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Fluorine-Free Foam (F3) Application Techniques and Firefighting Tactics

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14. ABSTRACT
This report provides a high-level summary of the lessons learned during large-scale fire extinction validation tests conducted at the Naval Air Warfare Center Weapons Division (NAWCWD) – China Lake (CL) of five leading fluorine-free foam (F3) candidates for replacement of aqueous film-forming foam (AFFF.) The report provides a detailed description of how to effectively fight fire in Aircraft Rescue and Fire-Fighting (ARFF) type scenarios using the new F3 products.

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	Three Dimensional
AFFF	Aqueous Film-Forming Foam
ARFF	Aircraft Rescue and Fire-Fighting
C	Celsius
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
F	Fahrenheit
F3	Fluorine-Free Foam
FESWG	Fire and Emergency Services Working Group
ft	feet
ft^2	square feet
FY	Fiscal Year
gpm	gallon per minute
gpm/ft^2	gallon per minute per square foot
in	inch
lbs	pounds
lbs/sec	pounds per second
LCDR	Lieutenant Commander
NAVSEA	Naval Sea Systems Command
NDAA	National Defense Authorization Act
NFPA	National Fire Protection Association
NRL	Naval Research Laboratory
NSWCWD-CL	Naval Surface Warfare Center, Weapons Division – China Lake
PFAS	Per- and Polyfluoroalkyl Substances
PKP	Purple-K Potassium Bicarbonate
psi	pounds per square inch
QPL	Qualified Products List
SERDP	Strategic Environmental Research and Development Program
TFT	Task Force Tips

Executive Summary

This report provides a high-level summary of the lessons learned during the large-scale validation tests of fluorine-free foams (F3) conducted at the Naval Air Warfare Center Weapons Division (NAWCWD) – China Lake (CL) and a detailed description of how to effectively fight fire in Aircraft Rescue and Fire-Fighting (ARFF) type scenarios using the new F3 agents. In general, the tests demonstrated that the same techniques work well for both AFFF and F3s, however the finesse aspect of applying the foam to the fuel surface must be emphasized during training and real life application of F3 agents. The hardware, tactics and techniques that optimize the capabilities of the F3s also tend to increase AFFF performance (but to a lesser degree). Even with the use of the optimized techniques, the leading F3s typically took about 1.5-2 times longer than AFFF to extinguish the fires in most scenarios. The bottom-line differences between AFFF and F3 agents are summarized as follows:

- F3s are less forgiving than AFFF due to the absence of the film-forming component and the sole reliance on the bubble blanket to smother the fire.
- F3s generally work better when aspirated but aspirated foam is hard to throw far distances and doesn't flow well around obstructions.
- F3s require better application techniques and some level of finesse to optimize performance and prevent plunging into the fuel and disruption of the foam blanket.
- F3s are effective in ARFF type applications with the proper application techniques but typically take multiple application passes to control and extinguish the fire versus one for AFFF.

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Fluorine-Free Foam (F3) Application Techniques and Firefighting Tactics

1.0 INTRODUCTION

The National Defense Authorization Act (NDAA) for fiscal year 2020, section 322 “Replacement of Fluorinated Aqueous Film-Forming Foaming Foam with Fluorine-Free Fire-Fighting Agent”, established the requirement to develop and publish a new military specification for fluorine-free firefighting agents for use at all military installations no later than January 31, 2023 [1]. As a result of this Congressional mandate, the Naval Research Laboratory (NRL) Code 6186 submitted a statement of work to the Department of Defense’s (DoD’s) Environmental Security and Technology Certification Program (ESTCP) office that resulted in the establishment of multiple projects to support DoD’s need to develop and/or identify an environmentally acceptable, Per- and Polyfluoroalkyl Substances (PFAS) free, alternative to existing Aqueous Film-Forming Foam (AFFF) agents.

Five SERDP/ESTCP programs [2-6] were conducted over the past four years to develop the firefighting performance metrics for use in the new land-based military specification (MIL-PRF-32725) [7]. During the initial program, a detailed literature search was conducted to identify commercially available products. Over sixty products were identified being marketed as “environmentally friendly” AFFF alternatives. Twenty-five of them were selected and tested against approval scale fires (i.e., 28ft^2 pan fires conducted with gasoline and Jet A). During these screening tests, five fluorine-free foams (F3s) demonstrated superior firefighting capabilities and were selected for inclusion in the four follow-on ESTCP-funded test programs. All five products were Type III foam concentrates (i.e., proportioned/mixed at ratios of 97% water and 3% foam concentrate). During the follow-on efforts, these products were tested to the requirements for chemical and physical properties, and fire performance in the AFFF military specification (MIL-PRF-24385F) [8]. In addition to the MIL-PRF-24385F tests, many of the tests were repeated with modified parameters (such as fuel type and increased foam discharge rates) to better understand the capabilities of these commercially available F3 products. Although not as good as AFFFs, the F3s performed very well, supporting the need for large-scale validation tests. The validation tests were conducted over a two-year period using the facilities and fire scenarios that were the basis for the development of AFFF over 40 years ago.

The results of the validation tests are published in two separate reports [9-10]. This report provides a high-level summary of the lessons learned during the large-scale validation tests conducted at the Naval Air Warfare Center Weapons Division (NAWCWD) – China Lake (CL) and a detailed description of how to effectively fight fire in Aircraft Rescue and Fire-Fighting (ARFF) type scenarios using the new F3s.

Manuscript approved May 16, 2023.

2.0 OBJECTIVES

The ultimate objective of the five SERDP/ESTCP programs was to support the DoD in meeting the FY20 NDAA requirements. Specifically, data needed to be collected to develop and publish the new land-based F3 MILSPEC (MIL-PRF-32725) [7]. In addition, information needed to be collected on the capabilities of these products and how to use them effectively to combat fires, in order to assist in a smooth transition away from AFFF to the new F3s at DoD military installations.

The intent of this report is to provide a high-level description on how to effectively use new F3 products by answering the following questions:

- What are the differences between AFFF and F3s?
- How does foam quality play into the fire extinguishing performance?
- What are the best nozzles to use?
- What is the best spray pattern?
- What are the best application techniques?
- What are the best tactics?
- Why does it take 1.5-2 times longer to put out fires with F3s as compared to AFFF?

