

# **VALIDATION OF FLOURINE-FREE Fire Suppression Alternatives (FF\_FSA) AGAINST MILITARY SPECIFICATIONS**

**WP20-5335**

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Battelle Memorial Institute**

Final Brief  
August 30, 2023



# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> The Technical Objectives of this project are listed below: <ul style="list-style-type: none"><li>● Assessment, optimization, and demonstration of 13 PFAS-Free Foams (PFFs) against MIL-PRF-24385F</li><li>● Assessment/Down-selection including<ul style="list-style-type: none"><li>-Environmental (LC50, BOD20, COD)</li><li>-Corrosivity</li><li>-Fire Performance (extinguishment time and burnback time)</li></ul></li><li>● Optimization of PFFs using commonly available technologies<ul style="list-style-type: none"><li>-Compressed Air Foam (CAF)</li><li>-Ultra-high Pressure (UHP)<sup>3</sup></li></ul></li><li>● Demonstration/Validation against military relevant fire-fighting scenarios</li><li>● Technology Transition</li></ul>					
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# Project Team

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- Environmental and Ecological Advisor: Dr. Kavitha Dasu, Battelle
- Advisors: Mr. William Kavanaugh, ARMY IMCOM EUROPE; Jeff Eichler, Navy; Keith Bagot, FAA; Marc Mills, EPA

# Technical Objectives

- Assessment, optimization, and demonstration of 13 PFAS-Free Foams (PFFs) against MIL-PRF-24385F
- Assessment/Down-selection including
  - ◆ Environmental ( $LC_{50}$ ,  $BOD_{20}$ , COD)
  - ◆ Corrosivity
  - ◆ Fire Performance (extinguishment time and burnback time)
- Optimization of PFFs using commonly available technologies
  - ◆ Compressed Air Foam (CAF)
  - ◆ Ultra-high Pressure (UHP)
- Demonstration/Validation against military relevant fire-fighting scenarios
- Technology Transition



# Performance Objectives & Results for Physical, Corrosivity, and Environmental Properties

Performance Objective	Data Requirements	Success Criteria (MIL-PRF-24385F)	Success Criteria Achieved?
<b>Quantitative Performance Objectives (Laboratory-based Mil-Spec Testing)</b>			
Physical properties	<ul style="list-style-type: none"> <li>Refractive Index</li> <li>Viscosity</li> <li>pH</li> <li>Spreading Coefficient</li> </ul>	<ul style="list-style-type: none"> <li>RI: <math>\geq 1.3630</math></li> <li>Viscosity: <math>25\text{ }^{\circ}\text{C} \geq 2\text{ cSt}</math>, <math>5\text{ }^{\circ}\text{C} \leq 20\text{ cSt}</math> (<math>&lt;300\text{ cSt}</math> New Spec)</li> <li>pH: <math>7.0 \leq \text{pH} \leq 8.5</math></li> <li>Spreading Coefficient: <math>\geq 3</math></li> </ul>	<ul style="list-style-type: none"> <li>None meet all requirements</li> <li>Some PFFs are highly non-Newtonian</li> <li>Some barely fail pH &amp; RI</li> <li>All fail spreading coefficient</li> </ul>
Corrosivity	<ul style="list-style-type: none"> <li>Low carbon steel (UNS G10100)</li> <li>Copper/Nickle (UNS C70600)</li> <li>Nickle/Copper (UNS N04400)</li> <li>Bronze (UNS S30400)</li> <li>Localized, corrosion resistant steel (CNS S30400)</li> </ul>	<ul style="list-style-type: none"> <li>UNS G10100: <math>&lt;1.5\text{ milli in/yr}</math></li> <li>UNS C70600: <math>&lt;1.0\text{ milli in/yr}</math></li> <li>UNS N0400: <math>&lt;1/0\text{ milli in/yr}</math></li> <li>UNS C90500: <math>&lt;100\text{ mg}</math></li> <li>CNS S30400: no pitting</li> </ul>	<ul style="list-style-type: none"> <li>7 of 8 passed all</li> <li>1 other with partial failure of bronze</li> </ul>

# Performance Objectives & Results for Physical, Corrosivity, and Environmental Properties (cont'd)

Performance Objective	Data Requirements	Success Criteria (MIL-PRF-24385F)	Success Criteria Achieved?
<b>Quantitative Performance Objectives (Laboratory-based Mil-Spec Testing)</b>			
Environmental Impact	<ul style="list-style-type: none"> <li>LC<sub>50</sub> (Fathead minnows)</li> <li>Chemical oxygen demand (COD)</li> <li>Biological oxygen demand (BOD<sub>20</sub>)/COD</li> </ul>	<ul style="list-style-type: none"> <li>LC<sub>50</sub>: ≥ 500 mg/L (New Spec &lt; 30 mg/L)</li> <li>COD: ≤ 1000 K mg/L</li> <li>(BOD<sub>20</sub>)/COD: &gt;0.65</li> </ul>	<ul style="list-style-type: none"> <li>All PFFs generally “slightly toxic”</li> <li>All PFFs tested and C6 AFFF pass BOD<sub>20</sub>/COD specification</li> <li>None meet COD specification</li> </ul>
Stability	<ul style="list-style-type: none"> <li>Stratification</li> <li>Precipitation</li> </ul>	<ul style="list-style-type: none"> <li>Stratification: No visible evidence</li> <li>Precipitation: 0.05% by volume</li> </ul>	<ul style="list-style-type: none"> <li>5 of 6 passed precipitation requirements</li> </ul>

# Methods

## Quantitative Objectives (Laboratory)

- **Corrosion**
  - ◆ 5 metals submerged for 60 days in foam concentrate (10% by volume with sea water)
- **Environmental Impact**
  - ◆ **LC<sub>50</sub>**
    - Evaluated on fathead minnows
  - ◆ **Ultimate Biological Oxygen Demand (BOD<sub>20</sub>)**
    - Serial BOD measurements recorded using a respirometric device, and ultimate BOD was measured using conditioned inoculum
  - ◆ **Chemical Oxygen Demand (COD)**
    - Measured using a Hach test kit
- **Spreading Coefficient**
  - ◆ Surface and interfacial tension measured using Kruss Tensiometer
  - ◆ Surface tension ( $S_{a/b}$ ) is found by the following equation:

$$\frac{S_a}{b} = \gamma_b - \gamma_a - \gamma_i$$

Where:

$\gamma_b$  = surface tension cyclohexane

$\gamma_a$  = surface tension 3% foam solution

$\gamma_i$  = interfacial tension foam solution/cyclohexane

# Performance Objectives

Performance Objective	Data Requirements	Success Criteria (MIL-PRF-24385F)	Success Criteria Achieved?
<b>Quantitative Performance Objectives (28-ft<sup>2</sup> Mil-Spec, Gasoline Fires)</b>			
Foamability/Drain Time	<ul style="list-style-type: none"> <li>Expansion ratio (ER)</li> <li>25% foam drain time</li> </ul>	<ul style="list-style-type: none"> <li>ER: <math>\geq 5</math></li> <li>25% drain time: <math>\geq 150</math> s</li> </ul>	<ul style="list-style-type: none"> <li>All PFFs pass</li> </ul>
90% Control	<ul style="list-style-type: none"> <li>Heat flux</li> </ul>	<ul style="list-style-type: none"> <li>N/A to Mil-Spec</li> </ul>	<ul style="list-style-type: none"> <li>Measured</li> </ul>
Fire Extinguishment	<ul style="list-style-type: none"> <li>Stopwatch</li> </ul>	<ul style="list-style-type: none"> <li>Extinguishment time: <math>\leq 30</math> s (New Spec for gas <math>\leq 60</math> s)</li> </ul>	<ul style="list-style-type: none"> <li>No PFF passed with Mil-Spec nozzled (2 of 10 failed to extinguish)</li> <li>25% lower extinguishment time with CAF</li> </ul>
Burnback/Cold Burnback	<ul style="list-style-type: none"> <li>Stopwatch</li> <li>Heat flux</li> </ul>	<ul style="list-style-type: none"> <li>Burnback time: <math>\geq 360</math>s (New Spec for gas <math>\geq 240</math> s)</li> </ul>	<ul style="list-style-type: none"> <li>1 of 10 passed with Mil-Spec nozzle</li> <li>8 of 9 passed with CAF</li> </ul>
<b>Quantitative &amp; Qualitative Performance Objectives (315-ft<sup>2</sup> with Gasoline and Jet-A; 6504-ft<sup>2</sup> with Jet-A)</b>			
Extinguishment time Handling/Usability	<ul style="list-style-type: none"> <li>Stopwatch</li> <li>Testing notes</li> </ul>	Fire control and extinguishment	Yes, for all 4 F3s tested so far with CAF and UHP

# Methods

## Quantitative/Quantitative Objectives (Fires)

- **Foamability/Drain Time (Mil-Spec Fire)**
  - ◆ Foam dispensed onto backboard as described in MIL-PRF-24385F and NFPA 412 and collected in graduated cylinders.
  - ◆ Foamability assessed using the weight of collected solution, assuming a density of 1mg/mL. Drain time assessed by recording the time at which the volume of the drained liquid is equal to a quarter of the volume of the collected liquid.
- **Extinguishment and Burnback Time (Mil-Spec Fire; 28-ft<sup>2</sup>)**
  - ◆ Time at which all flames have been extinguished is observed visually and recorded to the nearest second.
  - ◆ Once the fire is extinguished, 1 gallon of ignited fuel is inserted into the foam layer, and the time at which 25% of the foam layer has ignited is observed visually. This value is compared to the time at which the heat flux value has reached to 25% of the peak heat flux value of an unsuppressed fire.
- **Medium-Size Field-Scale Demonstration Fires (6-ft-dia pan; 315-ft<sup>2</sup>)**
  - ◆ Testing with a commercial CAF skid, with gasoline and Jet-A fires; 10 second full pre-burn
  - ◆ Testing with an UHP (P-34) fire truck, with Jet-A fires; 10 seconds full pre-burn
- **Large-Size Field Scale Demonstration Fires (91-ft-dia, gravel-lined pit; 6,504-ft<sup>2</sup>)**
  - ◆ Testing with Jet-A fires; measure 90% control and extinguishment times; 10 seconds full pre-burn
  - ◆ Evaluate on ease of use by firefighters; Questionnaire and one day workshop (Navy, Army and FAA observer feedback)
- **Mini-CAF Exploratory Fire Testing (0.3-ft<sup>2</sup>)**
  - ◆ Typically tested all new PFFs before proceeding to Mil-Spec or field testing

