AFFF Alternatives: Art of the Possible

15 November 2019

SERDP ESTCP

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AFFF Alternatives: Art of the Possible
November 15, 2019

The Aqueous Film Forming Foam (AFFF) Alternatives summit was held at the Residence Inn Pentagon City. The goal for this summit was to provide the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) with an initial set of short-term objectives and long-term goals to address AFFF alternatives from the research and development, and the demonstration validation and implementation perspectives.

There were approximately 100 attendees representing DoD, other federal agencies, academia, and the firefighting manufacturing industry. HON Robert McMahon, Assistant Secretary of Defense for Sustainment, provided initial comments to the group describing the great need for out of the box thinking to provide solutions to the DoD and our nation regarding AFFF alternatives.

A group of military fire chiefs and the Ohio State Fire Marshal provided the group with a rationale for providing a solution that would not add additional risk to our first responders, but they also described the constraints they all face regarding training in relevant environments.

A Naval Sea Systems Command engineer provided a review of the current military specification for AFFF and the historical background regarding Naval firefighting.

A series of lightning round presentations provided perspective from the Federal Aviation Administration, National Fire Protection Association, Naval Air Warfare Center, Air Force Civil Engineering Center, National Aeronautics and Space Administration, and the National Institute of Environmental Health Sciences.

All of the above presentations set the stage for several hours of intensive discussions on materials and engineering solutions to address AFFF alternatives. Those discussions are summarized in the following documents and presentations.

Dr. Herb Nelson

Director – SERDP & ESTCP

Honorable Robert McMahon

Assistant Secretary of Defense for Sustainment

DOD-wide Research Towards a Fluorine Free Alternative to Aqueous Film Forming Foams (AFFF)

Robin Nissan
Program Manager Weapons Systems and Platforms
October 2019

SERDP
DOD ▪ EPA ▪ DOE

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DoD's Environmental Technology Programs

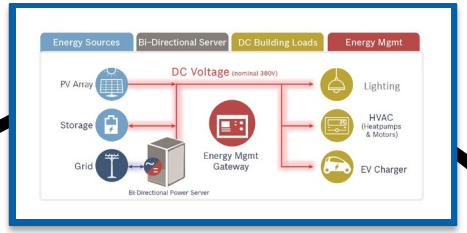
Science and Technology

- Statutory Program Established 1991
- DoD, DOE, EPA Partnership
  - Advanced technology development to address near-term needs
  - Fundamental research to impact real world environmental management

Demonstration and Validation

- Demonstrate Innovative Cost-Effective Environmental and Energy Technologies
  - Transition technology out of the lab
  - Establish Cost and Performance
  - Partner with End User and Regulator
  - Technology Transfer
    - Accelerate Commercialization or Broader Adoption
    - Direct Technology Insertion

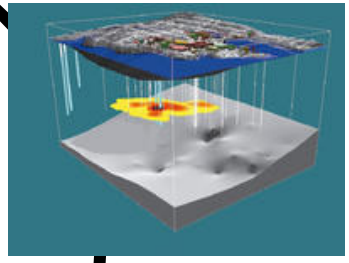
Program Area Management Structure



Energy & Water (ESTCP only)

Weapons Systems & Platforms

Environmental Restoration

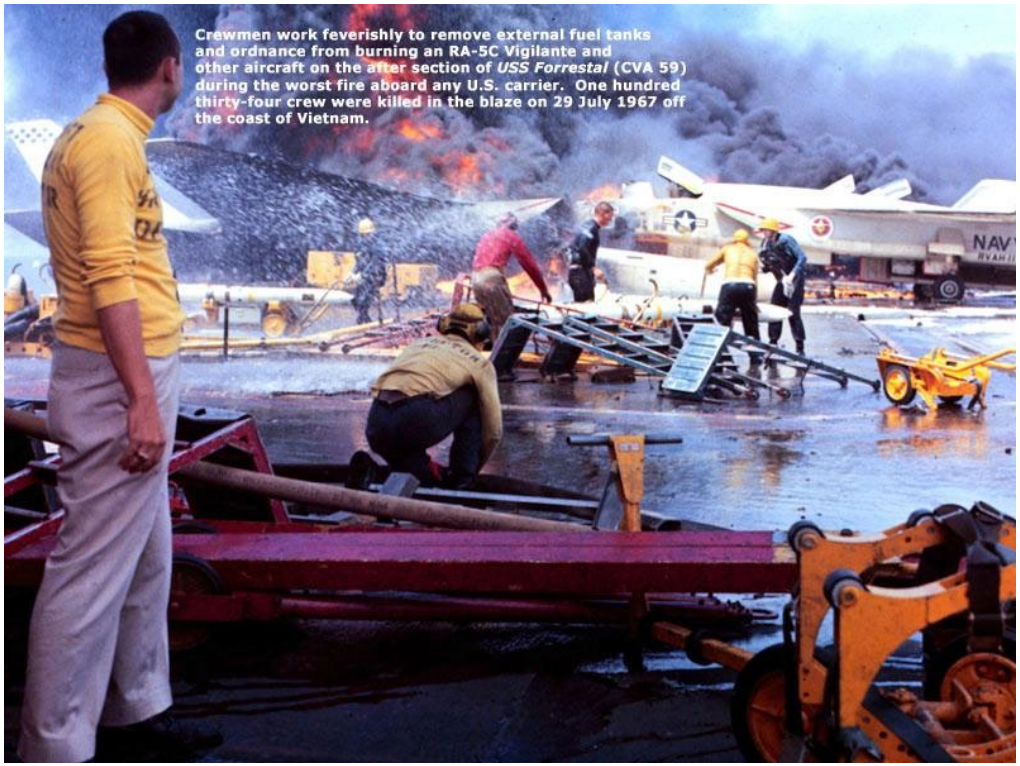


Resource Conservation & Resiliency

Munitions Response

SERDP & ESTCP

Then



USS Forrestal Fire, 1967 (134 Sailors Killed/161 Injured)

Now

Fully fueled C-5 Galaxy, Dover AFB 2006 (17 crew and passengers, 0 fatalities)

AFFF Replacement Challenges

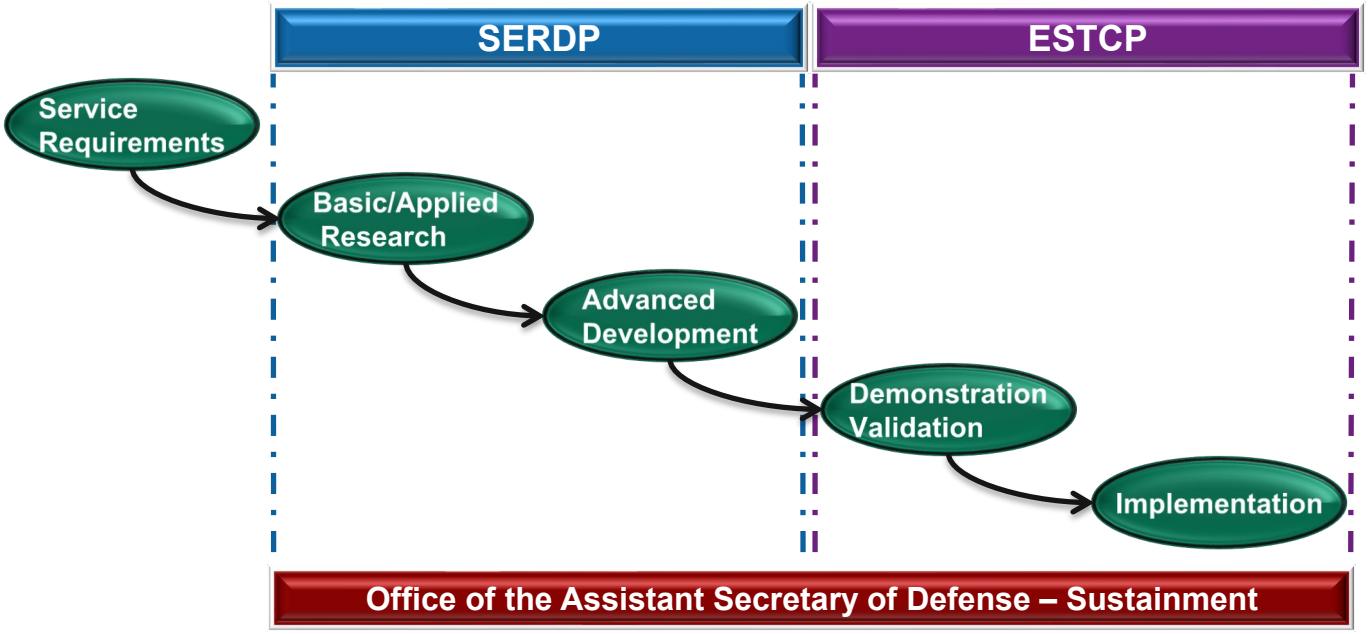
- **Unique chemical nature of the carbon-fluorine bond**
- The call for a “drop-in replacement”
- While the MilSpec no longer requires fluorine, many of the performance requirements still favor its unique characteristics
- The need to decide at what point engineering and firefighting methodology can bridge remaining material performance gaps
- A lack of analytical tools to determine with confidence that a product is truly fluorine free
- Unknown toxicity of alternatives

