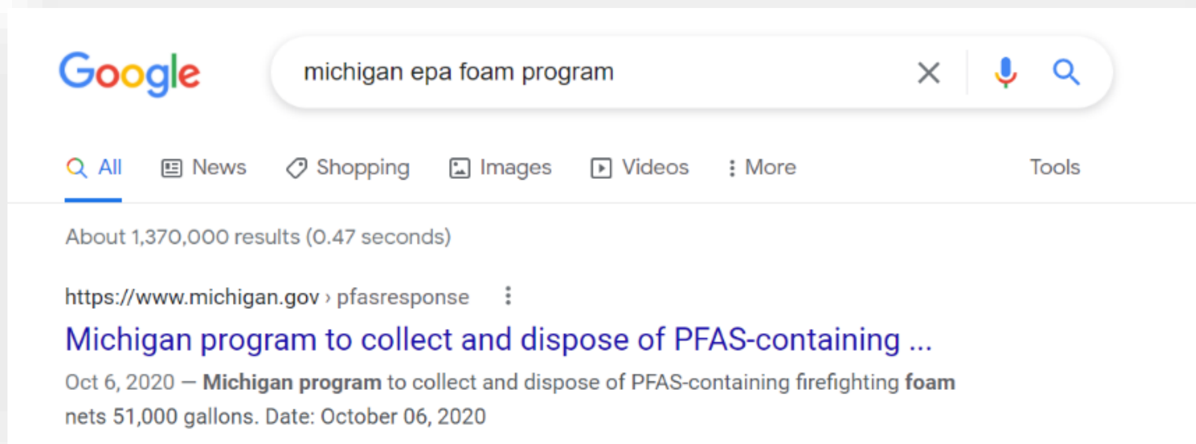
- Interim storage (2-5 years) while alternative methods are developed
- Permitted deep well injection (Class I)
- Permitted hazardous waste landfills (RCRA Subtitle C)
- Solid waste landfills (RCRA Subtitle D) that have composite liners and leachate collection and treatment systems

The EPA is continuing to evaluate emerging options to determine destruction efficiency for hazardous waste combustors (commercial incinerators, cement kiln, etc.) and other thermal treatment (municipal waste combustor, thermal oxidizer, etc.). EPA anticipates revised recommendations for destruction technologies as early as 2023 via a revised guidance document. In addition, the 2022 National Defense Authorization Act prohibited the incineration of covered materials by the DoD until EPA publishes a final rule regarding the destruction and disposal of AFFF. Multiple states established regulations restricting incineration of AFFF as a disposal method, with more being restrictions being proposed. As of 2021, at least two states have proposed regulation to prohibit incineration of AFFF in specific circumstances.

Additional details on destruction technologies are provided below; however, a more thorough summary of these alternatives can be found through DoD research programs. The Office of the Secretary of Defense Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program (SERDP/ESTCP) is funding research for PFAS treatment and destruction technologies. Destruction and separation technologies are currently at various stages of maturity and are being demonstrated at DoD facilities. More information is available at https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs.

E.2. STATE AFFF TAKE-BACK PROGRAMS

Several states have implemented take-back programs for PFAS-containing foams. Consult with your local state environmental protection agency to obtain more details on available take-back programs. Effective programs may be completely free of charge for pick-up, transport and safe disposal of all forms of legacy AFFF. Most of these regulations can be found by search your State EPA on your browser. An example of such a search is provided in the figure below.



The Interstate Technology Regulatory Council (ITRC) website (https://pfas-1.itrcweb.org/) is also a good source for this type of information.

E.3. Available Options for Disposal (State/Local and Waste Companies)

There are a range of disposal options currently being investigated. These include thermal destruction, separation and isolated landfills or deep well injection. The EPA is currently reviewing the information available on the various disposal/destruction options and will provide a list of approved methods in the near future. As of today, the disposal and destruction are currently regulated on a state level and should be documented on the state's EPA website.

Thermal treatments have been the most commonly used disposal methods for AFFF and PFAS-containing substances. These treatments can be divided into two categories: thermal destruction and thermal desorption.

E.3.1. Thermal Destruction

Incineration was one of the most common AFFF treatment methods and is used for both production and municipal waste disposal, as well as a product's end-of-life disposal. This process has been reported to destroy up to 99.9% of fluoropolymers and residual contaminants in emission gases are cleaned up with scrubbers or electrostatic precipitators. Any residual gas products are further treated with off-gas treatment technologies and ash that remains from the incineration process is either disposed of in a landfill or used in construction. Currently, there are no dedicated incinerators for solely PFAS-containing wastes. Historically, incineration has been recommended for unused AFFF solutions and non-residential spent treatment media. However, the EPA has been studying the potential fluorine-containing products of incomplete combustion that are emitted during incineration. The EPA advised that AFFF incineration methods be stopped until further research can address the current data gaps and the EPA can make a more informed recommendation on the proper disposal of PFAS compounds and PFAS-containing substances using incineration.

Emerging Technologies include cement kiln treatment, pyrolysis or smoldering. Cement kiln treatment utilizes rotary kilns to incinerate material and convert them into a final cement product. Further research needs to be conducted on this topic to determine potential emission levels and destruction efficiency, but the EPA has stated that this is a promising option for PFAS waste removal once the technology is fully developed. Pyrolysis, also referred to as thermolysis, chemically decomposes organic materials at high temperatures under inert conditions. It can be used to treat soils containing PFAS through a two-step process; first by desorption at the hydrocarbon's boiling point, generally between 150°C and 350°C, followed by pyrolysis which occurs between 400°C and 500°C. The end products from pyrolysis are carbonaceous materials that can be used in agricultural applications, while any volatile contaminants can be further incinerated or reused. The pyrolysis method of disposal is being reviewed and evaluated by the EPA to determine its cost and efficiency for public or private use. Smoldering is a self-sustaining thermal destruction method that uses flameless combustion in a condensed fuel surface to produce carbon dioxide, water, and energy in the presence of oxygen. More research needs to be conducted to evaluate the efficiency of this method.

E.3.2. THERMAL DESORPTION

Thermal conduction heating is a thermal desorption method that is still undergoing field trials but has reported to remove up to 99.9% of PFAS when soil was heated to 350-400°C over a one-week period. Another field trial demonstrated the capability to heat contaminated soil to a desired temperature for thermal desorption of PFAS over time (79 days at 400º C). While this disposal method is still under review, it is one of the most promising methods for the removal of PFAS and other substances from soil.

Another recognized thermal desorption method is infrared heating. This treats contaminated materials including soils and sludges at high temperatures. The heating occurs in a small, mobile thermal desorption unit and uses vapor-phase activated carbon in combination with indirect infrared heating to destroy PFAS. It has also been successfully applied in several PFAS desorption technology pilot tests.

E.3.3. TREATMENT/SEPARATION

Granular Activated Carbon (GAC) reactivation, also referred to as carbon activation, is one of the most common treatment methods to separate PFAS from a contaminated media (water). GAC is a two-step process that utilizes either bituminous coal or coconut carbon to separate contaminants from water. GAC is reported to have a removal efficiency between 90% and 99% but must be replaced or reactivated regularly. This technology has the benefit of being widely used and having a high efficiency, but cost and the requirement of secondary treatment may not make it ideal for widespread use as a permanent PFAS solution.

Ion exchange resins have also been used to separate PFAS from contaminated water. The resins used in this treatment are highly porous and remove negatively charged contaminant ions and are therefore very effective at removing long-chain PFAS. Ion exchange treatment is a viable method for PFAS destruction, as it can treat a wide range of PFAS compounds, has a smaller infrastructure footprint than most other disposal methods, and can be altered for site-specific needs.

An additional treatment method that is becoming more prevalent is high-pressure membranes. These membranes, either nanofiltration or reverse osmosis, are highly effective at removing both short- and long-chain PFAS. Nanofiltration membranes can retain more minerals than reverse osmosis. Despite their high effectiveness, these membranes are costly to use and may be more suitable for smaller-scale applications.

E.3.4. LANDFILL

Landfills are a commonly utilized method of disposing of PFAS-contaminated waste. The Resource Conservation and Recovery Act (RCRA) monitors landfill types and how they are operated, monitored, waste they can receive, and how they are closed. RCRA Subtitle C hazardous waste landfills are licensed to accept hazardous wastes that have been evaluated and determined to pose potential risk to humans and the environment. Subtitle C landfills are subjected to the most stringent environmental controls in place. These landfills are optimal for AFFF product or AFFF-related waste that exceeds regulatory concentration limits and has been properly managed for disposal. RCRA Subtitle D landfills can accept non-hazardous and non-putrescible waste and have environmental controls based on the waste they receive as well as the local and state requirements. These landfills are practical for low volume, low concentration waste, with little probability for drinking water contamination, and as such are not recommended for large-scale PFAS destruction. Hazardous waste landfills are the only Subtitle C landfills that can receive waste that is defined as “hazardous”. These landfills are required to have a double liner system as well as a final cover that consists of a flexible membrane liner covered by soil. Leachate from these landfills are required to be collected and treated through another disposal means.

E.3.5. UNDERGROUND INJECTION

Injection wells are used to store fluids such as water, wastewater, or water mixed with chemicals underground in porous geological formation (i.e., sandstone, limestone). There are six classes of underground wells, but injection wells used for PFAS disposal are classified as Class I under EPA guidance. Class I wells are constructed in deep, confined rock formations thousands of feet below the lowermost underground source of drinking water. Both hazardous and non-hazardous liquid wastes can be disposed of in these wells. There are four subcategories of Class I wells: hazardous waste disposal wells, non-hazardous industrial waste disposal wells, municipal wastewater disposal wells, and radioactive waste disposal wells. Of these, PFAS is most likely to be disposed in hazardous waste and non-hazardous industrial waste disposal wells. Hazardous waste disposal wells are the most strictly monitored wells and are required to follow RCRA and Safe Drinking Water Act regulations. EPA currently advocates underground injection as a feasible and effective disposal option, but there are limited wells available for disposal, which should be taken into consideration when selecting this as a disposal method.

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Firefighting Foams: Fire Service Roadmap

Annex F
Implementation

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F.1. INTRODUCTION

This annex provides the guidance for implementing the fluorine-free foam product from a functionality and performance standpoint. Prior to starting the process, reviewing one of the case studies documented during this program is highly recommended. Reaching out to an organization that has completed the transition may reduce the learning curve and expedite the transition.

The implementation of the selected product will first require the cleaning of the legacy equipment and the disposal of the effluent (i.e., rinsate) and legacy foam products. The cleaning of the legacy equipment is covered in Annex D and the disposal of the cleaning effluents and AFFF concentrates is covered in Annex E. Many states have take-back programs in effect which aid in this process. Information on these take-back programs is provided in Annex E.

There are a number of documents that need to be reviewed to ensure that the product is deployed withing its tested/approved parameters. These include: any applicable fire codes (i.e., NFPA, ICAO, etc.) and the approval test / UL listing parameters. Most of the NFPA and international standards have been or are being updated to allow these new fluorine-free products. With that said, the legacy test and design requirements have not changed significantly allowing many of these products to be used with currently installed systems (with some minor adjustments). The exception to this may be sprinkler applications which is discussed later in this annex.

The implementation process will require assistance/consulting from both the proportioning system hardware manufacturer as well as the next-generation foam manufacturer. This is predominantly true for the first responder community since their applications are typically not governed by specific codes and standards.

F.2. PROPORTIONING ISSUES AND CONCERNS

The following proportioning system discussion applies to all types and foam applications (i.e., fixed proportioning systems and mobile proportion systems (i.e., ARFF vehicles, fire trucks / pumpers and inline eductors).