3.0 VALIDATION TESTING OVERVIEW

The final validation testing of the leading F3s was conducted under two SERDP Programs (WP21-3461 and WP21-3465) against large-scale ARFF type fire scenarios. These fire scenarios included both three-dimensional running fuel fires (with a growing spill fire component) and large uncontained fuel spill fires.

The final validation testing was conducted in four phases. The Phase I fire scenarios were fought using a standard fire hose equipped with a 125 gpm vari-nozzle as well as other discharge devices. The Phase II fire scenarios were fought using a 250 gpm turret nozzle installed on a small ARFF vehicle. During Phase II, the fire sizes were scaled up by a factor of two to maintain a similar foam application rate (i.e., 0.05 gpm/ft^2) between the two phases. The Phase III tests investigated various methods and hardware for improving the firefighting performance of these F3s by developing better application techniques and firefighting tactics/doctrine, as well as the development of novel nozzle designs specifically suited to discharge F3s (i.e., variable aspiration). During the Phase IV tests/demonstrations, the DoD Fire and Emergency Services Working Group (FESWG) was invited to witness and participate in the development and the refinement of training materials required to effectively field these new F3s throughout the various DoD facilities. The goal of Phase IV was to share the knowledge and lessons learned throughout this program with the FESWG as a first step in implementing F3s in DoD applications.

A description of the test setup(s), fire scenarios, firefighting equipment and a high-level discussion of the results is provided in the following sections. During each of the four phases of this program, the capabilities of the new F3s were baselined against a Type III AFFF currently on the Qualified Products List (QPL) [11].

3.1 Test Facility

The tests were conducted on the "Mini Deck" at Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake CA. The Mini Deck is an 80ft-by-80ft concrete pad. The deck is equipped with an effluent drainage and collection system for waste disposal. The Mini Deck is surrounded by a concrete apron that is used to stage equipment such as the fire pump(s) and fuel truck. The deck is constructed of high temperature concrete, which allowed the fuel to be dumped or flowed directly onto the concrete surface representative of an actual aviation crash-type scenario. Photographs of the Mini Deck are provided as Figure 3.1-1.

Fig. 3.1-1 – Mini Deck

3.2 Fire Scenarios

The fire scenarios included large uncontained fuel spill fires and three-dimensional running fuel fires (with a growing spill fire component). All fires were produced using F-24, which is a kerosene-based aviation fuel that has a minimum flashpoint of 100°F (38°C). F-24 is the military variant of Jet A (including additional corrosion inhibitors). The details of each fire scenario are shown in Figure 3.2-1.

Spill Fire Scenario (hose line) 400 gallons F-24 (Jet A) 2400-2800 ft^2 / 125 gpm/ 0.05 gpm/ft^2	**Debris Pile Fire Scenario (hose line)** Steel enclosure, fuel cascade, cinder blocks 45 gpm F-24 (Jet A)
	
Spill Fire Scenario (turret) 1000 gallons F-24 (Jet A) 5500-6000 ft^2 / 250 gpm/ 0.05 gpm/ft^2	**Running Fuel Fire Scenario (hose line and turret)** Pipe manifold, slit wing configuration 45 gpm F-24 (Jet A)
	

Fig. 3.2-1 – Fire Scenario Descriptions

With respect to timing/procedures, the attack on the spill fires began about 10-15 seconds after the fire reached full involvement, as witnessed by the entire fuel surface being ignited. For the running fuel fire scenarios, the fuel was allowed to flow for one minute at ~45 gpm prior to ignition. Once ignited, the fire was then allowed to burn for an additional minute prior to initiating the attack on the fire. By the time the attack on the fire began, the spill fire was usually about 400-600 ft^2 as shown in the two photographs on the right side of Figure 3.2-1. The fuel flowed continuously from the start of the test until the fire had been extinguished.

3.3 Foam Concentrates

The top five commercially available F3s identified during the WP19-5324 program were included in Phase I, II and III of this validation test program. Three of the F3s were Newtonian concentrates (low viscosity that flowed like water) and the other two were non-Newtonian concentrates (high viscosity with a consistency of molasses). Since the non-Newtonian concentrates were not expected to meet the viscosity requirements of the draft land-based MILSPEC (MIL-PRF-XX727) only the three Newtonian F3s were included in Phase IV and were the focus of the tactic's development.

3.4 Firefighting Equipment

The names of the products used during this assessment are provided for information purposes only. They are not meant as an endorsement and/or a condemnation of the product in any way.

The test fires were combatted using either a 125 gpm nozzle on a 1.75 inch firefighting hand line or a 250 gpm turret nozzle installed on the P-25A (depending on the test). During a limited number of running fuel fire tests, the fires were combated using a dual agent attack. During the dual agent attack, the initial attack on the fire was made using a 125 gpm hose line nozzle (referred to in NPFA 403 as the primary agent [12]) and after the fire had been controlled and contained near the fuel source, a portable extinguisher containing either a potassium-based dry chemical (Purple-K Potassium Bicarbonate (PKP)) or a halogenated agent (Halotron – hydrochlorofluorocarbon)) was discharge toward the 3-D component. These products are referred to as complimentary agents in NFPA 403 [12].

3.4.1 Hose Line Description

The hose line setup used to combat the test fires consisted of a pre-mixed solution storage tank (2500 gallons), a fire pump (1500 gpm) and a 1.75 inch fire hose equipped with a 125 gpm vari-nozzle (sometimes referred to as a combination nozzle). All of these components were located in the east side of the Mini Deck.

3.4.2 Hose Line Nozzles (Standard Water Type Nozzles)

The hose line was equipped with a 125 gpm, 1.5 inch constant flow nozzle manufactured by either Akron Brass (referred to as the "Navy Nozzle") or Task Force Tips (TFT). The nozzles are designed to flow 125 gpm at 100 psi (K factor 12.5 gpm/psi$^{1/2}$). The nozzles have a 1.5 inch hose connection, an integral pistol grip handle and bale control as shown in Figure 3.4-1.

Akron Brass Co.

Task Force Tips, Metro 1

Fig. 3.4-1 – 125 gpm Vari-no*zzles*

3.4.3 Hose Line Hybrid Nozzle

A hybrid TFT Quadracup Nozzle Model # FQS125BCP was included in Phases III & IV to assess new nozzle designs that have the capability of providing higher aspirated foam solutions. The nozzle can be switched to higher aspirating mode by sliding a sleeve on the outside of the barrel forward, which allows the entrainment of air at the back side of the sleeve. The nozzle has the same flow characteristics as the standard nozzles mentioned previously (i.e., constant flow rate K factor 12.5 $gpm/psi^{1/2}$). A photograph of the TFT Quadracup Nozzle is provided as Figure 3.4-2.