Bottom line is that the MilSpec may need to change

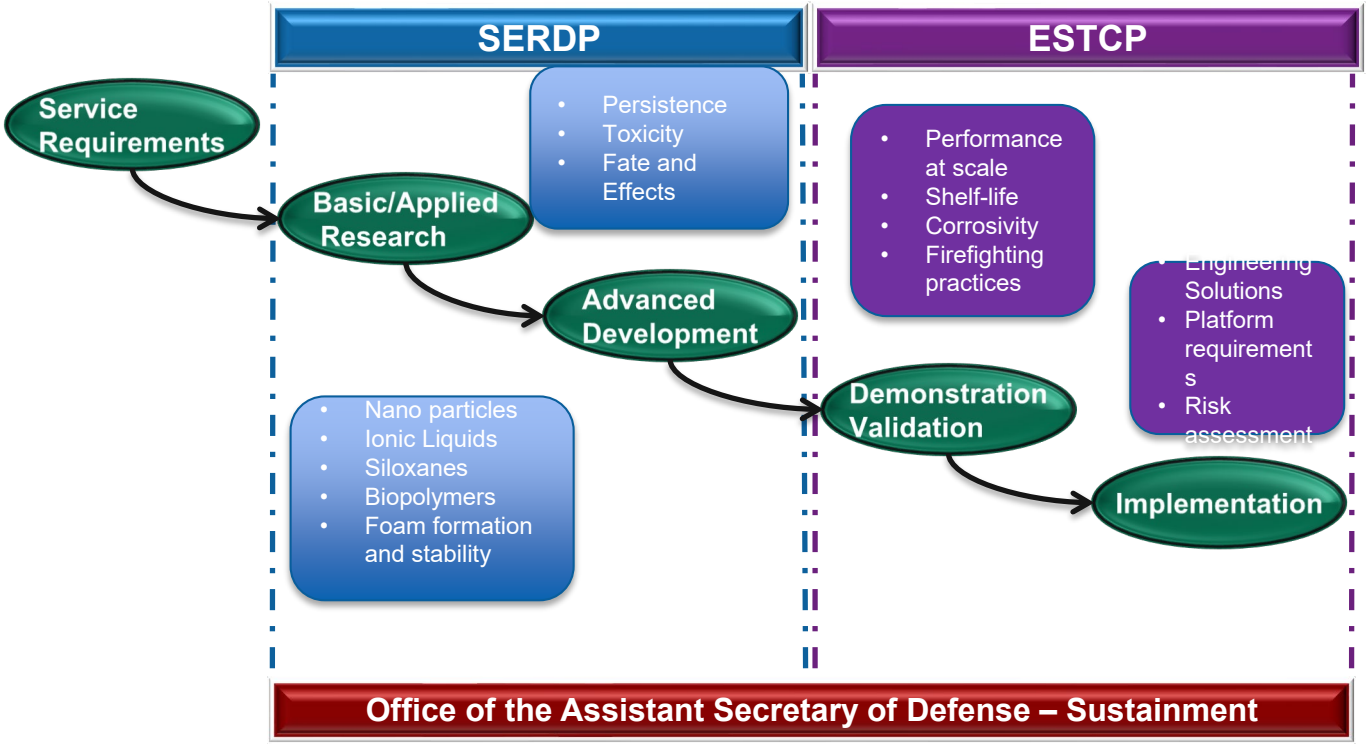
Important Knowledge Gaps

Fluorine Free AFFF Characteristics	Related Research Questions
• Tend to be quite viscous	• Can we drive viscosity down?
• Foam stability may not be equivalent	• Can we make more stable foams? • Are there other measures of foam quality that we need to understand?
• Do not work as well with salt water vs. fresh	• Why is that? • Is there an additive that can improve salt water performance?
• They do flow across the fuel / fire interface	• The alternatives do not flow as well • What can be done to improve flow?
• The assumption, without data, that they are more sustainable	• Environmental persistence? • Fate and Transport? • Toxicity to plants or animals or humans?

Environmental Technology Development Process



Environmental Technology Development Process



Preliminary Results on Fluorine-Free Formulation from National Foam

Fire performance – heptane / fresh water

90% control in 23 seconds

99% control in 36 seconds

Extinguishment in 43 seconds

Burnback > 360 seconds

28 square foot fire test with heptane fuel and fresh water
MIL F 24385 F requires 30 second extinguishment and > 360 seconds burnback

International Efforts Towards AFFF Alternatives

- Fluorine-free AFFF alternatives have been developed but none has so far demonstrated the required level of performance for DoD deployment
- One formulation was patented in 2003 by 3M
  - This formulation came close to passing the Navy's standard fire test (35 seconds extinguishment time versus a 30 second requirement)
  - Non-military users, such as the Copenhagen Airport in 2009 and Heathrow Airport in 2012 made the switch to that fluorine-free AFFF
  - The formulation was commercialized by Solberg
  - Enhanced performance is achieved with compressed air
- Other fluorine-free (or near free) formulations are now available on the marketplace
  - Orchidee, Dafo Fomtec, and Angus Fire have commercial products
  - These products have not met the MilSpec

SERDP • ESTCP

SYMPOSIUM

25 YEARS OF ESTCP

2019 | Enhancing DoD's Mission Effectiveness

- December 3 – 5, 2019 at the Marriott Wardman Park
- Plenary session the first morning then two days of technical sessions and one day of short courses.
- Attendance ~1,000

http://www.symposium.serdp-estcp.org/

For More Information

https://www.serdp-estcp.org/

Military & State Fire Chief's Assessment

MIL-PRF-24385
Aqueous Film Forming Foam (AFFF)

U.S. Navy

AFFF Alternatives: Art of the Possible

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Why AFFF?

- 1940-1970: U.S. Navy used Protein Foam as the primary Class B (flammable/combustible liquid) firefighting agent.
- Protein Foam had good burnback resistance but had slow fire knock down due to reduced flow and spreading capabilities.
- Rapid extinguishment time is considered critical for crew safety and mission restoration, especially when considering the additional hazards posed by the presence of ordnance at the fire scene.
- Aqueous film forming Foam (AFFF) was developed in the 1960's to make up for this recognized fire protection shortfall.

USS Forrestal Fire, 1967
(134 Sailors Killed/161 Injured)

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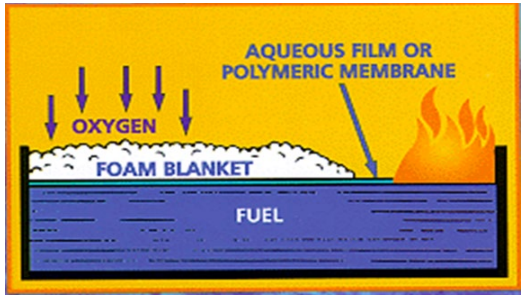
History and Usage

- Initial specification issued 1969, with first product on the qualified products list (QPL) in 1970. Synthetic foam made from chemical surfactants that produces a thin film of water with low surface tension between the fuel source and the foam blanket.
- Extinguishing Mechanism:
  - Aqueous film creates fuel vapor seal
  - Film reseals quickly if ruptured (prevents reflash)
  - Foam blanket limits oxygen access to the fuel and vapor transport to the fire
  - Foam blanket adds cooling effect



- Used shipboard in areas subject to fuel spills and fires for rapid control and extinguishment.
- Required for US Navy ships, USCG operated ships, DoD aviation facilities, and most major commercial airports.
- Used at many foreign airfields and by some foreign navies.
- Non-MILSPEC (i.e. UL, ICAO, EN) AFFF also marketed and used worldwide.

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Key MILSPEC Requirements

- Viscosity
- Dry Chemical compatibility
- Extinguishment time
- Burn back time
- Seawater and freshwater extinguishing tests
- Half strength and 5X strength extinguishing tests
- Compatibility among vendors

USS Nimitz, following flight deck crash and fire, 1981.

AFFF MILSPEC Qualification testing.