In general, the primary concern associated with accurately proportioning FFFs is the concentrate viscosity. Current FFFs cover a wide range of viscosities from products that flow like water to products that are semi-solids and have the consistency of jelly/jam. The fire protection industry tends to refer to these thicker products as either non-Newtonian or pseudo-plastic concentrates. As general a statement, it appears that concentrates that have maximum viscosities (i.e., the viscosity at the lowest use temperature) of 200 mm^2/s (as determined using EN ISO 3104), can be proportioned with legacy AFFF hardware with little to no modification or adjustments.

The ability to accurately proportion non-Newtonian type products is system and concentrate specific and basically needs to be assessed on a case-by-case basis. There have been some successful transitions to non-Newtonian products, but they typically came with a learning curve (i.e., some trial and error was involved). One point that has been overlooked by many, is the ability of the concentrate to flow from the concentrate tank to the concentrate pump/proportioner driven by the static head pressure. Since the flow of non-Newtonian concentrates cannot be predicted using typical hydraulic calculations (i.e., Hazen-Williams), the system performance must be assessed empirically. In addition, since the static head pressure is typically a function of the concentrate fill level, the proportioning accuracy needs to be verified at the two extremes (i.e., a completely full concentrate tank and an almost empty concentrate tank)

There are a few positive displacement type proportioning systems that have been shown to work well with non-Newtonian concentrates. The FAA has also conducted a recent study that suggests that many of the ARFF vehicles can be adjusted to proportion almost all the new FFFs independent of the concentrate viscosity. This information should be available on the FAA website: https://www.faa.gov/. Many of the leading ARFF vehicle manufacturers participated in the study and are also good sources of information.

In any case, both the concentrate and proportioning system hardware manufacturers will need to be consulted during the transition process with the final setup being system calibration and concentration verification.

One of the considerations identified during the selection of the next-generation foam (ANNEX C) included hardware compatibility. For many applications, the foam concentrate is listed for use with a specific set of hardware (i.e., proportioning system and discharged devices). Most of the industry leading AFFF manufacturers are developing FFFs and there is a good chance that this product has been tested with legacy system hardware which would minimize potential future modifications.

If the end user application does not match the proportioning system and discharge hardware with a specific foam concentrate (e.g., ARFF vehicles/scenarios), contacting the hardware manufacturer is highly recommended, if not required. Many of the FFF manufacturers have been working with equipment manufacturers to verify compatibility between their concentrates and equipment used throughout the industry. If the hardware manufacturers do not have any information on the use of the selected next-generation foam with their equipment, they should still be able to provide some of the limits on the physical and chemical characteristics for the foam concentrates. At a minimum, this would require the definition of an acceptable range of concentrate viscosities that can be accurately proportioned by their system and the compatibility (i.e., corrosiveness) of the concentrate with the materials use in the system (storage tank, piping, and nozzle components). Ultimately, the foam concentration produced by the final arrangement will need to be verified empirically.

F.3. DISCHARGE DEVICES

The new fluorine-free foams are similar to the basic legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors and prevent them from mixing with oxygen/air above the fuel surface resulting in fire extinguishment (i.e., fluorine-free foams typically do not produce a surfactant film on the fuel surface like AFFF). There are a few fluorine-free foams that are advertised as film formers, but the degree of film formation is inadequate to significantly increase the capabilities of the product. Due to the reliance on the foam blanket, air-aspirating discharge devices may be required to optimize the capabilities of these products. With that said, it needs to be noted that these new products are “foamier” than the legacy products (including AFFF) and that the expansion ratios are usually about 1-2 points (and sometime even more) higher for FFFs than AFFFs over a wide range of discharge devises and typically have significantly longer drainage times than AFFF. This is a general observation of the technology, but the foamability of some products may vary. In addition, it needs to be noted that all of these products are tested and approved for most applications using low flowrate air-aspirating nozzles. These air-aspirated nozzles tend to make even the less foamy products produce a good foam blanket. During a couple of SERDP-ESTCP programs, the less foamy products did OK during the approval scale tests but failed on a larger scale when discharged with typical hose line nozzles. Prior to final deployment of the selected product, measuring the foam quality (i.e., expansion ratio and drainage time) produced by your specific hardware is recommended. A discussion of critical foam quality values is provided later in this section.

The first detailed parametric study of the capabilities and limitations of FFFs was conducted by the NFPA Fire Protection Research Foundation (FPRF) in 2019 to provide input to NFPA 11. The fire-fighting capabilities were assessed as a function of application rate (gpm/ft^2) and extinguishment application density (gal/ft^2) for a range of test parameters including foam quality (foam aspiration representative of both air aspirating and non-air-aspirating discharge devices), fuel type (heptane, Isopropyl Alcohol (IPA) and two grades of gasoline (E0 / MIL-PRF-24385F and E10)), water type (fresh and salt), and ambient fuel temperature.

The three major findings of the study include: (1) foam aspiration has a significant effect on the fire-fighting capabilities of FFFs, (2) there are variations in extinguishment performance associated with the fuel type, and (3) there are variations in extinguishment and burnback capabilities between listed FFFs. With respect to foam aspiration, the lower aspirated foam solutions (expansion ratios in the 3-4 range) had 20-50% higher extinguishment densities as compared to the higher aspirated foam solutions (expansion ratios in the 7-8 range). In some cases, higher application rates were required to extinguish the fires using the lower aspirated foam solutions.

During a recent SERDP-ESTCP program (WP19-5374: Foam Quality Effects on PFAS Free Foam Firefighting Capabilities), the firefighting and burnback capabilities of five higher performance FFFs were quantified as a function of aspiration. The study was conducted on an approval scale (i.e., 28 ft^2 pan fires) using both gasoline (E0) and Jet A as the test fuels. The foam was applied to the pan using a 2 gpm air-aspirating nozzle which corresponds to an foam application rate of 0.07 gpm/ft^2. The aspiration/expansion of the foam solution was varied by blocking/closing the aspirating holes in the nozzle. The average extinguishment times of five FFFs for the two test fuels as a function of foam aspiration/expansion are shown in Figure F.3.0-1.

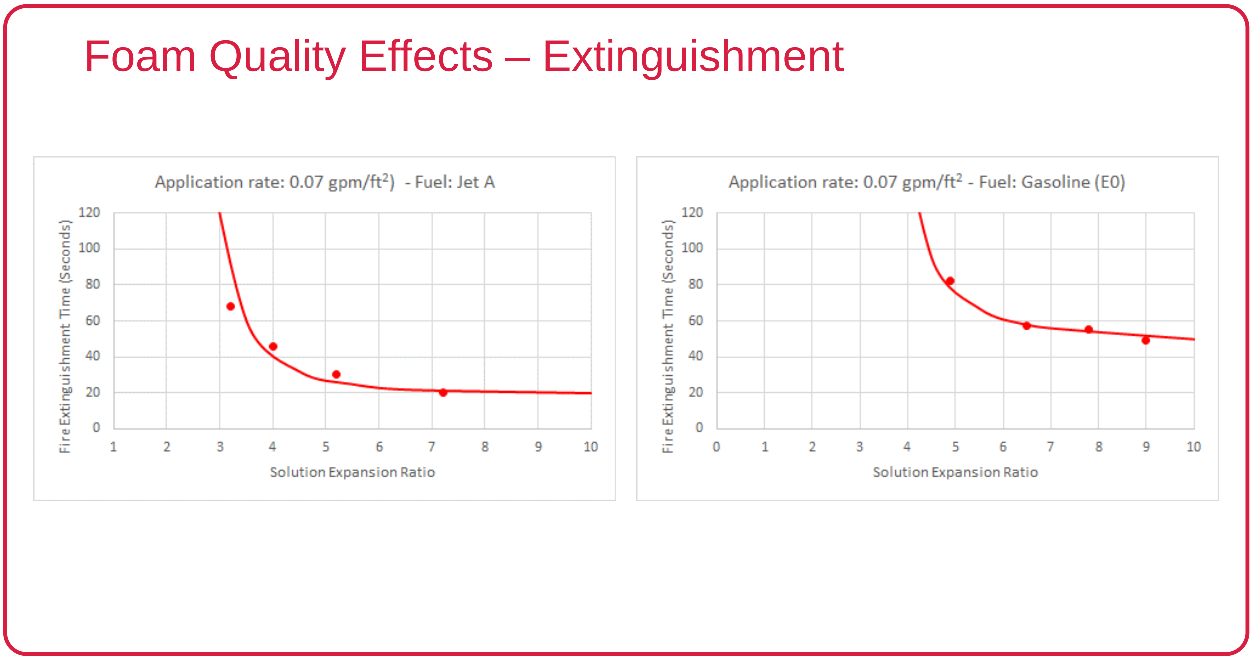

Figure F.3.0-1 Foam Quality (Aspiration/Expansion) Effects on Extinguishment Time

Prior to discussing the data in detail, it needs to be noted that the extinguishment times are a function of application rate, foam quality (i.e., aspiration/expansion), and application technique. Specifically, reduced foam quality can be compensated for by increased application rate and vise-a-versa. In addition, this data was conducted on an approval scale where the foam was "rained down" onto the fuel surface providing a gentle application of the foam and does not require the foam blanket to flow (or be pushed) to remote/obstructed areas in the pool. In addition, there is minimal fuel pickup in the foam blanket due to the gentle application of foam to the fuel surface. During an actual incident, hose streams tend to be much more forceful resulting in fuel pickup in the foam blanket. Some of the application technique issues will be discussed in the following section of the annex. The focus of the following discussion is to illustrate the effects/trends of foam quality on performance (i.e., both extinguishment and burnback/vapor suppression) to aid in the selection of discharge devices when deploying these products.

As shown in the figure, the extinguishment times tend to decrease with increased aspiration up to an expansion ratio in the three to six range, depending on the fuel. As can be seen from the curves, the lower flashpoint, higher vapor pressure gasoline is more difficult to extinguish and tends to push the line upward to the right. As a result, at lower application rates (i.e., 0.07 gpm/ft^2), the critical expansion appears to be in the four to five range. Conversely, the high flashpoint, lower vapor pressure Jet A (kerosene-based fuel) is much easier to extinguish (i.e., is extinguished faster) and is more forgiving with respect to foam aspiration (i.e., the critical expansion appears to be in three to four range for the 0.07 gpm/ft^2 application rate).

During that same SERDP-ESTCP program, typical hose line and turret nozzles were observed to produce foam expansion ratios on the order of 2-4 when set on straight stream and increase to 4-8 when set to a narrow angle fog (i.e., 15-30 degrees). This will be discussed further in the following section.

The burnback and vapor suppression characteristics as a function of foam aspiration/expansion are shown in Figure F.3.0-2. The results were obtained after the suppression the 28 ft^2 gasoline fires mentioned previously. During the test, the foam application rate was 0.07 gpm/ft^2 for a period of 90 seconds which corresponds to an application density of approximately 0.1 gal/ft^2. After discharge, a burning pan of gasoline is placed in the center of the 28 ft^2 pan and the time it takes for the fire to spread back over 25% of the fuel surface is recorded as the burnback time.