# Site Description-SkyX Fire Hanger

- **AFCEC/Tyndall AFB**
  - ◆ Located near Panama City, FL
- **Mini-CAF**
  - ◆ 0.3-ft<sup>2</sup> fires
- **Mil-Spec Fire Testing**
  - ◆ 28-ft<sup>2</sup> fires



# Site Description-Silver Flag Training Site

- **AFCEC/Tyndall AFB**
  - ◆ Located near Panama City, FL
- **Large Fire Testing**
  - ◆ 91-ft diameter (6,504-ft<sup>2</sup>) fire training pit
    - Met ring to minimize fire area to 20 – 24-ft-dia
  - ◆ Outdoor facilities at Silver Flag training area
  - ◆ Home to RED HORSE (Air Force Rapid Engineer Deployable, Heavy Operational Repair Squadron)



# Mil-Spec-Test Design

PFF Product	Physical Properties	Environmental Impact	Corrosion	28-ft <sup>2</sup> Fire Testing				
				M-S Nozzle E0 Gas	CAF E0 Gas	M-S Nozzle Jet-A	CAF Jet-A	UHP E10 Gas
0	✓	✓	✓	✓	✓	✓	✓	✗
4	✓	✓	✓	✓	✓	✓	✓	✗
6	✓	✓	✓	✓	✓	✓	✓	✓
8.2	✓	✓	✓	✓	✓	✓	✓	✗
12	✓	✓	✓	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✗	✗	✗	✗
14	✓	✓	✓	✓	✓	✗	✗	✗
15.2	✓	✓	✗	✓	✓	✗	✗	✗
16	✓	✓	✓	✗	✗	✗	✗	✗
21	✗	✗	✗	✓	✓	✓	✓	✗
22	✗	✗	✗	✓	✓	✓	✓	✗
24	✗	✗	✗	✗	✗	✓	✓	✗

# Nozzle Types

## Mil-Spec Nozzle

- Air aspirating nozzle
- Foam is created by air taken in via a venturi at the nozzle
- Specialty nozzle designed specifically for this test

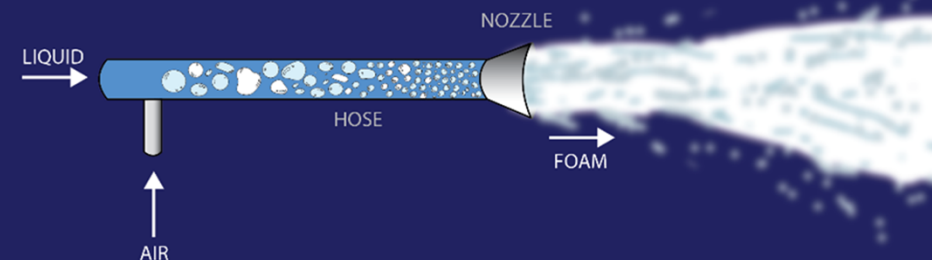
## Compressed Air Foam (CAF)

- Compressed (100–200 psi) air is injected into the line
- Produces foam with uniform bubble structure to improve both extinguishment time and burnback time
- Expansion ratio can be controlled
- Foam expansion occurs before exiting the nozzle

### ASPIRATING NOZZLE

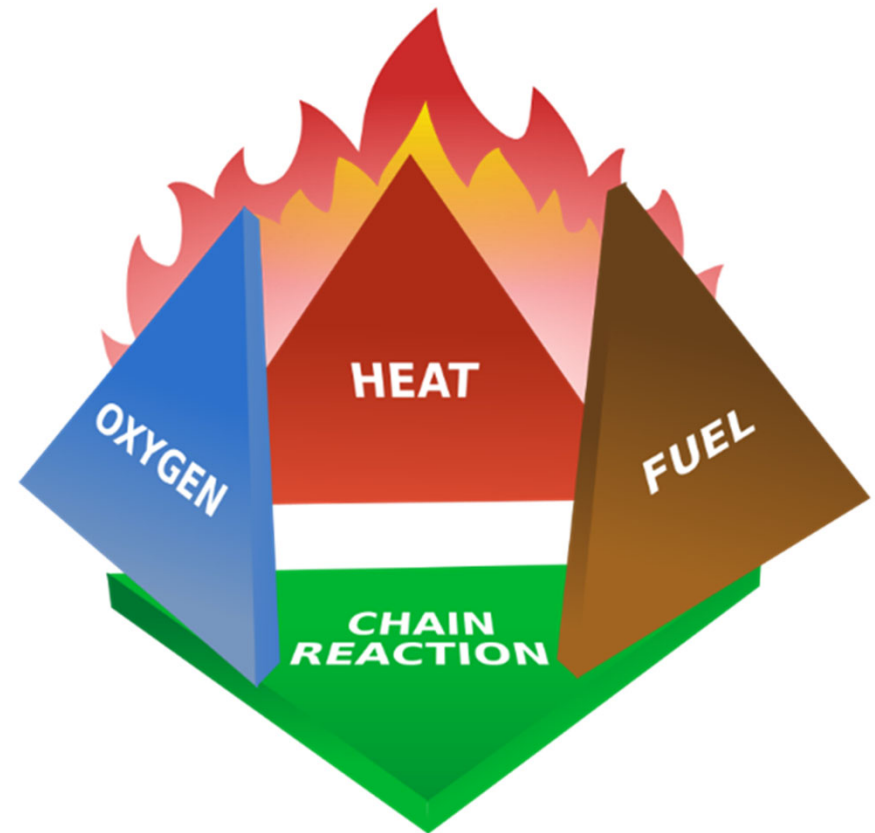


### COMPRESSED AIR FOAM



# Ultra High Pressure (UHP)

- Truck pressure 1100–1400 psi
  - Typically uses aspirating nozzle
- Reduces foam application rate
- Small droplet size enhances cooling effect
  - Can be combined with dry chemical to take out three sides of the “Fire Tetrahedron” at once to improve firefighting

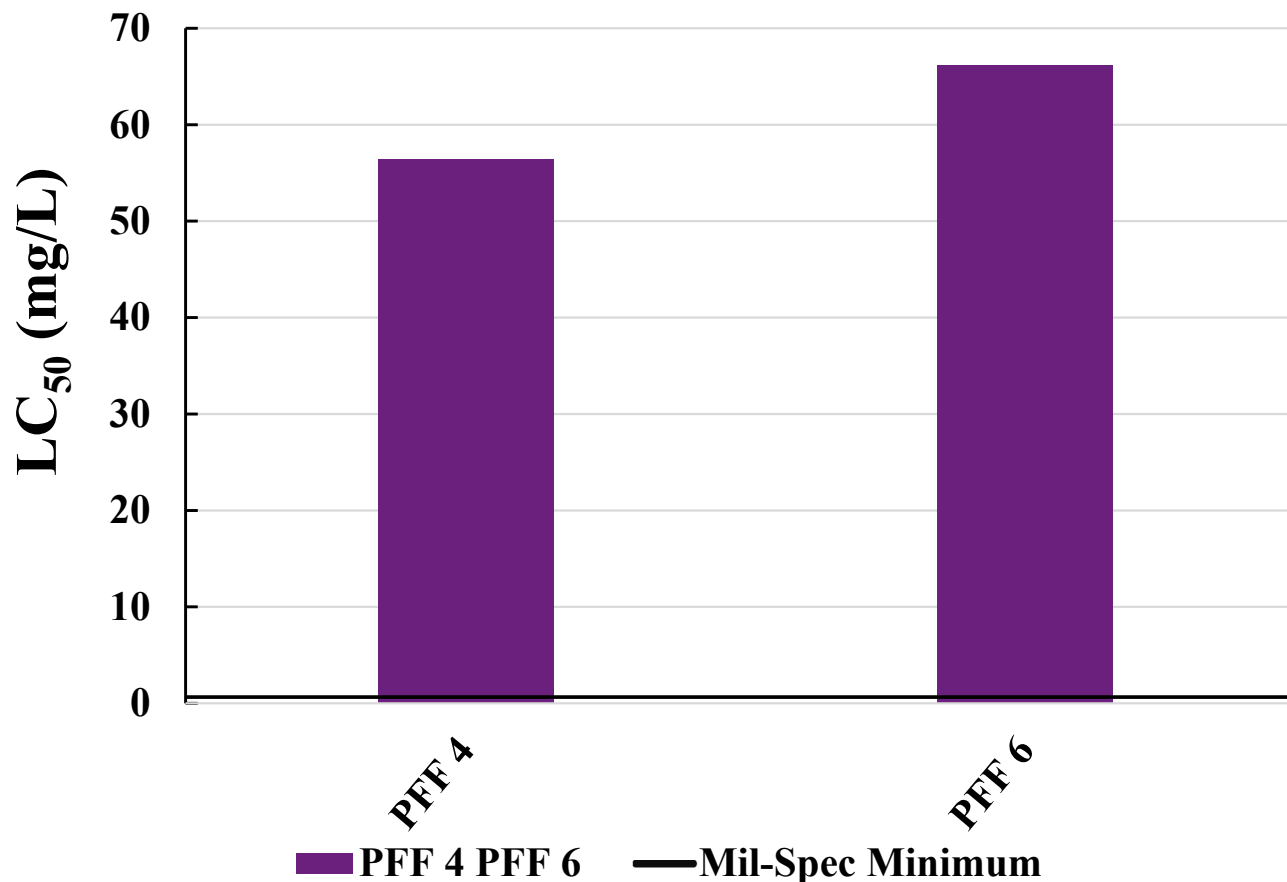


# 11 PFFs Selected for Mil-Spec Testing

Product	Vendor
1% Fluorine Free	Phos-Chek®
Solberg® 3% Re-Healing™	Solberg
Ecopol A3+	BioEx
Avio® Green KHC	National Foam
Prototype 11.2020 3%	BioEx
Fluorine Free Foam (GFFF)	Greenfire
FireBull F3 Fluorine Free	Enforcer®
FT Slam	Fire Terminator
Enviro ARF	Fomtec®
Solberg 3% Mil-Spec SFFF	Perimeter Solutions
3% SFFF Mil-Spec V20 Series	Perimeter Solutions