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Recent MILSPEC Changes

- MIL-PRF-24385F w/ Amendment 2 – Dated 7 September 2017
  - Instituted 800ppb maximum limit on PFOS and PFOA in concentrate
  - Identified DoD's goal *"…to acquire and use a non-fluorinated AFFF formulation or equivalent firefighting agent to meet the performance requirements for DoD critical firefighting needs. The DoD is funding research to this end, but a viable solution may not be found for several years. In the short term, the DoD intends to acquire and use AFFF with the lowest demonstrable concentrations of two particular per- and PFAS; specifically PFOS and PFOA. The DoD intends to be open and transparent with Congress, the Environmental Protection Agency (EPA), state regulators, and the public at large regarding DoD efforts to address these matters. AFFF manufacturers and vendors are encouraged to determine the levels of PFOS, PFOA, and other PFAS in their products and work to drive these levels toward zero while still meeting all other military specification requirements."*
- MIL-PRF-24385F w/ Int. Amendment 3 – Dated 7 May 2019
  - Deleted requirement for a "fluorocarbon" surfactant. Permits non-fluorinated *film-forming foams to qualify for the MILSPEC

***Fluorosurfactant is key to making AFFF effective. No non-fluorinated film-forming surfactant alternative is currently known to exist, although research is ongoing**

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Future MILSPEC Changes

- MIL-PRF-24385G – ETA 2020
  - Will define new analytical procedure for PFOS/PFOA analysis.
  - Continue to drive PFOS and PFOA lower via new, lower maximum permissible limits made possible by new analytical procedure.
- Fluorine-Free Foam (FFF) MILSPEC – ETA ?
  - Lack of film-forming alternative may drive the need for a new MILSPEC which may have different physical and chemical properties than legacy AFFF.
  - A MILSPEC for FFF is advantageous to DoD as it permits:
    - Definition of minimum fire performance goals
    - Definition of allowable agent physical/chemical characteristics (ensures equipment and material compatibility)
    - Implementation of inter-compatibility requirements among manufacturers
    - A Qualified Products List (QPL) – DoD tracking of product conformance
  - Initial effort may be focused on shore-side applications to allow quicker implementation.

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Current AFFF-Usage Mitigations

- Non-emergency shoreside use (training/testing) of AFFF is now prohibited by Military Department policy.
- Only fire emergency use of AFFF is permitted, and releases are then treated as a HAZMAT incident to minimize impact to groundwater.
- Existing Military Department shoreside systems and fire apparatus have, or are currently undergoing (or are soon to undergo), an AFFF change out process, with the intent of replacing older legacy AFFF formulations with newer formulations with significantly lower content of PFOS and PFOA.
- More recent facility designs have included effluent retention capabilities to prevent AFFF release to the environment. Older designs are being surveyed and upgrades are being assessed.
- Firefighter and Service Member Personal Protective Equipment (PPE) for PFAS exposure preventions are in-place.

DoD is fully aware that these measures limit, but do not eliminate the PFAS concern. Transition to a fluorine-free AFFF alternative is the goal.

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Assessment of AFFF Alternatives

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Types of Agent

Many different foams, with different uses:

- Class A foams (ordinary combustibles, i.e. wood/paper) - typically medium and high expansion foam
- Class B foams (flammable liquids) – typically low expansion foam
  - Protein
  - Fluoroprotein
  - Film Forming Fluoroprotein (FFFP)
  - Aqueous Film Forming Foam (AFFF)
  - Alcohol Resistant
  - Synthetic (Fluorine-Free)
- Non-foams (wetting agents; water additives)

US Navy ships require a low-expansion foam for use on Class B fires

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Main Class B Foam Uses

Somewhat Different Worlds

Commercial / Petrochemical Industry (UL 162 – EN 1568)

- Tank
- Fuel storage
- Fuel handling systems

DoD/ARFF (MIL-PRF-24385F) and *FAA/ARFF (MIL-PRF-24385F and ICAO)

- Vehicle Stowage
- Hangars
- Flight Decks
- *Aviation / Crash
- DoD munitions
- Machinery Spaces
- Pump rooms

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Key Transition Considerations

- Rapid fire knockdown and extinguishment essential for Aircraft Rescue Firefighting (ARFF) scenarios.
  - Very extensive research and usage (50+ years) history with MILSPEC AFFF with large/medium/small demonstrations in many different scenarios. Demonstrated correlations between large and small scale fires.
  - Large gap in applicable FFF research to date. Many unknowns.
- Effectiveness when proportioning out-of-specification.
  - MILSPEC tests include ½ and 5x design concentration strength, allowing effectiveness during misapplication or equipment failure/damage. Essential for shipboard.
- Agent compatibility between manufacturers
  - Essential to intermix, for logistical support and supply availability
- Effectiveness with aspirated and non-aspirated nozzles
- Compatibility with existing equipment is highly desirable.

Current FFFs can not meet MILSPEC performance requirements

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Standards Comparison

Test	Pan Size	Fuel	Application Rate	Max. Ext. Time	Ext. App. Density	Max Solution Flowed
			gpm/ft²	(sec)	gal/ft²	Gallons
MIL-PRF-24385 AFFF	28 ft^2	Mogas	0.071	30	0.036	1.8
	50 ft^2	Mogas	0.04	50	0.033	1.65
UL 162 AFFF	50 ft^2	Heptane	0.04	180	0.12	6
UL 162 Synthetic (Fluorine-Free)	50 ft^2	Heptane	0.06	300	0.3	15
ICAO Level B	~50 ft^2	Kerosene	0.06	60	0.061	3.05
ICAO Level C	~80 ft^2	Kerosene	0.04	60*	0.038	3.04

>9X

* Flickering flame permitted
Extinguishment Application Density = Application Rate x Max Extinguishment Time (min)
Max Solution Flowed = Extinguishment Application Density x Pan Size

Many Different Variables!

- Fuel
- Fire Size
- Application Rate
- Application Method
- Allowable Extinguishment Time

Need to Evaluate/Compare Consistently

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Standards Comparison (cont.)

DoD Takeaways:

- To compare foams, we first need to understand and correct for the deltas in test standards.
  - Current fluorine-free foams are not film formers. UL 162 holds them to different test requirements than an AFFF.
  - Need to test with the appropriate fuels for the expected hazard.
- Commercial standard test results are not public record.
  - FFF performance can vary widely by manufacturer.
- Commercial standards demonstrate only basic fire extinguishing capabilities.
  - MILSPEC - 23 different fire tests
  - Commercial standards - often only a single full-strength fire test
- Commercial standards not focused on agent's chemical and physical property testing.
  - MILSPEC is a performance standard – many tests to demonstrate compliance with performance requirements.

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Current Navy Research Paths

- **NRL SERDP Grant WP 2739**; Synthesizing and developing novel siloxane surfactants through combination of bench and large scale testing
- **NRL Core 6.2 fluorosurfactant replacement program**; developing new measurement methods and computational models to guide the development of novel surfactants
- **NRL/Jensen Hughes NFPA Research Foundation Fluorine Free Foam fire test evaluations**; to access capabilities of currently listed (AFFF/Synthetic & Alcohol Resistant) foam products using the UL 162 test standard employing a modified ICAO nozzle at various application rates, expansion ratios, and hydrocarbon fuel sources (Gasoline (ethanol-free), Gasoline (E-10), Heptane, and Isopropyl Alcohol (IPA))
- **DoD ESTCP Fluorine Free Foam (F3) fire test evaluations**; to assess the extinguishing capabilities of commercially available Fluorine Free Foam and Wetting Agents when exposed to military specific fire threat scenarios

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Navy Testing of Commercial Fluorine-Free Foams (FFF)

1. Commercial FFF products have improved over the years, but there are still a number physical property and engineering issues that need further investigation.
2. FFFs are not film-forming but “mimic” film formation through slow liquid drainage from the established foam blanket.
3. Many commercial FFF products use fluorine-free hydrocarbon or sulfonated surfactants, but also use a number of solvents, stabilizers and thickeners.
4. The presence of thickening agents dramatically increases viscosity of the FFF concentrate.
5. FFF products tend to have better firefighting performance with Heptane versus Gasoline fueled fires.
6. There is an absence of data, notably large-scale fire testing including those simulating large Flight Deck fire scenarios, that still needs to be investigated/ conducted to demonstrate the efficacy of these AFFF alternatives for DoD applications.