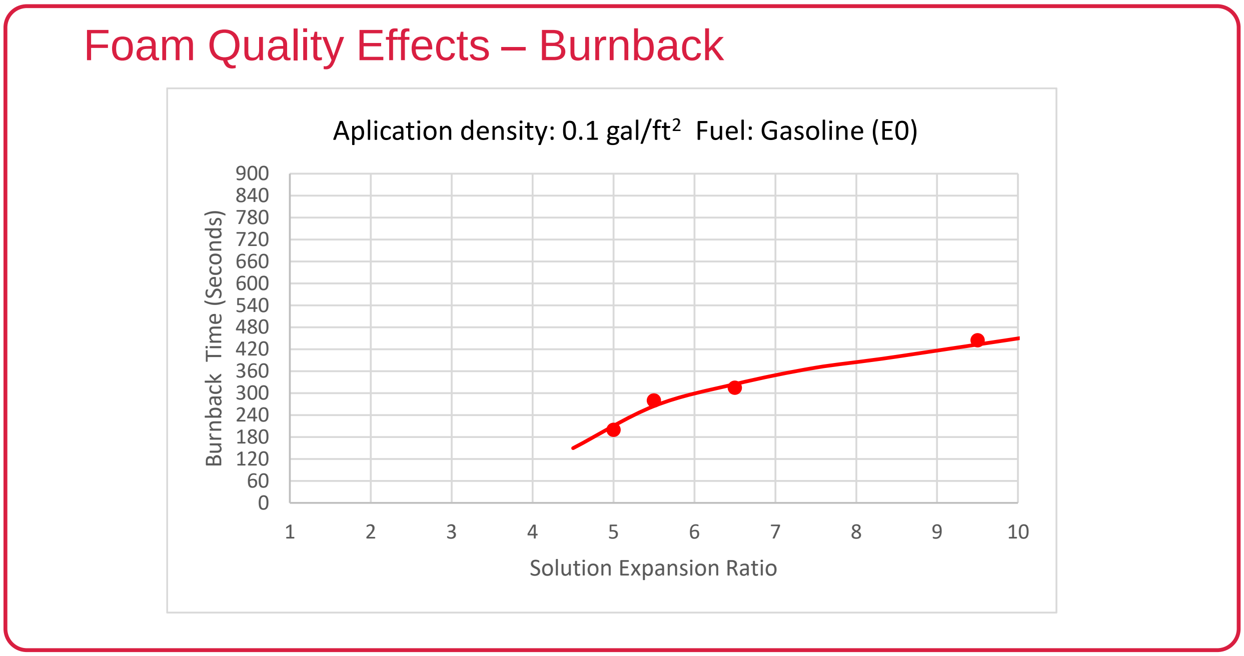

Figure F.3.0-2 Foam Quality (Aspiration/Expansion) Effects on Burnback Time

As shown in the figure, the burnback times (and vapor suppression capabilities) tend to increase with increased aspiration. These trends suggest that after a fire is extinguished and/or there is a fuel spill of a flammable liquid requiring vapor suppression, higher aspirated foam would be more effective. This will be discussed in more detail in the following section. Also, since FFFs rely strictly on the foam blanket to extinguish the fire and for vapor suppression, these products are formulated to have much longer drainage times with many of these products having 25% drainage times that are greater than 20 minutes.

Another point worth noting, the data shows that there is little, if any, burnback protection against gasoline, if the expansion ratio is less than 4 and the application density is only 0.1 gal/ft^2. Consistent with the extinguishment trends, adding more foam (i.e., increasing the application density) can compensate for lower aspirated foam to some degree.

The previous burnback and vapor suppression discussion was focused on gasoline which is a flammable liquid (i.e., a flashpoint less than 100^{o}F) as opposed to Jet A, which is a combustible liquid (i.e., a flashpoint of 100^{o}F or above). The lower flashpoint and higher vapor pressure characteristics of gasoline represents a fairly worst-case scenario from a burnback and vapor suppression standpoint.

The need for vapor suppression for combustible liquids will be driven by the temperature of the fuel at the time of incident. As an example, if a tanker truck overturned in the winter and developed a leak, a combustible liquid may be difficult ignite since it is well below its flashpoint. Conversely, if the truck had been engulfed in fire and was extinguished, the fuel could have been heated above its flashpoint requiring vapor suppression to prevent reignition.

Several studies have also been conducted looking at Compressed Air Foam Systems (CAFSs) to enhance the capabilities of FFFs. As a short explanation, a CAFS incorporates a mixing/aspiration chamber in the pipe network, where air is injected and mixed into the solution prior to the discharge device. These systems have been shown to produce foam blankets with a high density of smaller bubbles which tends to increase the capabilities of these products (i.e., faster extinguishment times and better burnback/vapor suppression characteristics). Most of this research (i.e., foam quality effects and CAFS performance) is available at https://www.serdp-estcp.org/.

LASTFIRE has recently completed a program to assess the capabilities of these products when discharged through typical petroleum industry discharge devices (i.e., non-air aspirated monitors, semi-aspirated monitors, and tank top pourers) against realistic scale, fuel storage tank fire scenarios. The study was conducted at typical NFPA 11 discharge rates (minus a factor of safety). The study concluded that the FFFs that were selected for the assessment were able to meet the legacy performance objectives when deployed using typical petroleum industry hardware and at current design discharge rates. The FFFs that were selected for the assessment are the current industry leaders with the greatest depth of approvals and listings and do not represent the capabilities of the technology as a whole. Restating these findings differently, the foam quality produced by the FFFs when discharged through legacy petroleum industry hardware was adequate to meet the intended performance objectives. The LASTFIRE website (http://www.lastfire.co.uk) provides a significant amount of this information including tabs to the workshop conducted in Dallas TX (DFW Airport) in 2018 and recent conferences conducted in Rotterdam in April of 2020 and France in September of 2021.

The ability to effectively discharge these FFFs through standard sprinkler nozzles is still a work in progress. The products work well when discharged through air-aspirating nozzles like the Tyco B-1 open-head foam-water sprinklers, but the capabilities vary significantly when discharged through closed head, standard sprinkler nozzles. There are some FFFs with limited UL listings and FM approvals for sprinkler systems, but these are product and nozzle specific and by no means represent a technology-wide capability. If considering FFFs for sprinkler type applications, the designer will need to deploy these products strictly within the listed or approved parameters to increase the likelihood for success.

F.4. TECHNIQUES AND TACTICS

The previous two sections have focuses primarily on hardware, both proportioning equipment and discharge devices. This section will provide a high-level discussion on manual firefighting application techniques and tactics. Most of this information was collected during two recent SERDP-ESTCP programs (WP21-3461 & WP21-3465: Validation Testing of the Leading Commercially Available PFAS-Free Foams). The final reports are available on the SERDP-ESTCP website (link provided in the previous section).

The tests were conducted to validate the capabilities of five higher performance, commercially available FFFs against two large scale fire scenarios (i.e., running fuel/debris pile and fuel spill fire scenarios) representative of ARFF type incidents. All fires were produced using F-24 as the fuel. F-24 is the U.S. Navy's equivalent to Jet A. The capabilities of the five FFFs were benchmarked against a MilSpec C6 AFFF. During Phase I, the fires were fought using a 125-gpm fire hose and during Phase II, the fire were fought with a 250-gpm turret nozzle installed on a small ARFF vehicle.

The following discussion will focus primarily on the fuel spill fires combated with the 125-gpm hose line. The fuel spill fires were produced by discharging 400 gallons of F-24 onto a concrete surface which produced a spill area of about 2500 ft^2. The 125-gpm nozzle over the 2500 ft^2 spill area corresponds to an application rate 0.05 gpm/ft^2. A photograph of the 2500 ft^2 spill fire is provided as Figure F.4.0-1. The fire sizes were doubled during the turret tests to keep the same application rate.

Figure F.4.0-1 ARFF Spill Fire Scenario

The 2500 ft^2 fuel spill fires were combatted with three hose line nozzle configurations: the standard nozzle without attachments, the standard nozzle with a long (lower aspiration) foam tube, and the standard nozzle with a short (higher aspiration foam tube). The optimal standard nozzle setting was a narrow angle fog pattern (approximately 10-degree spray angle). At this setting, the standard nozzle provided a 75 ft effective reach of foam solution with an expansion ratio in the range of 4-6. The longer foam tube provided a 65 ft effective reach of foam solution with an expansion ratio in the range of 7-9. The shorter foam tube provided a 45 ft effective reach of foam solution with an expansion ratio in the range of 12-23. Photographs of the nozzles and hose streams are provided in Figure F.4.0-2.

Figure F.4.0-1 Hose Line Nozzle Configurations

To summarize the results of the program, the MilSpec AFFF outperformed the five FFFs in both scenarios and under all conditions (i.e., discharge devices). However, the FFFs demonstrated the ability to control and extinguish the test fires conducted during this series with application rates well below those fielded in the ARFF industry. The AFFF was able to extinguish the fuel spill fires in about 30 seconds, independent of the discharge nozzle. All five FFFs were also able to extinguish the spill scenarios but the extinguishment times were typically about 1.5-2 times longer than the AFFF (but typically in less than a minute).

With respect to the discharge device, there are trade-offs associated with using standard nozzles versus foam tubes. The standard nozzle provides more reach and pattern control but with limited foam aspiration. This provides the firefighters with flexibility with respect to how they fight the fire. The foam tubes produce higher aspirated foams but are limited to a set spray pattern and reduced reach. However, the higher aspirated foam produced by the foam tubes by nature, is applied more gently to the fuel surface, had better extinguishment and vapor sealing capabilities but required more technique and faster advancement (i.e., the firefighting party had to advance through the spill in order to reach the other side/completely extinguish the fire).

When comparing the AFFF and FFFs against the fuel spill fire scenario, a few observations were noted. First, when the FFFs were applied forcefully to the fuel surface, there appeared to be significant fuel pickup in the foam blanket allowing the fire to continue to burn on top of the blanket. In addition, the firefighters tended to punch holes in the existing foam blanket at the stream impingement location. As a result, a “gentle” application of FFF appeared to work more effectively. Second, the FFFs tended to leave small burning pockets in the spill that required to the firefighting party to circle back and extinguish, slowing their advancement into the spill. These small burning pockets were not observed using AFFF presumably due to the film formation provided by the AFFF. Lastly, shadowing effects caused by obstructions tended to have a greater impact on the

FFFs as compared to AFFF. Specifically, one pass of a stream of AFFF typically extinguished all the fire in application, including on the far side of smaller obstructions. Conversely, the FFFs tended to leave small holes in the foam blanket and needed more agent to extinguish all of the obstructed fires. In short, the FFFs typically took two passes of foam application to match the single pass of AFFF explaining the 1.5-2 times longer extinguishment times. These phenomena were observed for both the hose lines and well as for the fires fought with the ARFF truck turret and are shown in Figure F.4.0-3. But again, during both test series, the FFFs demonstrated the ability to control and extinguish the test fires conducted during this series with application rates well below those fielded in the ARFF industry.

