PERFORMANCE CHALLENGES OF FLUORO FREE FOAMS

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3M and fire fighting foams

Forty years ago, seminars were being held to discuss new 3M fluorosurfactant technology and the newly derived AFFF fire fighting foams.

3M™ LIGHT WATER™ AFFF

- 1960's developed from fluorochemical surfactants, joint research with 3M and US Naval Research Laboratories-- Aqueous Film Forming Foam (AFFF)
- Low surface tension of FC allowed water to float on liquid fuel--film formation
- Fast fire knock down, fast extinguishment

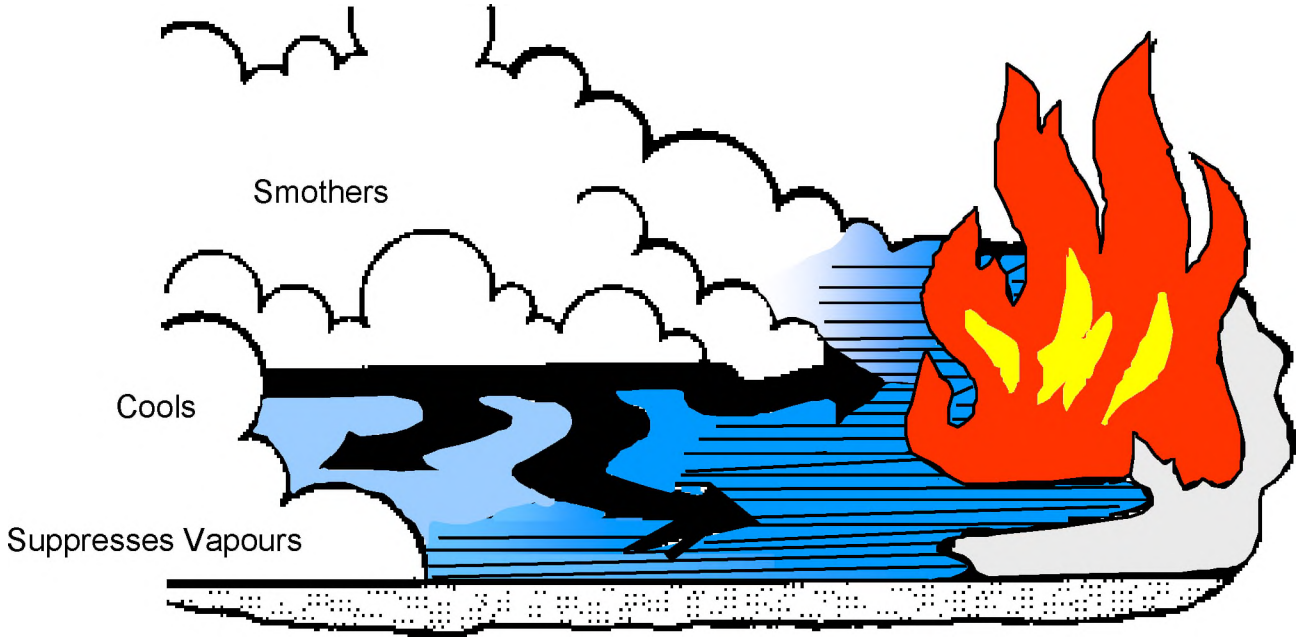
3M Direction by 2000

- Discontinue PFOS based AFFF products through 2003

Types of Foams (Mechanical Foam Generation)

- **Protein based**
  - Protein Foam
  - Fluoro Protein Foam
  - FFFP
  - FFFP/AR
- **Synthetic based**
  - Class A wildland
  - High Expansion
  - Medium Expansion
  - AFFF
  - AFFF/AR
  - Training Foam

How Foams Work



Various Foams can work by:

- **Excluding oxygen, smothering flames**
- **Cool surfaces with water from foam**
- **Prevent release of vapours from fuel surface**

Class B Foams

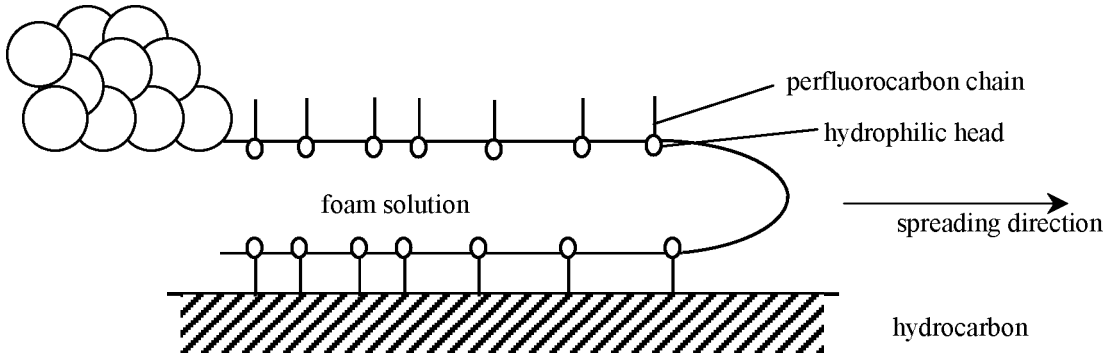
- **Protein Based**
  - Thick foam
  - Slower moving
  - High yield stress
    - Poor foam re-flow
  - Mono dispersed bubble size
- **Synthetic based (AFFF)**
  - Thinner foam
  - Fast moving
  - Low yield stress
    - Good foam re-flow
  - Poly dispersed bubble size

Benefits of AFFF

- Rapid fire knockdown
- Spill and tank fires
- Long shelf life
- Secure spills
- Dry Chem compatible
- Use conventional nozzles
- Self-healing

Benefit of Fluorosurfactants

- Low surface tension ~ 16 mN/m
- Formation of aqueous film from bubble drainage
- Spreads rapidly on fuel - initial spreading coefficient
- High temperature resistance to flame front



A new category of fire fighting foams is emerging.

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  - AFFF
  - AFFF/AR
  - Training Foam
  - Fluoro Free Foams (new)

Foams without Fluorosurfactants

What challenges would need to be overcome?

Fluoro-Free Foams

- Existing foams that are fluorosurfactant free have limited effectiveness on Class B fuels
- Class B foam companies now doing research for effective non-FC foams
- Need to achieve drop in capability

Fluorine Free Foams

- Fluorine Free Foam implies no fluorine, in either organic or inorganic form
- 3M™ RF3 fluorine content measured
  - 0.00 % by 3M Australia Lab (NATA)
    - Compared against distilled water blank
  - <0.02 % by LASTFIRE Report 2003
    - Assuming this is the limit of test method

Key foam characteristics

- no longer have aqueous film technology
- long drain time, to keep foam on fuel
- good heat resistance
- free flowing like AFFF
- self repairing of punctures
- re-healing for burn back resistance

No fluorosurfactants,

No aqueous film formation.

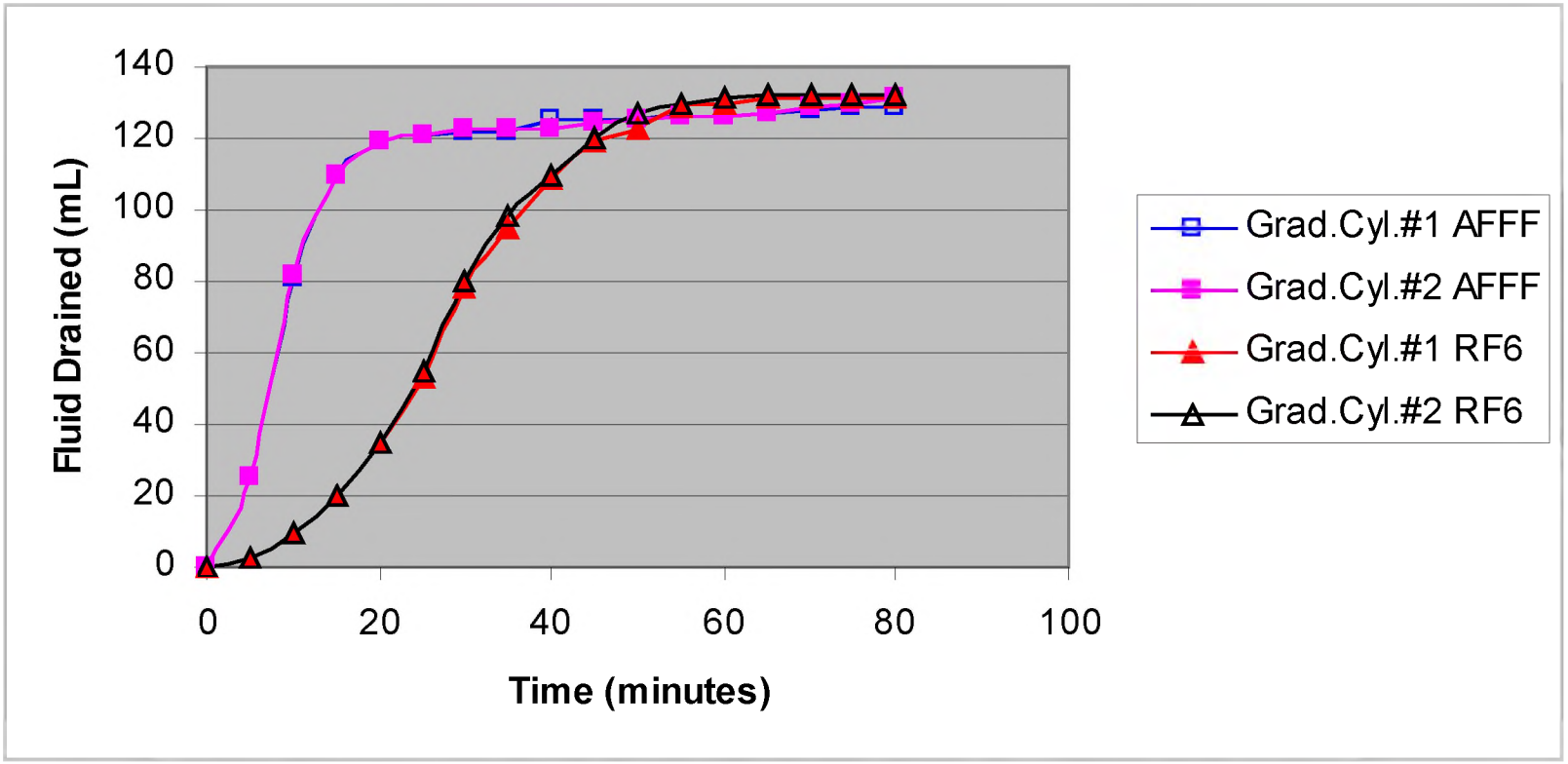
No aqueous film? How can it work?

- Bubble structure must compensate
  - Foam is a series of aqueous films separated by air
- Longer drain time foam
- Should have good heat resistance
  - Achieve burn back resistance like AFFF/FFFP

NFPA 412
Foam Expansion & Drainage

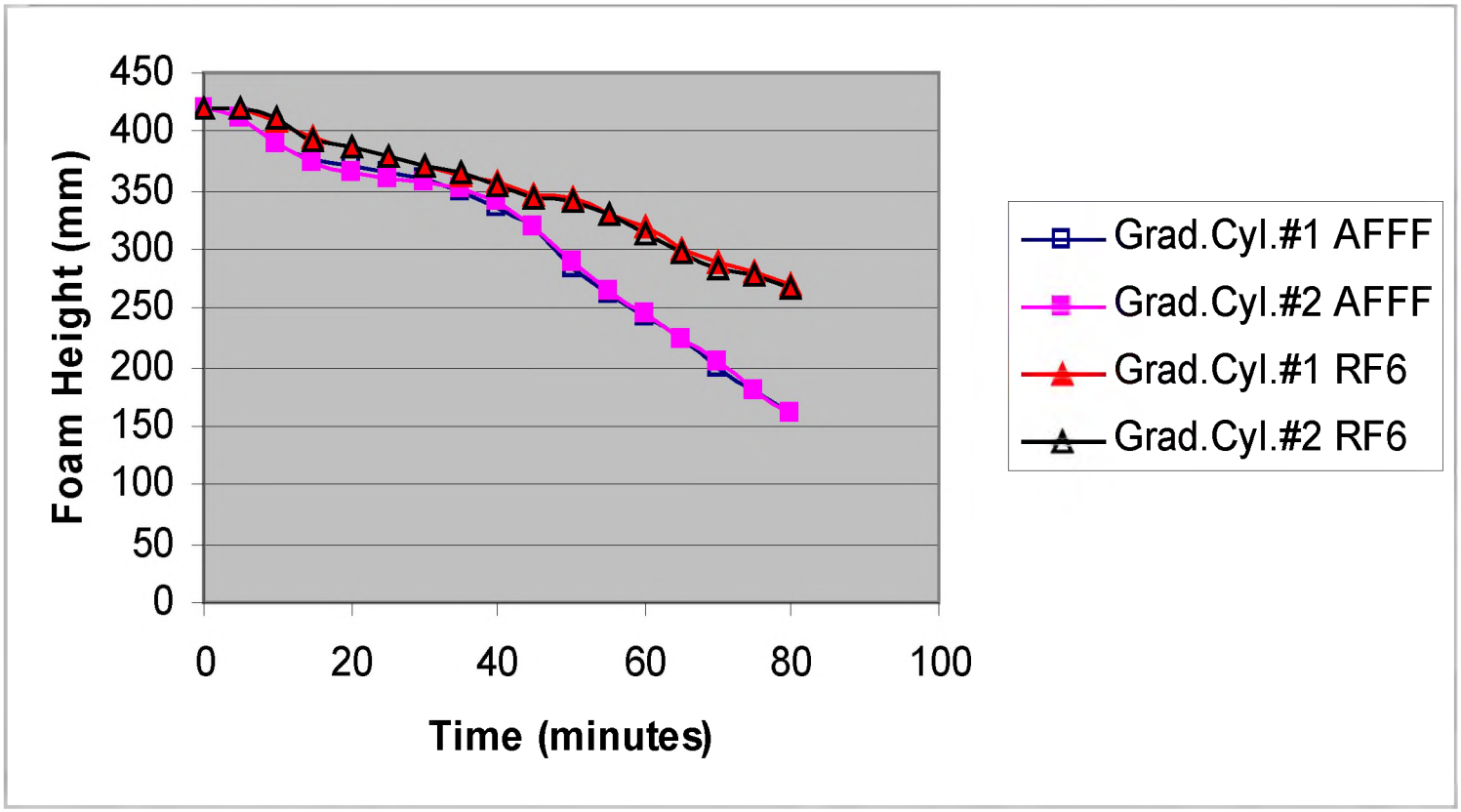
	Foam Expansion Ratio	25% Drain Time
3M™ AFFF	**9:1**	**6:20**
3M™ RF6 (Fluoro Free)	**9:1**	**14:20**

Foam Drainage



Note the slower fluid drainage for RF6

Foam Height

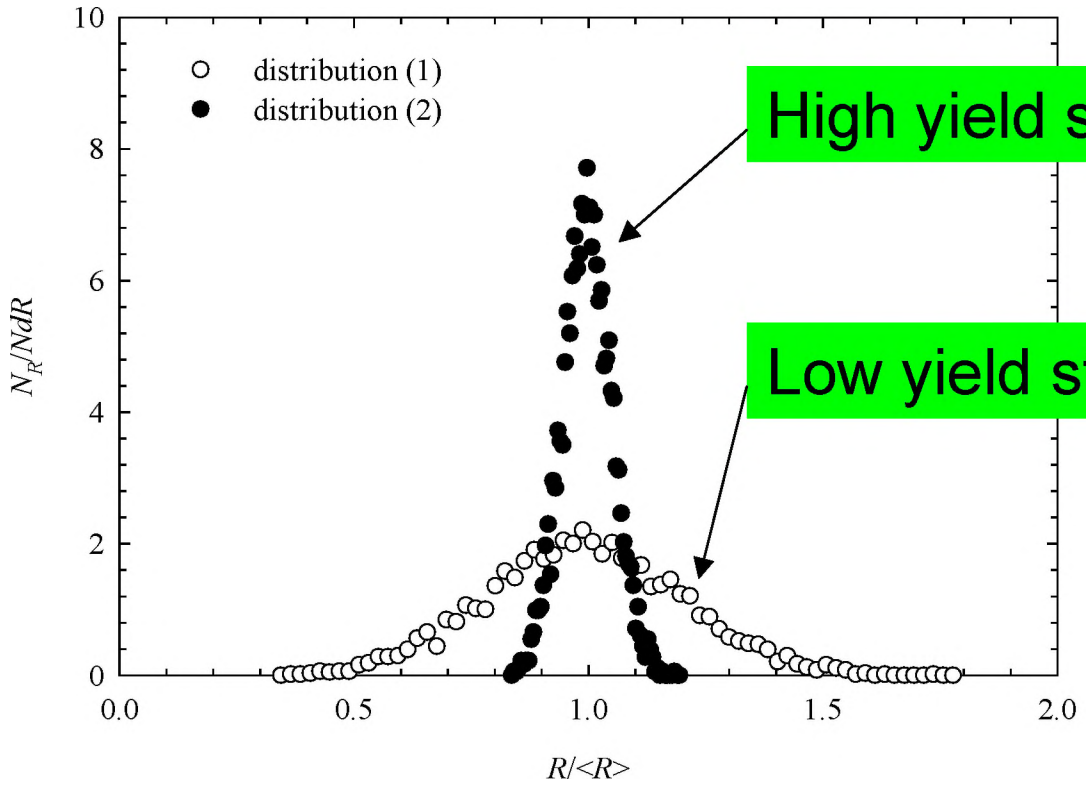


Note the more linear relationship for RF6

Free Flowing Foam

- A result of being a low yield stress foam
  - Compromise foam rigidity for flow
- Achieved through a foam structure with poly-dispersed bubble sizes
  - Many sizes of bubbles promote foam flow
- Allows foam movement for self repair
- Achieve extinguishment times like AFFF

Bubble Size Dispersion



High yield stress foam

Low yield stress foam

Gardiner et al (2000)

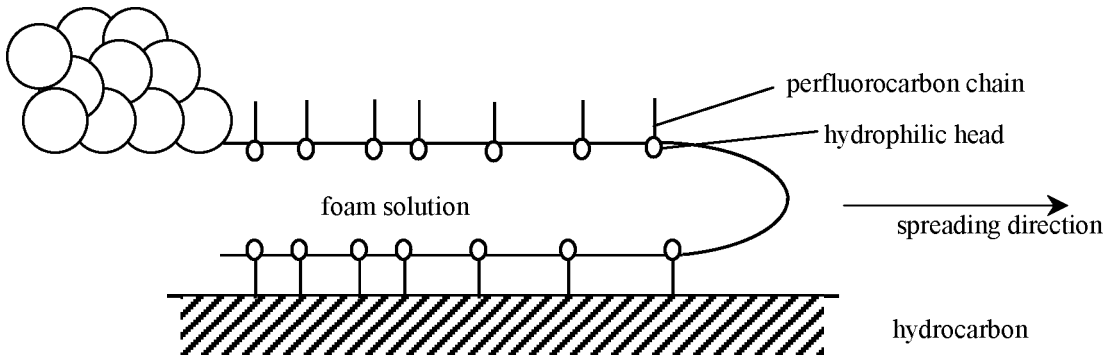
Low Yield Stress Foam Flows Around Obstacles

3M™ RF6 demo at Queensland Fire & Rescue Service Training Academy

AFFF Foam Theory

Spreading Of An Aqueous Film

- Low surface tension ~ 16 mN/m
- Formation of aqueous film from bubble drainage
- Spreads rapidly on fuel - initial spreading coefficient



What Makes Up a Spreading Coefficient?

- Air / Foam Solution Interface
- Air / Fuel Interface
- Fuel / Foam Solution Interface

Spreading Coefficient $(S_{a/f})$ of an Aqueous Phase Over Fuel

$$S_{a/f} = \gamma_f - (\gamma_a + \gamma_i)$$

γ_a = surface tension of aqueous phase

γ_f = surface tension of fuel

γ_i = interfacial tension

Foam Spreading Coefficient On Cyclohexane

(as reported by the Univ. of Newcastle, Australia, using static method)

	Surface Tension of Cyclohexane	Foam Solution Surface Tension	Foam Interfacial Tension with Cyclohexane	Spreading Coefficient
3M™ 1% AFFF	24.0	16.4	4.3	3.3
3M™ 6% AFFF	24.0	16.2	4.7	3.1
3M™ ATC™ @ 3%	24.0	16.2	3.2	4.6
6% AFFF	24.0	17.9	1.4	4.7
AFFF/AR @ 3%	24.0	18.6	2.0	3.4
Fluoro Free Foam @1%	24.0	24.0	0.6	- 0.6
3M™ RF6 @ 6%	24.0	26.4	2.4	- 4.8

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Spreading Coefficient

- From the data, fluoro free foams have:
  - higher surface tensions
  - a negative spreading coefficient
- Therefore, fluoro free foams do not form an aqueous film.

Fire Performance

Does the lack of ability to form an aqueous film effect fire performance?

ICAO Level B Fire Test

	ICAO Level B Spec	3M™ Foam RF6	3M™ FC-3003	3M™ FC-206CF	Arctic Foam™ 203**
Fluorosurfactant Technology		No Fluoro-surfactant	PFOS	PFOS	Telomer
Solution Strength	3 or 6%	6	6	6	3
90% Control	-	30 s	-	38 s	26 s
Extinguishment	<60 s	46 s	50 s	46 s	44 s
Burn Back Time	> 5:00	> 8:00*	7:06	> 8:00*	> 8:00*

Note: * No indication of re-ignition or burn back of foam was observed after 8:00

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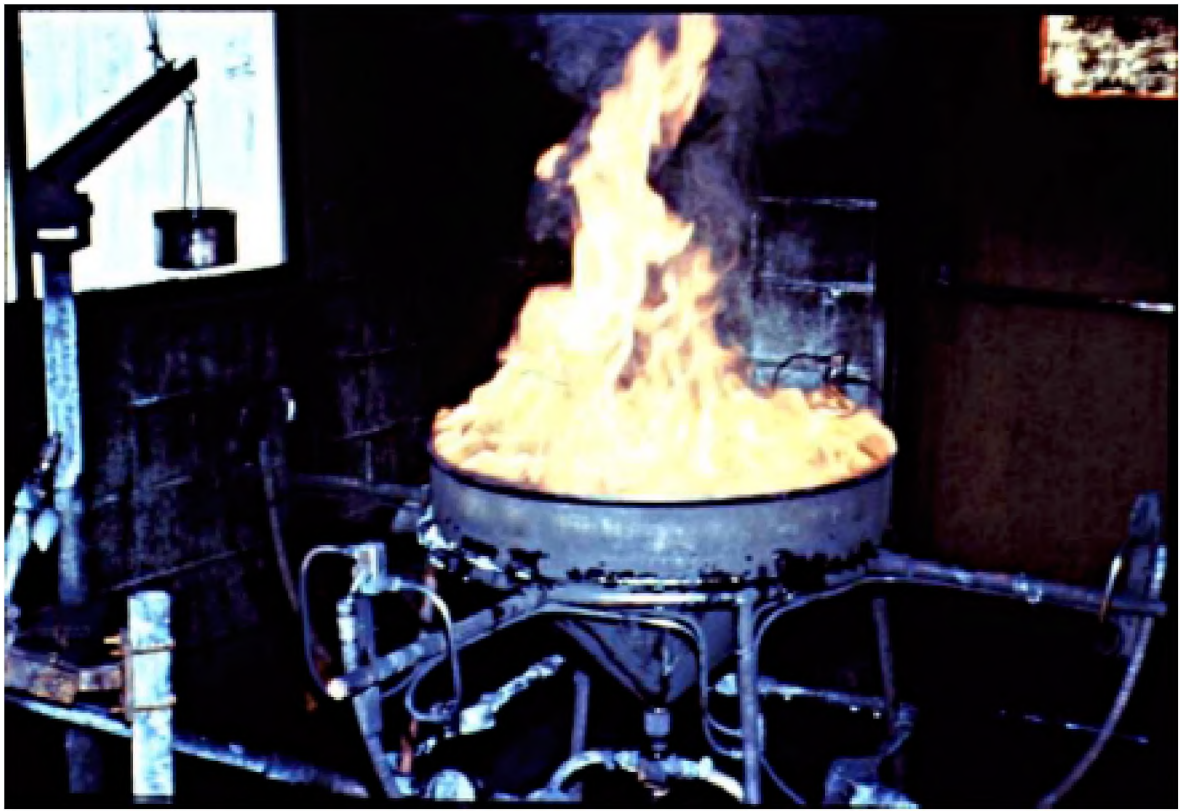
Comments on ICAO Fire Test

- Application density was 2.53 lpm/m^2
- ICAO has two levels of performance
  - A – protein or fluoroprotein foam (small pan)
  - B – AFFF or FFFP foam (large pan)
- No discernable difference between AFFF and RF6 on:
  - Extinguishment
  - Burn back

0.28 m^2 Fire Test

- Test method found in the Australian Defence Force specification Def(Aust)5706
- Similar to UK MOD specification method, but lower foam flow and lower application time

0.28 m^2 Fire Test



0.28 m^2 Fire Tests with Potable Water

(as reported by the Univ. of Newcastle, Australia)

Fuel	AVGAS			AVTUR		
Water Type	Potable			Potable		
Test Criteria	75% Cont. (s)	Ext (s)	33% Burn Back (min)	75% Cont. (s)	Ext (s)	33% Burn Back (min)
RF6 (6%)	29	52	12:30	25	50	13:36
FFF #1 (0.4%)	35	68	3:30	40	110	5:48
FFF #2 (2%)	29	122	5:06	26	69	5:12
FC-206CF (6%)	27	42	12:12	24	40	21:18

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0.28 m^2 Fire Tests with Synthetic Sea Water

(as reported by the Univ. of Newcastle, Australia)

Fuel	AVGAS			AVTUR		
Water Type	Sea Water			Sea Water		
Test Criteria	75% Cont. (s)	Ext (s)	33% Burn Back (min)	75% Cont. (s)	Ext (s)	33% Burn Back (min)
RF6 (6%)	27	50	11:36	25	52	11:00
FFF #1 (0.4%)	31	69	4:48	27	67	5:42
FFF #2 (2%)	32	No Ext	No Result	27	120	<1:00
FC-206CF (6%)	31	40	13:30	26	38	14:30

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Comments on 0.28 m^2 Fire Test

- Application density was 2.42 lpm/m^2
- NFPA 11 recommends 4.1 lpm/m^2 with hand line
- Discernable differences between the three fluoro free foams on:
  - Extinguishment
  - Burn back
  - Sea water compatibility
- Fluoro free foams are not all equal in performance

Evaluation Program by US Navy NAVFAC / NRL

- Evaluation initiated in 2002 by NAVFAC on "environmentally benign AFFF" products
- Testing of 3M™ RF6 on 28 ft^2 fire (gasoline)
  - 50 s extinguishment (spec limit 30 s max)
  - 7:55 burn back (spec limit 5:00 min)
- Failed film formation
- Operator familiarity with the product will improve results (39 s)

Comparison of 3M™ RF6 Fire Test Results

Spec	Exting. (s)	App Density (LPM/m^2)	Fuel
ICAO Level B	46	2.53	Aviation Kerosene
Australian Defence	52	2.42	AVGAS
US Mil (28 ft^2)	50	2.91 (0.07 gpm/ft^2)	Unleaded Gasoline

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Fire Test Result

Is film formation necessary for AFFF like fire performance?

- **NO!**
- Achieved near AFFF performance with 3M™ RF foam technology

Challenges for Fluoro Free Foams

In conclusion…

- Rapid fire extinguishment – like AFFF
- Good burn back resistance – like AFFF/FFFP
- Capable of good vapour suppression
- Free flowing foam – to support above points
- Achieve drop in capability
- Sea water compatible
- Responsible environmental profile
  - Customer decision process

Thank You!