Fig. 3.4-2 – TFT Quadracup Aspirating Nozzle (Hybrid)

3.4.4 Foam Tubes

Two foam tube adapters for the TFT Metro 1 were also assessed during validation test program. Images of the foam tubes are provided as Figure 3.4-3. The long foam tube had significant reach (~ 90 ft) with a straight bore design and produced aspirated foam with an expansion ratio on the order of 10:1. The short foam tube produced foam with an expansion ratio on the order of 20:1 but had limited reach (~ 45 ft).

Task Force Tips Model # FJ-LX-HM
Low Expansions (up to 10:1)

Task Force Tips model # FJ-MX-HM
Medium Expansions (up to 20:1)

Fig. 3.4-3 – Foam Tubes

3.4.5 Complementary Agents

The complementary agents used during a limited number of running fuel fire tests included portable extinguishers containing either PKP dry chemical or Halotron and are shown in Figure 3.4-4.

The dry chemical extinguisher consisted of an Ansul Model MIL-RP-K-20. The extinguisher is designed in accordance with MIL-E-24091 and contains 18 lbs of dry chemical (Purple K – potassium bicarbonate) propelled by approximately 5 ounces of CO_2. The dry chemical was discharged through a small hose at a rate of approximately 1 lb/sec equating to an 18 second discharge time. The extinguisher has a UL rating of 80B:C.

The Halotron extinguisher consisted of an Amerex Model #398. The extinguisher contains 14.5 lbs of Halotron and has a UL rating of 2A:10B:C. The Halotron was discharged through a small hose at a rate just over 1 lb/sec equating to a 14 second discharge time.

18 lb. Dry Chemical Portable Fire Extinguisher

14.5 lb. Halotron Portable Fire Extinguisher

Fig. 3.4-4 – Complementary Agents/ Portable Extinguishers

3.4.6 P-25A Shipboard Fire Truck

The P-25A shipboard fire truck was used as the ARFF vehicle during these validation tests [13]. The P-25A holds 750 gallons of water and 60 gallons of foam concentrate. The fire truck comes equipped with a 500-gpm turret and a 1.5 inch, 100-foot-long hard hose reel with a 95-gpm vari-nozzle. During these tests, the 500 gpm turret nozzle was replaced with a 250 gpm nozzle and the water tank was be filled with 750 gallons of premixed foam solution and the discharge system set for a "water only" discharge. Premixing was selected to ensure accurate foam solution concentrations during the test. An illustration of the P-25A is provided as Figure 3.4-5 and photograph is provided as Figure 3.4-6.

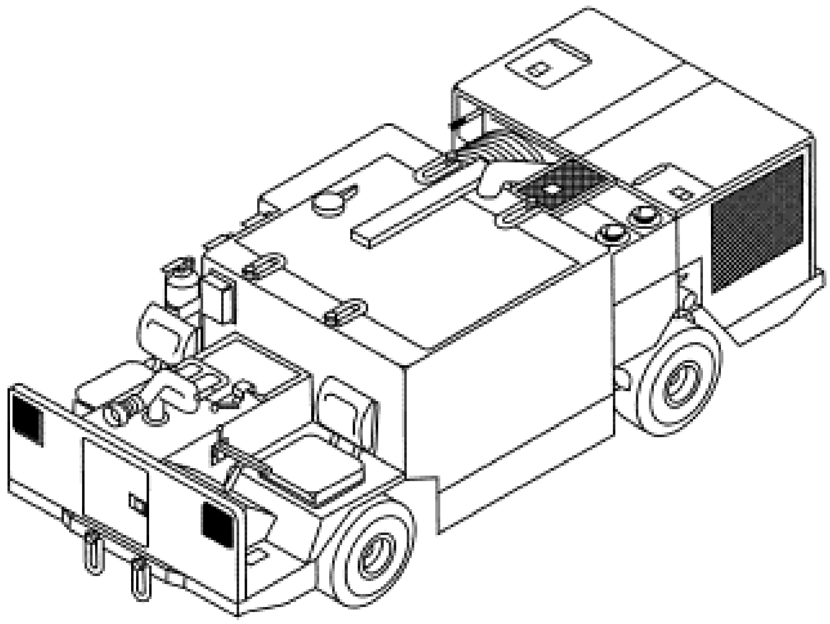

Fig. 3.4-5 – P-25A Shipboard Fire Truck (Illustration)

Fig. 3.4-6 – P-25A Shipboard Fire Truck (Photograph)

The standard 500 gpm turret nozzle was replaced with a TFT Master Stream 1000, Model # M-RS1000-NJ as shown in Figure 3.4-7. The TFT nozzle has selectable flow rates (250, 350, 500, 750, and 1000 gpm) at 100 psi. During these tests, the selector ring was placed at 250 gpm position, making it perform as a constant flowrate, 250 gpm nozzle. The nozzle is designed to accept the Task Force Tips FJ-H low expansion foam tube attachment, also shown in Figure 3.4-7. The low expansion foam tube produced foam solutions with expansion ratios on the order of 10:1.

TFT Stream Master 1000 Turret Nozzle

TFT Foam Jet FJ-H

Fig. 3.4-7 – Task Force Tips Constant Flow Turret Nozzle and Foam Tube Adapter

3.5 High-Level Summary

Approximately 150 validation tests and demonstrations were conducted during the four phases of this program (i.e., 107 hose line tests and 43 turret tests).

It was concluded during all four phases of this study that the leading F3s typically took about 1.5-2 times longer than AFFF to extinguish the fires in most scenarios. Specifically, the spill fire extinguishment times for AFFF were between 30-45 seconds (i.e., 30 seconds using the hose line and 45 seconds using the turret) while the F3 extinguishment times were between 45-60 seconds for the hose line and 60-90 seconds using the turret. The running fuel fires were typically extinguished using AFFF in less than 60 seconds and in about 90-120 seconds using the F3s. The five F3s all demonstrated similar extinguishment capabilities and times.