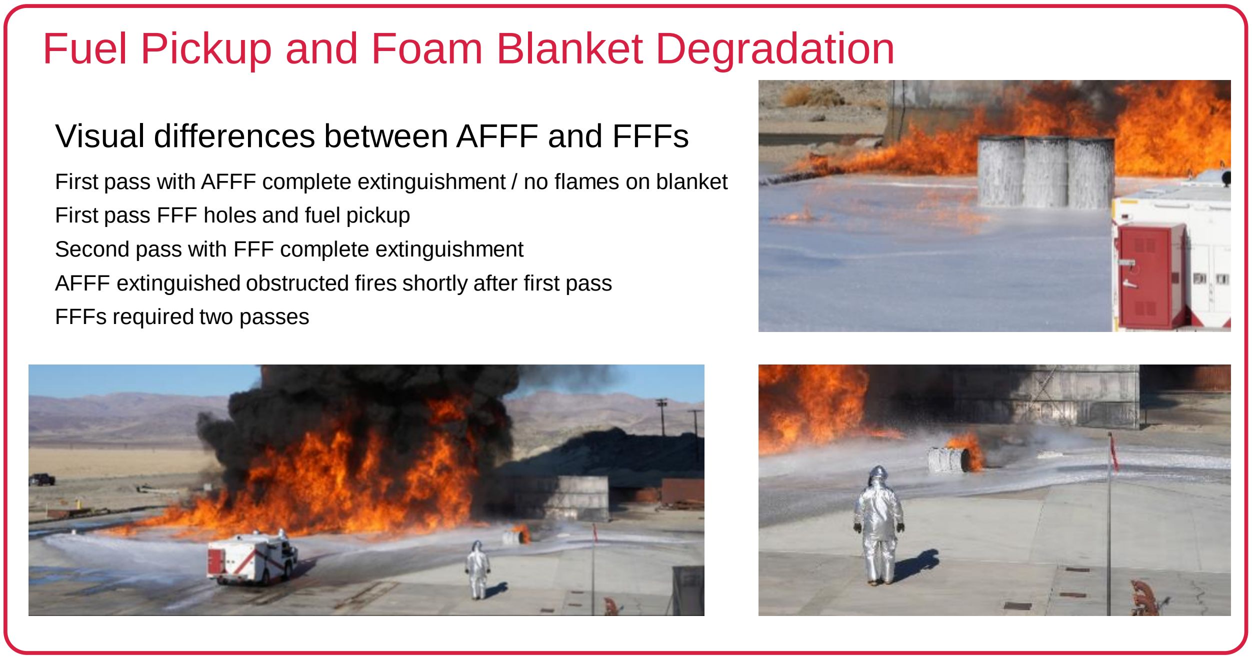

Figure F.4.0-1 Fuel Pickup and Obstructed Fires

A technique that worked reasonably well, was to attack the fire with a narrow angle fog pattern (i.e., 5-10 degrees) directed at the front edge of the spill to rapidly gain control of the fire, and then widen the pattern slightly (i.e., 10-20 degrees) to fully cover the fuel with a thicker blanket of aspirated foam.

It needs to be noted that these tests were conducted with kerosene-based fuels (i.e., F-24 is a combustible liquid with a minimum flashpoint of 100oF) which could reduce the effects of fuel pickup within the blanket when compared to lower flashpoint fuel. As a result, these conditions could have been even more pronounced if the tests had been conducted with a flammable liquid like gasoline.

In addition, the previous observations were made when combatting spill fire scenarios (i.e., thin layers of fuel) and may be different when combatting deep pools or tank fires. Specifically, the fuel pickup may be less but plunging of the stream into the burning fuel should always be avoided.

There were a few main take-aways from the two programs that apply to manual firefighting. First, the FFFs are not as forgiving as AFFF with respect to application technique. Specifically, the first pass with the FFFs provided good knockdown and control, but it typically took two passes to extinguish all of the fires as opposed to one for AFFF. In addition, the FFFs required better application techniques and a little more finesse to be effective. As a result, pre-fire planning and training will be key to successful implementation/deployment of these products going forward. With that said, the current approach of using propane burners for training will not simulate these fire conditions and will not allow the development of optimal application techniques (i.e., no fuel pickup due to plunging and no burning at the stream impact location in the foam blanket). Large water-filled burn pits are also potentially problematic for the same reasons.

Going forward, training and education will be the key to success. Although these new foams are being developed and implemented as environmentally friendly AFFF alternatives, the industry trends will require collection and disposal of these products in the same manner as AFFF is being handled today. So unfortunately, the ability to train with these foams will have the same cost burden as the legacy AFFFs requiring special facilities and waste containment/collection. As a result, innovative training approaches (e.g., immersive reality approaches) should be considered/developed to more effectively and efficiently address the increased challenges of transitioning to these new products. Additional training resources will be required to address new foam alternatives (e.g., model procedures, model strategies or tactics with new foams, training facilities, equipment transition, etc.). Special education and training are needed for foam stewardship (e.g., why the transition is needed, why environmental contamination is important, how to dispose of foam concentrates and/or rinse water, etc.).

F.5. CONTAINMENT AND CLEANUP

With the rapidly changing environmental landscape, it is recommended that ALL foams/agents be contained, collected and disposed of based on federal, state and local requirements and the most current technical information.

Event-initiated manual containment measures are operations usually executed by the responding fire department to contain the flow of foam water solution (and fuel) when conditions and manpower permit. Those operations include the following measures:

1. Blocking sewer drains: this is a common practice used to prevent contaminated foam water solution from entering the sewer system unchecked. It is then diverted to an area suitable for containment.
2. Portable dikes: these are generally used for land-based operations. They can be set up by the fire department personnel during or after extinguishment to collect run-off.
3. Portable booms: these are used for marine-based operations in the absence of better techniques, which are set up to contain foam in a defined area. These generally involve the use of floating booms within a natural body of water.

NPFA 11 (Annex E) has some initial guideline for containment and collection. The final, collection, disposal and remediation of the area is still a work in progress and is described in more in Annex H of this document.

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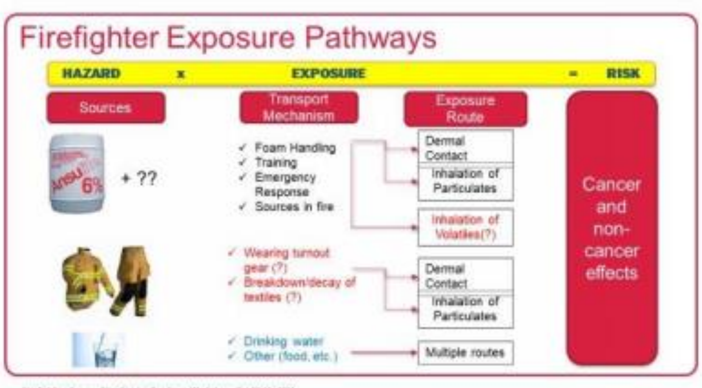
Firefighting Foams: Fire Service Roadmap



Annex G
Firefighter Exposures & Health Concerns

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G.1. INTRODUCTION

Aqueous Film Forming Foam (AFFF) has been the industry standard for combatting liquid fuel fires and hazards for almost 50 years. AFFF is a water-based solution that contains a fluorinated, film forming surfactant (per- and poly- fluoroalkyl substances (PFAS)) to seal the fuel surface during suppression/extinguishment.

- PFAS are a family of human-made chemicals in products used by consumers and through various industries.
- Some PFAS are described as forever chemicals that do not naturally breakdown in the environment and/or in the human body.
- Some PFAS have emerged as contaminants of concern.
- Some PFAS have been associated with human health and ecological effects.

PFAS exposures are not unique to firefighters. In fact, it is estimated that only about 3% of fluorochemical production was used for making AFFF. The general public is exposed to PFAS through a variety of media, including ground and drinking water, stain and water repellant textiles, food packaging or even consumption of meat/produce exposed to PFAS (e.g., fish from contaminated groundwater). Firefighters face additional PFAS exposure risks due to extensive use of legacy PFAS-containing AFFF in training and firefighting foam applications. Handling, training and emergency use of AFFF exposes emergency personnel to PFAS through ingestion, inhalation or dermal absorption. Firefighters can also be exposed to PFAS through the combustion of PFAS-containing products (e.g., carpets, upholstery, etc.). Additionally, firefighters can be exposed to PFAS via turnout gear. PFAS have been used in water-repellent fabrics in all layers of gear to provide water-resistance and to protect firefighters from steam. Additional research is ongoing to determine the risks of PFAS exposure through turnout gear.

G.2. PFAS CONTAINING AFFF

All AFFF's contain PFAS (a well as all other fluorinated firefighting foams). In the early 2000s, the scientific and regulatory communities developed an increased understanding of the potential environmental, safety and occupational health risks associated with continued use of some PFAS, which has resulted in evolving, increasingly strict regulations at the federal, state, local and international levels. It was initially believed that the hazards were specific to longer chain (C8) surfactants (i.e., perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)) which were eventually phased out of production in the United States and replaced with shorter C6 chain PFAS. Similar restrictions have occurred in other countries. However, these shorter chain molecules have also emerged as potentially hazardous chemicals to both health and the environment and are also under significant regulatory scrutiny. Exposures to these chemicals are a concern for long-term firefighter health including possible carcinogenic effects. They are also a concern to the general public due to the potential ground water contamination if discharged into the environment.

There is only limited information quantifying the effects of foam exposures on firefighters. Initial research focused on PFOS but has quickly changed to other families of PFAS. Studies on PFOS have shown increased level in the environment with values measured in plants and aquatic life in the range of parts-per-million and parts-per -billion which are much higher that the values in parts-per-trillion stated in the ecological and human health advisories. Most of this information is explained in detail under the "Health Effects Tab" on the Interstate Technology and Regulatory Council (ITRC) website: https://pfas-1.itrcweb.org/ - https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas/

G.3. Understanding Health Risks of PFAS

During the project workshop conducted in October 2021, Shalene Thomas, of Wood provided an exceptional overview of the risks of PFAS exposures. The presentation titled "Science of PFAS Environmental and Health and Safety Risks Overview" provided a systematic approach for identifying the hazard, the exposure pathways, dosage and resulting risk. The presentation is available at the following link: www.nfpa.org/foamroadmap

PFAS exposure can have both short and long-term effects on the human body. Exposure to AFFF and PFAS can cause short-term effects such as irritation of the skin, throat, nose and eye and mucous membranes, rashes, dizziness, headaches, and drowsiness. Research also ties leukemia, lymphoma, and neuroendrocrine tumors to prolonged exposure to some PFAS.

Firefighters are shown to have disproportionately high rates of cancer in comparison to the public. Additional data is being collected through the FEMA-funded Firefighter Cancer Cohort Study to provide an epidemiological survey of PFAS exposure and cancer – www.ffccs.org

The Centers for Disease Control and Prevention (CDC) have also conducted research on exposures and ailments and have posted a significant amount of information and guidance on their website: https://www.cdc.gov/biomonitoring/PFAS_FactSheet.html

The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) table is outdated and contains only limited information on PFAS exposures (if any). However, the OSHA webpage that discusses these permissible exposure limits (https://www.osha.gov/annotated-pels) provides links to state specific OSHA websites, the National Institute for Occupational Safety and Health (NIOSH) website and American Conference of Governmental Industrial Hygienists (ACGIH) website.

ACGIH is a private, not-for-profit, nongovernmental corporation that develops recommendations or guidelines to assist in the control of occupational health hazards. Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs) are health-based values published by ACGIH and are not intended to be used as legal standards. TVLs refer to airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse effects. BEIs are guidance values for assessing biological monitoring results – concentrations of chemicals in biological media (e.g., blood, urine). BEIs® represent the levels of determinants that are most likely to be observed in specimens collected from healthy workers who have been exposed to chemicals in the same extent as workers with inhalation exposure at the TLV. The ACGIH TLVs are widely recognized as authoritative and are required to be included on safety data sheets by the OSHA Hazard Communication Standard.

A summary of the international and national regulations, advisories, and guidelines is available at: https://www.atsdr.cdc.gov/toxprofiles/tp200-c7.pdf.

G.4. EXPOSURES / PREVENTION / FIRST AID

Firefighters can be exposed to PFAS by various means including exposure to PFAS containing foam solutions and concentrates, through contact with the PFAS coatings on typical firefighter PPE, and through the products produced by the fire during combustion of typical combustibles. Firefighters should minimize these PFAS exposures using proper safety equipment (for exposure prevention). If an exposure occurs, immediate action should be taken to minimize the dosage and remediate the continued exposures. A high-level summary of the exposure type, prevention and first aid are shown in Figure G.4.0-1 below.

Exposures / Prevention / First Aid

Exposure	Prevention	First Aid
Dermal / Skin	Protective gloves when handling concentrate Firefighter PPE when in use	Wash skin with soap and water. Get medical attention if irritation develops and persists.
Eye	Safety glasses when handling concentrate Eye Protection in combination with breathing protection when in use (Firefighter PPE).	Rinse thoroughly with plenty of water for at least 15 minutes, lifting lower and upper eyelids.
Inhalation	Respirators when handling Eye Protection in combination with breathing protection when in use (Firefighter PPE).	Remove to fresh air. If breathing is difficult, give oxygen. (Get medical attention immediately if symptoms occur.).
Ingestion	Do not eat, drink, or smoke while working with concentrate or solution. Wash hands when complete.	Rinse mouth. Do not induce vomiting without medical advice. If swallowed, call a poison control center or physician immediately.