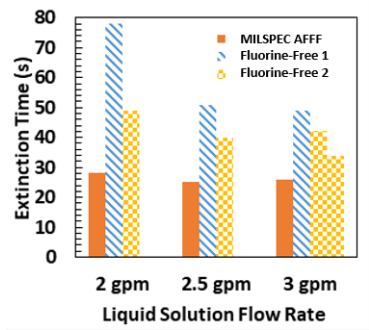

Fig 1 – Preliminary 28 ft^2 *Gasoline* Pool Fire Extinction Results

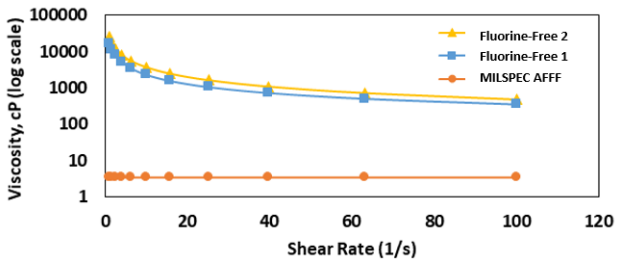

Fig 2 – Viscosity of AFFF, Fluorine-Free-1 and Fluorine-Free-2 Foam Concentrates as a Function of Applied Shear Rate in a Plate rheometer. Y-axis is on a Log-Scale

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Current FFF Knowledge Gaps for US DoD

- Limited performance data
  - Mostly small scale approval tests
  - No application specific testing (i.e., realistic with ordnance)
- Flow of an aspirated foam blanket through obstructions (foam transport)
- Varying effectiveness based on fuel type.
- Aging and shelf life is an unknown.
- Effectiveness at elevated ambient temps.
- Equipment compatibility (i.e., viscosity).
- Need to verify environmental suitability to avoid replacement regret.

NFPA FPRF photo

FFFs much thicker / non-Newtonian

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US DoD Shipboard

- Current shipboard AFFF systems are designed to minimum requirements due to ship impact (space and weight).
- Shipboard systems use many non-aspirated nozzles.
  - Aspirated: Better foam quality but shorter throw distance.
  - Non-aspirated: Lesser foam quality but greater throw distance.

    (AFFF works with both nozzle types, current FFF prefer aspirated)
- Compatibility concerns with existing proportioning systems. (viscosity is a huge concern)
- Increased discharge rates with FFF result in shorter durations for firefighting operations with existing tank sizes.
- Increased discharge rates and viscosity may drive substantial modifications to existing pumps, pipe networks, and nozzle locations. Huge undertaking to retrofit existing systems.

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US DoD Shore-Based

Shore-based firefighting operations face similar operational concerns as shipboard usage (ordnance, fuel, personnel, vital assets), however differ in the application environment (not as constrained as shipboard).

AFFF alternatives are currently being researched by DoD for shore-based applications.

- Lesser extinguishing capabilities can potentially be compensated for with higher application rates/more equipment.
- Alternative application methods being studied. (CAF, UHP)
- Shore based implementation easier than shipboard (not restricted as much by weight/space/manpower).
- Not all current MILSPEC requirements are expected to be deemed essential for shore-based applications (i.e. seawater effectiveness).

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Closing

DoD is committed to researching and identifying a fluorine-free AFFF alternative that is capable of providing the required firefighting capabilities needed to ensure the safety of our service members, civilian workforce, and mission critical assets.

In the interim, DoD is committed to:

- Minimizing AFFF use (emergencies only)
- Procuring and using AFFF with the lowest demonstrable levels of PFOS and PFOA

Rapid Suppression of Large Scale Aviation Fires remains a Navy Priority

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Lightning Round

NASA AND AFFF

Chris Scheer, P.E.
NASA Institutional Safety Management Division

- NASA USES AFFF IN THREE OPERATIONAL AREAS
  - Aircraft Rescue Fire Fighting (ARFF) Apparatus
  - Structural Fire Apparatus
  - Fixed Systems

- 7 NASA Centers with NASA fire departments
  - 3 with ARFF apparatus
- 19 NASA owned/operated hangars
  - 9 with AFFF systems

- NASA CONCERNS WITH AFFF REPLACEMENTS
  - Effectiveness as a suppression agent
  - Drop-in replacement
  - Suppression system alternatives
  - Cost/feasibility to retrofit fire apparatus & fixed systems
  - Phase-in/sunset time frame

- NASA RESTRICTIONS ON AFFF AS OF 10/24/2018
  - For active fire suppression only
  - May be installed in Class 3 Hangars only
  - All training use is prohibited

Relative Characterization of Bioaccumulation & Biological Responses to AFFF Exposures

Stephen S. Ferguson, Ph.D.
Division of the National Toxicology Program
National Institute of Environmental Health Sciences

Evaluations of AFFF Formulations

- DoD & stakeholders seek to better understand AFFF products that:
  - meet fire suppression MilSpec requirements
  - minimize the potential for downstream human health effects (e.g., contaminated ground water)
- AFFF products have used fluorosurfactants such as PFOS, PFOA, and fluorotelomers with low density flammable liquid fires
- Concerns with PFAS:
  - known to be environmentally persistent
  - potential to bioaccumulate in humans (e.g., PFOS/PFOA) with very long half-lives (i.e., years)
  - associated with various human toxicities: reproductive, developmental, hepatic, and renal effects

– Ongoing PFAS Research Activities at the DNTP include:
  - REACT Program: new approach methods & ADME
  - in vivo mammalian targeted testing
  - AFFF exploratory studies

https://www.nrl.navy.mil/accomplishments/materials/aqueous-film-foam

Assumptions

- Project not intended to evaluate acute toxicity/hazard to workers handling/applying AFFFs
- Focus on PFAS constituents, given their potential for bioaccumulation in humans through non-occupational environmental exposures (e.g., ground water)
- Bioaccumulation & biological responses to PFAS constituents from current AFFF products not well characterized
- Bioavailability of PFAS in AFFF formulations is similar to that in environmental media

Objectives

- Identify and compare constituent PFAS profiles for AFFF products on the Qualified Products List, and where possible estimate individual and/or total PFAS concentrations

- Estimate the relative potential for bioaccumulation of constituent PFAS within AFFF products

- Characterize biological responses to AFFF products and provide interpretive context regarding their potential translation to human health effects

Bioaccumulation/Response Model System Summary

- Bioaccumulation & biological response relative characterizations comprised of 3 approach models to address stated objectives:
  - In vivo AFFF exposures
  - In vitro primary human and rat hepatocyte bioaccumulation models
  - In vitro HepaRG models to survey a broad range of biological response pathways for relative characterization

Charge to Break Out Groups

Dr. Robin Nissan

Backup

Current Funded Efforts

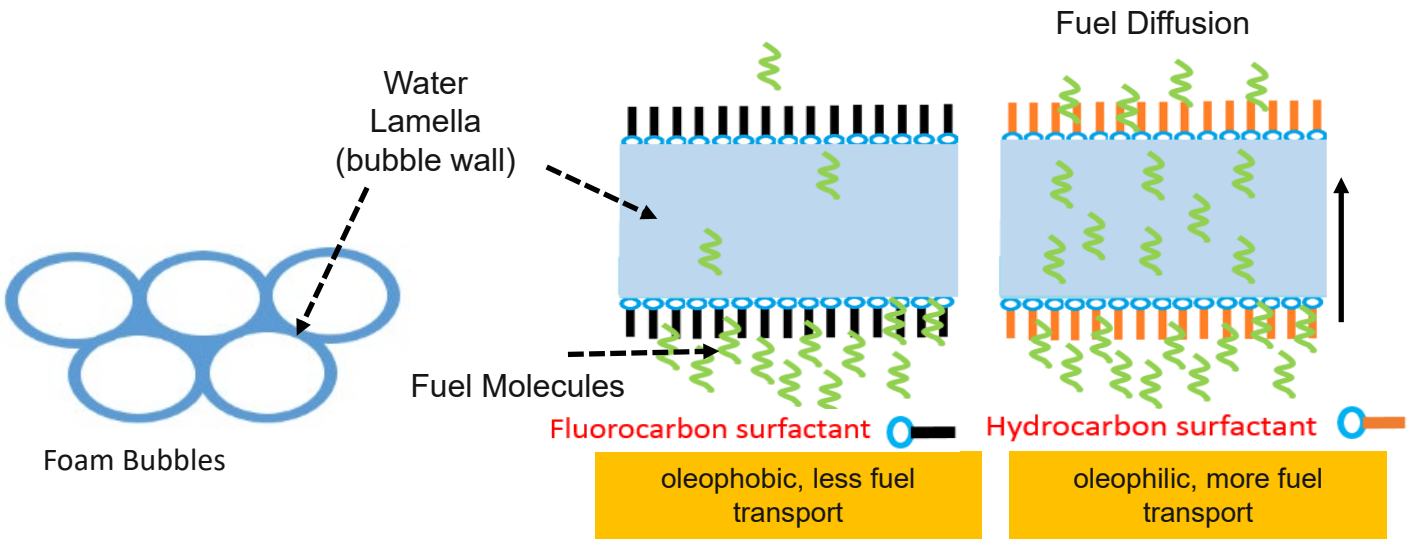
SERDP

- WP-2737: Novel Fluorine-Free Replacement For Aqueous Film Forming Foam- NAWC WD China Lake
- WP-2738: Fluorine-Free Aqueous Film Forming Foam-National Foam
- WP-2739: Fluorine-free Foams with Oleophobic Surfactants and Additives for Effective Pool Fire Suppression-Naval Research Laboratory
- WP18-1519: Surfactants with Organosilicate Nanostructures for Use as Fire-Fighting Foams (F3)- NAWC WD China Lake
- WP18-1559: Designing Next Generation Polymer-Based Surfactants for Fire Suppression- Virginia Polytechnic University
- WP18-1592: Stability of Fluorine-free Foams with Siloxane Surfactants for Improved Pool Fire Suppression- Naval Research Laboratory
- WP18-1597: Innovative Nano-Encapsulated Ionic Liquid Based Surfactants for Fluorine-Free Fire Extinguishing Foams- Molekule, Inc
- WP18-1630: Fluorine-free Ionic Liquids for Aqueous Film Forming Foam-Materials Modification, Inc
- WP18-1638: Fluorine-Free Aqueous Film Forming Foams Based on Functional Siloxanes- Materials Modification, Inc