The burnback capabilities of the F3s were also assessed during the spill fire scenarios. Immediately after the spill fires were extinguished, a small hole was created in the foam blanket and ignited using a propane brush burner torch. The burnback time was defined as the time from ignition until the fire had grown to 100 ft^2. In general, all the foams tested during this program demonstrated good burnback capabilities against the F-24 spill fire scenarios. The burnback time for AFFF was about three minutes when discharged through the standard nozzle and about four minutes when discharged through the foam tube(s). The addition of the foam tube typically increased the burnback times by about a minute for almost all the foams. When comparing the F3s to AFFF, the burnback times were typically about 30-seconds shorter (i.e., the fire burned back slightly faster) for the Newtonian F3s.

Additional details of the lessons learned during these validation tests are provided in the following section. The actual test results are published in two separate reports [9,10].

4.0 LESSONS LEARNED

The following sections provide a detailed description of the lessons learned on how to fight liquid fuel fires in ARFF-type scenarios (i.e., large fuel spill and running fuel fires) using these new F3s. The tactics and techniques discussed in the following sections pertain to both hose lines and turrets since the application techniques and the approach for combatting the fires are basically the same for both sets of hardware. The tactics and techniques were developed for non-air-aspirating water type nozzles when used against aviation fuels (i.e., kerosene-based fuels with minimum flashpoints of 100°F (38°C)). Combatting fires produced with lower flashpoint fuels may require different tactics and techniques.

With this said, the tests used to develop these tactics and techniques were developed under controlled circumstances and in many respects provide ideal conditions to combat these fires. Specifically, the test area was flat, accessible (i.e., relatively unobstructed) and the weather conditions were within a prescribed set of parameters. The firefighters were also well trained and intimately familiar with combating liquid fuel fires using AFFF. The weather conditions (i.e., precipitation), wind speed and direction, terrain/topography, ground conditions and accessibility need to be considered and compensated for during an actual event. In other words, these general tactics and techniques serve as a starting point but may need to be modified depending on the conditions at hand.

4.1 Foam Differences/Types

Foam firefighting agents extinguish liquid fuel fires by providing a physical barrier between the fuel and the surrounding air. The barrier prevents the fuel vapors from mixing and reacting/combusting with the air, which is where the burning occurs. Depending on the nature of the fuel (i.e., flashpoint and boiling point), the cooling aspects of the foam solution may also contribute to the extinguishment process.

For AFFF, the barrier between the fuel and the surrounding air consists of two components: an aspirated foam/bubble blanket and a fluorinated surfactant film that forms and floats on the fuel surface as the liquid from the bubble blanket drains into solution. The degree of contribution for the two mechanisms varies with the fire conditions. Under most situations, both mechanisms provide major contributions in extinguishing the fire but in some instances, the film component may be an adequate barrier. As a point worth noting, the film component is a liquid and flows more easily across the fuel surface and around obstructions than the aspirated foam/bubble blanket. In addition, the film component can encapsulate fuel and fuel vapors trapped in the foam blanket preventing them from igniting and contributing to the fire.

The current F3s do not contain fluorinated surfactants and/or chemicals that can form a film on the fuel surface. **As a result, F3s rely solely on the aspirated foam/bubble blanket to provide a physical barrier between the fuel and the surrounding air.** The lack of the film component reduces the firefighting capabilities of the F3s when compared to AFFF but can be compensated for, to some degree, by producing better aspirated foam. However, there are some issues with aspirated foam. Specifically, aspirated foam does not flow as well as a liquid, limiting its' ability to flow around debris to extinguish obstructed fires. In addition, it is difficult to throw aspirated foam long distances especially in windy conditions. In any case, foam aspiration will be a key variable for optimizing the use/effectiveness of F3s going forward.

As a final note, there are some F3 manufacturers that claim to form a film on a fuel surface. There is limited data to support their claims and if they do form a film, it is likely inadequate to contribute to the extinguishment process.

4.2 F3 Foam Blanket Discussion

When comparing the capabilities of AFFF and F3s against the fuel spill fire scenario, a couple of observations were noted. First, when the F3s 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. This is shown in Figure 4.2-1. This low intensity, ghosting type flames are difficult to see through typical tinted firefighting face pieces, especially in situations where they are not the nozzleman's direct line of sight. The F3 hose stream also tended to punch holes in the foam blanket at the impact location making the fire somewhat more persistent at that location than observed with AFFF. **As a result, a "gentle" foam application of F3 works more effectively than a forceful application**.

Fig. 4.2-1 – Fuel Pickup in an F3 Foam Blanket

In addition, under some circumstances, gusty winds would open small holes in the F3 aspirated foam blanket allowing the fuel to reignite at that location. When this occurred, the hose team had to circle back and extinguish the fire, slowing their advancement into/through the spill and lengthening the overall extinguishment time. A series of photographs showing this phenomenon is provided as Figure 4.2-2. These small burning pockets were not observed when using AFFF due to the film formation provided by the AFFF. **Based on these observations, it is recommended that the hose line handler, 3rd man on the handline, slide back about 10-15 feet behind the nozzleman and backup firefighter to allow better surveillance of the previously extinguished area when advancing through the spill**. This distance also allows for reasonable communication between the hand-line team while still providing adequate hose handling if the nozzleman needed to make quick adjustments to respond to re-ignition of fires behind them.

Fig. 4.2-2 – Openings in F3 Aspirated Foam Blanket

Lastly, there were several instances where the F3 foam blanket degraded quickly making it look milky as opposed to aspirated foam. The milky nature of the foam blanket reduced the extinguishment capabilities and burnback protection and was attributed to a combination of the following variables: poor initial application/aspiration, plunging into the fuel, and elevated fuel and deck temperatures. Under some circumstances, the fire would burn through the milky foam blanket as shown in Figure 4.2-3. As a point worth noting, the AFFF experienced similar foam blanket degradation, but the film formation prevented the fire from reigniting.

Fig. 4.2-3 – Milky F3 Foam Blanket Shortly after Reignition

In closing, it needs to be restated that these tests were conducted with kerosene-based fuels (i.e., F-24 is a combustible liquid with a minimum flashpoint of 100°F), which reduces the consequence of fuel pickup in the foam blanket (i.e., higher flashpoint fuels have lower vapor pressures that can be reduced by cooling of the fuel). Conversely, these conditions could have been significantly worse if the tests had been conducted with a flammable liquid like gasoline that has a much lower flashpoint temperature and a much higher vapor pressure.

4.3 Hardware

There are two basic types of legacy manual firefighting nozzles that have been used by the fire service; ones that were designed to discharge water (non-air-aspirating) and others that were designed to aspirate foam. The water type nozzles have the greatest reach and adjustable spray patterns that cover the range from straight stream to a wide fog. The nozzles designed to aspirate foam were developed originally for the use of protein foam that relied solely on a thick foam blanket to smother the fire. These aspirating nozzles have limited reach and spray pattern characteristics but were necessary to optimize the effectiveness of protein foam solutions.

During the rollout of AFFF years ago, it was determined that the non-air-aspirating, water type nozzles could still be used with AFFF for several reasons. First, the shearing produced by the higher velocity liquid droplets as they flew through the lower velocity surrounding air tended to provide some degree of air-aspiration. This limited aspiration combined with the film formation of AFFF was adequate to combat most liquid fuel fire scenarios. In addition, foam application techniques used for protein foams such as roll-on and banking were carried over for use with AFFF (i.e., new application techniques intended specifically for AFFF were never pursued). These application techniques produced a thicker, more aspirated foam blanket and increased the capabilities of the AFFF using water type nozzles.

A variety of discharge devices were used during the validation test program. These included standard water type nozzles (non-air-aspirating), foam tube adapters, and a hybrid nozzle that could switch from non-air-aspirating to air-aspirating mode using a sliding mechanism on the barrel. Examples of these nozzles/devices are shown in Figure 4.3-1.

Water Type Nozzle
Task Force Tips, Metro 1

Foam Tube Task Force Tips
Model # FJ-LX-HM

Hybrid Nozzle TFT QuadCup
Aspirating Nozzle

Fig. 4.3-1 – Example Discharge Nozzles/Devices

Although the water type nozzles provided minimal foam aspiration, they were still able to extinguish all of the fires conducted during this effort, but their effectiveness was highly dependent on the application techniques used by the firefighter. The foam tubes provided slightly faster control and extinguishment times but required the firefighting party to advance further through the spill area due to the reduced reach of the foam stream. With the reduced throw distance, it is important that the hose team works together while using foam tubes to move laterally across the entire pool to ensure complete fire extinguishment prior to advancing further. In general, the foam tubes significantly increased the expansion ratio/aspiration of the foam solution and tended to discharge the foam more gently on the fuel surface. The biggest disadvantage of the foam tube was the inability to adjust the spray pattern of the nozzle. The hybrid nozzle also worked well if the firefighter was familiar with how the nozzle worked. In short, to optimize the overall performance, the firefighter needed to focus on fighting the fire while changing the nozzle settings without looking down at the nozzle. In some instances, adjusting the nozzle tended to distract the firefighter, slowing the extinguishment process.

With that as the background, all the nozzles/devices were made to work well with F3s with notable advantages and disadvantages. With the proper techniques and training, the water type nozzles should be adequate for using F3s. Some of the optimization techniques are discussed in the following sections. The foam tubes are more forgiving but require time to install, are cumbersome to use, and were found inadequate for combating some running fuel 3-D debris pile fire scenarios. Foam tubes do not have the ability to be adjusted to a wide-angle fog for radiant heat protection but make well aspirated foam. Foam tubes are optimal for covering unignited fuel spills to prevent ignition and/or for applying a thick foam blanket over hot fuel that was recently extinguished. The hybrid nozzle may be the way of the future with the proper training and familiarization of the nozzle by the firefighter.

4.4 Pattern Selection

Pattern selection was shown to be a key variable in optimizing the performance of F3s discharged from non-air-aspirating water type nozzles. **During testing, a narrow angle spray pattern proved to be optimal from both a stream reach and foam aspiration standpoint. Specifically, the optimal pattern tended to produce foam with expansion ratios in the 6-8 range with only about a 10% reduction in stream reach**. A photograph of the optimal pattern is provided in Figure 4.4-1.

Fig. 4.4-1 – Optimal Spray Pattern (narrow angle)

A technique developed by the firefighters to set the optimal spray pattern was to place one hand on opposite sides of the nozzle barrel with the hands parallel to the stream and increase the pattern until the stream touches their fingers as shown in Figure 4.4-2.

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Fig. 4.4-2 – Finger Width Pattern Selection/Setting

The firefighters would widen the pattern slightly as needed to apply foam to closer-in areas (i.e., trying to minimize the forceful application of the foam onto the fuel surface). A photograph showing them widening the spray pattern is provided as Figure 4.4-3. The application of foam to the fuel surface using spray patterns wider than 15 degrees had minimal effect on the fire but could be used as a radiant shield when advancing on the fire.

Fig. 4.4-3 – Slightly Wider Spray Pattern Used for Close-in Application

As a final note on spray patterns, straight stream is effective in cutting paths through the fuel spill to establish egress paths or to cool ordnance but tends to push the fuel and move the fire(s) to other locations (i.e., does not necessarily extinguish the fire).

4.5 Foam Application Techniques for Combatting Spill Fires

The following is a list of observations and suggested foam application techniques that produced the fastest control and extinguishment times against the spill fire scenarios. These techniques were developed for use with non-air-aspirated discharge nozzles and kerosene-based fuels (i.e., F-24 with a minimum flashpoint of 100^{o}F (38^{o}C)). Lower flashpoint fuels may require different techniques and discharge devices.

The application technique that worked best for spill fires is referred to as a horizontal sweep. Using the narrow angle, finger width spray pattern described in the previous section, sweep the foam parallel to the ground about waist height above the front edge of the fuel surface during the initial approach to the fire. This tends to "lob" aspirated foam onto the burning fuel (i.e., a gentle application from a low elevation) during the initial approach on the fire (i.e., 50-75 ft away). This application technique worked well for both hose lines and turrets as shown in Figure 4.5-1.

Fig. 4.5-1 – Horizontal Sweep Foam Application

While advancing on the fire, sweep the stream horizontally across the entire width of the leading edge of spill/fire with the objective of extinguishing horizontal strips during the approach. This is shown in Figure 4.5-2. The optimal speed of the sweeping motion is scenario specific and will need to be determined based on the effectiveness of application (i.e., sweeping too fast may not apply enough foam to a given location to be effective). The nozzleman/turret operator in some scenarios may have to apply additional foam to areas adversely affected by the wind and areas where the heat is causing the foam blanket to breakdown quickly.

When applying the foam with a hose line, once the firefighters have reached the spill area, a hybrid approach for applying the foam to the fire appeared to work best (especially if the firefighters decide to advance into the spill area). From here, the center of the nozzle spray pattern should be trained at the leading edge of the fire. Using this technique, the top half of the spray pattern is basically lobbed onto the burning surface while the bottom half tends to provide more of a "roll-on" effect. Once the fire has been controlled, some localized targeting may be required to completely extinguish some of the small residual fires and areas that have reflashed due to foam break-down.

During the tests conducted at NSWCWD-CL, the ARFF vehicle was not allowed to progress into the spill area, so the operators typically fought the fire using the horizontal sweeping technique for the duration of the test. However, some localized targeting was required to completely extinguish some of the small residual fires.

Some precautions should be taken when using the horizontal sweeping technique. First, applying the foam at higher elevations (i.e., higher than waist height) or angled slightly upward may cause the foam to be entrained into the fire/smoke plume preventing it from ever reaching the fuel surface. In some application, such as discharge from an ARFF Truck's roof turret, a slightly downward angle may be preferred. In addition, the lower aspirated foam produced by the non-air-aspirated nozzles (even with the optimal spray pattern) tends to breakdown quickly resulting in a risk for reflash/burnback. This could be a significant concern when combatting lower flashpoint fuels. A photograph showing rapid foam breakdown is provided as Figure 4.5-3.

Fig. 4.5-2 – Horizontal Sweep Suppression Sequence

Fig. 4.5-3 – Rapid Foam Breakdown Shortly After Application

To compensate for the rapid breakdown of the foam blanket, the hose team should continue to apply foam to the fuel surface well after the fire has been extinguished. This is a good example of where a hybrid nozzle would be beneficial and/or the installation of a foam tube on the nozzle. Specifically, the ability to increase the aspiration of the foam provides better foam blanket formation for vapor suppression and reflash protection.

The horizontal sweep appears to be the best technique with the following exception (and the caveats associated with the flashpoint of the fuel). **If rapid extinguishment is required near a hazard (e.g., ordnance or egress path), straight stream would initially be the best choice to push the fuel away from the area and cool the hazard (i.e., weapon or fuselage). After the fire has**

been pushed away from the hazard, the "roll-on" method described below should be used to develop a robust/thick blanket of foam to ensure any residual fuel does not re-ignite.

Many organizations have been teaching a "roll-on" or "bouncing/indirect" technique for applying foam to a fuel surface independent of the foam type (i.e., even with AFFF). A roll-on technique and/or a bouncing/indirect application technique where the foam is ricocheted off the ground just before the leading of the fire or nearby object, produces higher aspirated foam through agitation that can then be pushed with the hose stream onto the fire. **During the China Lake tests, the roll-on technique was used successfully to extinguish the spill fires, but the control and extinguishment times were 30-40% longer than the horizontal sweep**. The ricochet technique does provide the most robust foam blanket but takes longer to produce and push it toward the fire (as opposed to sweeping the hose stream across the leading the edge of the fuel). In addition, the roll-on application can be problematic for inexperienced firefighters since it tends to pick up fuel in the foam blanket if the foam is not applied properly. The roll-on technique also has the potential to disturb the existing foam blanket potentially exposing the fuel to the fire. A photograph of the roll-on technique is provided as Figure 4.5-4.

Fig. 4.5-4 – Roll-on Foam Application

In general, the use of the roll-on and/or bouncing/indirect technique can be considered a viable tactic if the conditions warrant. As an example, if there is a dry deck area adjacent to the spill that allows the ricochet of the foam onto the burning fuel, the roll-on or bouncing may be a viable tactic. In addition, bouncing the foam off aircraft parts (e.g., fuselage, engine, or wings) or off exposed ordnance can provide cooling during the development of the foam blanket. These types of decisions will need to be made by the nozzleman or turret operator based on the conditions at hand.

4.6 Foam Application Techniques for Combatting Running Fuel Fires

The following is a list of observations and suggested foam application techniques that produced the fasted control and extinguishment times against the running fuel fire scenarios using hose lines. These techniques were also developed for use with non-air-aspirated discharge nozzles and kerosene-based fuels (i.e., F-24 with a minimum flashpoint of 100°F (38°C)). **Air-aspirating nozzles showed good capabilities against the flowing fuel/growing spill component but had limited capabilities against the three-dimensional, running fuel component (i.e., from the fuel source to the ground)**.

The flowing fuel fire scenario consisted of a manifold located about 7-8 ft above the ground that contained a half inch slit ~ 2.5-3 ft long designed to simulate a damage airplane wing. The fuel (F-24) flowed from the slit at a rate of 45-50 gpm and impacted an elevated steel plate directly below the manifold and accumulated on the deck (i.e., a growing fuel spill fire). A photograph of the flowing fuel fire is provided in Figure 4.6-1 below. As the fire continued to burn and the fuel system began to heat up, the fire became established at the fuel source as well as on the fuel spill surface.

Fig. 4.6-1 – Flowing/Running Fuel Fire Scenario

The foam application technique that worked best against the running fuel fire is somewhat different than the stagnant spill fire suppression techniques mentioned previously. The horizon sweep was adequate for controlling the spill but allowed the fuel to reignite once the stream was directed toward the three-dimensional component. As a result, a thicker, more robust foam blanket was required to provide the needed time to combat the three-dimensional, running fuel component (i.e., from the fuel source to the ground).

Fluorine-Free Foam (F3) Application Techniques and Firefighting Tactics

The technique that worked the best against the flowing/running fuel fire was the legacy roll-on application technique. Using the narrow angle, finger width spray pattern described in Section 4.4, the hose nozzleman should direct the stream toward the ground about 10-15 ft in front of them to accumulate a robust foam blanket at the leading edge of the fire. Once the foam accumulation looks adequate, the hose team should quickly roll the foam banket toward the base of the three-dimensional component. The intent is to cut a path through the spill and quickly cool the area around the falling fuel to minimize the likelihood for reignition. The accumulated, aspirated foam was more resilient and was less susceptible to being washed away by the flowing fuel. The aspirated foam also tended to remain intact adjacent to heated objects/obstructions and helped to prevent reignition of the fuel at these locations. The roll-on technique is shown in Figure 4.6-2. During the approach, sweeping the stream upward toward the fuel source every 15-20 seconds also provided cooling of the fuel source and the surrounding materials.

Fig. 4.6-2 – Roll-on Foam Application Pushing Toward the Base of the Falling Fuel

Once the area at the base of the falling fuel is extinguished and a robust foam blanket has been established in this area, the focus should shift to extinguishing the fuel source. This can be achieved by directing the hose stream at the source with the intent of blowing the flame away from the fuel or using a dual agent attack using a complementary agent like dry chemical. Both techniques are shown in Figure 4.6-3. It should be noted that small fires located away from the falling fuel can be extinguished later and should not burn back toward the falling fuel due to the robust foam blanket that has been established at this location.

Pushing the flame away from the source

Dual agent attack with dry chemical

Fig. 4.6-3 – Options for Extinguishing the Fuel Source

Once the fuel source has been extinguished and cooled, the focus should then shift to extinguishing any remaining fires located around the edges of the spill using the horizontal sweep and localized targeting to extinguish any residual fires. Although the roll-on technique worked well up to this point, the horizontal sweep is less likely to disturb the existing foam blank allowing the fire to spread back toward the fuel source.

The same tactics worked well against the debris pile fires conducted during Phases I & III. A photograph of the initial approach on the debris pile is shown in Figure 4.6-4.

Fig. 4.6-4 – Roll-on Foam Application Pushing Toward the Debris Pile Fire

Since foam extinguishing agents have limited capabilities against three-dimensional, running fuel fires, highly obstructed fires such as our debris pile and three-dimensional fires consisting of lower flashpoint fuels will most likely require the use of a complementary agent such as dry chemical.

4.7 Why Does it Take F3s 1.5-2 Times Longer to Extinguish Fires than AFFF?

As mentioned in Section 3.5, the leading F3s typically took about 1.5-2.0 times longer than AFFF to extinguish the fires in most scenarios. The differences in the F3's capabilities as compared to AFFF's are best described through the visual observations made during the tests. As the firefighters approached and attacked the fire with AFFF, one sweep with either a hose line or a turret tended to extinguish all the fire within the sweep area including behind small obstructions. However, one sweep with the F3s tended to leave holes in the foam blanket and typically would not extinguish the obstructed fires. Any plunging of the spray into the fuel with the F3s typically resulted in fuel pickup in the foam blanket causing the foam blanket itself to burn but at a lower intensity than the open spill area. Photographs of these conditions are provided in Figure 4.7-1. The flowing fuel component of the running fuel fire also tended to wash-away the F3 foam blanket requiring continued application of foam at that location. None of these conditions were observed for AFFF during these scenarios and was attributed to the film-forming component of AFFF. As a result, it typically took two passes with the F3 stream, and sometimes more to completely extinguish all the fires within the sweep area as opposed to only one pass with AFFF. Bottom line, the need for the two passes resulted in longer extinguishment times for the F3s as compared to AFFF.

Fig. 4.7-1 – Single Stream Pass Resulting Conditions for F3s

4.8 Learning From Inexperienced Firefighters

During the Phase III effort, two trained but inexperienced firefighters were brought in to assist in conducting the tests. As the series progressed, the inexperienced firefighters were given the opportunity to extinguish the fires at the end of each burnback test. The lessons learned watching them fight the fires provided valuable information on the need for hands-on training during the deployment of F3s throughout DoD applications.

During their first few attempts, it was obvious that the firefighters were thinking more about the techniques they had been taught as opposed to adjusting to situation at hand. Their approach to the fire was robotic and awkward and they had no feel for how to apply the foam to the fire.

Specifically, they would set the nozzle on a wide-angle fog pattern, advance a few steps toward the fire, and then apply foam to the fire using a straight stream or narrow angle spray pattern (i.e., 30 degrees). This process was repeated numerous times as they slowly progressed toward the fire. The process looked awkward, and the fire tended to grow during the process. During the attack on the fire, the firefighters tended to punch holes in the foam blanket at the stream impingement location. As a result of the slow/awkward advancement and the poor foam application techniques, the fires always got worse (i.e., larger) before they got better.

The good news was that by the end of the week, the inexperienced firefighters had developed their techniques and could rapidly control and extinguish the test fires. An analogy to spackling or painting comes to mind where the concept is simple, but it takes time and hands-on experience to develop a technique. A photograph showing one of the lead firefighters directing the inexperience firefighters on F3 application techniques is provided as Figure 4.8-1.

Fig. 4.8-1 – Inexperience Firefighters being Taught to Apply F3 to the Fire

The inexperienced firefighters definitively showed that training will be key to effectively fielding these F3s in DoD applications. In addition, the techniques for combatting these fires cannot be taught using propane burners since they cannot be used to assess foam application techniques (i.e., plunging and/or blanketing of the fuel surface with aspirated foam). Large burn pits with deep water substrates are also problematic since the effect of plunging the stream into the fuel and the resulting fuel pickup in the foam blanket is not representative of a fuel spill on a hard surface. Lastly, the fire scenarios become much more challenging as the fuel and hard surfaces increase in temperature. The higher temperatures cause the foam blanket to breakdown faster and provide a greater potential for reflash. This also occurs with AFFF, but the film formation tends to help contain the vapors. A photograph of steam being produced by hot fuels and hard surfaces during these tests is provided as Figure 4.8-2.

Fig. 4.8-2 – Steam Produced by the Heated Fuel and Hard Surfaces

4.9 AFFF Versus F3 Tactics

The same application techniques work well for both AFFF and F3s products although, the finesse aspect of applying the foam has never been a point of emphasis during training with AFFF. In general, the hardware, tactics and techniques that optimize the capabilities of the F3s also tend to increase AFFF performance, but to a lesser degree. Specially, AFFF is much more forgiving of poor application techniques due to the film formation. As an example, the AFFF film minimizes the effects of plunging the stream into the fuel, both from a fuel pickup and holing of the foam blanket perspective.

The bottom-line differences are summarized as follows:

- F3s are less forgiving than AFFF due to the absence of the film formation.
- F3s generally work better when aspirated but aspirated foam is hard to throw far distances and does not flow well around obstructions.
- F3s require better application techniques and some level of finesse to optimize performance and prevent plunging into the fuel and disruption of the foam blanket.
- F3s are effective in ARFF type applications with the proper application techniques but typically take multiple stream passes versus one pass for AFFF to control and extinguish the fire.

The reduced capabilities and the need for proper application techniques emphasizes the importance of proper hands-on training for application of F3s going forward. Over the past 20 years or so, techniques for training firefighters for combatting liquid fuel fires have been demonstrated/taught using propane burners and water hose streams. These are inadequate for training firefighters to effectively use and apply F3s to a burning fuel surface. In addition, the use of legacy burn pits where the fuel is floated on top of a deep-water substrate are also problematic since plunging the stream into the fuel will not have the same consequences as would occur in an actual fuel spill scenario. Specifically, mixing the hot fuel with the cooler water substrate tends to cool the fuel and aid in extinguishment and opposed to picking up the fuel in the foam blanket, potentially causing it to ignite and burn.

4.10 Hose Team Manning and Responsibilities

In addition to the proper foam application techniques and tactics described previously, additional emphasis also needs to be placed on hose team training. **The lack of the film-forming component and the rapid degradation of the F3 foam blanket requires increased situational awareness for all hose team members when combatting the fire**. Preplanning, knowing individual responsibilities, and communications (both physical and verbal) will be key to successfully using these products.

It is recommended that the 1.75 inch hose team consist of three personnel: a nozzleman (1st in line), a backup firefighter (2nd in line) and hose handler (3rd in line). These positions are shown in Figure 4.10-1. The nozzleman is the architect for the initial attack on the fire and is responsible for applying the foam using the application techniques described in the previous sections. The backup firefighter should be located within an arm's reach of the nozzleman and is responsible for surveying the entire scene and directing the nozzleman where to apply the foam. Proper planning and good communication between the nozzleman and backup firefighter are considered imperative to effectively advance on the fire. The hose handler (sometimes referred to as the choke man) is located about 10-12 feet behind the backup firefighter and is responsible for providing slack in the hose and preventing the hose from kinking as the team advances on the fire. The hose handler watches the backup nozzleman provide direction to nozzleman on where to apply the foam and anticipates the movement in that direction. Most importantly, the hose handler is on reflash watch and provides continued surveillance of the previously extinguished areas. Potential burning around the edges and holing/degradation of the foam blanket need to be continuously monitored during the entire evolution.

Fig. 4.10-1 – Hose Line Manning

Communications will be key to coordinate the attack effectively and safely on the fire and the advancement of the hose. During testing and in most instances, the nozzleman typically communicated verbally or by exaggerated head movements to indicate the direction to advance the hose. The backup firefighter typically used hand signals or taps on the shoulders or thighs of the nozzleman to indicate the direction in which to aim the hose (i.e., what fires needed to be extinguished). Since the hose handler is behind and out of sight of the nozzleman and backup firefighter, verbal communication is the only option.

The ability to effectively function as a team will require significant training to combat the fire, advance the hose, circle back to extinguish residual fires and reignition, and to provide final confirmation that the fire has been extinguished.

5.0 SUMMARY AND CONCLUSIONS

The tactics and techniques discussed in this report pertain to both hose lines and turrets since the approach for combatting the fire and the application techniques are similar for both sets of hardware.

With this said, the tests used to develop these tactics and techniques were developed under controlled circumstances and in many respects provide ideal conditions to combat these fires. Specifically, the test area was flat, accessible (i.e., generally unobstructed) and the weather conditions were within a prescribed set of parameters. The firefighters were also generally well trained and intimately familiar with combating liquid fuel fires using AFFF. The weather conditions (i.e., precipitation), wind speed and direction, terrain/topography, ground conditions and accessibility need to be considered and compensated for during an actual attack on a fire. In other words, use the guidance provided in this report but make the needed adjustments as required to increase the likelihood of success depending on the conditions at hand.

The intent of this document was to convey the information on how to effectively use F3s by answering the following questions:

- What are the differences between AFFF and F3s?
- How does foam quality play into the fire extinguishing performance?
- What are the best nozzles to use?
- What is the best spray pattern?
- What is the best application technique?
- What are the best tactics?
- Why does it take F3s 1.5-2 times longer to put out fires than AFFF?

In general, the same techniques work well for both AFFF and F3s, however the finesse aspect of applying the foam to the fuel surface must be emphasized during training and real life application of F3 agents. The hardware, tactics and techniques that optimize the capabilities of the F3s also tend to increase AFFF performance (but to a lesser degree). Even with the use of the optimized techniques, the leading F3s typically took about 1.5-2 times longer than AFFF to extinguish the fires in most scenarios. The bottom-line differences between AFFF and F3s are summarized as follows:

- F3s are less forgiving than AFFF due to the absence of the film-forming component and the sole reliance on the bubble blanket to smother the fire.
- F3s generally work better when aspirated but aspirated foam is hard to throw far distances and doesn't flow well around obstructions.
- F3s require better application techniques and some level of finesse to optimize performance and prevent plunging into the fuel and disruption of the foam blanket.
- F3s are effective in ARFF type applications with the proper application techniques but typically take multiple application passes to control and extinguish the fire versus one for AFFF.

The reduced capabilities of the F3s compared to AFFF and the need for proper application techniques emphasizes the importance of proper hands-on training with F3 agents going forward. Over the past 20 years or so, techniques for training firefighters for combatting liquid fuel fires have been demonstrated/taught using propane burners and water hose streams. These are inadequate for training firefighters to effectively use F3s. In addition, the use of legacy burn pits where the fuel is floated on top of a deep-water substrate are also problematic since plunging the stream into the fuel will not have the same consequences as would occur in an actual fuel spill scenario on a hard surface. Specifically, mixing the hot fuel with the cooler water substrate will tend to cool the fuel and aid in extinguishment as opposed to picking up the fuel in the foam blanket, potentially causing it to ignite and burn.

In addition to the proper foam application techniques and tactics described in the body of this report, emphasis also needs to be placed on hose team training. The lack of the film-forming component and the rapid degradation of the F3 foam blanket requires increased situational awareness for all hose team members when combatting the fire. Preplanning, knowing individual responsibilities, and communications (both physical and verbal) will be key to successfully using these products. The ability to effectively function as a team will require significant training to combat the fire, advance the hose, circle back to extinguish residual fires and reignition and to provide final confirmation that the fire has been extinguished.

In closing, the tactics and techniques provided in this report were developed for non-air-aspirating water type nozzles when used against aviation fuels (i.e., kerosene-based fuels with minimum flashpoints of 100°F (38°C)). Combatting fires produced with lower flashpoint fuels may require different tactics and techniques.

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