Figure G.4.0-1 Exposures / Prevention / First Aid

It is recommended that firefighters (and other emergency response personal) wear proper personal protective equipment (PPE) when there is a risk of exposure to AFFF. This equipment should be properly fitted, worn, maintained and ultimately decontaminated after exposure to AFFF. Personnel should use self-contained breathing apparatus of positive pressure-supplied air respirators during handling, mixing, application or immediate clean-up of AFFF. In addition, skin should be covered with proper water-resistant clothing and gloves to avoid dermal contact with AFFF. AFFF can be a skin irritant on exposure. During standard fire operations, firefighters should wear turnout gear per specific department requirements. First responders should also follow best hygiene practices to reduce PFAS exposure. Firefighters should wash hands or other exposed skin after using AFFF reduce irritation. Firefighters should also wash hands prior to eating or smoking to prevent accidental ingestion of PFAS.

G.5. PPE CLEAN-UP AND DECONTAMINATION

After exposure to AFFF, PPE should be decontaminated to reduce potential exposures to PFAS. PPE should be removed and safely stored before being cleaned or laundered after AFFF exposure. Additional guidance for PPE decontamination is provided in NFPA 1851: Selection, Care and Maintenance of Protective Ensembles for Structural Firefighting and Proximity Firefighting. It is recommended that turnout gear should be spot treated with a soft brush and mild detergent prior to machine washing in warm water in the normal cycle. Personnel should wear protective gloves when handling or washing PPE. Turnout gear should not be washed in home washing machines and should be washed in a dedicated washing machine to avoid contaminating other clothes. PPE has an expected lifecycle for use. At the end of life, PPE should be discarded due to damage or excessive use in accordance with local, State and federal regulation.

As one additional consideration, the wastewater stream from PPE decontamination should be contained and disposed of as PFAS-containing waste, if possible. There is limited guidance for the potential environmental release or impacts due to laundering PFAS-containing PPE or textiles.

G.6. HEALTH RISKS OF FFFS

As a starting point, it needs to be understood that the elimination of PFAS and/or fluorine from the product/foam does not address all the potential health and environmental hazards (only one family of chemicals). In the past, most environmental and health assessments were very high-level and only based on the information provided in the MSDS/SDS which has been shown to be inadequate. However, although the information on the MSDS/SDS is limited in nature, they still provide some pertinent information and should be kept available for the foam products on hand.

The fire protection industry is working with environmental and health groups to develop a quasi-standard approach for assessing environmental and health concerns associated with the new FF products (i.e., FFFs). Unfortunately, the development of such a standardized approach is still in its infancy.

On a regulatory level, most assessments and approaches developed to date consist of comparing the list of chemicals in the foam concentrate to standard databases of chemicals that are known to be health hazards (i.e., carcinogens) and/or are known to have ecotoxicity issues. These assessments are typically based on composition data provided by the manufacturer which is, in only a limited number of scenarios, ever empirically/analytically verified. Two such assessments are GreenScreen (https://www.greenscreenchemicals.org/) and the US EPA's Safer Choice (https://www.epa.gov/saferchoice).

GreenScreen has become a standard for evaluating these products (i.e., FFFs). GreenScreen is comprised of three main steps: assess and classify hazards, assign a benchmark score, and make informed decisions. Ultimately, the product will receive a rating of gold, silver or bronze. Most FFFs that have been assessed by GreenScreen have received bronze ratings. It is understood that the “foamability” of these products (which is the characteristic that makes them effective) creates a hazard to aquatic life which explains the lower rating.

The EPA’s Safer Choice is gaining traction and will most likely become the default standard for FFFs here in the United States. Safer Choice is like the GreenScreen analysis. Each chemical ingredient in a formulation is evaluated against a Master and Functional-Class Criteria document, as appropriate. These documents define the characteristics and toxicity thresholds for ingredients that are acceptable in Safer Choice products. The criteria are based on EPA expertise in evaluating the physical and toxicological properties of chemicals, and while they incorporate authoritative lists of chemicals of concern, they go far beyond these lists. Safer Choice applies the criteria using EPA research and analytical methods to ensure that Safer Choice products contain only the safest possible ingredients. All criteria documents are part of the Safer Choice Standard.

Since there are not any widely enforced specific requirements on the health and environmental hazards of FFFs (other than possibly PFAS or Fluorine content), it is typically left to the foam manufacturer to have the product assessed. In future, this may change, and a list of the various certified products may become available. Until then, the end user will need to ask the manufacturer(s) for these types of certifications.

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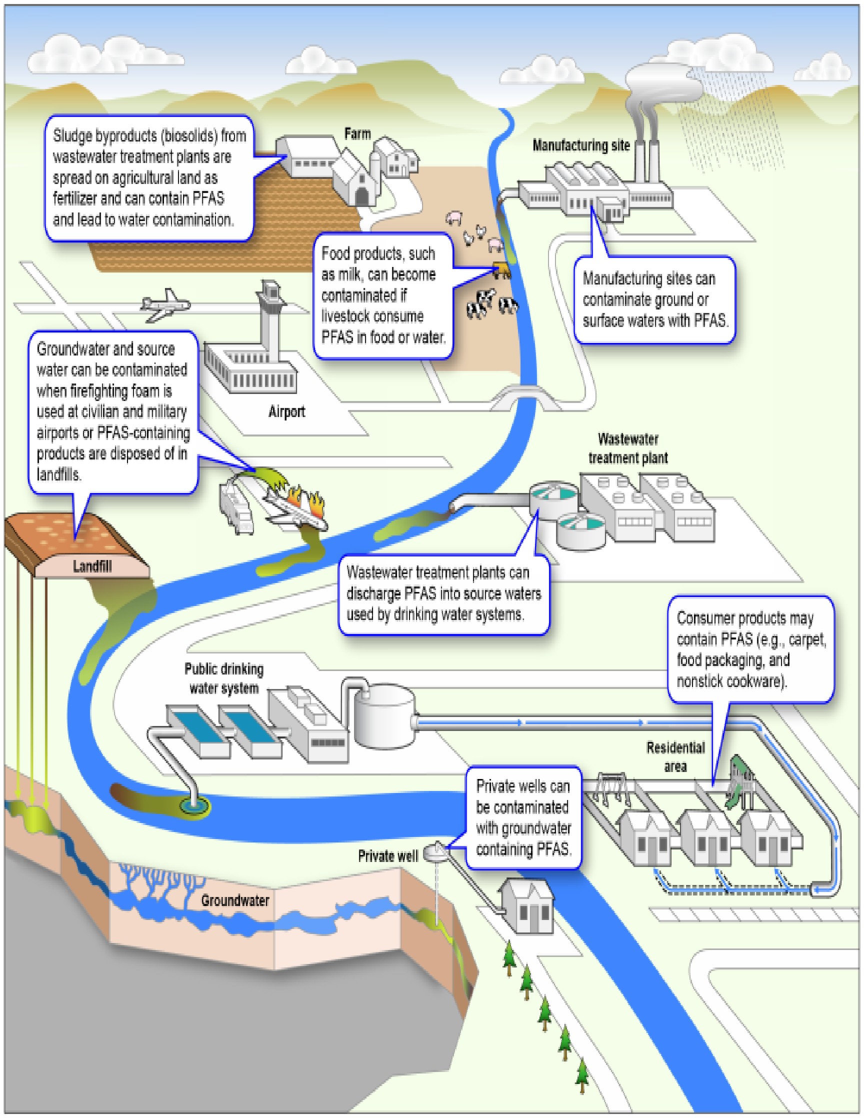

Source: GAO. | GAO-21-421

Reference: United States Government Accountability Office
https://www.gao.gov/assets/gao-21-421.pdf

Annex H
Cleanup and Documentation

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H.1. CLEANUP BACKGROUND

Cleanup for AFFF is used to refer to short-term actions to manage, contain and collect spent AFFF and fuel from recent discharge events. After a live fire or discharge scenario, cleanup should start as soon as possible after the incident and the site is safe to enter to reduce potential ground contamination from PFAS-containing wastes. It is important to note that the previous recommended practice of dilution and release to the environment and/or wastewater treatment systems are obsolete and unacceptable for fluorinated foams. This annex specifically does not provide guidance for cleanup and remediation of contaminated water, soil or other environmental media. Individual State environmental agencies set required cleanup goals across a variety of scenarios. Multiple removal and destruction processes are available with varying efficacy, with more in development through multiple Department of Defense partners. The Office of the Secretary of Defense Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program (SERDP/ESTCP) is funding research PFAS treatment/destruction technologies, including PFAS remediation and cleanup, with multiple remediation technology demonstrations at DoD facilities. More information is available at https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs.

Cleanup efforts and tactics will vary between facilities and response capabilities, as no single set of containment tactics will be applicable to all facilities. Due to this, it is important for each user to conduct preplanning to identify solutions that fit its facilities, objectives, and specific response scenarios. It is recommended that, where possible, infrastructures with foam-applying fire suppression systems or a high likelihood of needing AFFF for extinguishment be designed with storage tanks or containment structures for discharged foam to help minimize cleanup efforts. AFFF discharge can be contained with surface inlets such as ditches, dikes, damns, and blocked storm drains to reduce the potential environmental impact of the foam, as well as minimize the amount of area that is required to be cleaned up. Large volumes of AFFF concentrate or concentrate mixture may require pumps or vacuums for cleanup, while smaller releases may only require absorbent materials.

H.2. EMERGENCY OR UNCONTROLLED RELEASE

In an emergency fire event, foam solution and fuel may not be able to be collected. Best practices are to block sewer drains and divert the foam and fuel to an area for containment, set up portable dikes for land-based applications and use portable booms for temporary containment in marine-based operations. It is also recommended that users document their foam usage to help establish the potential extent of release or contamination in the environment. First responders should collect information regarding the emergency event itself (size, fuel type, duration, etc.), as well as information about the foam product used. This should include volume of AFFF discharged, its concentration, product information (and potentially SDS/ingredient lists if available) and discharge location information. This can be used to inform State regulators, environmental remediation managers or even insurance companies about the nature of the release.

After immediate cleanup, most AFFF protected sites require field-screening or sampling to determine AFFF removal. Field-screening methods are limited to visual observation or placing potentially contaminated materials into a clear container and shaking to check for foam. This informal shake test will produce foam if there are very high concentrations of AFFF in the sample, but lower concentrations may not foam. Additional chemical sampling and analysis may be required. If either of these methods indicate the presence of AFFF, further cleanup is required and consultation with environmental professionals may be required to ensure compliance with regulatory requirements and to minimize potential leaching to groundwater or runoff to nearby surface water. Sampling may be required after initial cleanup to determine the removal of PFAS from an area. If concentrations are less than applicable State or facility actions levels, then no additional remedial activities may be necessary.

H.3. FIXED INSTALLATION CLEANUP AND CONTAINMENT

In a fixed installation, it is possible to preplan release and containment of AFFF. Recommended best practices are to design containment systems for the most probable worst case of AFFF discharge, which would vary based on factors such as hanger protection and open air versus closed extinguishing systems. Systems such as floor drainage systems are recommended in aircraft hangers to restrict the spread of foam and fuel. However, these systems should be equipped with valves to divert foams to containment systems to prevent foams from entering oil-water separators and damaging the separators. Containment systems are to be designed to handle site-specific maximum anticipated flows for either one event with the largest possible discharge or anticipated flow during acceptance and system testing, whichever is higher.