ESTCP

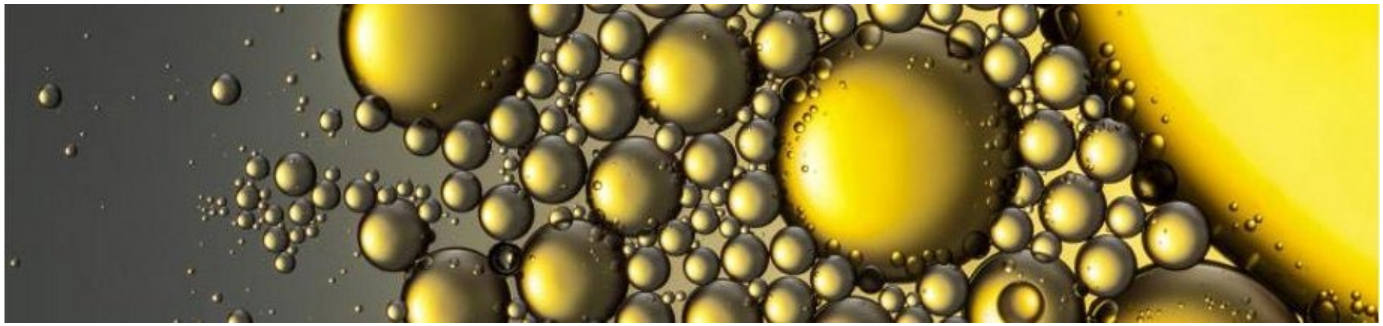
- WP19-5299: Validation of Fluorine-free AFFF against Military Specification Performance Criteria- Batelle Memorial Institute
- WP19-5324: Capabilities Assessment of Commercially Available Fluorine-Free Foams – Jensen Hughes, Inc
- WP19-5332: Screening Tests for Fluorine-Free Firefighting Foams- Jensen Hughes, Inc
- WP19-5348: Fluorine-free, 100% Bio-based Fire-fighting Materials – Nu Element, Inc

NRL Key Findings



- **Foam is the major barrier to fuel transport from pool to the fire** (because of myriad of bubble walls)
  - **Forming an "aqueous film" to minimize surface tension – *Typical commercial target for non fluorine surfactants***
  - **Reducing fuel transport in the foam – *NRL's target for a new approach***

Unique Concept: Oleophobicity



- Think of your non-stick pan: both oil and water bead up
- Oleophobic surfactants form a barrier layer of insulating bubbles between the fuel pool, the vapor above (and the water below, if ship based)
- This is a unique property of PFAS containing AFFF
- Some other chemicals have similar characteristics that can be exploited, but are unlikely to work as well

AFFF MIL-PRF-24385F Amendment 3 Basic Requirements

- Extinguishes a 28 sqft fire in under 30 seconds, 50 sqft in under 50 seconds, at 2 gpm flow rate.
  - (UL listed AFFF, 50 sqft fire, allowed up to 180 seconds at 2 gpm)
  - (UL listed Fluorine Free, 50 sqft fire, allowed 300 seconds at 3 gpm – almost 9x the amount of MILSpec)
- Burnback resistance of >360 seconds. (Measures ability to prevent re-ignition)
- Compatible with seawater and freshwater. (Useable by ship and shore facilities)
- Tested at half strength and quintuple strength. (Allows for mis-proportioning by the system)
- Compatible with other qualified AFFF so they can be mixed without concern for adverse reactions while maintaining extinguishing performance. (Permits any qualified manufacturer's product in any system.)
- Compatible with dry chemical, another agent used in fire fighting.
- Tests for viscosity, corrosion, etc to ensure compatibility with systems.
- Tests for film formation, sealability, no precipitation, to help ensure performance.
- Tested with gasoline as a reasonable comparison to JP or DFM. (UL uses heptane, shown by NRL to cause some fluorine free product to pass, but then fail when tested with gasoline.)
- PFOS and PFOA <800 ppb.

AFFF Alternatives: Art of the Possible
November 15, 2019

Materials Solutions Working Group Narrative

The Materials Solutions Working Group consisted of primarily Department of Defense representatives, as well as one fire chief, at least four foam manufacturers, multiple toxicologists or environment, safety, occupational health experts and academia. Discussion focused on shore-side applications, but each of these issues would apply to shipboard applications as well.

Initial Discussion

Material developers do not believe that a straight drop-in fluorine-free foam (F3) will be available. This problem will likely need to be addressed through an integrated approach. This would include coupling engineering design to available foam performance, while also reducing exposure and release of any foams whenever possible through revised training and facilities.

Training with foams is currently restricted; which means that our firefighters are potentially at risk of not being fully prepared to fight live fires. This is in part due to environmental issues related to open burning of petroleum products in large scale pool fires, as well as the impacts of the foams. The working group recommended investment in virtual, hyper realistic training that could alleviate this issue. Training would need to mimic the feeling of true fires (e.g., tactile sensation, heat, noise, smells), while also providing accurate performance of firefighting foam.

Formulation/Mechanism and Viscosity/Flow:

To date, most if not all viable F3 do not produce a film. Performance is primarily due to bubble quality. Film formation is dominated by surface tension, but in a very dynamic fire system with changing temperatures, it is not clear if film formation is the primary mechanism for extinguishment. Future foam development would be aided by a more fundamental understanding of the fire suppression mechanism for F3.

Formulators need a variety of chemical parameters to predict foam performance. This includes surface tension, interfacial tension, oleophobicity, viscosity, pH, and temperature dependence. The industry needs more effective computational models to inform material selection. Models for surface tension, interfacial tension exist; however, there is not a complete foam production model.

Foam developers need a set of hard requirements to evaluate against. This should include fuel types, concentrations, viscosities (concentrate, mixed foam and as-delivered foam) and operational temperature. F3 have proven to be more viscous or even non-Newtonian fluids. The working group recommended that foams should be tested across a range of temperatures, including the most extreme temperatures that would be seen in airports. There is some evidence to suggest that F3 are not effective at temperatures over 100ºF. Future solutions will likely be limited to less than 10% use concentration for procurement, storage and application of foam. Higher concentrations mean shorter firefighting duration with current equipment.

It was recommended that DoD promote more interaction with industry and provide a usable forum/repository for this sharing data.

Does it have to be a foam?

The working group argued that the product is dependent on the final mission/goal. For applications that need to put out a fire quickly, it's possible that a non-foam option could work. However, foams are one of the only options that have proved useful at blanketing a fuel to prevent burnback, which is a concern for realistic firefighting methods. Powders could be used in potentially smaller areas, but this would be difficult to dissipate over large surfaces. Gels have been used on some Class B fires, but if they don't float on the surface of a liquid pool they would be ineffective. Other ideas include free radical chemistry that uses a chemical reaction to extinguish the fire. It's possible that a two-stage system could be proposed where the first step focuses on fire extinguishment and a second would stabilize/blanket the fuel to prevent burnback. This would require additional capability, personnel and training. Another idea was to make foam without using air to reduce available oxygen (possibly nitrogen or carbon dioxide).

How good is good enough?

The consensus was that MIL-PRF-24385 AFFF is currently the best available option. Any reduction in performance represents a real risk, not only to our firefighters and warfighters, but also to commercial air travelers who also depend on first responders to extinguish fires quickly. The current specification is written around prior performance and may not be the best method to represent real scenarios, but there is a proven correlation between passing the specification and providing reliable performance in the field. One area that can be improved is by developing new small scale tests that could be extrapolated to real world performance. This includes tests to measure foam fluidity, small burnback, foam stability over a variety of conditions (time, temperature, degradation due to fuel reaction, radiative heat, etc.), and bubble quality.

