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Preliminary Investigation into Fluorine-Free Foam (F3) Products using Saltwater Solutions & Ultra-High Pressure (UHP) Handline Testing - "Quick Look" Summary Report

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14. ABSTRACT

This report documents the preliminary findings for the firefighting performance and Dynamic Foam Analyzer (DFA) analysis for two commercially available Fluorine-Free Foam (F3) products when using saltwater foam solutions and reviews experiences gained when using a Ultra-High Pressure (UHP) foam delivery system.

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Preliminary Investigation into Fluorine-Free Foam (F3) Products using Saltwater Foam Solutions & Ultra-High Pressure (UHP) Handline Testing – "Quick Look" Summary Report

1. INTRODUCTION

The FY23 Environmental Security Technology Certification Program (ESTCP) WP20-5373 "Fluorine-Free Foam (F3) Military Specification Transition" and the WP21-3461 "F3 Large-Scale Validation" programs were recently expanded to include investigations into the efficacy of using saltwater foam solutions and the use of ultra-high pressure (UHP) foam delivery systems with commercially available F3 products. The intent of this "Quick Look" summary report is to document the preliminary F3 saltwater foam solution and F3 UHP test results.

2. SELECTED FLUORINE-FREE FOAM (F3) PRODUCTS

For this preliminary study, we chose to use the two F3 products that are purported to be saltwater compatible per the manufacturer's information:

1. Perimeter Solutions Solberg® 3% Milspec SFFF (Lot # RDGB3MSFF2301 & MFG Date 04-23)

2. BIOEX ECOPOL A3+ Milspec (Lot # 23E35F0 & MFG Date 06-23)

3. F3 SALTWATER FOAM SOLUTION FIREFIGHTING TESTING

The F3 saltwater foam solution 28ft^2 firefighting performance testing was conducted using the MIL-PRF-32725 foam delivery hardware with the military specification (Milspec) nozzle set at a 2 GPM (0.07 gpm/ft^2 application rate) foam flow rate using aviation Jet A fueled fires and included freshwater foam solution testing to provide a comparative metric in performance. The 28ft^2 fire tests were conducted at the Naval Research Laboratory's Chesapeake Bay Detachment (CBD) fire test facility located in Chesapeake Beach, MD. The fire tests included an assessment of extinguishment capabilities, burnback resistance, and expansion ratio & drainage testing. Tables 1-2 provides the firefighting performance test results.

Table-1: Perimeter Solutions Solberg® 3% Milspec SFFF Unaged Concentrate Firefighting Test Results

Fire Test	Fuel Type	Extinguishment (seconds)	Expansion Ratio	Burnback Time (seconds)	Drain Time (minutes:seconds)
Full-strength (Freshwater Solution)	Jet A	25	8.2	426	8:33
Full-strength (Saltwater Solution)	Jet A	22	6.4	301	3:18
Half-strength (Freshwater Solution)	Jet A	24	N/A	322	N/A
Half-strength (Saltwater Solution)	Jet A	24	N/A	273	N/A
Double-strength (Freshwater Solution)	Jet A	22	N/A	408	N/A
Double-strength (Saltwater Solution)	Jet A	30	N/A	319	N/A

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Table-2: BIOEX ECOPOL A3+ Milspec Unaged Concentrate Firefighting Test Results

Fire Test	Fuel Type	Extinguishment (seconds)	Expansion Ratio	Burnback Time (seconds)	Drain Time (minutes:seconds)
Full-strength (Freshwater Solution)	Jet A	18	8.7	408	8:33
Full-strength (Saltwater Solution)	Jet A	23	6.1	293	3:18
Half-strength (Freshwater Solution)	Jet A	24	N/A	371	N/A
Half-strength (Saltwater Solution)	Jet A	24	N/A	266	N/A
Double-strength (Freshwater Solution)	Jet A	20	N/A	384	N/A
Double-strength (Saltwater Solution)	Jet A	23	N/A	247	N/A

NOTE: MIL-PRF-32725 firefighting foam testing only requires expansion ratio & drainage testing for full-strength solution testing [1].