There are several varieties of containment systems that can be utilized to hold foam concentrate and water until it can be sent for further disposal, such as underground tanks, aboveground tanks with sumps, earthen retention ponds, and containment trenches. Underground tanks are costly but have the advantage of not having to be sized to account for rainfall, have a double-walled design, or have leak detection. Aboveground tanks with sumps can be used for both open and closed AFFF systems. For open systems, a sump pit with a vertical shaft or submergible pump diverts AFFF solution to a vertical storage tank. This system, primarily the pump, requires high maintenance and increases long term facility maintenance costs. For closed systems, which only receive AFFF waste during system testing, discharge can be directed to a containment system using hoses connected to a test header. This eliminates the need for sumps and makes aboveground tanks a more cost-effective solution for closed systems. Earthen retention ponds are generally used in areas where a large capacity containment system is required. Ponds are designed with impermeable, ultraviolet resistant liners to eliminate the chance of ground or surface water contamination. This solution should then be collected and disposed of per all local, State and eventually Federal regulation. Containment trenches use lengthy containment trenches with steel safety and rain cover to contain foam solution until it can be further disposed

In the event of AFFF discharge in hangers, the recommended cleanup actions are to knock down any present foam layer with water and use brooms or other similar materials to push foam and water into drains to be sent to containment tanks. For other potential discharge sites, such as fire-fighting training facilities or flight decks, contaminated surfaces can be washed down with hoses, pumps, or a fixed washdown system. Additionally, it is recommended that any affected AFFF contaminated materials (soil, vegetation, etc.) be removed to reduce the migration of potential contaminants. This removal would reduce the need for additional investigation and future cleanup as well as reduce the footprint of PFAS-contaminated materials and lower the cost of the total mitigation effort.

Additionally, the implementation of a response plan for sites that contain a significant flammable hazard requiring AFFF storage or use for extinguishment is recommended by states and the military. The purpose of these plans is to minimize the volume of non-collected firewater runoff through the use of spill and containment equipment.

H.4. DOCUMENTATION

Due to AFFF's increasing restrictions and regulations, documentation is often required for military and state applications of foam discharge, which includes both accidental and intentional usage. See local and statewide regulation to determine required reporting for any release of AFFF. This is primarily reporting to State environmental agencies with details specific to release (intentional or through a spill) for any AFFF. Additional guidance is being developed on a federal level for reporting and documenting the release of AFFF. This information should eventually be posted on the EPA's website: https://www.epa.gov/laws-regulations

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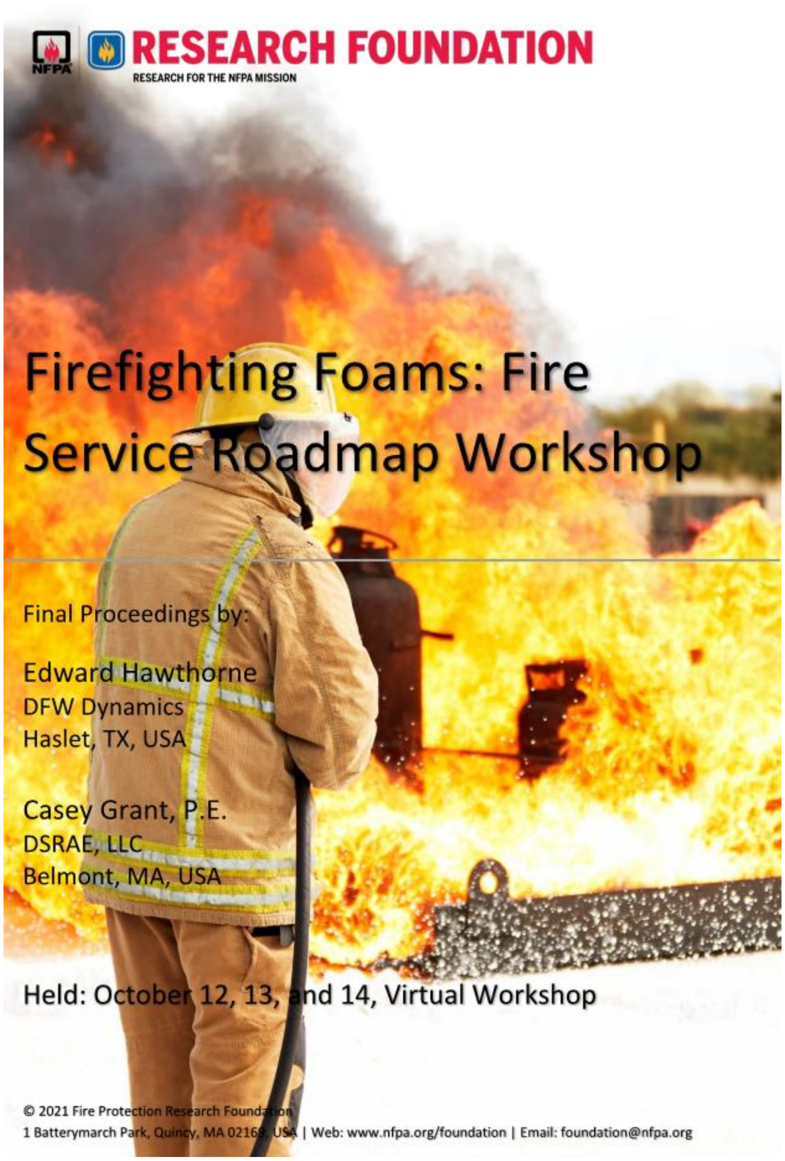

Annex I Workshop Overview

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I.1. WORKSHOP OVERVIEW

A three-day virtual workshop was held on October 12-14 (2021) as part of this AFG funded project titled: "Firefighting Foams: Fire Service Roadmap". The purpose of this workshop was to:

- Review the current information/knowledge level on various pertinent topics;
- Stimulate cross dialogue between ongoing research efforts;
- Facilitate discussion to receive commentary from fire service representatives and industrial fire brigade subject matter experts to improve project deliverables;
- Develop the strategic roadmap for fire service during this foam technology transition; and
- Identify knowledge gaps and future research required to assist first responders going forward.

The various presentations given during the workshop can be viewed by clicking on the link provided on the program's website: www.nfpa.org/foamroadmap.
A PDF of the workshop proceedings and the slides for each presentation are available at the following link: www.nfpa.org/foamroadmap .

I.2. WORKSHOP PROGRAM AND ATTENDEES

I.2.1. WORKSHOP PROGRAM

This three-day workshop included a Presentation Series followed by a Discussion Group Session on each of the three days. All workshop activities were conducted virtually due to the global COVID-19 pandemic. This presented special logistical challenges, all of which were effectively addressed to provide a streamlined and well-run event.

One of the adjustments made to accommodate the virtual workshop environment was the use of presentations in a more condensed, more swiftly moving format to maintain attendee engagement in the virtual setting. This approach was effective based on attendee feedback following the workshop. Each day's Presentation Series were approximately three hours in length with actual presentations ranging from approximately 10 to 30 minutes depending on the topic. These presentations were provided by recognized, credible subject matter experts for each topic area. The Discussion Group Sessions on each day likewise continued using a more swiftly moving format and were approximately one hour in length each day.
A specific theme was utilized for each of the three days. These daily themes guided the Presentation Series and were:

- Day 1: (a) Workshop and Project Background & (b) Foam Replacement Overview. Day One theme was devoted to updating workshop participants on what is known about the issue of firefighting foams and their risks, and the issues that we are trying to answer in the workshop.

- Day 2: (a) Fire Control Testing & (b) Best Practices and Programs. Day Two theme was devoted to Fluorine Free replacement foams – What the fire control/extinguishment testing says about: (a) will they put out the fires (spills ARFF fires and full in-depth tank fires); and (b) best practices and programs.

- Day 3: (a) Health, Safety & Environment & (b) Best Practices & Programs. Day Three theme was devoted to the Health, Safety and Environmental issues associated with PFAS in firefighting foam and our transition to effective, safe and sustainable alternatives.

Each day's Discussion Groups likewise had a theme, though these themes were fire service stakeholder centric rather than topic centric like the presentation series. This facilitated the opportunity for each key stakeholder group to discuss the topics addressed by each day's presentation series. The themes for each day's Discussion Group were:

- Day 1: Major Class B Spill Fires - Shorter duration spill fires with life hazard such as an Airport Crash/Rescue fire inside the facility fence line (Airport Fire Departments)
- Day 2: Complex Class B Tank Fires - Fuel in depth fire with limited life hazard such as a large storage tank fire inside the facility fence line (Industrial and Community Fire Departments)
- Day 3: Class B Fires with Community Risk - Combination of the above (small or large) where the initial fire can spread to the larger community, such as a fuel truck that overturns and fuel impacts community exposures (e.g., local hospital) with the potential to impact the much larger community with life and asset hazards. (Community Fire Departments and mutual aid responses by the Day one and Day two organizations)

The Workshop Programs for each day of the three-days are shown in Figures I.2.1-1, I.2.1-2, and I.2.1-3 on the following pages. These figures provide detailed information on each presenter during a particular day's Presentation Series, as well as the additional details on the particular day's Discussion Group Session.

I.2.2. ATTENDEES AND PARTICIPANTS

The workshop was well attended, including the specific Discussion Group Sessions on each of the three days. The virtual nature of the workshop allowed large numbers of attendees from all geographic locations. This was a significant contributor to the workshop success despite the logistical challenges. In summary, the following are the key demographics of the final workshop attendance:

- Presenters: 24 presenters including 4 from outside North America (that presented live), that in total provided 27 presentations.
- Attendees: 509 individuals registered for the workshop as attendees, representing 49 different countries.

ANNEX I – WORKSHOP OVERVIEW

DAY ONE: Tuesday, October 12th, 2021.				
Theme: **(1.a) Workshop and Project Background & (1.b) Foam Replacement Overview** Day One theme is devoted to updating workshop participants on what is known about the issue of firefighting foams and their risks and what are the issues that we are trying to answer in the workshop.				
Sl. No.	**Time (US Eastern Time)**	**Subject**	**Presenter/s**	**Organization**
1.00	11:00-11:10	Workshop Kick off: Welcome & Technology Overview	Sreeni Ranganathan	FPRF
1.01	11:10-11:30	Firefighting Foams: Fire Service Roadmap, Overview	Edward Hawthorne	DFW Dynamics
1.02	11:30-11:55	History of AFFF and fluorinated foams: 1960-2020.	Bob Darwin	Jensen Hughes
1.03	11:55-12:20	***Case Study:*** History of Fluorine Free Foam in Europe and the Experience of Major Airport (Schiphol, Amsterdam) with Fluorine Free foam	Arjan Bruinstroop	Schiphol Airport, Amsterdam
	12:20-12:25	*---Break---*		
1.04	12:25-12:50	History of Class B Fluorine Free Foams and how they work	Mark Siem	Perimeter Solutions
1.05	12:50-13:15	Review Process of Firefighting Foams: Foam Assessments	David Plant and Shari Franjevic	Angus Int. & Clean Production Action
1.06	13:15-13:40	Analytical Methods for Testing PFAS in Fire Fighting Foam	Joan Leedy	Dyne USA
	13:40-13:45	*---Break---*		
1.07	13:45-14:10	Present understanding of the science of Environmental, Health and Safety risks of firefighting foams	Shalene Thomas	Wood PLC
1.08	14:10-14:35	Overview of firefighting foam user segments and approval test protocols: UL 162, Mil Spec, FAA, LASTFIRE and other tests – How do they work and what do they test?	Jerry Back	Jensen Hughes
1.09	14:35-14:55	Panel discussion: Update on NFPA Standards (NFPA 11, 30, 460)	Moderator: Casey Grant Panel: Joan Leedy Ed Hawthorne Rob Mathis	 Dyne USA DFW Dynamics The Port of Portland Fire and Rescue
		---End of Day 1 Presentations---		
Discussion Group on Day 1				
	15:00-16:00	**Day 1: Major Class B Spill Fires** - Shorter duration spills fire with life hazard such as an Airport Crash/Rescue fire inside the facility fence line (Airport Fire Departments)	Moderators: Casey Grant & Ed Hawthorne	Facilitated discussion followed by summary of “Key Takeaways”.
		Adjourn Day One		