Toxicology of Alternatives

It is essential to evaluate the proposed alternatives for impacts to the environment and human health. There are phased tests available that can be used to predict toxicity, ranging from *in silico* methods to screen chemicals, *in vitro* testing which can provide a first order approximation of impact and *in vivo* repeated dose, sub-chronic testing. These tests can be leveraged from existing industry (food and drug, pesticide). Individual chemicals and foam formulations would need to be evaluated for persistence, bioaccumulation, toxicity and fate and transport in the environment. The gold standard for bioaccumulation testing would be a 90 day sub-chronic rodent study; however, this is a relatively costly test and should only be conducted for the most promising materials. It is important not to vilify the fluorine atom by itself. It's possible that there are fluorine containing compounds that could be used in a safe, effective foam. The working group discussed the need for evaluation of the existing C6 AFFF to provide a realistic evaluation of ESOH risks against risks of using the legacy PFOA/PFOS foams or F3.

Corrosion, Ageing and Compatibility

To date, DoD has not evaluated F3 against the entire suite of MIL-PRF-24385 testing. They have received test data from manufacturers as available, but because these products have not passed full scale fire testing, they have not sent products to the government for qualification. The working group discussed the benefits of collecting this information to be able to make informed decisions on what a future requirement should include. It was recommended that this could use a tiered approach to collect data consistent with technology maturity.

Current ageing protocol is to store the foams at an elevated temperature to simulate long term ageing. Current and legacy foams have shown stability in the field for decades. Future iterations of the specification may need to include cyclic ageing, where the foams are transitioned through different temperatures over time, to truly evaluate long term stability.

DoD will need to figure out the best method to determine compatibility between different foam chemistries. There will likely be multiple surfactant packages that will include multiple chemistries. It will be difficult to use foams that require their own equipment if incompatible.

Data sharing will be an important aspect of making decisions going forward. ESTCP projects are collecting a database of performance data for F3 and there are multiple environmental organizations that will start to compile toxicity data for PFAS and eventually, F3 components.

MIL-PRF-24385 Issues

MIL-PRF-24385 will need to be updated and/or bifurcated (split into two or more firefighting specifications) in order to effectively transition F3 products. There was some discussion about the need to bifurcate/split the specification into shore and shipboard applications. Additional clarification on test methods and/or new test methodologies were recommended. This includes testing on a solid surface (not floating on water) to mimic real fires, developing a metric for foam quality, potentially removing sea water requirement and identifying novel small scale tests as previously discussed. This should also evaluate the need for a “film forming” requirement.

Path Forward:

Near Term:

- Evaluate and demonstrate F3 against current specification and realistic fire scenarios
- Collect toxicity data for existing C6 and F3 commercially available foams
- Establish data repository for performance, chemical/physical properties and toxicity

Mid Term:

- Develop more fundamental understanding of F3 mechanism
- Develop, validate improved small scale test methodology with correlation to large tests
- Modify MIL-PRF-24385 and/or establish new specification
- Improved computational models for predicting performance

Long Term:

- Transition F3 into applications through either retrofit or new procurement

AFFF Alternatives: Art of the Possible
November 15, 2019

Engineering Solutions Working Group Narrative

The Engineering Solutions Group consisted of about 50% Fire Marshals, First Responders and End Users, 25% Regulatory Types / Tech Warrant Holders and 25% Researchers and Subject Matter Experts.

Initial Discussion

The initial discussion provided the opportunity for the First Responder (FR) Community to vet concerns associated with replacing the legacy AFFF with a less effective product. They emphasized that all the equipment, manning and tactics that have been used over the past 50 years were developed based on the characteristics and capabilities of AFFF. They also emphasized that changing to a less effective agent will have major impacts on manning. During the conversation, the group discussed the need to minimize the future environmental exposures by socializing “best practice” information and handling and cleanup of AFFF discharges. The intent would be to allow additional time for DoD and the fire protection industry to develop and deploy an effective AFFF alternative. The FR Community also expressed concerns associated with the impacts of these changes on the civil aviation community which does not have the DoD funding base to help with the transition to a new product (i.e., where will their funding come from?).

The conversation then transitioned into a discussion on the need for the replacement product to mimic the capabilities of the legacy AFFF. Much of this discussion was based on the evolution of firefighter training over the past 20 years driven by the need to reduce the potential environmental impact of training. Over the past 20 years, firefighter training has transitioned from the actual extinguishment of large flammable liquid pool fires using AFFF to propane burners which are remotely secured based on the ability of the firefighter to hit the fire with a stream of water. The FR Community stated that the transition into the use of water as the agent and propane burners to create the fires has led to inadequate training. However, much of these inadequacies have been compensated through the superior capabilities of AFFF in actual scenarios. In general, the FR Community stated the need to revisit how firefighters are being trained especially if the use of AFFF becomes restricted and the replacement product has reduced capabilities. The USAF stated that they currently have 6 hydrocarbon-based trainers and other organizations such as TEEX have been able to successful test under more realistic conditions/scenarios (i.e., hydrocarbon fuels and foam extinguishing agents). The group agreed that these training facilities, e.g. USAF and TEEX, need to be studied with the potential to transition training back to more representative scenarios. However, this transition potentially includes an effluent removal and disposal cost that can range from $3-8/gallon.

MILSPEC Considerations

The initial discussion was based primarily on aviation/ARFF and identified the need to bifurcate or split the MILSPEC into two sections; one for land-based and one for sea-based applications. Additional discussion recommended that the land-base section include a section on fixed systems and one on manual application (i.e., ARFF and FR). A detailed outline should be developed to use as a starting point for the development of the land-based section.

Engineering Solutions / Nuts and Bolts

To initiate the discussion of engineering solutions, the current "state of the art" of Fluorine Free Foams (FFFs) was discussed, in order to serve as the baseline for solution development. In summary, the available information demonstrates that FFFs tend to be extremely viscous (non-Newtonian) substances that will be problematic for use in existing legacy AFFF systems and hardware. The information also demonstrated that foam quality (namely expansion ratio) is key in optimizing the capabilities of these products, and that even under optimal conditions, FFFs will need to be discharged at an increased rate (perhaps 50% to 100% more) to provide comparable firefighting capabilities to the MILSPEC AFFFs. As a result, current FFFs are not a "drop in" replacement for AFFF resulting in significant modifications if not complete replacement of legacy systems (with the possible exception of ARFF trucks). It is also unlikely that the FFFs can be made to be compatible with other FFFs due to the vast differences in chemical compositions/formulations.

In addition, there was a concern about reusing any components due to difficulty in cleaning and decontaminating the item. Research should be conducted to identify the procedures (and chemicals) needed to decontaminate legacy hardware/components (and acceptable limits after cleaning).

Agent Storage

The increased flow rate requirements (assumed to be as much as a factor of 2 greater than AFFF) will require doubling the tank size or adding additional tanks. This will have significant impact on applications where pump room space is limited (as well as a weight penalty in mobile applications). ARFF vehicles are discussed below.

Proportioning

The viscosity of the concentrates will need to be considered when designing proportioning systems. The concentrate pump will need to be able to draw the concentrate out of the storage tank and unload/recirculate the unused quantity back into the tank. The plumbing from the storage tank to the pump inlet will need to be analyzed/designed to compensate for these conditions. The unloader/pressure regulating valve that recirculates the concentrate back to the tank will need to be designed to handle higher viscosity fluids.

The current AFFF proportioning systems have small orifices and some have moving parts (e.g., piston operated balancing valves). Using highly viscous fluid in these components may be problematic and will need to be assessed.

Since the flow through the orifice/opening used to regulate the solution concentration is dependent on fluid viscosity, an assessment needs to be done to determine the range of

viscosities of potential FFFs and how these viscosities change as a function of temperature (i.e., over the range of application conditions (e.g., 35ºF – 95ºF).

The corrosive properties of the concentrates and solutions will need to be assessed in term of "typical" materials used in legacy AFFF systems. (Collateral damage corrosion should also be assessed depending on the application).

Piping

Due to the higher flow rates required for the FFFs, the pipe sizes will need to be increased adding additional cost and weight to the system.

Nozzles

Since the capabilities of FFFs are highly dependent on foam quality (i.e., FFFs do not produce a film and function solely on the foam blanket to smother the fire and contain the fuel vapors), the FFFs should be discharged through "aspirating" nozzles. There are only a very limited number of nozzles currently used by DoD that are designed to produce aspirated foam. Research is required to assess the foam qualities produced by legacy nozzles and to investigate potential replacements (i.e., other aspirating nozzles such as the ones developed for protein foams). The foam qualities produced by CAFS (compressed air) and UHP (ultra-high pressure) hardware should also be assessed.

ARFF

There are conflicting reports on the prospects of using FFFs in the legacy ARFF trucks. A survey should be initiated to collect information on the success/failures of current and previous attempts to discharge FFF solution from these vehicles. In addition, the viscosity and corrosion information mentioned previously should be socialized with the various truck manufacturers to get their thoughts on using FFFs in their vehicles (and potential tweaks that could be made to them to allow compatibility with these new agents).

Since many ARFF trucks have selector switches to allow the flexibility of using either Type 3 (3%) or Type 6 (6%) foam concentrate), a fire performance assessment should be conducted using Type 3 concentrate discharged at 6%. There is a limited amount of data that suggests that increasing the agent concentration may increase the firefighting capabilities.

With respect to concentrate capacity, the addition of a concentrate tanker/nurse truck has the potential of providing the additional concentrate and could be considered.

There was also a discussion pertaining to extinguishment mechanisms and that protein foam (which also does not produce a film and functions solely on the foam blanket to extinguish the fire) was typically discharged by the crash truck on the ground in front of the fire to aspirate the foam and then pushed onto the burning fuel. One FR mentioned that this requires additional manpower (i.e., two personnel in the truck versus a single occupant used for AFFF). The implications of using a non-film forming alternative should be assessed in terms of increased manpower needs if the DoD moves in that direction.

Potential Alternative Approaches

Compressed Air Foam (CAFS)

The group discussed the option of using CAFS as a potential replacement for the current AFFF systems. There was a brief discussion on the results obtained by LASTFIRE which showed

increased capabilities of FFFs when discharged through CAFS hardware. The FAA also mentioned limited data with similar results and informed us of some upcoming research being conducted by them with CAFS. A SME on various foam systems from the commercial industry provided a quick discussion on the Pros and Cons of CAFS. Pros included flexibility in “dialing” a foam quality, lower concentrate/solution usage/requirements and increased throw characteristics associated wit some of the technologies. Cons included complexity, cost, scaling to larger scenarios and susceptibility to wind. The group agreed that additional research should be conducted on CAFS to better understand their capabilities in DoD/ARFF applications and the associated impact of switching to this technology.

Ultra-High-Pressure (UHP) Systems

The USAF provided insight on the capabilities of UHP for a range of applications and conditions. They noted that the velocities produced by UHP monitors using only water have been observed to “blow fires out”. The group agreed that additional research should be conducted on the current FFFs discharged through UHP hardware to assess their capabilities under representative/real scale conditions.

Hybrid/Dual Technologies

The group was open-minded to using hybrid/dual technologies but noted the likely need to segregate the dual systems which would require increased manning.

Other Chemicals

The group was open-minded to the use of legacy chemicals like protein foams as well as new approaches such as wetting agents and/or encapsulating agents. The group agreed that additional research/testing should be conducted on chemicals/approaches that show the most promise for success. However, the deployment of any legacy/new chemical should be assessed based on both cost and manning implications.

Recommended Research and Action Items

Recommended areas of research and action items are shaded in gray in the text above.

AFFF Summit (15-Nov-2019)

Breakout Session

- 5-6 Issues to Address: Near, Mid, Long Term

Materials Solutions

- Formulation / Mechanism
- Viscosity and flow
- Why are F-Compounds magic?
- Does it have to be a foam?
- How good is good enough?
- Toxicology of Alternatives
- Corrosion, Ageing, and Compatibility

SERDP ESTCP

Opening Discussions

Overview of how AFFF works and detailing foam vs film

- Which plays a bigger role foam or film? Foam being more important?

1. Film-foaming: lower surface tension of solution. AFFF film formation is fuel specific. Film forming not correlated to fire suppression
2. Surface tension is a dynamic system influenced by temperature
3. Surface elasticity is important to stability of foam
4. Logistically difficult to procure and use over 10% use concentration (impacts firefighting duration)
5. Fluorosurfactant tail is hydrophobic and oleophobic (prevent transport of fuel into foam)
6. Foam density/thickness relates to vapor suppression and spreadability
7. Spreading coefficient not necessarily correlated to performance (FAA research, 1980s), drainage of water tends to maintain film and reduces fuel temperature/vapor pressure
8. Fluorine-free foam tends to pick up fuel
9. Integrated methods (reducing exposure, performance issues, etc.)

Opening Discussion (3)

TRAINING ALTERNATIVES:

- Issues with training with water vs. AFFF. Leads to dumping more AFFF in actual situations. Is there a way to develop a better training foam substitute (maybe not even the same extinguishing properties) but will allow to train with that vs. water.
- Possibility of using virtual solutions (but nothing realistic exists right now). Needs to be a realistic feel for the heat. Difficulties with doing with PPE on.
- Training foams are already on the market but not as effective, but need to address heat, noise, etc. Also not effective in simulating real experience

Formulation / Mechanism

- MICROSCALE tasks (AKA relevant parameters for chemicals (knowing there is a difference between performance and chem)
  - **Viscosity**
  - **Interfacial tension**
  - **Is there chemical interaction**
  - **Foam drainage, Foam stability** (with and without radiation)
  - **Temperature dependence** (importance high to low: foam solution temp, then ambient temp, then fuel temp)
  - **pH**
  - **Corrosion**
  - **Surface tension**
  - **Oleophobicity**
- Solutions with radicals- Radical production (Via additives) – may be toxic and may have their own concerns?
- Cooling of surface, creating less fuel vapor (important mechanism)
- Do we know enough about how these foams work to tweak them (additives) or do we need to learn more?
- Surface tension consideration between CF2 vs. CF3 as a surfactant. You lose all oleophobicity with CF3. Also need hydrophilicity
- Issues with accessibility to fuel. Implications of costs for testing. Benefits of heptane is that it is chemical and it standard throughout compared to gasoline where blends can vary by source. Gasoline is a lower supply but higher to extinguish (if it works on gasoline, will work on jet fuel). MOAs exist with DoD that may limit testing new surfactants.
- What needs to be solved? When does this become a problem?
  - Application density
  - Can we measure oleophobicity and is there modeling for this?

Formulation / Mechanism (2)

Process to test/select next surfactant:

- Is there order in place to decide with surfactants or does this need be modelled? Not necessarily just 1 surfactant but a mix of several and composition of water and other components. Model of these surfactant mixtures.
- Need more effective computational models to inform material selection (individual models for surface tension, interfacial tension exist; however, there is not a complete foam production model)
- More interaction with subject matter experts at foam manufacturers needed
- Need to know parameters on the engineering side: some short term goals and some long term
  - Setting goals for viscosity, other physical properties
- Fundamental understanding of F3 mechanism
- Specific interactions between fluorine free foam and fuel type
- Need to evaluate foams at different temperatures. Previous research suggests that most important factor is foam solution temp, then ambient temp, then fuel temp

Viscosity and flow

- When does viscosity become a problem?
- Newtonian fluid vs. non-Newtonian fluids
- Viscosity of foam concentrate and the actual foam. Related but the viscosity of foam is more important in practice? But have some requirements of viscosity for transport/trucks
- Different trucks exist that may address viscosity issues (de-icing).
- Modelling and use engineering solutions
- Viscosity will depend on whether it is foam concentrate, solution, or as delivered

Why are PFAS Compounds magic?

- Components of AFFF vs. FFF:
  - 1) film formation
  - 2) FS: oleophobicity and hydrophobicity in the same compound
  - 3) HS: oleophilicity

- Fluorine atom give best stability to carbon chain. Best fit for carbon chain and forms protection that is very rigid.

- Other molecules use F and are safe, so maybe not make it all about the F. Pharmaceuticals use F. Not all are bad. F vs. perfluro chemicals. Why are we dismissing F in C chain when we can focus on making it non-toxic? New surfactants that have structures that will degrade?

Does it have to be a foam?

- Depends on what is the mission/goal.
- If you are just worrying about speed of putting out fire then no. But need to worry about burn back
- Extinguishment is entirely related to covering fire and surface.
- Powder may be a lot harder, but has been tested with high pressure cones. Powder still has issue of environmental risks. Fire trucks have the capability to use dry chem. Foams are better at drop down of temperature. Very different mechanism between powder and foam. Powder can be difficult to use in certain conditions. One ex of powder is bicarbonate. Will powder dissipate larger area than foam? If you add powder would it interrupt foam blanket.
- Does it have to be foam full of air? Looking at Nitrogen or CO2. If you want to manipulate physics of foam what about using inert gases?
- Gels exist but for class B, but hard to get them to float. May actually risk spreading fuel. Foam may be able to be collected easier. Need to find solution of with quick action.
- Is it possible to have a 2-stage system: 1) put out fire 2) blanket to prevent burnback. Good thought but AFFF already eliminates burn back even behind firefighters.

How good is good enough?