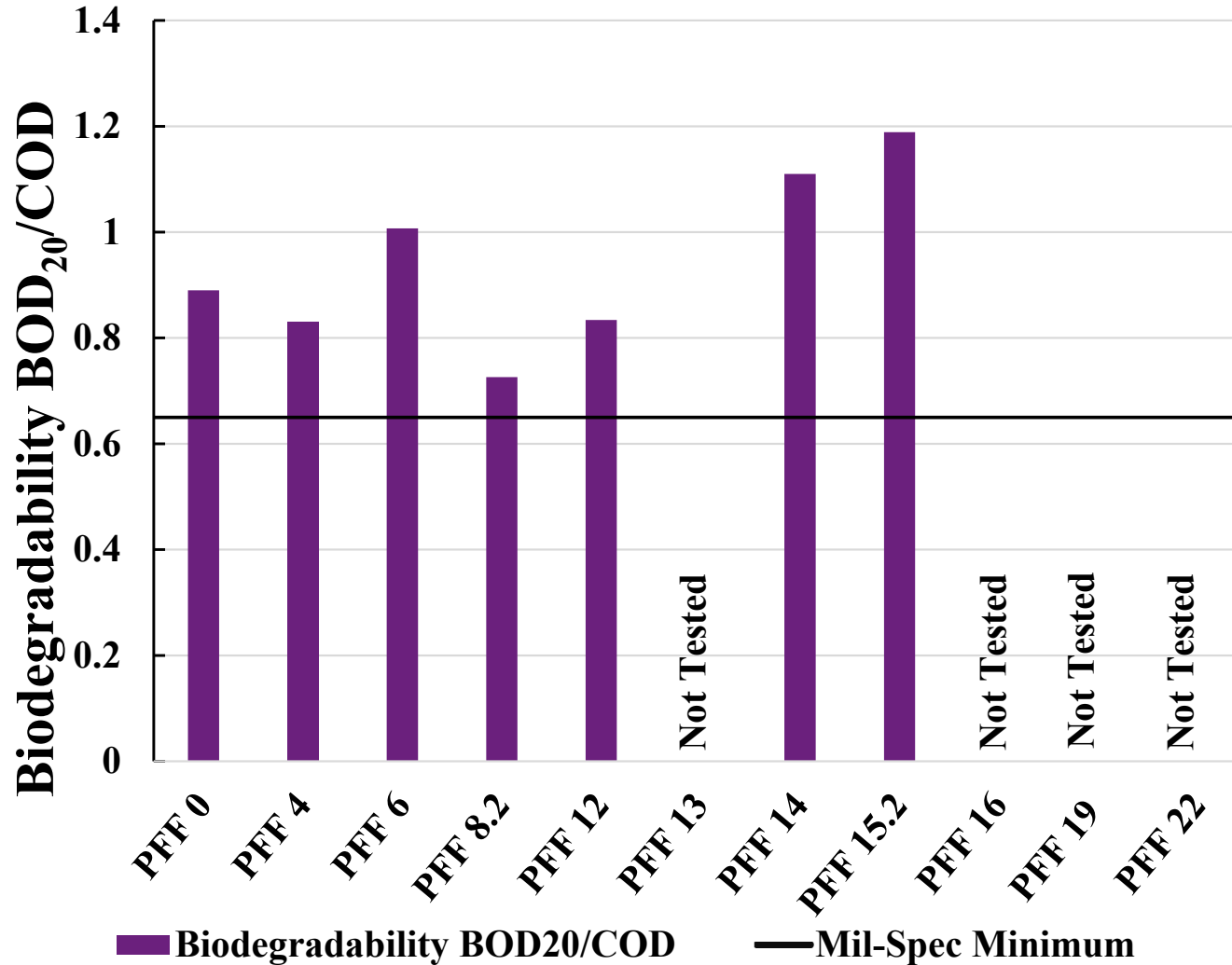
# Performance–Toxicity

- LC<sub>50</sub> data obtained for *fat minnows* as we were unable to find a lab doing *killifish*, as specified in Mil-Spec
- PFFs are typically “*slightly toxic*”



# Performance–Biodegradability

All PFFs are less biodegradable than specified in Mil-Spec



# Performance– Physical Properties

	MIL-SPEC value	PFF 0	PFF 4	PFF 6	PFF 8.2	PFF 12	PFF 13	PFF 14	PFF 15.2	PFF 16
<b>pH</b>	7–8.5	8.01	5.94	6.76	8.01	8.41	8.15	8.59	6.98	8.64
<b>Refractive Index (RI)</b>	1.363 (min)	1.367	1.386	1.386	1.362	1.383	1.366	1.357	1.361	1.367
<b>Spreading Coefficient (mN/m)</b>	3 (min)	6.947	-3.272	-5.133	0.547	-2.463	NP	-1.833	-3.173	NP
<b>Viscosity (cSt, 5°C )</b>	20 (max)	6.99 (k)	7.95	44,134	26.20	145.00	7.12	1,031	12,785	2.37
<b>Viscosity (cSt, 25°C )</b>	2 (min)	3.29 (k)	3.99	24,135	11.36	60.10	3.57	1,011	11,828	1.41

Green= Complies with MIL-SPEC; Yellow= within 10% variance of MIL-SPEC range; Red= Does not comply

- RI and pH have little to no impact on fire performance.
- Positive spreading coefficient corresponds to spontaneous film forming behavior.
- PFFs can either be Newtonian or non-Newtonian fluids

# Corrosion Performance of PFFs

Material Type	MIL-SPEC Max (mpy)	PFF 0	PFF 4	PFF 6	PFF 8.2	PFF 12	PFF 13	PFF 14	PFF 16
<b>G10100 Steel</b>	1.5	0.98	0.81	0.18	0.34	0.10	0.40	0.13	0.83
<b>C70600 Cu-Ni</b>	1	0.01	0.98	0.02	0.98	0.21	0.88	0.86	0.27
<b>N04400 Ni-Cu</b>	1	0.00	0.00	0.02	0.01	0.00	0.04	0.06	0.09
<b>C90500 Bronze</b>	100 mg mass loss	6.02	85.26	68.80	93.13	28.26	118.56	83.34	14.53

*Note: mpy = milli-inches per year*

# Performance–Foam Properties

- Foam expansion ratio (ER) Spec  $\geq 5$
- 25% foam-drainage time Spec  $\geq 150$  s

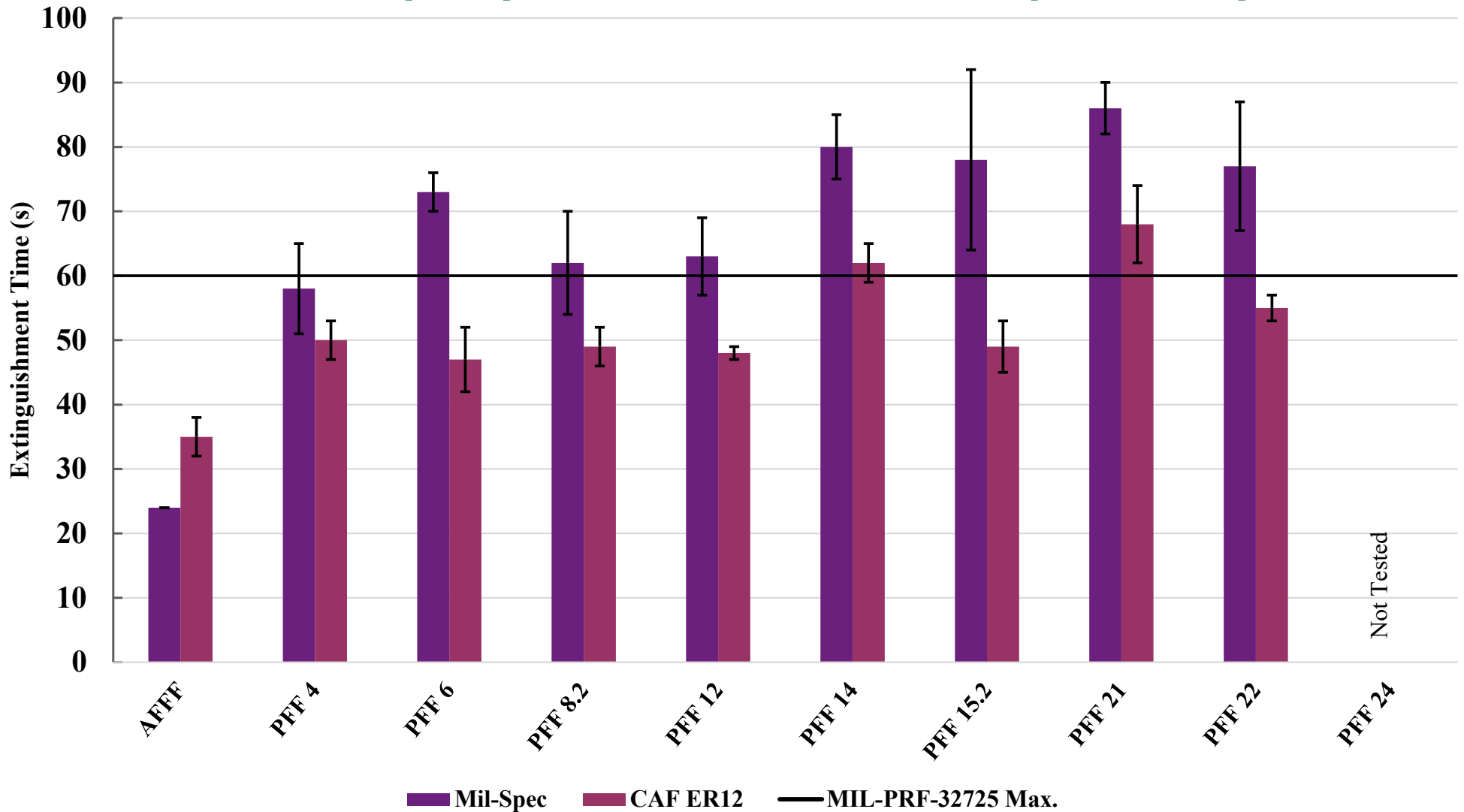
PFF Product	MIL-SPEC (ER=6-8)	CAF (ER=10)	CAF (ER=12)	CAF (ER=15)
<b>0</b>	295 (6.9)	NP	519	NP
<b>4</b>	345 (7.0)	NP	364	NP
<b>6</b>	2220 (7.1)	2208	2649	3360
<b>8.2</b>	502 (6.8)	419	620	292
<b>12</b>	247 (6.4)	330	386	NP
<b>14</b>	444 (7.0)	NP	643	NP
<b>15.2</b>	926 (7.0)	NP	1220	NP
<b>20</b>	890 (7.7)	NP	1570	NP
<b>21</b>	232 (6.6)	NP	853	NP
<b>24</b>	1044 (7.7)	NP	1401	NP

# Performance–Aged Foam Properties

- Foam expansion ratio (ER) Spec  $\geq 5$
- 25% foam-drainage time Spec  $\geq 150$  s

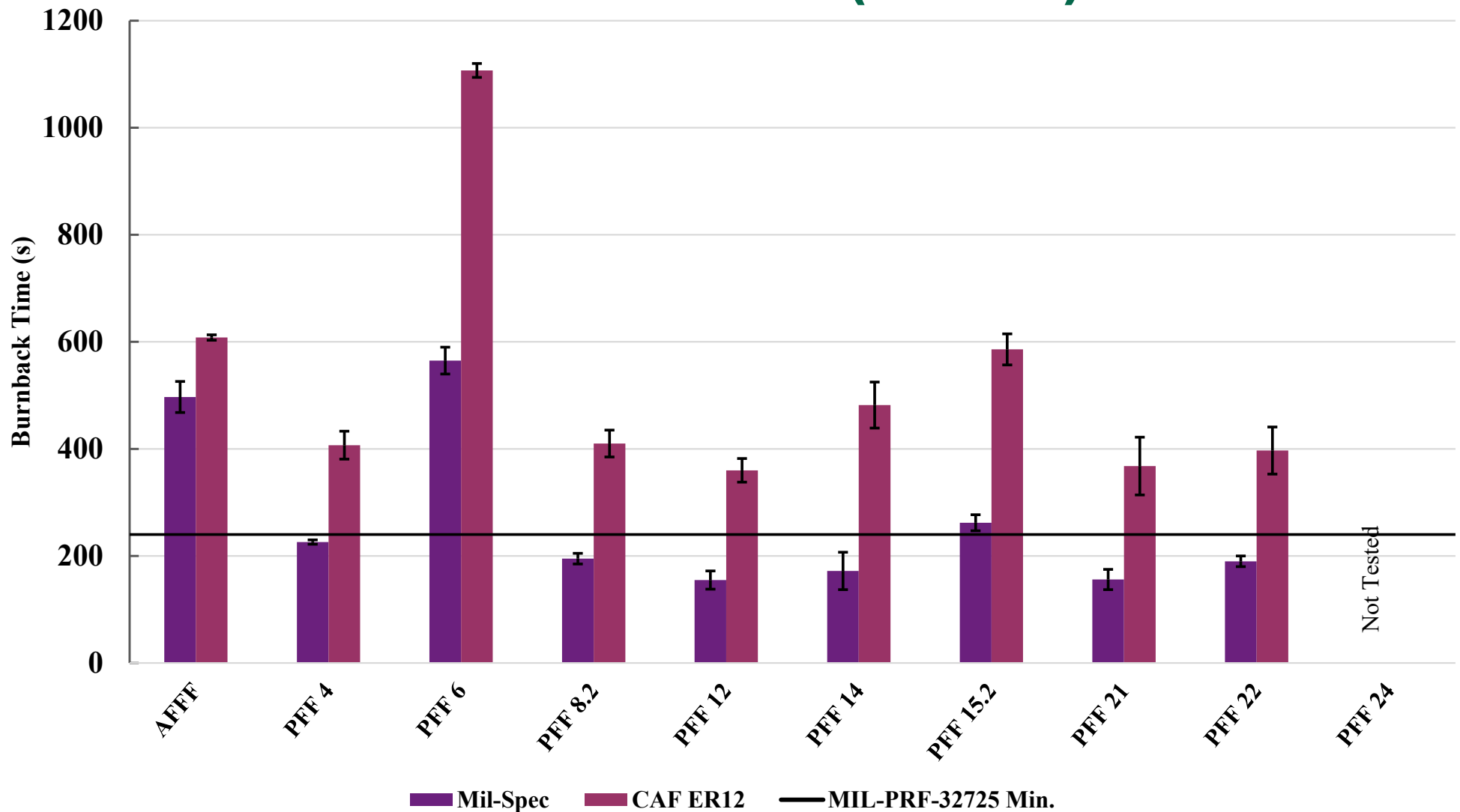
PFF Product	Aged Concentrate Mil-Spec (ER value)	Aged Solution Mil-Spec (ER value)
<b>0</b>	NP	NP
<b>4</b>	249 (6.6)	179 (6.4)
<b>6</b>	1253 (8.0)	1138 (7.9)
<b>8.2</b>	195 (6.7)	137 (6.7)
<b>12</b>	238 (7.1)	276 (7.0)
<b>14</b>	278 (7.3)	325 (7.5)
<b>15.2</b>	441 (7.4)	527 (6.1)

# Extinguishment Time for 28-ft<sup>2</sup> Ethanol-Free (E0) Fire with CAF (ER 12)



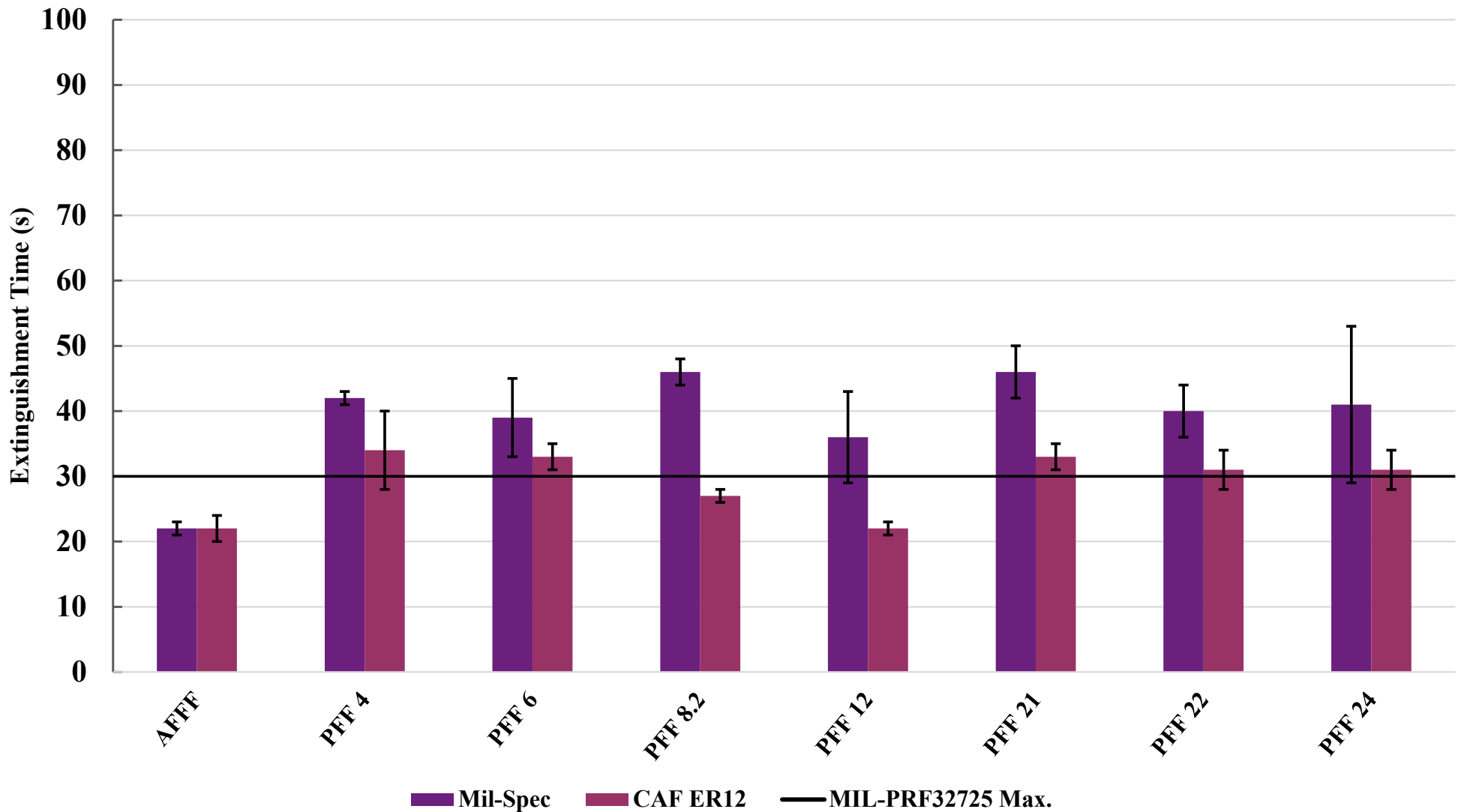
- Average reduction (improvement) of 25% in extinguishment time with CAF

# Burnback Time for 28-ft<sup>2</sup> Ethanol-Free (E0) Fire with CAF (ER 12)

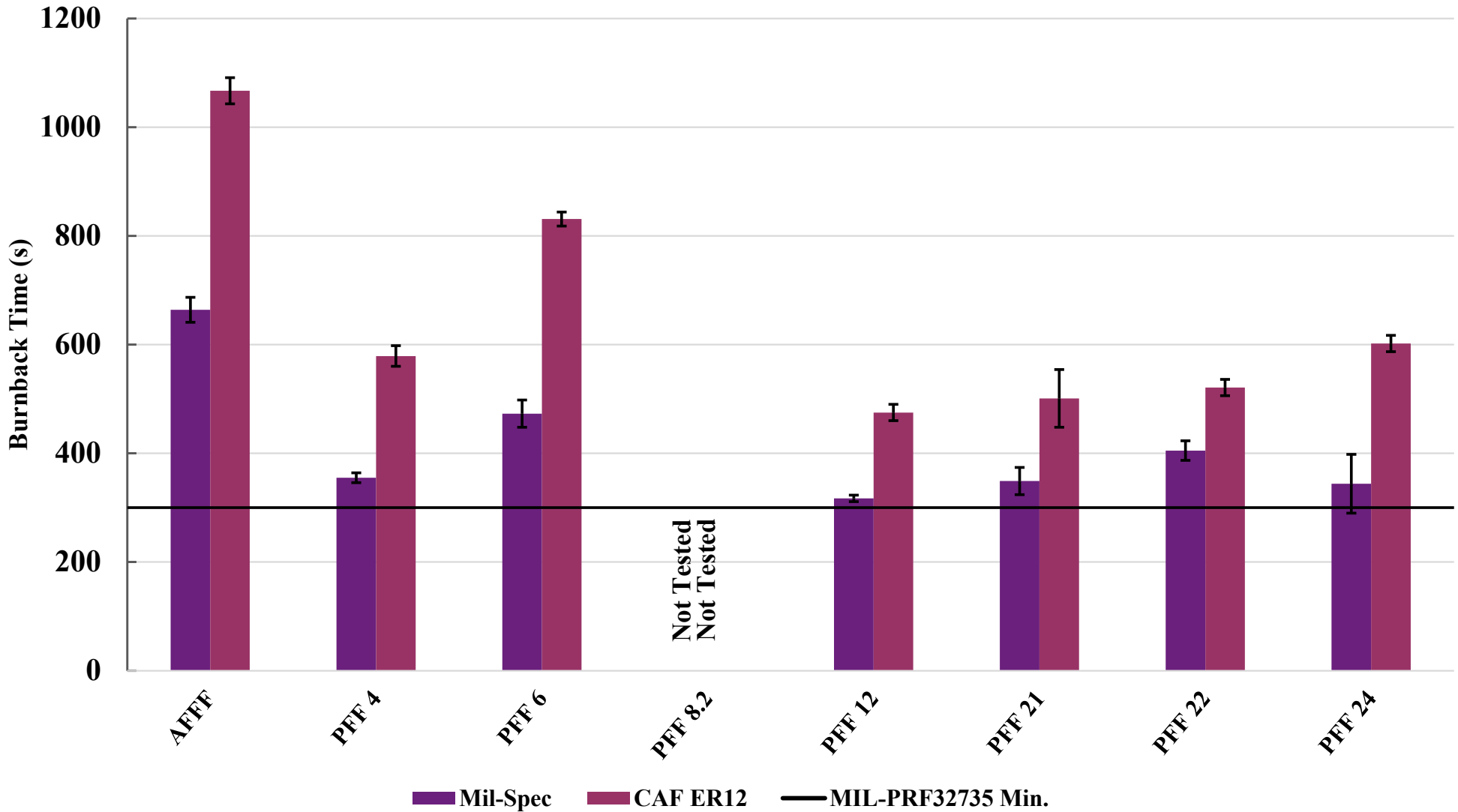


- Average increase (improvement) of 105% in burnback time with CAF

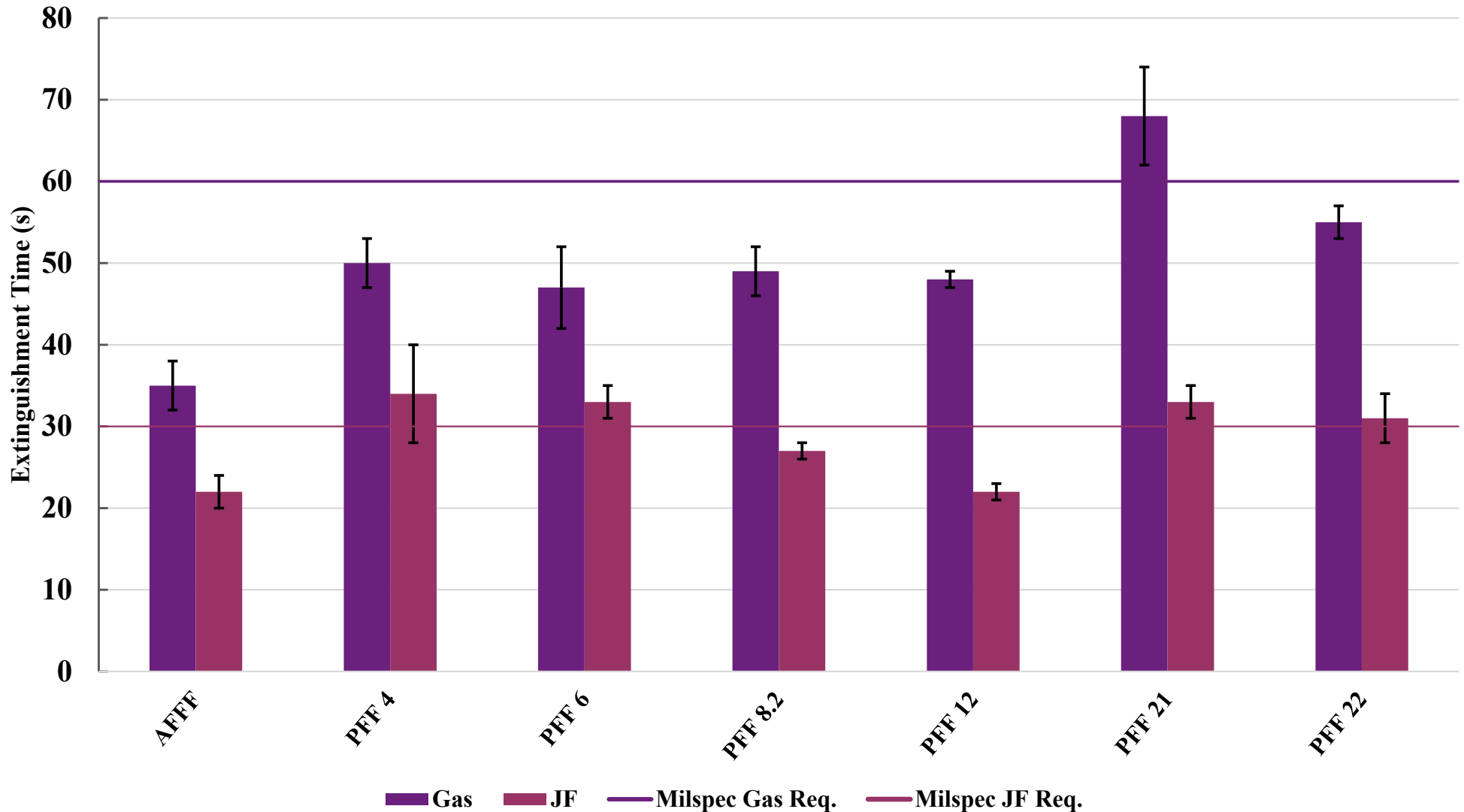
# Extinguishment Time for 28-ft<sup>2</sup> Jet-A Fire with CAF (ER 12)



# Burnback Time for 28-ft<sup>2</sup> Jet-A Fire with CAF (ER 12)



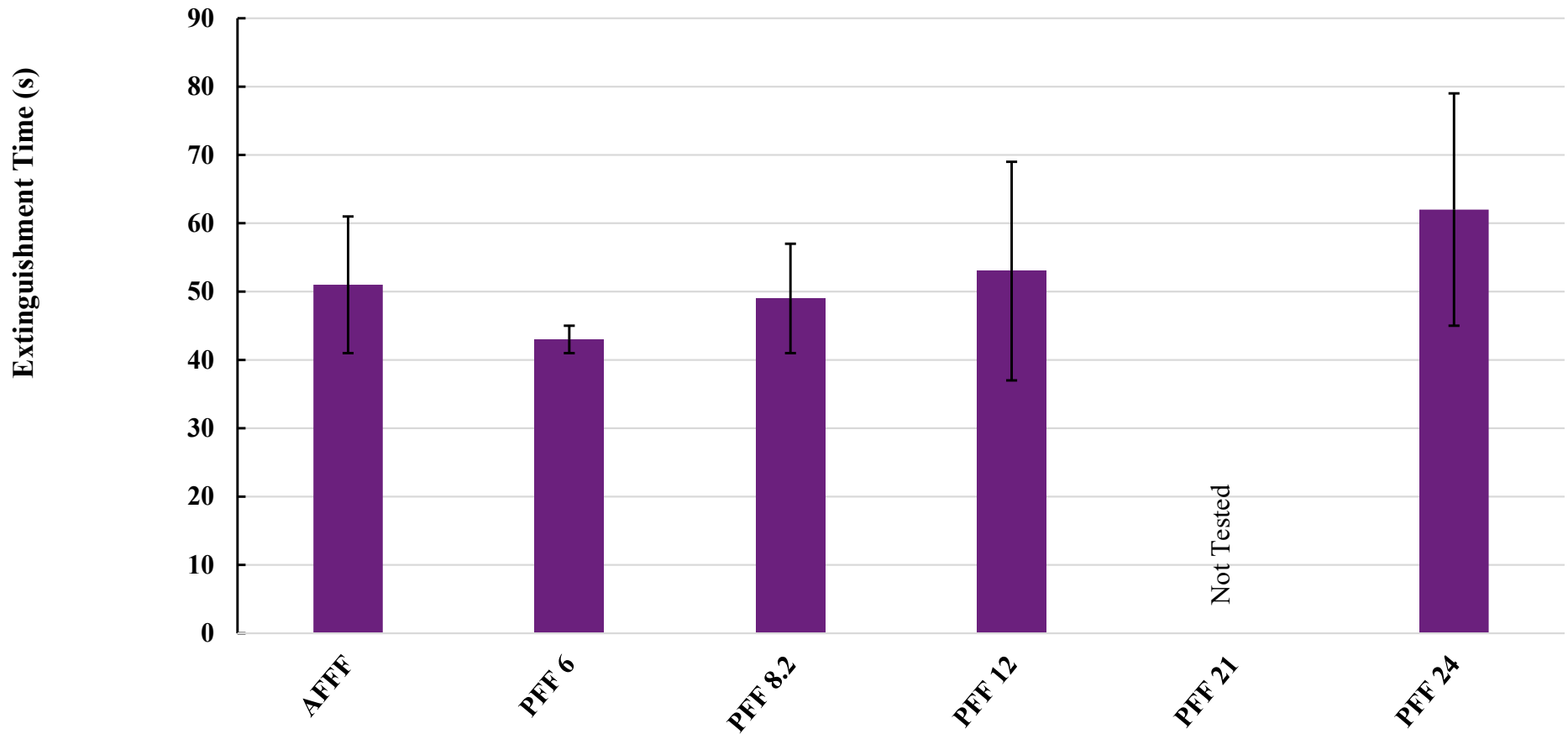
# Extinguishment Time for 28-ft<sup>2</sup> E0 vs. Jet-A Fires with CAF (ER 12)



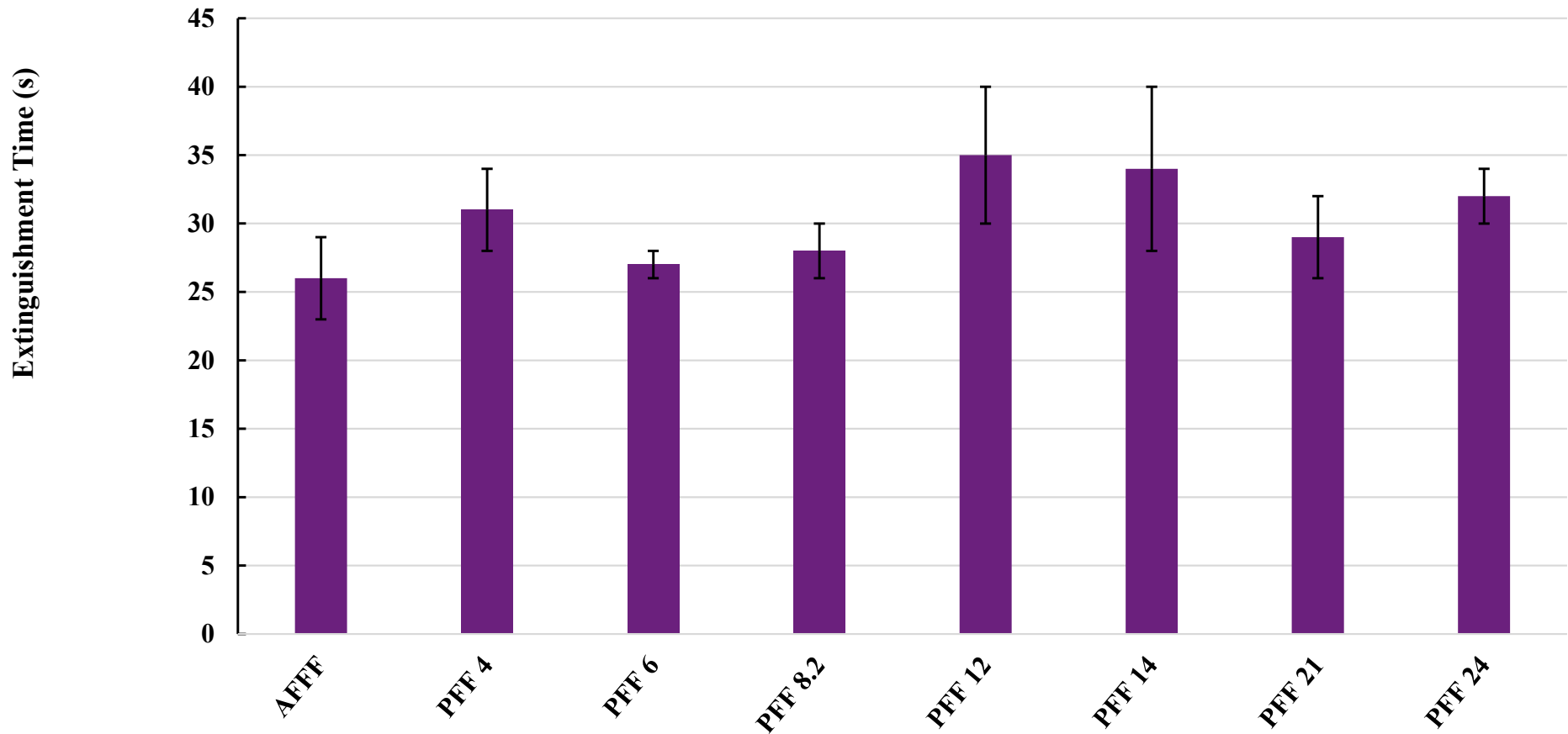
# Field-Scale Fire-Test Design

PFF Product	315-ft2 E0 Gas CAF @ ER 12	315-ft2 E0 Gas NonCAF	315-ft2 Jet-A CAF @ ER 12	315-ft2 Jet-A NonCAF	315-ft2 Jet-A UHP	6,504-ft2 Jet-A NonCAF	6,504-ft2 Jet-A CAF @ ER 12	6,504-ft2 Jet-A UHP
0	✓	✗	✓	✗	✓	✗	✗	✓
4	✗	✗	✓	✗	✓	✗	✗	✗
6	✓	✗	✓	✗	✓	✓	✓	✓
8.2	✓	✗	✓	✓	✓	✓	✓	✓
12	✓	✗	✓	✓	✓	✓	✓	✓
14	✓	✗	✓	✗	✗	✗	✗	✗
15.2	✓	✗	✓	✗	✗	✗	✗	✗
21	✗	✗	✓	✓	✗	✗	✗	✗
22	✗	✗	✗	✗	✗	✗	✗	✗
24	✓	✓	✓	✓	✗	✗	✗	✗

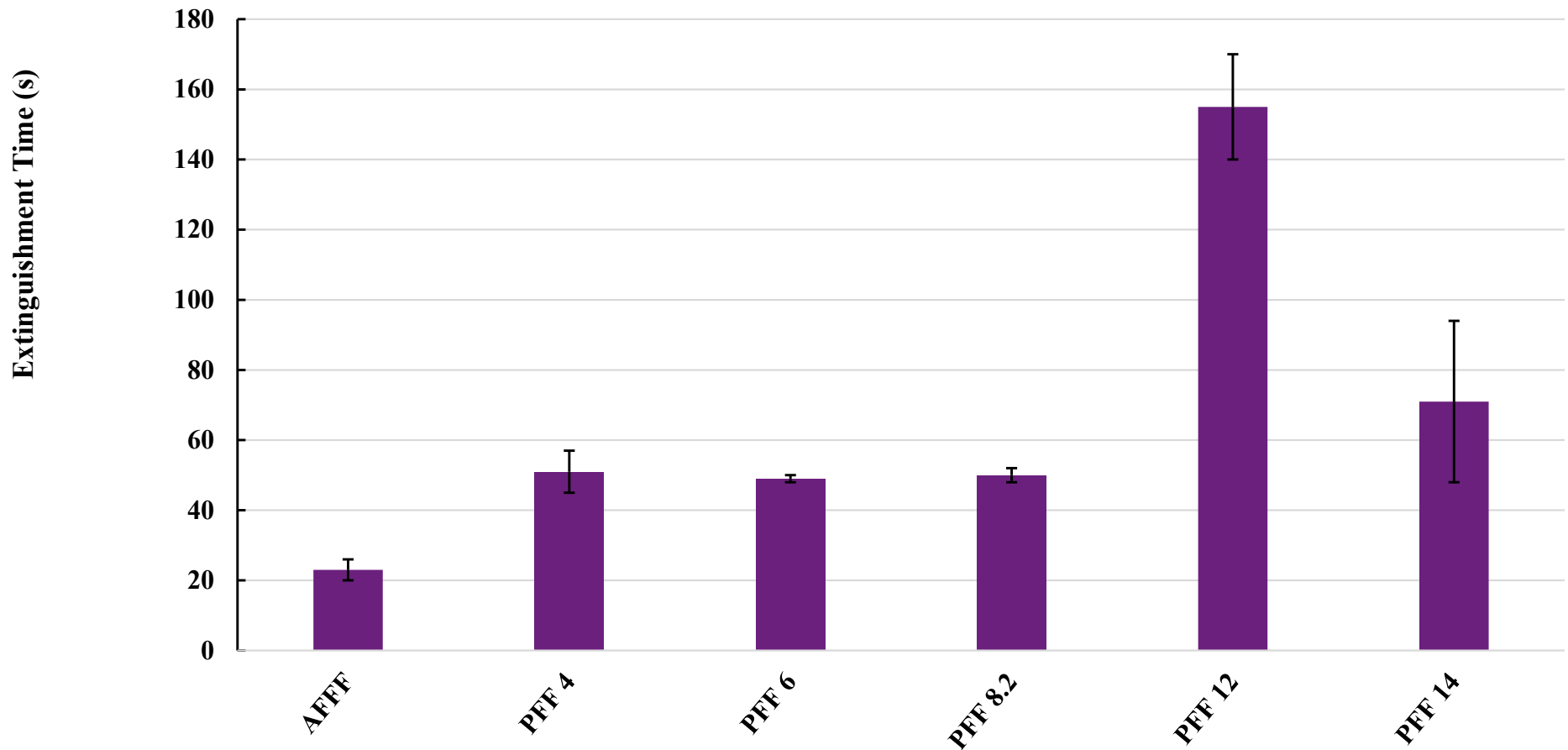
# Extinguishment Time for 315-ft<sup>2</sup> E0 Fires with CAF (ER 12)



# Extinguishment Time for 315-ft<sup>2</sup> Jet-A Fires with CAF (ER 12)



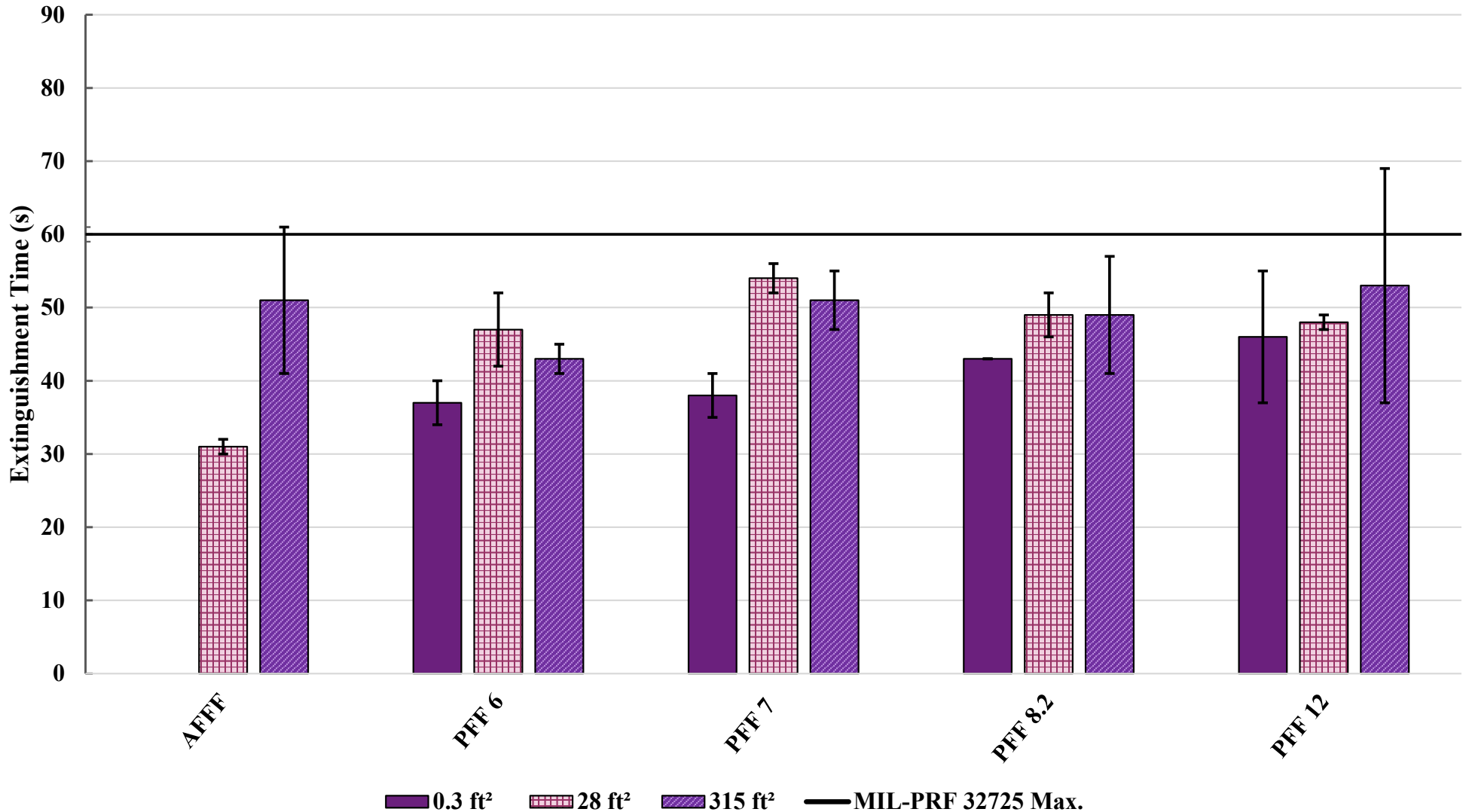
# Extinguishment Time for 315-ft<sup>2</sup> Jet-A Fire with UHP



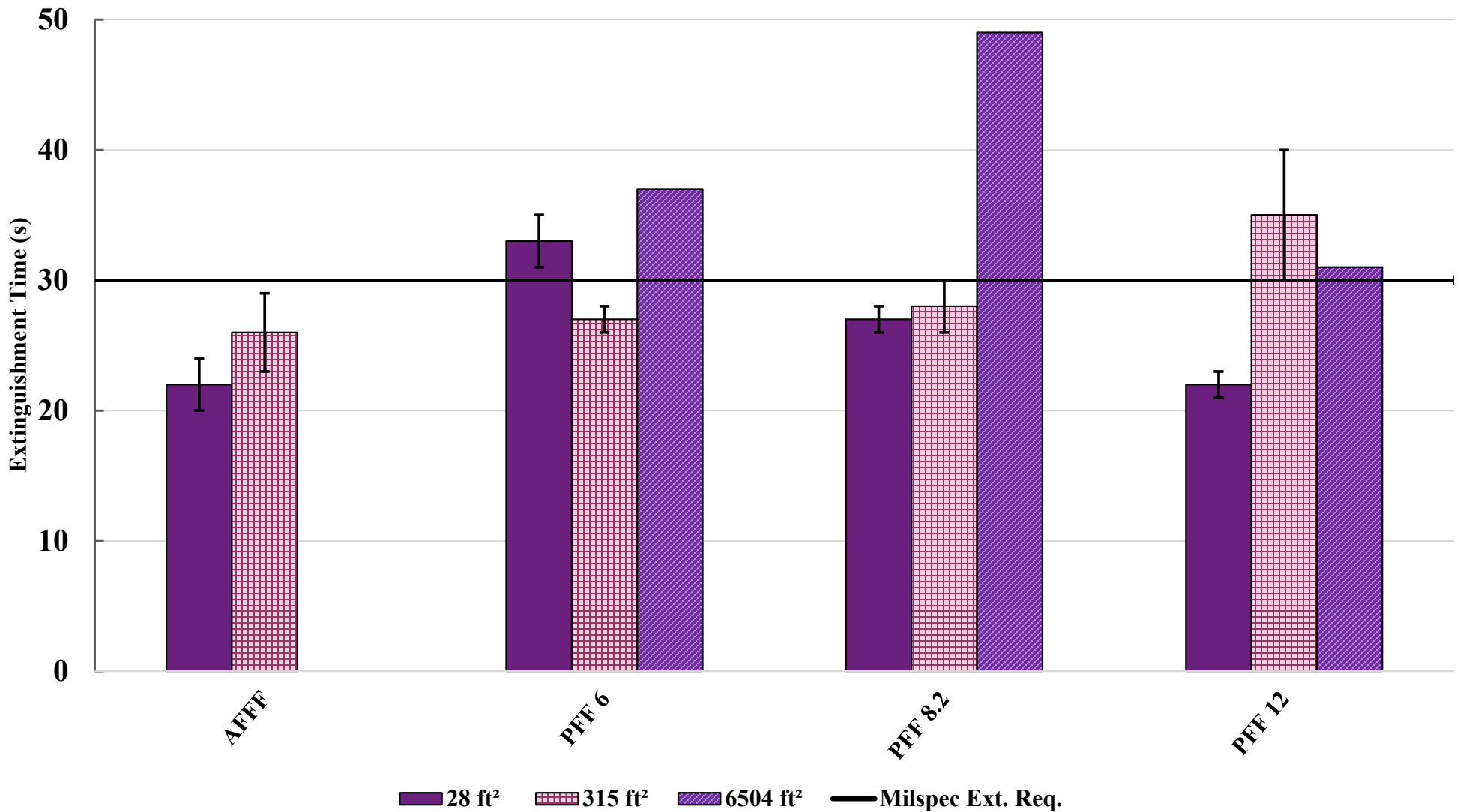
# Extinguishment Time for 6500-ft<sup>2</sup> Jet-A Fires with CAF (ER 12), UHP & NonCAF Technologies

Technology	AFFF		PFF 6		PFF 8.2		PFF 12	
	90% Control Time (s)	Ext. Time (s)	90% Control Time (s)	Ext. Time (s)	90% Control Time (s)	Ext. Time (s)	90% Control Time (s)	Ext. Time (s)
<b>UHP @ 0.046 gpm/ft<sup>2</sup></b>	25	40	58	74	47	65	44	58
<b>CAF @ 0.071 gpm/ft<sup>2</sup></b>	NP	NP	26	37	34	49	21	31
<b>nonCAF @ 0.071 gpm/ft<sup>2</sup></b>	NP	NP	32	44	64	72	25	37

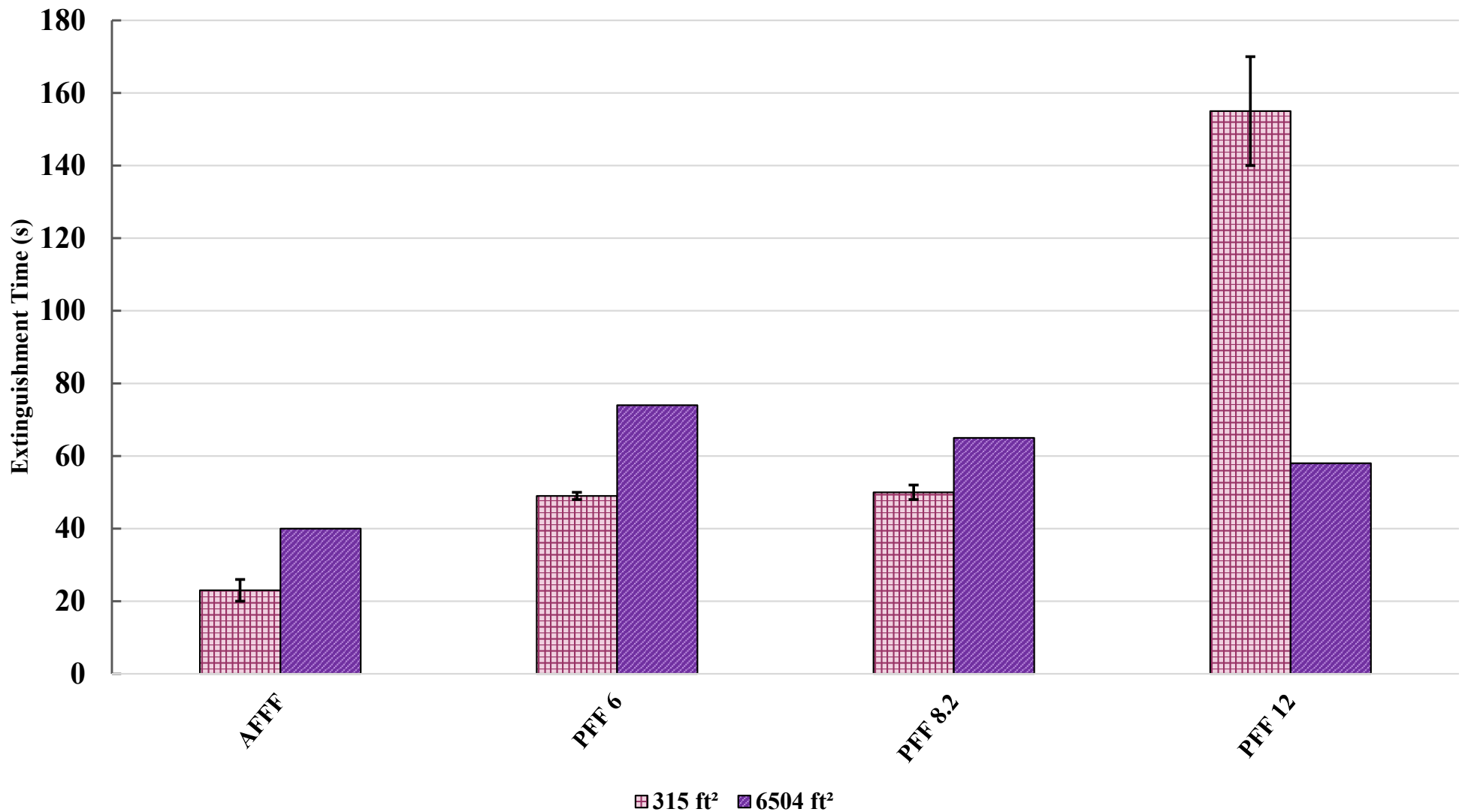
# Effect of E0 Fire Size on Performance of PFFs with CAF (ER 12)



# Effect of Jet-A Fire Size on Performance of PFFs with CAF (ER 12)



# Effect of Jet-A Fire Size on Performance of PFFs with UHP (6,504-ft<sup>2</sup> tests at 2/3<sup>rd</sup> application rate)



# Preliminary CAF Cost/Benefit Assessment

- Adoption of PFFs will remove toxicity, persistence, and bioaccumulation issues of legacy AFFF agents; reduces subsequent remediation at DoD and civilian facilities
- Baseline/Assumptions for Cost/Benefit Assessment (CBA)
  - ◆ 1.12 million gal/yr estimated PFF use across DoD (per LCA by Bruckner of Noblis)
  - ◆ Estimated PFF selling price (Fy24 basis): \$28/gal (based on 5-gal pails)
  - ◆ Wastewater volume is ~67X amount of PFF; treatment/disposal cost of \$2.68/gal (Noblis estimate) or \$0.60/gal (Battelle/AFCEC estimate based on actual plant data for 750 kgal/yr)
- CAF reduces fire extinguishment time by an estimated 30%
  - ◆ Reduces DoD's foam cost by 30%; potential savings of \$9.4M/yr
  - ◆ Reduces wastewater treatment/disposal cost by 30%; potential savings of \$60.4M/yr (based on estimates in Noblis LCA) to over \$13.5M/yr (Battelle/AFCEC; excludes cost of disposal of solids)
  - ◆ Total, DoD-wide, operational cost savings between \$23M/yr and \$70M/yr
- Estimated Capital Cost of CAF Retrofit/Implementation
  - ◆ Few Military bases (of the ~2,000 ARFF trucks across DoD) already have CAF
  - ◆ Retrofitting current fire trucks is possible at \$50,000 (adding compressed-air bottles) to \$100,000 (for adding a compressor) each; \$100M to \$200M capital estimated for retrofitting current non-CAF
- Simple Payback Analysis
  - ◆ 1.4 yrs (air bottles) to 2.8 yrs (compressor) payback period (based on Noblis/NAVFAC wwt cost est)
  - ◆ 4.3 yrs to 8.7 yrs years payback period (based on more conservative Battelle/AFCEC wwt cost est)

# CAF Scale-up/Implementation

- Scale-up of CAF for PFF
  - ◆ The data from this project and companion WP20-5335 project provides CAF performance data for 20+ PFFs at Mil-Spec scale (28-ft<sup>2</sup> fire; 2 gpm flow rate) for gasoline and Jet-A
  - ◆ The data from this project confirms PFF performance at field scale (6,504-ft<sup>2</sup> fire; 450 gpm flow rate) for jet fuel; lower application rates are planned for future testing
  - ◆ One remaining need is to demonstrate CAF with gasoline at field scale (962-ft<sup>2</sup> fire; 70 gpm flow rate); this work is underway
- CAF Implementation
  - ◆ The CAF equipment itself has been scaled-up to field scale; several units are available across DoD, especially USAF
  - ◆ For DoD-wide CAF use, the non-CAF ARFF trucks can be retrofitted with CAF capability; suggest a pilot retrofit effort to compare two retrofit options: (a) add compressed-air bottles; (b) add a compressor

# UHP Scale-up/Implementation

- Scale-up of UHP
  - ◆ The data from this project provides UHP performance data for 5 PFFs at 315-ft<sup>2</sup> scale (20 gpm foam application rate) for Jet-A fires; this size is the minimum required to demonstrate the potential of UHP technology
  - ◆ This project has demonstrated the UHP technology at 6,504-ft<sup>2</sup> for 3 of the down-selected PFFs, with excellent performance at 2/3rd the foam application rate compared to Mil-Spec rate
  - ◆ Based on previous data on AFFF, even lower application rates than the 0.046 gpm/ft<sup>2</sup> should be possible; on the other hand, the critical application rate for PFFs with conventional nozzles is 0.071 gpm/ft<sup>2</sup>
  - ◆ A 2-step UHP nozzle needs to be tested to improve the burnback time; proposed to ESTCP
- UHP Implementation
  - ◆ The modern ARFF trucks are already suitable for UHP nozzles, so just need to demonstrate effectiveness of UHP with all qualified PFFs

## Next Steps

- Pilot retrofit of an ARFF truck with CAF to validate retrofit cost for the two retrofit options
- Field-scale testing of CAF with gasoline at 962-ft<sup>2</sup> fire size (70 gpm application rate)
- Further exploration of best way to utilize UHP benefits, including demonstration of an alternative (2-stage) nozzle to help improve the burnback time
- Need a more comprehensive examination of the following (propose to SERDP)
  - Compatibility among leading PFF candidates
  - Shelf-life
  - Performance at extreme temperatures

# Technology Transition Underway

- Under the ESTCP WP15-5335 project, prepared a PFF Qualification Guidance Document, with input from stakeholders, that covers
  - ◆ Overview of PFFs and foam-delivery technologies
  - ◆ Performance data to guide PFF developers and firefighting equipment users
  - ◆ Proposed test and training protocols
  - ◆ Lessons learned from ESTCP testing
  - ◆ Guidance in training firefighters to use the new technology and techniques
  - ◆ Lifecycle and cost analysis
- Conducted two Workshops at AFCEC/Tyndall AFB to demonstrate recommended practices for PFF with aspirating nozzle, CAF, and UHP
  - ◆ Attended by tri-services, FAA, and selected foam manufacturers
- Expected First DoD Users
  - ◆ The Fire Chief of the Air Force
  - ◆ Naval Sea Systems Command (holder of MIL-PRF-32725)
  - ◆ USARMY IMCOM EUROPE

# Technology Transition (continued)

- Involvement of USEPA, FL Dept of Environmental Protection, and FAA to insure the technologies meet regulatory guidance
- Worked with various PFF manufacturers to help improve the performance of their products by providing performance data on multiple iterations of formulations
- Communicating Technology Facts
  - ◆ One-page fact sheet
  - ◆ MP3 with key takeaways from the project with an accompanying graphic
  - ◆ MP4 video detailing key points and the applications of the technologies
- Battelle/AFCEC presented to the wider scientific community
  - ◆ 3 SERDP/ESTCP annual symposiums
  - ◆ Aircraft Rescue and Firefighting (ARFF) Working Group conference
  - ◆ 1 SERDP/ESTCP Webinar

# Key Points

- No PFFs tested so far meet **all** of the MIL-PRF-24385F
  - ◆ All fail the fire extinguishment time requirements and most fail burnback time requirements; at least 2 PFFs are likely to pass the newer, MIL-PRF-32725
  - ◆ Aquatic, acute toxicity is an order of magnitude higher, but are within limits of the newer Spec; all are “slightly toxic”
  - ◆ Viscosity of some products is high even under the newer Spec
  - ◆ Some products pass corrosion and biodegradability specs
- CAF improves firefighting performance
  - ◆ Extinguishment times reduced by an average of 25% for PFFs tested in this project
  - ◆ Burnback times increased by an average of 105%, making most PFFs meet the Mil-Spec
- The 6 PFFs down-selected for field-scale testing successfully extinguished fires with CAF, UHP and NonCAF foam delivery, at 315-ft<sup>2</sup> and 6,504-ft<sup>2</sup>
- No significant change in ext time for CAF over 4 order of mag fire scale
- UHP testing at 6,504-ft<sup>2</sup> scale was very effective in ext of Jet-A fires, even at 2/3<sup>rd</sup> the delivery rate required for Mil-Spec nozzle
- CAF provides an attractive payback period over standard AARF trucks.

# Acknowledgements

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- Keith Bagot; FAA

# BACKUP SLIDES

# Acronyms and Symbols

- AFB Air Force Base
- AFCEC Air Force Civil Engineer Center
- BOD Biological oxygen demand
- CAF Compressed Air Foam
- COD Chemical oxygen demand
- Dem/Val Demonstration and Validation
- cST Centistokes
- EPA U.S. Environmental Protection Agency
- ER Expansion Ratio
- Ext Extinguishment
- FF\_FSA Fluorine Free Fire Suppression Alternatives
- MIL-PRF Military Performance Specification
- MIL-SPEC Military Specification
- NP Not Planned
- UHP Ultra-high Pressure

# Publications

- SERDP/ESTCP Webinar #120: Assessment of Commercially Available PFAS-Free Foams”; Oct 8, 2020.
- 2020 SERDP Annual Symposium Paper: “Progress in Enhancing Mil-Spec Performance of Mature PFAS-Free Foams”; Dec1, 2020
- AFCEC/CXAE 2<sup>nd</sup> Annual Fire protection Workshop: “Performance of Next Generation of Firefighting Agents against Military Specification Criteria”; Nov 17, 2021
- 2021 SERDP Annual Symposium Paper: “Demonstration of Selective Approaches for Enhancing Performance of PFAS-Free Foams”; Dec 1, 2021
- 2022 SERDP Annual Symposium Paper: “Demonstration of CAF and UHP with PFAS-Free Foams”; Nov 30, 2022.

# WP20-5335 Validation of Fluorine-Free Fire Suppression (FF\_FSA) Alternatives Against Military Specification

Performers: Battelle and AFCEC/Tyndall AFB

## Technology Focus

- Enhancing fire performance of mature FF\_FSA (aka PFAS-Free Foam; PFF) using compressed air foam (CAF), ultra high pressure (UHP) and COTS additives

## Demonstration Site

- Tyndall AFB, FL

## Demonstration Objectives

- Enhance fire performance to meet MIL-SPEC requirements for fire extinguishment time and burnback time

## Project Progress and Results

- Completed physical property testing; explored COTS additives; completed CAF, NonCAF, and UHP fire performance testing at Mil-Spec-scale as well as field-scale (315-ft<sup>2</sup> and 6,504-ft<sup>2</sup>)

## Implementation Outlook

- CAF consistently improves the fire performance; UHP significantly reduces the critical foam application rate but the burnback performance needs to be improved; finding suitable functional additives may enhance overall foam properties but requires more developmental research (ongoing under a SERDP program)



# Four Scales of Fire Testing

Fire Size	Standard Foam	CAF and UHP Foam
0.3-ft <sup>2</sup> (1-ft. diameter)	<ul style="list-style-type: none"> <li>N/A</li> </ul>	<ul style="list-style-type: none"> <li>80 mL/min flow rate</li> <li>~50 mL concentrate per test series (3 mL per fire)</li> <li>Mini-CAF system, No UHP</li> </ul>
28-ft <sup>2</sup> (6-ft. diameter)	<ul style="list-style-type: none"> <li>2 gpm flow rate</li> <li>0.071 gpm/ft<sup>2</sup> application rate</li> <li>~0.5 gal concentrate (3 fires)</li> <li>CAF/Mil-Spec prototype skid</li> </ul>	<ul style="list-style-type: none"> <li>2 gpm flow rate</li> <li>0.071 gpm/ft<sup>2</sup> application rate</li> <li>~0.5 gal concentrate (3 fires)</li> <li>UHP prototype trailer</li> </ul>
315-ft <sup>2</sup> (20-ft. diameter)	<ul style="list-style-type: none"> <li>20 gpm flow rate</li> <li>0.071 gpm/ft<sup>2</sup> application rate</li> <li>~2.5 gal concentrate (2 fires)</li> <li>Dual-agent CAF skid</li> </ul>	<ul style="list-style-type: none"> <li>20 gpm flow rate</li> <li>0.071 gpm/ft<sup>2</sup> application rate</li> <li>~10 gal concentrate (3 fires ea)</li> <li>P-34 UHP handline</li> </ul>
6,504-ft <sup>2</sup> (91-ft. diameter)	<ul style="list-style-type: none"> <li>455 gpm flow rate</li> <li>0.071 gpm/ft<sup>2</sup> application rate</li> <li>~55 gal concentrate (1 fire)</li> <li>Research Truck Bumper Turret</li> </ul>	<ul style="list-style-type: none"> <li>455 gpm CAF (0.071 gpm/ft<sup>2</sup>)</li> <li>300 gpm UHP (0.05 gpm/ft<sup>2</sup>)</li> <li>~110 gal concentrate (1 fire ea)</li> <li>Rosebauer CAF</li> <li>P19 Bumper Turret (UHP)</li> </ul>