Figure I.2.1-1 Workshop Program Day One

DAY TWO: Wednesday, October 13th, 2021.				
Theme: **(2.a) Fire Control Testing & (2b) Best Practices and Programs** Day Two theme is devoted to Fluorine Free replacement foams – What the fire control/extinguishment testing says about (a) will they put out the fires (spills ARFF fires and full in-depth tank fires) (b) best practices and programs				
Sl. No.	**Time (US Eastern Time)**	**Subject**	**Presenter/s**	**Organization**
2.00	11:00-11:05	Workshop Day Two Kick off.	Casey Grant & Sreeni Ranganathan	DSRAE & FPRF
2.01	11:05-11:30	***Case Study:*** Ampol Risk Management Framework to Foam Transition	Jaco Erasmus & Rod Rutledge	Ampol, Australia
2.02	11:30-11:45	FAA Update on PFAS–free Firefighting Foam Research	Keith Bagot Jon Torres	FAA
2.03	11:45-12:30	Summary of Major Research on Fluorine Free Foam firefighting performance by DoD, FPRF	Jerry Back & Robin Nissan	Jensen Hughes & SERDP ESTCP, DoD
2.04	12:30-13:10	Summary of LASTFIRE research on Fluorine Free firefighting performance	Niall Ramsden	LASTFIRE
	13:10-13:15	*---Break---*		
2.05	13:15-13:40	What have we learned from the latest foam testing – CAF Foam	Dave Munroe	ACAF Systems, Inc.
2.06	13:40-14:05	"From Film to Bubbles" - Translating the research and testing information into strategic and tactical guidelines for the fire service.	Ed Hawthorne	DFW Dynamics
2.07	14:05-14:30	Learnings from DFW Airport Research Center	Brian McKinney & Mitchell Iles	DFW Airport Research Ctr
2.08	14:30-15:00	***Panel Presentation & Discussion on State Programs:*** a) Michigan State AFFF Foam Management and Collection Program. b) Massachusetts State AFFF foam management and take-back program	Kevin Sehlmeyer (MI) Nick Child (MA)	Michigan SFM MA DEP
	15:00-15:10	***Live Q&A for the above two sessions***		
		---End of Day 2 Presentations---		
Discussion Group on Day 2:				
	15:30-16:30	**Day 2: Complex Class B Tank Fires -** Fuel in depth fire with limited life hazard such as a large storage tank fire inside the facility fence line (Industrial and Community Fire Departments)	Moderators: Casey Grant & Ed Hawthorne	Facilitated discussion followed by summary of "Key Takeaways".
		Adjourn Day Two		

Figure I.2.1-2 Workshop Program Day Two

DAY THREE: Thursday, October 14th, 2021.				
Theme: **(3.a) Health, Safety & Environment & (3.b) Best Practices & Programs** Day Three theme is devoted to the Health, Safety and Environmental issues associated with PFAS in firefighting foam and what we know about how to deal with them.				
Sl. No.	**Time (US Eastern Time)**	**Subject**	**Presenter/s**	**Organization**
3.00	11:00-11:05	Day Three Agenda Overview	Casey Grant	DSRAE
3.01	11:05-12:15	***Panel Discussion on Health-Related Research*** 3 presentations with moderated panel discussion & Q/A (a) DoD Exposure and Health-Related Efforts (b) Case Study: Human Toxicity (c) Case Study: Cell/Animal Toxicity Moderated by Jeff Burgess	Moderator: Jeff Burgess (a) Jody Wireman & John Seibert (b) Jackie Goodrich (c) Todd Stueckle	University of Arizona/FFCCS (a) DoD HRP&O (b) University of Michigan (c) NIOSH
	12:15-12:20	*---Break---*		
3.02	12:20-13:00	• What have we learned about how to deal with Health, Safety and Environmental issues when **cleaning fire protection equipment (mobile equipment and fixed systems)** • What have we learned about how to deal with Health, Safety and Environmental issues associated with **foam/fire water disposal during and after an incident?** • What have we learned about **how to dispose of AFFF concentrate?**	Jerry Back & Noah Lieb	Jensen Hughes
3.03	13:00-13:25	How can we protect Fire Fighters from C8/C6 foam risks? What do we know about the possible health hazards of Fluorine Free foam? Latest information on proper PPE and Standard Operating Procedures **Brief mention of primary exposure pathways (e.g., FF Gear)*	Jerry Back & Edward Hawthorne	Jensen Hughes & DFW Dynamics
	13:25-13:30	*---Break---*		
3.04	13:30-13:55	US Federal regulations on foam	William Barrett	US EPA
3.05	13:55-14:20	US State regulations on foam	Shalene Thomas	Wood PLC
3.06	14:20-14:45	Draft Roadmap for Fire Service	Jerry Back	Jensen Hughes
		---end of Day 3 presentations---		
Discussion Group on Day 3 (in the same online room as presentation series)				
	14:45-15:15	**Day 3: Class B Fires with Community Risk**- Combination of the Day 1 & 2 incident types (small or large) where the initial fire can spread to the larger community, such as a fuel truck that overturns and the fuel impacts community exposures (e.g., local hospital) with the potential to impact the much larger community with life and asset hazards. (Community Fire Departments and mutual aid responses by the Day one and Day two organizations)	Moderators: Casey Grant & Ed Hawthorne	Facilitated discussion followed by summary of “Key Takeaways”.
	15:15-15:45	Long Term vision of the FS^2 Centers of Excellence and the path forward from this workshop	Moderators: Casey Grant & Edward Hawthorne	DSRAE & DFW Dynamics
	15:45-16:00	Closing Discussion & Future Direction	Moderators: Casey Grant & Edward Hawthorne	DSRAE & DFW Dynamics
	16:00	*Workshop Adjourn*		

Figure I.2.1-3 Workshop Program Day Three

I.3. WORKSHOP PRESENTATIONS

The 27 presentations were provided by 24 separate presenters, including 4 from outside North America. For logistical purposes most presentations were pre-recorded, but with presenters live with the workshop audience both before and after their presentations. Each presentation included a question-and-answer (Q&A) period that provided engagement with the workshop attendees.

In addition to the 27 scheduled presentations, supplemental information was presented at times in extended specific discussions by some of the participants. This would occur during the Q&A after certain presentations or during the subsequent Discussion Group Sessions each day. The key points that were made are included in the Summary Observations of these Proceedings.

An example of one extended impromptu discussion during a Q&A period was one attendee providing detailed information on how his large metropolitan-city fire department in the United States used foam for Class B fires. He described how they would purchase their foam in significant quantities to be cost effective, but therefore have noteworthy inventories of legacy foams. Consequently, they now struggle with the challenges of safe storage, use, handling, and stewardship of these legacy foams. Further, like many fire departments they have limited budgets and they need assistance with transitions if they are to do so effectively. They want to transition to foams that have better health and safety characteristics for their members but have significant barriers like replacement costs.

As a supplement to certain Presentation Series, there were several Panel discussions among a small group of presenters to further facilitate a particular topic area. These addressed the sub-areas of (1) Update on NFPA standards activities on Day one; (2) Review of State based programs and legislation on Day two; and (3) Health-related research on Day three. Slides used with these Panel discussions are included among the 27 scheduled presentations.

I.4. EXECUTIVE SUMMARY

This report represents the Proceedings of the Fire Protection Research Foundation virtual workshop, “Firefighting Foams: Fire Service Roadmap”, conducted on October 12, 13, & 14 of 2021. This three-day workshop included a Presentation Series followed by a Discussion Group Session on each of the three days. The workshop is a key component of this one-year research project is funded by a DHS/FEMA Assistance to Firefighters Grant (AFG) Fire Prevention & Safety Program.

Aqueous Film Forming Foams (AFFFs) and other possible exposures in the fire ground are a concern for long-term firefighter health including possible cancer exposures. Obvious replacement agents are elusive. Current AFFF alternatives may have reduced capabilities and require additional knowledge and guidance to effectively address the wide range of Class B fires encountered by firefighters. Today, a strong need exists for guidance for fire departments to replace their legacy firefighting foams.

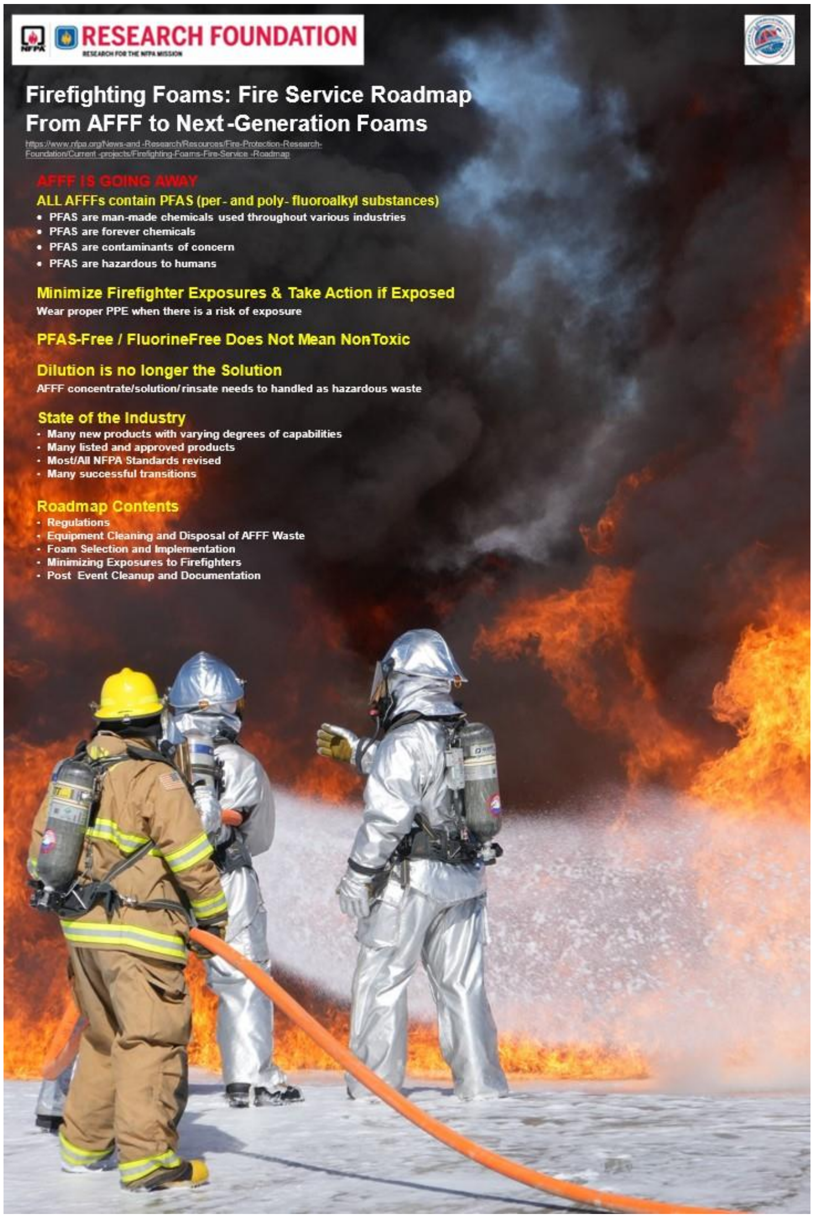
The overall goal of this project and workshop is to enhance firefighter safety and health by developing a strategic fire service roadmap to effectively and efficiently transition from fluorinated foam (i.e., AFFF) usage to fluorine free foam technology. This workshop seeks to address the following for firefighting foams and their replacements: summarize and review baseline information, establish recommended best practices, coordinate a unified voice to support a fire service national strategy and policies, facilitate stakeholder and researcher interaction and engagement, identify knowledge gaps and future research, and stimulate dialogue between ongoing research efforts. The workshop has effectively addressed these issues as described by the documentation herein, along with a supplemental (separate) report on this overall project.