- This is best we have right now. Need to find a tool that is as good as AFFF, accounting for replacement of equipment.
- How much Fluorine is needed to reach military specification? How low can we go with what we know works. How was milspec established? Chosen as the best possible outcome. If it passes milspec, it works. But need to consider milspec was established a long time ago.
- What small scale testing can be done to assess this:
  - Foam fluidity
  - Burnback
  - Radiation breakdown
  - Foam layers over fuels and how fuels degrade them
  - Need for better specific foam quality tests: stability of foam blanket on fuel, in radiation, etc. Bubble size and quality

Toxicology of Alternatives

- Computational models of bio-accumulation (new and existing models). Example of existing models is pharmaceutical liver models (addresses bioaccumulation and working on toxicity) [NTP protocol]
- Tox of combustion F products need to be considered. Example, HF from combustion.
- 90 day sub-chronic rodent study. Not a screening tool more on the side of production.
- Screening can be leveraged in medicinal chemistry (in silico in vitro). Physical chemistry properties based on ability to get in biological systems
- Introducing any new compounds need to know if it is better. Also depends on where (highway, middle of runway, etc,)
- Persistence and other ecotox. Must consider other by products (degradation). Persistence of alternatives like siloxane. PBT classification.
- What can be done in next 1-2 years to address new formulations of perfloro compounds. Peer-reviewed paper shows that PFAS months tox while C6 is much shorter (days).
- Need to consider fate/transport, bioaccumulation, toxicity (not just acute but sub-chronic), persistence. Legacy bioaccumulation. – C6 (~30 days). Need to also consider foamability/pH?
- If molecule is big enough, then flows through body. Maybe incorporate this in modelling (ex of food study). Reducing tox risk. Concerns about breakdown products for large molecules

Corrosion, Ageing, and Compatibility

- Government needs to evaluate F3 product for full testing (including corrosion, ageing, comp). Promising formulations are not fully evaluated because they have not been proven to meet fire performance.
- Testing would give us better idea of how to move forward with tiered approach. Balance between biodegradability vs. stability for many years of use?
- Should we consider F3 if these tests have not been done?
- Compatibility has been done with mixture testing (with salt and fresh water testing). Aging tests needed for cycling temperatures?
- Should there be a tiered test protocol for new foams. More flexibility from milspec?
- Can corrosion tests be done by outside lab before full scale demonstration.
- Need data sharing capability for research. Database for select commercial F3 will be available from Battelle
- Ageing condition may form a precipitant fluorosurfactant. May be an issue with performance down stream

MIL-SPEC Issues

- Currently with floating fuel on water (as opposed to real world application on a hard surface).
- Quality of foams really matter. Foam can put out the fire but you will have burn back. Should think of practical application rather MilSpec floating on water.
- Fresh water vs. sea water
- Need for small scale tests that are correlated to full scale testing
  - Foam fluidity
  - Burnback
  - Radiation breakdown
  - Fuel foam degradation
  - Aging – temperature cycling
- How will DoD handle compatibility between novel chemistries?

Path Forward

- Near Term:
  - Evaluate new compositions
  - Collect tox data for existing C6 and F3 commercially available foams
  - Data repository
- Mid Term:
  - More fundamental understanding of F3 and AFFF mechanism
  - Improved small scale test methodology
  - Modify MIL-SPEC and/or new specification
  - Improved computational models for predicting performance
- Long Term:
  - Transition new material and change out

AFFF Summit (15-Nov-2019)

Breakout Session

- 5-6 Issues to Address: Near, Mid, Long Term

Engineering Solutions

- Delivery rate / Aspiration
- Retrofit or Redesign (Cost Constraints)
- Infrastructure, Equipment, and Compatibility
- Facility Fire Protection
- Compressed air UHP and other Engr. Alternatives
- Corrosion issues

SERDP ESTCP

Engineering Solutions: Assumptions and key questions

- Root question: How good is good enough, how do we close the gap?
- Based on current state of industry
- Assume cost is no barrier
  - What about for non DOD entities where it really is?
- Assumptions regarding a FFF product
  - ICAO level C has some certification process
    - Ask manufacturers for their ICAO certification (post 2015)
    - 2 FFF currently meet ICAO C
  - UL-162 (only current choice)
  - PCA / TCA (methodology that would enable good data collection)

Engineering Solutions: Assumptions, cont'd

- Delivery rate will need to go up
  - Faster delivery → run out faster
  - Increased pipe sizes, pumping, increased concentrate tank size
    - PEO (slippery water)
  - Manpower needs
  - More chemical run off
  - Want comparable rates
  - Auxiliary nurse trucks (concentrate or water)
    - Big tank truck; not firetruck

Engineering Solutions:

- Proportioning and addressing viscosity
  - Pump issues (i.e., inlet head)
  - Orifice sizes
  - Moving parts
  - Recirc / unloader / bypass
  - New proportioning approaches
  - Dual proportioners

  - Mid-Term Objectives:
    - Characterize viscosity as a function of temperature *
    - Survey of deployment issues at facilities that have made transition / truck companies / foam companies/ pump manufacturers / for adaptation equipment
    - Test results and best practices from survey

Engineering Solutions: Better Training

- Can more realistic training scenarios help close the performance gap?
- Moving firefighters away from the, “video game” mentality, (shooting water to turn off propane sensors)
- Training success/failure metrics?
- National training centers?
  - Concentrate “training trucks”
  - Find ways to bring back jet fuel fires in a safe arena?
  - 6 AF facilities still exist; pre-deployment training
- Structural fire certification
- Component collection / recycling?

- Short-Term: Look to successful training center models (DFW, TEEX)
- Mid-Term: Conversion and supplementation of training facilities into regional hubs
- Long-Term: Implementation of new training programs

Engineering Solutions: Aspiration

- Different foam expansion rates aspirated vs. not
- Require good aspiration
- Apply protein foam-like application methodologies
- Alternative (Hydrochem) nozzle types?

- Short-Term:
  - Test current AFFF nozzles with current F3
  - Test legacy aspirating nozzles with current F3
  - Identify application method
- Mid-Term: Test large scale and fixed systems
- Long-Term: Transition

Engineering Solutions: Retrofit or Redesign

- Retrofit or Redesign
  - Current FFFs will require system replacement (i.e., not a drop in)
  - Larger pipe sizes
  - Aspirating nozzles
  - Concentrate tank option (e.g., nurse truck for ARFF vehicles)
  - Develop clean-up / flushing protocols for all components
  - Analytic tools. Is it really gone?

  - Short-Term: Cost analysis of retrofit vs. redesign
    - Evaluate manufacturers for nurse trucks
    - Survey international community to their retrofit approach

Engineering Solutions

- Infrastructure, Equipment, and Compatibility
  - Splitting MIL-SPEC into ship and shore-fixed and shore-ARFF, other?
  - Mutual Aid agreements
  - Define testing standards
  - How clean is clean?
  - Consider other specifications for shore
  - Improve containment systems and procedures

  - Short-Term: Determine value of splitting MIL-SPEC (and how?) vs. existing standards
  - Mid-Term: Set and qualify products against new MIL-SPEC or adapt commercial
  - Long-Term: Demonstrate industry wide cross compatibility

Engineering Solutions: Alternatives

- Application Systems
  - CAF systems provide foams with small consistent bubbles; dry
  - UHP atomizes water
  - Decking systems (remove the fuel)
  - High-Ex Foam (hangar systems)
  - Wetting agents / encapsulating / others

- Considerations for each
  - Scaling
  - Cost
  - Weather
  - Regeneration
  - Dialing in foam quality

  - Short-Term: Go beyond pan test for UHP (China Lake)
  - Mid-Term:
    - Test CAF / UHP systems with FFF
    - Figure out scope of applicability (CAF / UHP / Hi-Ex)
    - Collateral damage assessment
  - Long-Term: transition successful demonstrations / applications

Engineering Solutions

- Corrosion Issues
  - Needs to be about as good as AFFF
  - Remember AFFF is corrosive (maybe)
  - This will change with revised MIL-STD
  - Shelf life?

  - Short-Term: Determine shelf life of current FFF

Engineering Solutions

- Interface with material solutions / Hybrid solutions
  - Test engineering components alongside material development
  - Can gels/wetting agents be used alongside FFF?
  - What about combined engineering and traditional foams?
  - Additives (slippery water?)
  - Use water only to put the fire out
    - Agent to keep fuel from reigniting

  - Short-, Mid-, and Long-Term objectives are needed.

Engineering Solutions: What to do today

- Until acceptable alternative is identified, formalize containment techniques for uncontrolled releases and best practices that can be adopted by our peers in civil aviation and municipal fire stations
  - Assess impact to civil aviation
  - Educate in best practices for entire industry
  - Track use and application