28ft² Firefighting Test Analysis: The test results noted in Tables 1-2 indicate that both the Perimeter Solutions Solberg® 3% Milspec SFFF and the BIOEX ECOPOL A3+ Milspec fluorine-free foam (F3) products had excellent and relatively comparative firefighting extinguishing performance with both the freshwater and saltwater foam solution testing. Both F3 agents showed reduced burnback resistance performance with the saltwater solution tests. This noted reduction in burnback resistance is possibly attributed to the reduction in the expansion ratio and drainage times documented for the saltwater foam solution test results noted in Tables 1-2.

4. DYNAMIC FOAM ANALYZER (DFA) ANALYSIS

DFA Background: To further investigate the differences in foam quality between the F3 freshwater and saltwater foam solutions, additional Dynamic Foam Analyzer (DFA) testing was completed during the 28ft² firefighting testing noted in Section 3.0 of this report. The Dynamic Foam Analyzer (DFA100 Krüss, Hamburg, Germany) is an instrument for the analysis of formability and foam stability. In lieu of these goals, it provides precise measurements of foam height, liquid drainage, and bubble size distributions via a 469 nm light-emitting diode (LED) light source, a video camera, and an optical sensor [2]. Foam generation can be performed internally in the DFA using a glass frit sparger or externally by generating foam into the DFA column [3]. Regardless of the generation method, foam is collected in a glass column (40 mm diameter, 25 cm height) with a prism along its length. The prism reflects light onto a video camera positioned at a height of 55 mm, enabling continuous capture of foam bubble images over the course of the instrument run time [3, 4]. The LED light is adjusted to 20% structure illumination and 12% height illumination based on the high transparency of liquids used to generate the firefighting foams in this work.

DFA Testing & Analysis: The two concentrates analyzed in this preliminary study were diluted into full-strength (3%), half-strength (1.5%), and double-strength (6%) using fresh and saltwater, resulting in 12 different foam solutions.

Foam volume, percent liquid drained beneath the foam, and bubble radius (μm) with time profiles were collected for these 12 solutions using the DFA as well as the initial bubble area distributions for each foam. Foam was collected into the DFA column following the MIL-PRF-32725 procedure of collecting foam from an inclined metal board. There was a lag time between foam collection and DFA data collection. For most of the testing, this value was roughly 40 s; however, a more significant time delay occurred for *Sol_Half_Salt*. Therefore, no data is plotted between 40-70 s for the *Sol_Half_Salt* and its data starts at 70 s. There were also data gaps in the *Eco_Double_Fresh* and *Eco_Double_Salt* trials between 100-200 s and 200-400 s respectively and no data is presented during those time ranges. No repeated trials were conducted for this preliminary DFA investigation.

Previous research by *Hinnant et al.* comparing the foam properties and firefighting performance of other fluorine-free foam (F3) concentrates has noted a disconnect between the two. Liquid drainage rate from the foams and bubble coarsening rates for a fluorinated and two commercial fluorine-free foam concentrates did not trend with $28ft^2$ fire extinction performance or burnback performance for gasoline or heptane fires. A trend between the foam properties and fire suppression performance is therefore not necessarily expected. However, this data provides deeper insight into the interactions between salt and the commercial concentrates that may be useful to research related to improving foam stability with the addition of saltwater.

Figure 1 plots the expansion ratio (ER) and 25% drainage times noted in Tables 1-2 above, demonstrating the relative decreases in value for the two commercial F3 concentrates

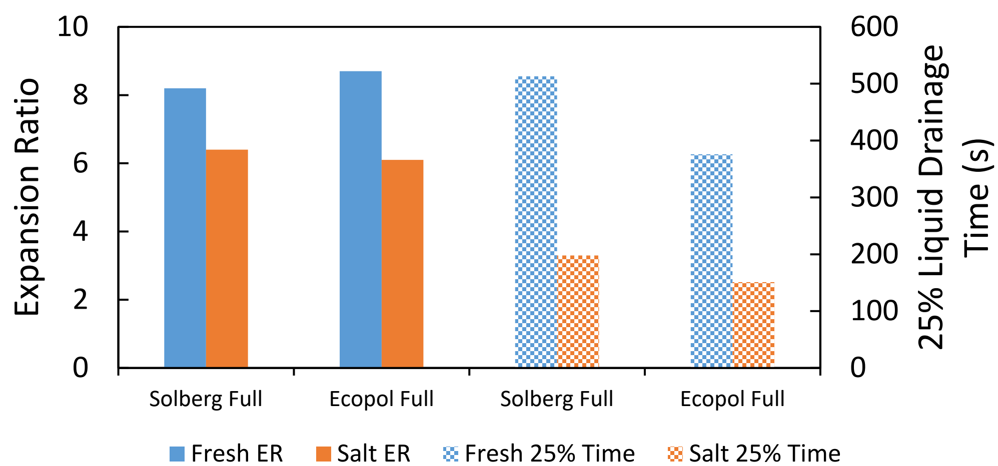

Figure-1: Comparison of foam ER and 25% liquid drainage time measured via procedure in MIL-PRF- 32725. Left axis corresponds to ER and the left two bar graphs, right axis corresponds to 25% liquid drainage time (s) and the right two bar graphs for Solberg® SFFF and ECOPOL A3+ full strength solutions.

Both Solberg® SFFF and ECOPOL A3+ showed a decrease in ER (22 and 29% respectively) and in 25% liquid drainage time (61 and 60% respectively) when saltwater was used to generate the foam solutions compared to freshwater.

The bubble size distributions are provided in Figure 2. Despite differences in drainage behavior and initial ER, similar initial bubble sizes and bubble area distributions were created between the 12 foams, regardless of concentrate type, amount, or fresh vs. saltwater. This agrees with anecdotal evidence over the years that the Milspec nozzle produces a very consistent foam initially; but with time, concentrate compositional differences result in foam property differences.

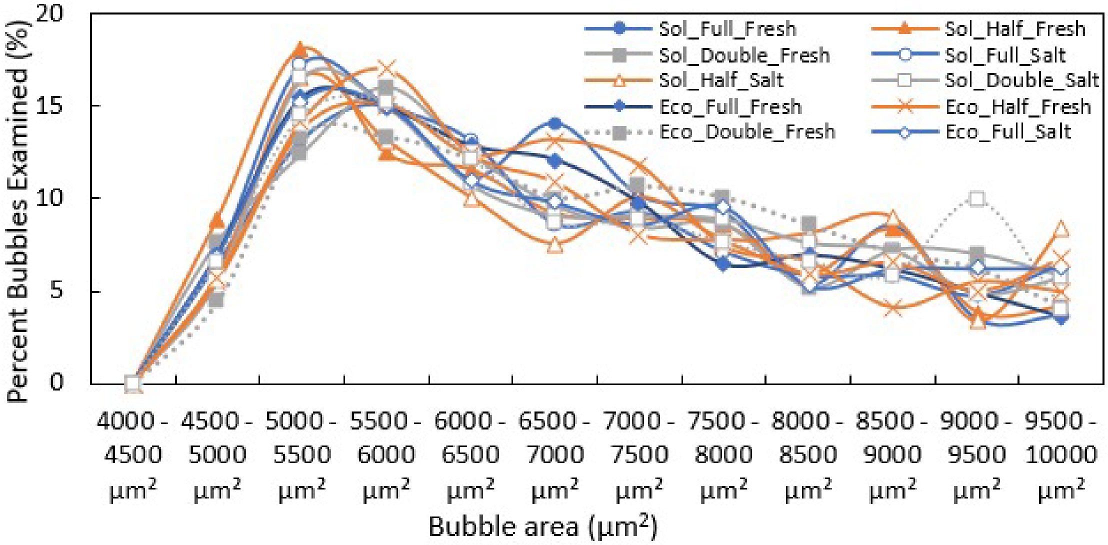

Figure-1: Initial bubble area distributions for foams generated using the Milspec nozzle, distribution represents a foam lifetime of roughly 40 s between fill and DFA data collection. No repeated trials.

Time dependent information about foam behavior was gained comparing the full, half, and double-strength solutions. Percent liquid drained with time profiles for the 12 foams are shown in Figure 3. Percentages were calculated assuming the ER for the full-strength solutions was like the half and double-strength solutions. This seemed reasonable as fresh vs. saltwater changed ER by less than 30% for both commercial concentrates. The same ER values were used for the full, half, and double-strength solutions respective of fresh vs. saltwater for the percent liquid drainage profiles.

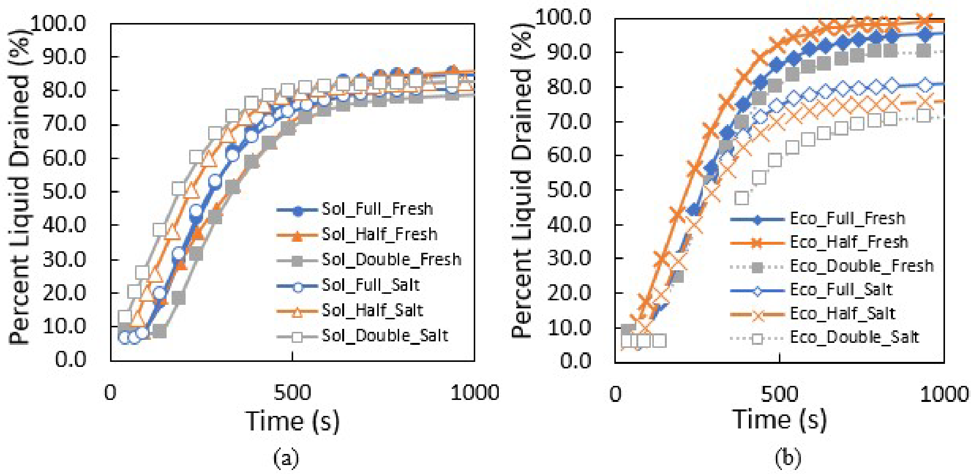

Figure-3: Percent liquid drained beneath a foam layer in the DFA with time for (a) Solberg® SFFF concentrate foams and (b) ECOPOL A3+ concentrate foams. No repeated trials.

The drainage profiles in the DFA were significantly different from the 25% drainage times measured via the Milspec method. In the DFA profiles, we see shorter drainage times, (less than 200 s) for fresh and saltwater containing foams. We also see smaller differences in fresh vs saltwater drainage times for the full-strength solutions: *Sol_Full_Fresh* and *Sol_Full_Salt* haves nearly identical profiles. *Eco_Full_Salt* appears to drain slower than *Eco_Full_Fresh*. Saltwater appears to increase the drainage rate of the half and double-strength Solberg® SFFF foams but decreases the drainage rate of the half and double-strength ECOPOL A3+ foams. Both the DFA and Milspec data show that the Solberg® SFFF containing foams drain slower than the ECOPOL A3+ containing foams. However, additional trends related to saltwater addition are in question as the full-strength DFA data disagrees with the 25% drainage times collected via the Milspec method. We turn to DFA measurements of bubble coarsening and changes in foam height with time to conclude the role of saltwater in foam properties for these two commercial concentrates.

The change in average bubble radius with time (bubble coarsening) is plotted in Figure 4.

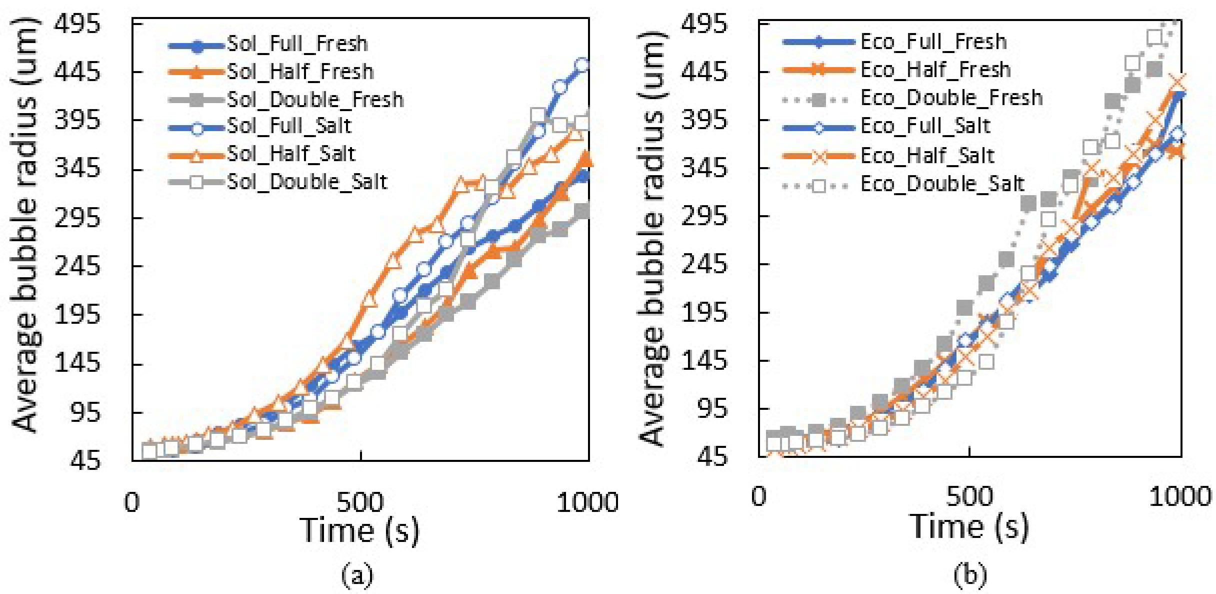

Figure-2: Average bubble radius (µm) for foams in the DFA with time for (a) Solberg® SFFF concentrate foams and (b) ECOPOL A3+ concentrate foams. No repeated trials.

The coarsening results for Solberg® SFFF containing foams have a similar trend to Solberg® SFFF containing foam drainage data: saltwater addition seems to destabilize the foams, increasing liquid drainage rate through the foam and increasing foam bubble coarsening rate. Solberg® SFFF does not appear to have drastic differences in foam properties related to concentration. ECOPOL A3+ shows differing behavior between coarsening and drainage results. ECOPOL A3+ generally showed concentration and saltwater dependency in liquid drainage data (saltwater addition slowed drainage, increased concentration slowed drainage), but the coarsening rate appears unaffected by saltwater or concentration.

Changes in foam volume with time are plotted in Figure 5. We see some consistency in measurement between the three foam properties for the Solberg® SFFF containing foams. Liquid drainage, coarsening, and foam volume all indicate that the Solberg® SFFF containing foams become less stable with saltwater addition. However, foam volume shows some concentration dependency with *Sol_Half_Salt* and *Sol_Half_Fresh* degrading faster than the full and double strength Solberg® SFFF foams. In Table 3, the half-strength Solberg® SFFF shows the largest deterioration in foam stability with saltwater addition while the full-strength is less effected by the saltwater addition. The double-strength Solberg® SFFF foam appears to be unaffected by saltwater addition at long time-scales event though Figure 5(a) shows worse performance of *Sol_Double_Salt* compared to *Sol_Double_Fresh* at earlier timescales.

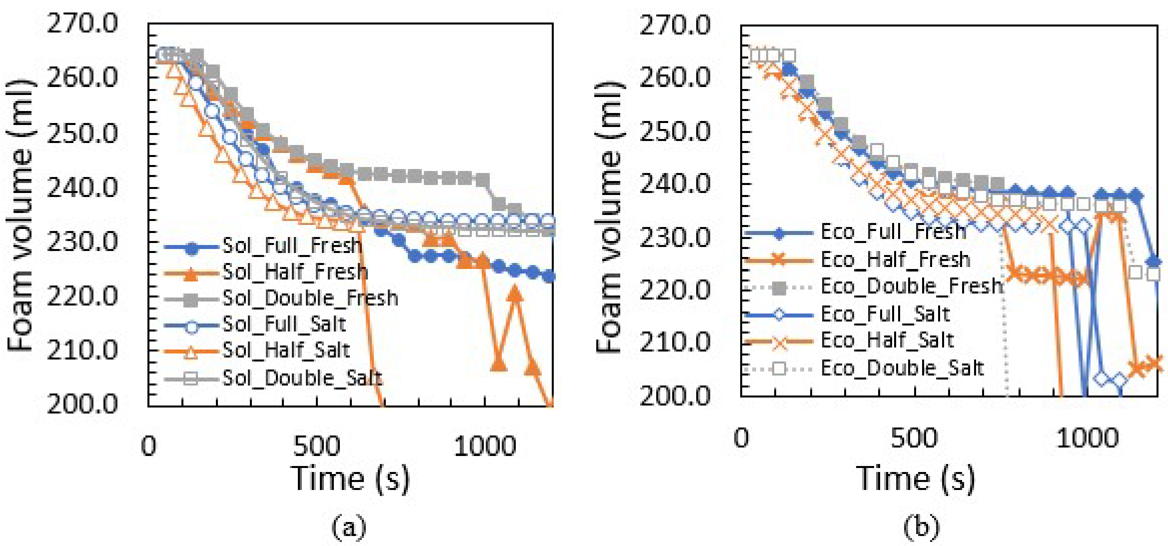

Figure-3: Plots of foam volume with time for (a) Solberg® SFFF foams and (b) ECOPOL A3+ foams.

Table-3 provides a summary of the percent foam volume lost after 1200 seconds during the DFA analysis for the 12 different (i.e., 6 freshwater and 6 saltwater) foam solutions studied in this F3 saltwater foam solution DFA study.

Table-3: Percent foam volume loss after 1200 s of evaluation in the DFA for 12 different foam solutions.

Percent Foam Lost 1200 s (%)	Full-Strength (Freshwater)	Full-Strength (Saltwater)	Half-Strength (Freshwater)	Half-Strength (Saltwater)	Double-Strength (Freshwater)	Double-Strength (Saltwater)
Solberg® SFFF	15.7	16.4	21.8	49.1	12.1	12.3
ECOPOL A3+	25.1	34.5	22.1	43.6	42.5	15.7

ECOPOL A3+ remains different from Solberg® SFFF in its trends with saltwater varying between liquid drainage, coarsening, and foam volume. While liquid drainage performance improved with salt, and coarsening rate appeared unaffected, half, and full-strength ECOPOL A3+ saltwater containing foams degraded faster than foams with freshwater. However, the half and full-strength fresh water ECOPOL A3+ foams were more stable than *Eco_Double_Fresh*. While saltwater deteriorated foam stability for the half and full strength ECOPOL A3+ foams, it stabilized the double-strength foam.

The Milspec method results differ greatly from the DFA collected drainage profiles and we consider both measurements in defining the role of saltwater on Solberg® SFFF and ECOPOL A3+ foam properties. Based on the data, we believe saltwater addition does increase the liquid drainage rate for the Solberg® SFFF and ECOPOL A3+ foams, regardless of concentration.

This is confirmed by DFA and Milspec data for Solberg® SFFF but does not agree with the DFA data collected for ECOPOL A3+. Saltwater addition appears to increase the coarsening rate of Solberg® SFFF containing foams but has minimal effect on the coarsening rate of ECOPOL A3+ containing foams. Saltwater appears to have concentration dependent effects on foam volume with time, more adversely effecting foams with half-strength concentrates compared to double-strength concentrates for Solberg® SFFF. For ECOPOL A3+, the double-strength appears to be detrimental to foam stability. Adding saltwater stabilizes this higher concentration foam but destabilizes ECOPOL A3+ foams with half and full-strengths. No apparent trends are seen with the extinction or burnback performance; however, the information is valuable to better understand the effect of saltwater on foam behavior.

5. ULTRA-HIGH PRESSURE (UHP) HANDLINE TESTING

UHP Handline Testing Background: The intent of the Ultra-High Pressure (UHP) handline testing was to enable an opportunity for the Fire Research Team to gain familiarity with the operation of the U.S. Navy Rapid Intervention Vehicle (RIV) and to glean some "hands-on" experience with the RIV pump/foam controls and UFP handline operations while combating a Class B fire.

The RIV UHP operations and handline testing was completed at the Naval Research Laboratory's Chesapeake Bay Detachment (CBD) fire test facility located in Chesapeake Beach, MD utilizing a U.S. Navy Rapid Intervention Vehicle (RIV) provided by the Naval District Washington (NDW) Naval Support Activities-Annapolis (see Figure-6).

Figure-6: U.S. Navy Rapid Intervention Vehicle (RIV) Support Unit (SU-47)

The RIV had a pumper turret in the front of the vehicle and a small diameter non-collapsible hose reel located in the back of the vehicle to support firefighting operations. The RIV water tank has a 200-gallon capacity, and the foam tank has a 20-gallon capacity.

NOTE: The RIV had a C6 AFFF product in the 20-gallon foam tank, which was emptied and flushed prior to filling the foam tank with a Fluorine-Free Foam (F3) product.

For this preliminary RIV UHP testing, only the small diameter hose reel was operated since the Phase V NAWCWD-China Lake testing currently plans to only include handline firefighting operations. Figure-7 provides photographs of the RIV UHP handline firefighting nozzle and the selected foam delivery spreader tip position. Only freshwater foam solutions were used for this preliminary UHP handline testing.

Figure-7: UHP Handline Nozzle & Selected Foam Delivery Spreader Tip Position

RIV Pump & Foam Control Operations: All pump and foam control operations were operated at the rear control panel of the RIV for the UHP handline testing (See Figure-8).

Figure-8: RIV UHP Pump and Foam Control Panel

The 7-step sequential procedure used to operate the RIV UHP pump and foam control system included:

1) Turn Selector Switch to "H/P pump mode" position.
2) Turn the Battery Control switch to the "ON" position to illuminate the LED tank level indicators.
3) Turn the Ignition Switch to the "Run" position.
4) Once the "Glow-Plug" LED indictor goes off, turn the Ignition Switch to the "Start" position.

5) Once the engine starts, adjust the Engine Speed Control to the 4,000 RPM position.
6) For UHP foam operations, adjust the Proportioner Control to the "3%" position.
7) Tune on the Foam Switch to the "ON" position.

UHP Handline Testing: The UHP handline firefighting testing included one aviation Jet A fueled fire and one unleaded ethanol-free gasoline fueled fire contained in the circular 78.8ft^2 International Civil Aviation Organization (ICAO) Level C fire test pan (diameter ~120.5 inches and inside lip ~8.125 inches). Each test fire included 15 gallons of fuel poured over a 4-inch water substrate. Each fire was allowed to pre-burn for a period of 60 seconds prior to initiating any firefighting action. The fluorine-free foam (F3) product used for the two UHP firefighting tests was the Perimeter Solutions Solberg® 3% Milspec SFFF agent.

UHP Handline Firefighting Test Results: The aviation Jet A fueled fire was extinguished in 24 seconds and the unleaded ethanol-free fueled fire was extinguished in 38 seconds. For both of these firefighting tests, the extinguishments times were somewhat increased due to the edge effects of the test pan, which produced some persistent fires burning along the perimeter of the test pan.

NOTE: Due to the RIV advertised UHP flow rate of 16 gpm @ 1500 psi and the fire surface area of 78.8 ft^2, the calculated application rate for these two fire tests was 0.2 gpm/ft^2, which is considerably higher than the MIL-PRF-32725 28ft^2 0.07 gpm/ft^2 and the 50ft^2 0.06 gpm/ft^2 qualification fire test application rates.

Figures 9 and 10 provide UHP fire test photographs and the generated foam blanket following extinguishment for the two test fire tests.

Figure-9: UHP 78.8ft^2 Jet A Fire Test & Generated Foam Blanket

Figure-10: UHP 78.8ft^2 Gasoline Fire Test & Generated Foam Blanket

UHP Pump & Foam Control Operations and Firefighting Test Lessons Learned: The following lessons learned from this RIV UHP preliminary testing include:

- The noted RIV 7-step operational pump & foam control procedure was easy to implement and took ~15-seconds to complete. For all "water only" nozzle checks and flushing operations steps 1-5 were followed.

  NOTE (1): To compensate for water usage, a 1.5 inch "nursing" line was used via the RIV water tank fill connection to help maintain and manage the water level in the RIV water tank.

  NOTE (2): Prior to using the RIV for foam applications the Foam Concentrate valve located at the foam storage tank must be opened.
- There were no issues identified using the Perimeter Solutions Solberg® 3% Milspec SFFF agent with the RIV proportioning system.
- For the anticipated NAWCWD-China Lake Phase V RIV UHP firefighting testing, it is highly recommended to use the RIV foam proportioning system and to not pre-mix the foam solution in the RIV water tank.
- Due to the UHP foam spray stream reach of ~65ft it is recommended that the firefighter position himself at a sufficient distance away from the fire to ensure the leading edge of the firefighting spray does not overshoot the burning fuel surface. It is also recommended to use a horizontal sweeping nozzle technique for the foam application.
- For firefighting foam applications there is no need to adjust the foam spray nozzle to the other provided straight stream or water fog nozzle settings.

6. SUMMARY AND CONCLUSIONS

The FY23 Environmental Security Technology Certification Program (ESTCP) WP20-5373 "Fluorine-Free Foam (F3) Military Specification Transition" and the WP21-3461 "F3 Large-Scale Validation" programs were recently expanded to include investigations into the efficacy of using saltwater foam solutions and the use of ultra-high pressure (UHP) foam delivery systems with commercially available F3 products. The intent of this "Quick Look" summary report was to document the preliminary F3 saltwater foam solution and F3 UHP test results.

This first experimental study and findings will certainly help to provide the Fire Research Team with important upfront experiences prior to conducting the NAWCWD-China Lake Phase V large-scale validation testing and is an important first step in acquiring the requisite knowledge for developing a future military specification for transitioning Fluorine-Free Foam (F3) products to U.S. Navy Shipboard applications.

7. REFERENCES

1. Naval Sea Systems Command (NAVSEA) "Fire Extinguishing Agent, Fluorine-Free Foam (F3) Liquid Concentrate, for Land-Based, Fresh Water Applications", MIL-PRF-32725(SH) w/INT. AMENDMENT 1, 17 August 2023.

2. *Dynamic Foam Analyzer DFA100*. https://www.kruss-scientific.com/en/products-services/products/dfa100?sort=modelnumber%2CASC&showcount=12 (accessed 9/12/2023).
3. R. Ananth, A.W. Snow, K.M. Hinnant, S.L. Giles, J.P. Farley, Synergisms between siloxane-polyoxyethylene and alkyl polyglycoside surfactants in foam stability and pool fire extinction, Colloids Surf., A, 579 (2019) 123686. https://doi.org/10.1016/j.colsurfa.2019.123686.
4. S.L. Giles, A.W. Snow, K.M. Hinnant, R. Ananth, Modulation of fluorocarbon surfactant diffusion with diethylene glycol butyl ether for improved foam characteristics and fire suppression, Colloids Surf., A, 579 (2019) 123660. https://doi.org/10.1016/j.colsurfa.2019.123660.