The key summary observations from this effort highlight the need to continue to address this overall topic, and that the fire service worldwide is seeking to transition to foam alternatives but needs continued guidance and assistance. Key summary observations address important sub-topics of direct interest to the fire service, including: fire control effectiveness, environmental impact, health and safety impact, resources to support transition, training and education, stewardship of legacy agents, and regulation and standardization.

RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

Firefighting Foams: Fire Service Roadmap

Annex J
Poster



www.nfpa.org/foamroadmap.

RESEARCH FOUNDATION

RESEARCH FOR THE NFPA MISSION

Firefighting Foams: Fire Service Roadmap

Annex K
References

K.1. REGULATORY LANDSCAPE (ANNEX A)

EPA laws and Regulations https://www.epa.gov/laws-regulations

Safe Drinking Water Act (SDWA)

Toxic Substances Control Act (TSCA)

Resource Conservation and Recovery Act (RCRA)

Clean Water Act (CWA), Clean Air Act (CAA)

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

EPA Roadmap https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

FY20 National Defense Authorization Act (NDAA) - https://www.congress.gov/bill/116th-congress/senate-bill/1790/text

FAA Reauthorization Act and updates

https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-19-01-AFFF.pdf

https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-21-01-AFFF.pdf

Interstate Technology and Regulatory Council (ITRC) link - https://pfas-1.itrcweb.org/ and https://pfas-1.itrcweb.org/3-firefighting-foams/#3_9

U.S. Fire Administration website: https://www.usfa.fema.gov/blog/ig-090221-2.html

K.2. FOAM TUTORIAL (ANNEX B)

NFPA Handbook (Foam Chapter) – https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/Handbooks

SFPE Handbook (Foam Chapter) - https://www.sfpe.org/standards-guides/sfpehandbook

Various NFPA Standards - https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards

NFPA 11, Standard for Low-, Medium-, and High-Expansion Foam
NFPA 18, Standard for Wetting Agents
NFPA 18A, Standard on Water Additives for Fire Control and Vapor Mitigation
NFPA 30, Flammable and Combustible Liquids Code
NFPA 402, Standard for Aircraft Rescue and Fire Fighting Operational Procedures
NFPA 403, Standard for Aircraft Rescue and Fire Fighting Services at Airports
NFPA 405, Standard for Training Programs for Aircraft Rescue Fire Fighting
NFPA 408, Standard for Aircraft Hand Fire Extinguishers
NFPA 409 Technical Committee of Aircraft Hangars
NFPA 412, Standard for Evaluating Aircraft Rescue and Fire Fighting Foam Equipment
NFPA 414, Standard for Aircraft Rescue and Fire Fighting Vehicles
NFPA 422, Standard for Guide for Aircraft Accident Response
NFPA 424, Standard for Airport/Community Emergency Planning

Military Specification – Performance Specification, Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water (MIL-PRF-24385F) - https://quicksearch.dla.mil

FY20 National Defense Authorization Act (NDAA) - https://www.congress.gov/bill/116th-congress/senate-bill/1790/text

FAA Reauthorization Act and updates

https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-19-01-AFFF.pdf

https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-21-01-AFFF.pdf

International Civil Aviation Organization (ICAO) Performance Levels A,B & C

https://www.icao.int/Pages/default.aspx

Underwriters Laboratories (UL) 162, Standard for Foam Equipment and Liquid Concentrates

https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL162

EN 1568, Fire-extinguishing-media-foam-concentrates-specification-for-low-expansion-foam-concentrates-for-surface-application-to-water-immiscible-liquids - https://www.en-standard.eu

Large Atmospheric Stationary Tank Fire (LASTFIRE), various internal standards and specifications - http://www.lastfire.co.uk/default.aspx?ReturnUrl=%2f

K.3. FOAM SELECTION ANNEX C

Foam/Agent Manufacturers

3F – Freedol	Foam	https://www.3fff.co.uk/chemistry/smart-foam/
Angus	Foam	https://angusfire.co.uk/products/foam-concentrates/product-range/fluorine-free-foam/
Ansul	Foam	https://www.ansul.com/en/us/DocMedia/F-2021111.pdf
Auxquimia	Foam	http://auxquimia.com/synthetic-multiexpansion-foam-concentrates/
Bio-Ex	Foam	https://www.bio-ex.com/en/our-products/compositions/fluorine-free-foam/
Bristol – EkoSol	Foam	http://www.bristol-fire.com/
Dr. Sthamer	Foam	https://sthamer.com/en/fluorine-free/index.php
Eau et Feu	Foam	https://eauetfeu.fr/produits/emulseurs/liste-des-emulseurs/airfoam/
FireBull PFF	Foam	https://enforcerone.com/products/firebull-fluorine-free-foam/
Fomtec	Foam	https://www.fomtec.com/fluorine-free/category38.html
GreenFire	Both	https://gogreenfire.com/greenfire-fire-protection/
National	Foam	https://nationalfoam.com/foam-concentrates/sfff-fluorine-free-foam/
Orchidee	Foam	https://orchidee-fire.com/products-solutions/?_sft_product_cat=fluorine-free-foams
Phos-Chek	Foam	https://www.perimeter-solutions.com/en/class-a-foam/
Solberg	Foam	https://www.perimeter-solutions.com/en/class-b-foam/solberg-avigard-fluorine-free/
vs FOCUM	Foam	https://vsfocum.com/foams/types/1-fluorine-free-newtonian/
Amiran	Wetting	https://www.jmesales.com/content/docs/AmiranBioChemicals/FlameOut_DataSheet.pdf
Coldfire	Wetting	https://firefreeze.com/cold-fire/
F500	Wetting	https://hct-world.com/products/chemical-agents/f-500-encapsulator-agent/
Geltech	Wetting	https://geltechsolutions.com/fireice/
Novacool	Wetting	http://novacoolfoam.com/

UL Fire Protection Equipment Directory now referred to as the UL Prodcut iQ™ available at the following web address: https://productiq.ulprospector.com/en

U.S. DoD Environmental Groups (ESTCP and SERDP) - https://www.serdp-estcp.org/.

WP19-5299 & WP20-5335: Validation of Fluorine Free Foams (PFFs) against Military Specification Performance Criteria
WP19-5324: Capabilities Assessment of Commercially Available Fluorine-Free Foams / PFAS-Free Foams
WP19-5332: Screening Tests for Fluorine-Free Firefighting Foams
WP19-5374: Foam Quality Effects on PFAS Free Foam Firefighting Capabilities: A Demonstration of the Link Between Foam Quality and Extinguishment Capabilities and What's Being Produced by DoD Hardware
WP20-3048 Identification of Critical Properties and Features of Surfactant Solutions for Firefighting Foams
WP20-5334: PFAS-Free Foam / Compressed Air Foam, Fire Suppression Alternative
WP21-3461 & WP21-3465: Validation Testing of the Leading Commercially Available PFAS-Free Foams

FAA fire performance research – FAA Technical Library - https://www.faa.gov/about/office_org/headquarters_offices/ang/library

NFPA Fire Protection Research Foundation (FPRF) report; "Evaluation of the Fire Protection Effectiveness of Fluorine Free Firefighting Foams", NFPA FPRF website at https://www.nfpa.org/News-and-Research/Resources/Fire-Protection-Research-Foundation.

LASTFIRE workshops proceedings: Dallas TX (DFW Airport) in 2018 & 2019, Rotterdam 2020, and France 2021. Proceedings are available on the LASTFIRE website - http://www.lastfire.co.uk

Wood Environment and Infrastructure Solutions Report, "The use of PFAS and fluorine-free alternatives in fire-fighting foams" - https://echa.europa.eu/documents/10162/28801697/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

International Pollutants Elimination Network (IPEN) "Fluorine-Free Fire Fighting Foams (3F) – Viable Alternatives to Fluorinated Aqueous Film-Forming Foams (AFFF)" -

https://ipen.org/sites/default/files/documents/IPEN_F3_Position_Paper_POPRC-14_12September2018d.pdf

Interstate Technology and Regulatory Council (ITRC) link - https://pfas-1.itrcweb.org/3-firefighting-foams/#3_10

API Transition Guidance - https://www.api.org/oil-and-natural-gas/health-and-safety/refinery-and-plant-safety/fire-protection

GreenScreen - https://www.greenscreenchemicals.org

US EPA's Safer Choice - https://www.epa.gov/saferchoice.

K.4. CLEANING OF EQUIPMENT (ANNEX D)

U.S. DoD's Environmental Group Research Programs

https://www.serdp-estcp.org/News-and-Events/Blog/Environmentally-Sustainable-Methods-Demonstrations-to-Clean-Firefighting-Delivery-Systems
https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs

K.5. DISPOSAL OF AFFF WASTE (ANNEX E)

U.S. DoD's Environmental Group Research Programs - https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs

EPA Roadmap Program - https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

Individual State EPA websites – (e.g., https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-541555--,00.html)

K.6. IMPLEMENTATION (ANNEX F)

UL Fire Protection Equipment Directory now referred to as the UL Prodcut iQ™ available at the following web address: https://productiq.ulprospector.com/en

U.S. DoD Environmental Groups (ESTCP and SERDP) - https://www.serdp-estcp.org/.

WP19-5374: Foam Quality Effects on PFAS Free Foam Firefighting Capabilities: A Demonstration of the Link Between Foam Quality and Extinguishment Capabilities and What's Being Produced by DoD Hardware

WP20-5334: PFAS-Free Foam / Compressed Air Foam, Fire Suppression Alternative

WP21-3461 & WP21-3465: Validation Testing of the Leading Commercially Available PFAS-Free Foams

FAA fire performance research – FAA Technical Library - https://www.faa.gov/about/office_org/headquarters_offices/ang/library

Wood Environment and Infrastructure Solutions Report, "The use of PFAS and fluorine-free alternatives in fire-fighting foams" – case studies section https://echa.europa.eu/documents/10162/28801697/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

Interstate Technology and Regulatory Council (ITRC) link - https://pfas-1.itrcweb.org/3-firefighting-foams/#3_10

K.7. MINIMIZING FIREFIGHTER EXPOSURES (ANNEX G)

Shalene Thomas, "Understanding of the Science of PFAS Environmental and Health and Safety Risks Overview", - www.nfpa.org/foamroadmap

Interstate Technology and Regulatory Council (ITRC) website: https://pfas-1.itrcweb.org/ "Health Effects Tab" - https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas/

API Transition Guidance - https://www.api.org/oil-and-natural-gas/health-and-safety/refinery-and-plant-safety/fire-protection

GreenScreen - https://www.greenscreenchemicals.org

US EPA's Safer Choice - https://www.epa.gov/saferchoice.

CDC Guidelines on PFAS exposures - https://www.cdc.gov/niosh/topics/pfas/default.html

OSHA Permissible Exposure Limits - https://www.osha.gov/annotated-pels

K.8. POST EVENT CLEANUP (ANNEX H)

Interstate Technology and Regulatory Council (ITRC) link - https://pfas-1.itrcweb.org/3-firefighting-foams/#3_6

U.S. DoD's Environmental Group Research Programs on remediation of PFAS in the soil - https://www.serdp-estcp.org/ and https://www.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs