Investigating Powerplant Halon Replacement in a Generic Nacelle Fire Simulator.

Presented to:
10TH Triennial International Aircraft Fire & Cabin Safety Research Conference

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Federal Aviation Administration

Presentation Content

- **Overview Halon-Equivalence Fire Testing[1]**
  - The Apt Circumstances of the Aircraft Powerplant
  - Its Test Methodology
  - Test Fixture & Environment

- **Review Accomplished CF3I Testing**
  - Recent MPSHRe Results
  - Proposed Certification Criteria

[1] known in short-hand as “MPSHRe/rev04”, the "Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments (MPSHRe rev04)"

Overview, Apt Circumstances

- **Three Concepts Intersect in FAA AC 20-100**[2]
  - Exigent powerplant fire-zone features
    - potential for fire in varying zonal structure & ventilation
  - Injection of a fire extinguishing agent
    - satisfying design criteria, the "certification" criteria
  - Use of a gas concentration analyzer
    - measuring a fire-extinguishing agent's zonal presence
- **This Reduces to a "Certification" Test**
  - Solely measuring a transient concentration field
  - Must satisfy certification criteria for "worst" case[s?]...

[2] FAA Advisory Circular 20-100/1977.

Overview, Apt Circumstances

- **Fire Extinguishment Here is a 2-part Problem, Transormed into 1; an Areal Problem...**
  - Need a <u>zonal concentration</u> for a <u>residence time</u>
  - Concentration : how much needed to eliminate fire
    - different phenomena combine to eliminate fire; altering thermal balances &/or combustion reactions [lean/rich, redirection]
    - due to precedent here, we focus on a requisite concentration
    - ”worst” case requires discarding non-concentration phenomena
  - Residence time must be satisfied throughout the zone
    - addresses all dynamic interactions of all involved fluids
    - 1/2 second[3]; unchanged from destructive testing, 1950s-1960s

[3] "Aircraft Installation and Operation of an Extinguishing-Agent Concentration Recorder”, Technical Development Report No. 403.

Overview, Apt Circumstances

- **About the Halon 1301 FAA Certification Concentration Criterion...**
  - It is a peak-inertion concentration [PIC]
  - Reviewing associated literature substantiates this
    - FAA AC 20-100, halon 1301 concentration criterion for its FAA certification criteria = 6%v/v CF3Br[4]; references Chamberlain[5]
    - Chamberlain connects 6%v/v CF3Br to work from Purdue[6]
    - Purdue included CF3Br in a substantial project for the US Army
    - Purdue's project investigated inhibiting flammable reactions in premixed, gaseous systems of oxidizer, fuel, & MANY fire-extinguishing agents; this type of assessment produces a PIC
    - *Historical level of safety = a CF3Br PIC resident for 1/2 second*

[4] Halon 1301 is bromotrifluoromethane, CF3Br.
[5] "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Recorder", Report No. FAA-DS-70-3.
[6] "Final Report on Fire Extinguishing Agents...W 44-009 eng-507..."

Overview, Assessment Concept

- **Task Group Derived; Multiple Revisions**
  - rev01, US Department of Defense
    - early 1990s; HFC-125 design model[7]
  - rev02-04, FAA
    - r02, *find* equivalence; “robust” fires; fire extinguishment behavior based on flow-over-plate, ‘hot’-surface reignition; repeated tests; improbable timely completion & repeatability
    - r03, *find* equivalence; reignition time delay; find largest effective concentration; its empiricism creates problems; related to candidate distribution; i.e. flooding versus streaming agents
    - r04, *prove* equivalence; much of rev03, but modified to a proof-test; requires predefining proposed criteria[8]; find the PIC...

[7] "Aircraft Engine/APU Fire Extinguishing System Design Model (HFC-125)”, Report No. AFRL-VA-WP-TR-1999-3068.
[8] MPSHRe/rev04, citation 4.A-2.d-i.

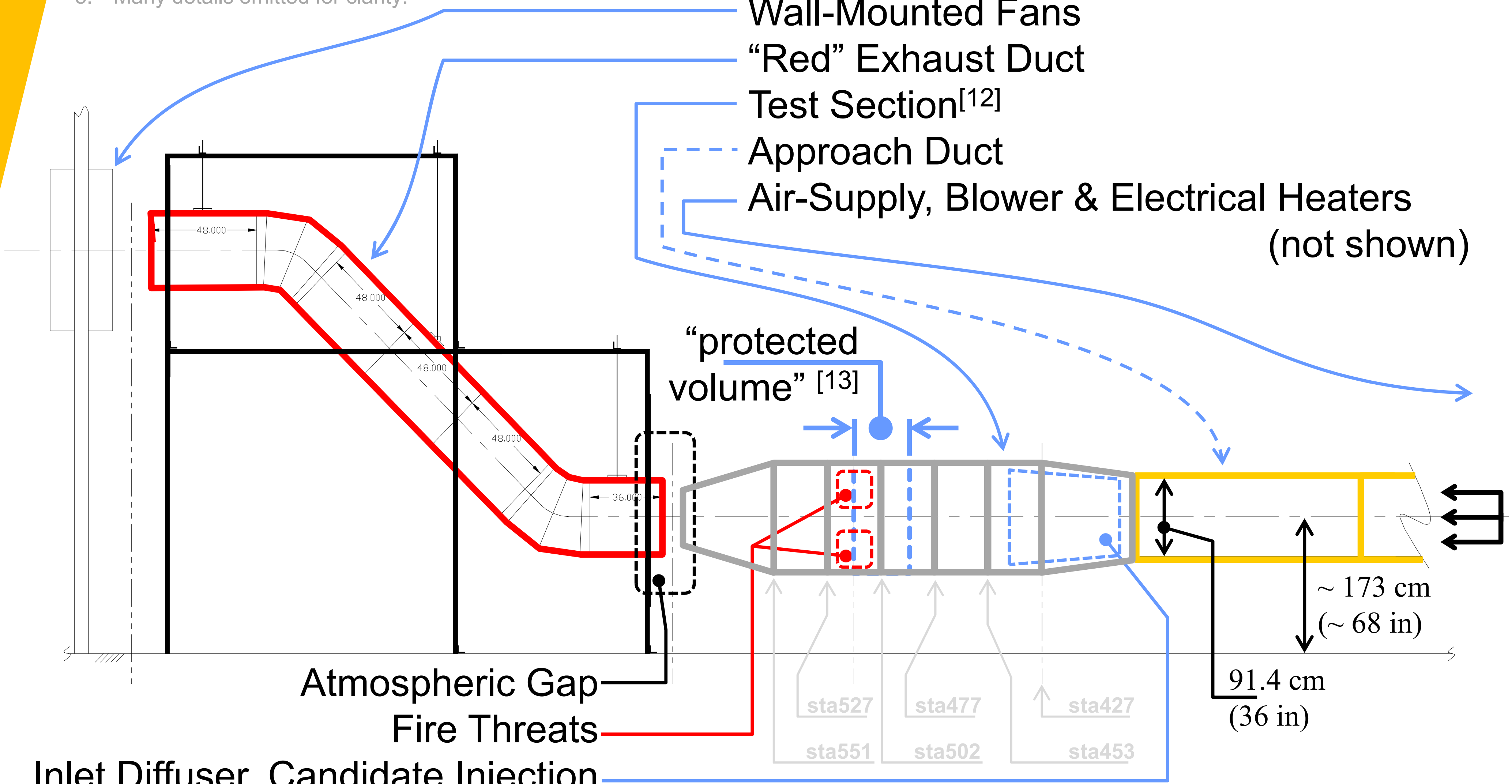
Overview, Assessment Concept

- **Reduced Zonal View to Applicable Phenomena**
  - Used basic elements to minimize interfering with creating test results & readily understanding them
  - Included basic elements of :
    - forced-ventilation; 2 conditions[9], “low” or “high”
    - representative types of fire; atomized spray[10] & pool[11]
    - “simple” flow-riling, flame-attaching, & “hot”-surface structures
    - representative fuels; turbine fuel, lubricant & hydraulic fluid
    - fire-extinguishing agent injection & migration; total-flooding
    - halon 1301 performance framed by its FAA certification criteria

[9] “low” ≈ 0.45 kg/s @ 127°C, “high” ≈ 1.2 @ 38° (~1.0 lbm/s @ 260°F, ~2.7 @ 120°).
[10] fuel spray ≈ 0.95L/min @ 66°C (0.25 US gal/min @ 150°F)
[11] exposed surface 0.52 m long, 0.14 m^2, 1.27 cm deep, T > 49°C (20.5 inches long, 220 in^2, 0.5 in deep, T > 120°F).

Overview, Assessment Concept

NOTES :
1. This is a schematic elevation view. Not drawn to scale.
2. Station (sta) numbers are incremented as inches.
3. Many details omitted for clarity.



[12] Some idealized/clean dimensional information : inlet diffuser exit flange [sta427] to exhaust nozzle entrance flange [sta551], 3.1 m long x 1.22 m outside diameter x 0.6096 m inside diameter, annular volume ≈ 2.74 m^3 (96.6 ft^3).
[13] sta490 to sta514

Overview, Assessment Concept

NOTES :

1. This model view is not drawn to scale.
2. Station (sta) numbers are incremented as inches.
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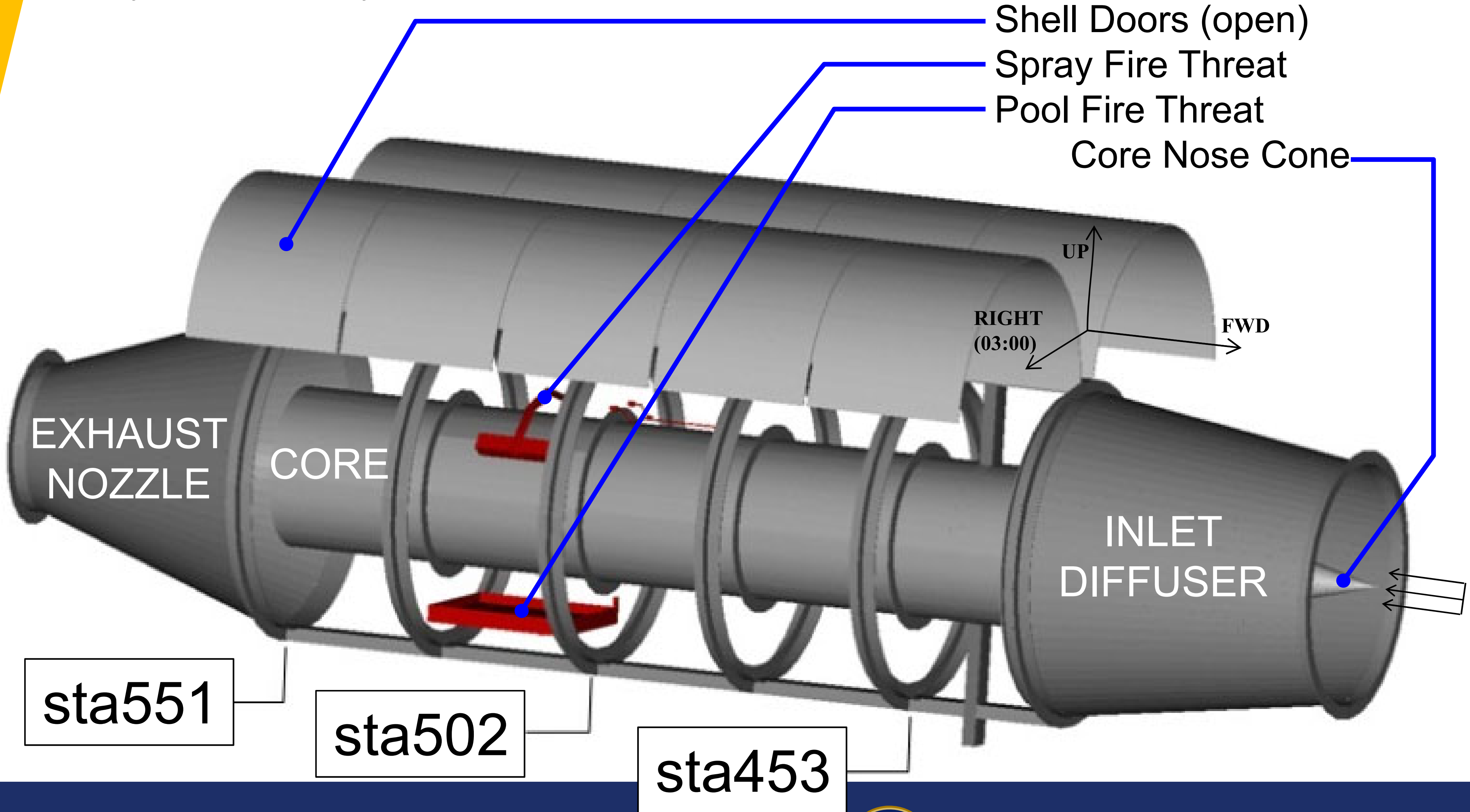


CF3I Testing, Generic

- **Testing Accomplished Intermittently**
  - 2003-2006 : 3 of 4 test conditions; MPSHRe/rev03
  - 2019-2022 : 4th & ancillary conditions; MPSHRe/rev04
- **CF3I Testing, MPSHRe/rev03**
  - FAA Fire Safety Branch; prioritized by working group
  - Finished all spray-fire & high-ventilation/pool-fire testing
  - Contributed to developing & stymying rev03
  - Interest faded, Fire Safety reprioritized, & dropped it
    - Toxicological uncertainty
    - Applicants had other interests : 2-BTP, FK-5-1-12

CF3I Testing, Generic

Condition	Effective Concentration
high, spray, turbine	5.6
low, spray, turbine	4.8
low, spray, lubricant	7.1
high, pool, turbine	2.7

- **CF3I Testing, MPSHRe/rev03** **[continued]**
  - High-ventilation/spray-fire results generally encouraging
  - Low-vent/spray-fire indirectly discouraging & abnormal
    - “large” mass injected for each test; CF3I supply ended before achieving required completion; a “few” tests left...
    - non-optimal injection; “odd” concentration fields
    - logically derived an effective concentration
  - High-vent/pool-fire generally encouraging but abnormal
    - quantities like high-vent/spray-fire stop flames on fuel surface
    - *but*, fire persists aft of fuel pan, outside the MPSHRe “protected volume”, & eventually reignited pool

CF3I Testing, Generic

Condition	Effective Concentration
high, spray, turbine	5.6
low, spray, turbine	4.8
low, spray, lubricant	7.1
high, pool, turbine	2.7

- **CF3I Testing, MPSHRe/rev03** [continued]
  - Per 2003-2006 testing, the largest interim effective half-second-resident volume concentration [HSRVC] was 7.1%v/v CF3I
  - Checked elsewhere for corroboration, via reported PICs
    - Purdue[14], CF3I in air/n-heptane : 6.8%v/v CF3I
    - US NFPA, NFPA 2001[15], CF3I in air/propane : 6.5%v/v CF3I
    - ...7.1%v/v CF3I is a plausible concentration criterion
  - Interim proposed criteria = 7.1%v/v CF3I for 1/2 second

[14] Part of the same reporting as previously cited for CF3Br in this file.
[15] "Standard on Clean Agent Fire Extinguishing Systems", NFPA 2001, 2008 Edition.

CF3I Testing, Generic

Condition	Proven Concentration
low, pool, turbine	7.1

- **CF3I Testing, MPSHRe/rev04**
  - Boeing/Parker-Meggitt initiative recognized by the FAA
  - Rev04 a *proof* test; prove 7.1%v/v CF3I for 1/2 second
  - Concentration field challenged low-ventilation/pool-fire
  - FAA also requested additional/ancillary testing
    - unusual prior testing experiences
    - thermodynamic disparity[16]
    - wanted to establish some confidence in functionality
  - Low-vent/pool-fire acceptable; threshold = 5.48 sec
    - 3.6 lbf CF3I : 7.0%v/v HSRVC & 5.91 sec average RTD
    - <u>7.1%v/v proven acceptable because 7.0 ≈ 7.1 but 5.91 > 5.48</u>

[16] implied by 1-atmosphere boiling points, CF3Br = -58°C [-72°F], CF3I = -22°C [-8°F]

CF3I Testing, Ancillary

- **FAA Considered Generic Fixture Plausible**
  - Flowed modified/ambient low ventilation
  - Concentration field represented proposed cert criteria
  - Set concentration field with ‘cold’ firex bottle & contents
  - Treated generic fixture interior like end use & stressed CF3I distribution/dispersion
    - needed to extinguish dual/simultaneous fires
    - expanded “protected volume” to envelope fire-related features
    - injected ‘cold’ fire extinguisher [firex] bottle
    - a portion of injection plumbing ‘cold’
    - a portion of generic fixture’s shell ‘cold’

CF3I Testing, Ancillary

- **3-Test Average HSRVC ≈ 7.0%v/v CF3I**
  - modified ‘low’ ventilation flow & sample-point geometry
  - individual tests were 7.4, 6.7, & 6.9%, respectively
- **180 Second-long Test**
  - Looking for extinguishment; once fire ignited, ignition off
  - “Warm” fuel; pool had 90-sec pre-burn, spray pre-burn 45 sec; firex bottle discharge at 110 sec; fuel spray continued for 10+ seconds to assure no fire reignition
- **<u>Credible Test on 4th Attempt; Acceptable Outcome</u>; Work Not Completed...**

CF3I Testing, Ancillary

NOTES :

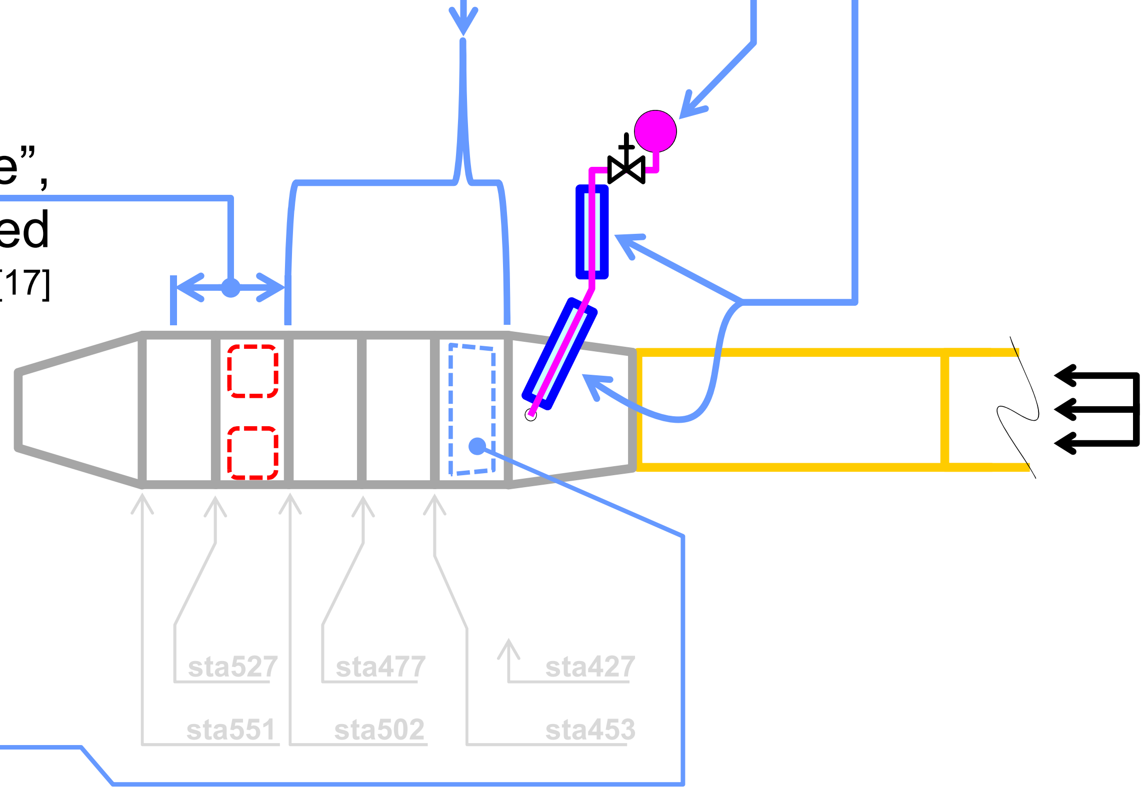
1. This is a schematic elevation view. Not drawn to scale.
2. Station (sta) numbers are incremented as inches.
3. Many details omitted for clarity.

Portions of exterior firex injection plumbing “cold”;
[approximately 52% of this length covered in dry ice]

Firex bottle “cold”; pre-test soak in dry ice

Part of test section shell “cold”; pre-test soak in dry ice

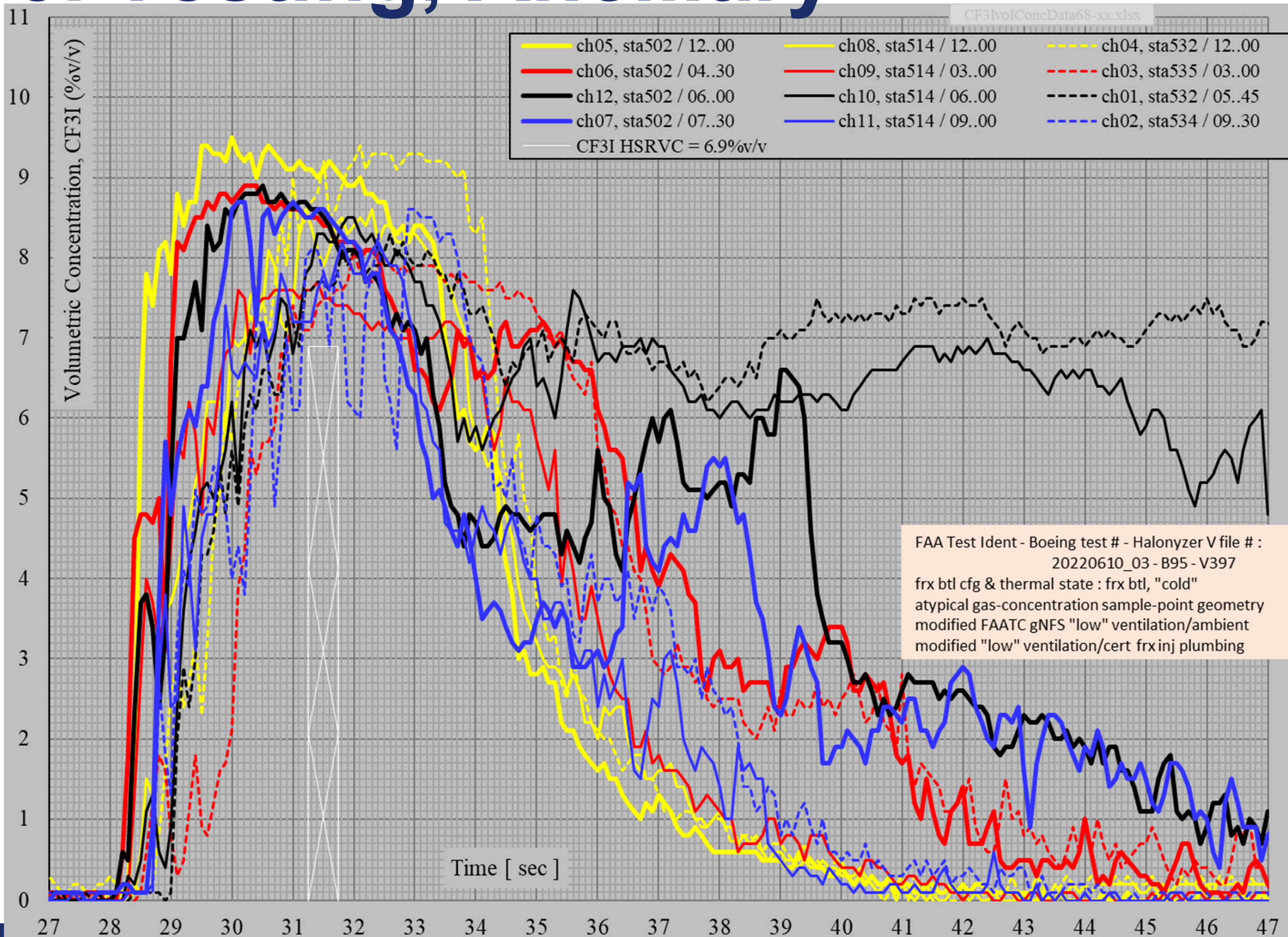
“protected volume”,
sampling points placed
analogous to AC 20-100[17]



Candidate injection,
within cross-sectional plane

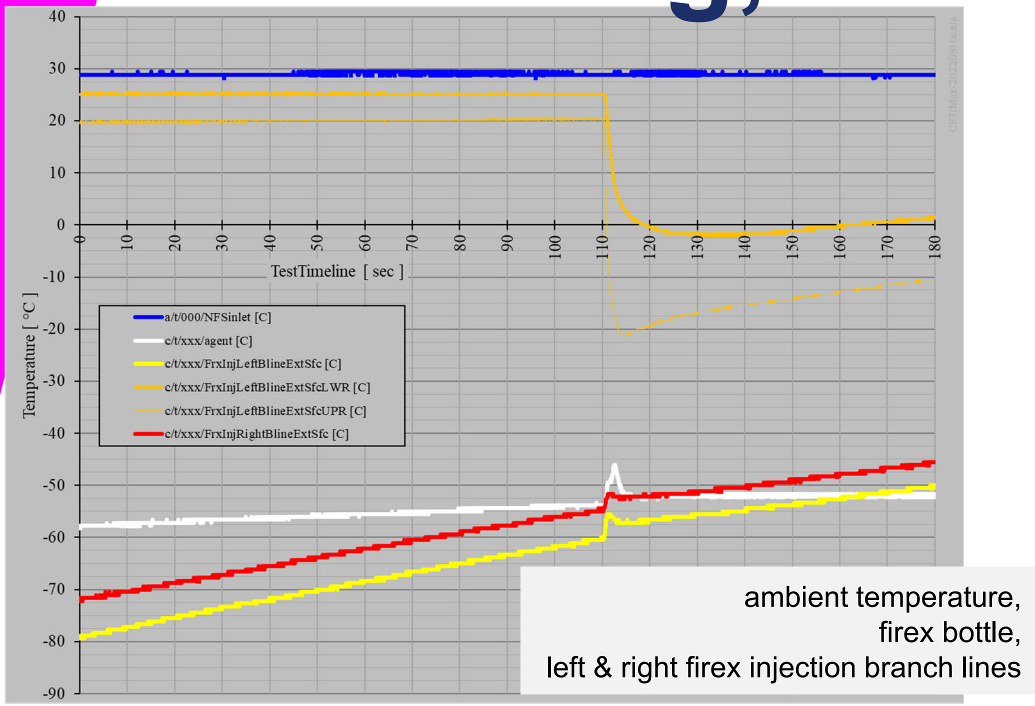
[17] sta502 to approximately sta535

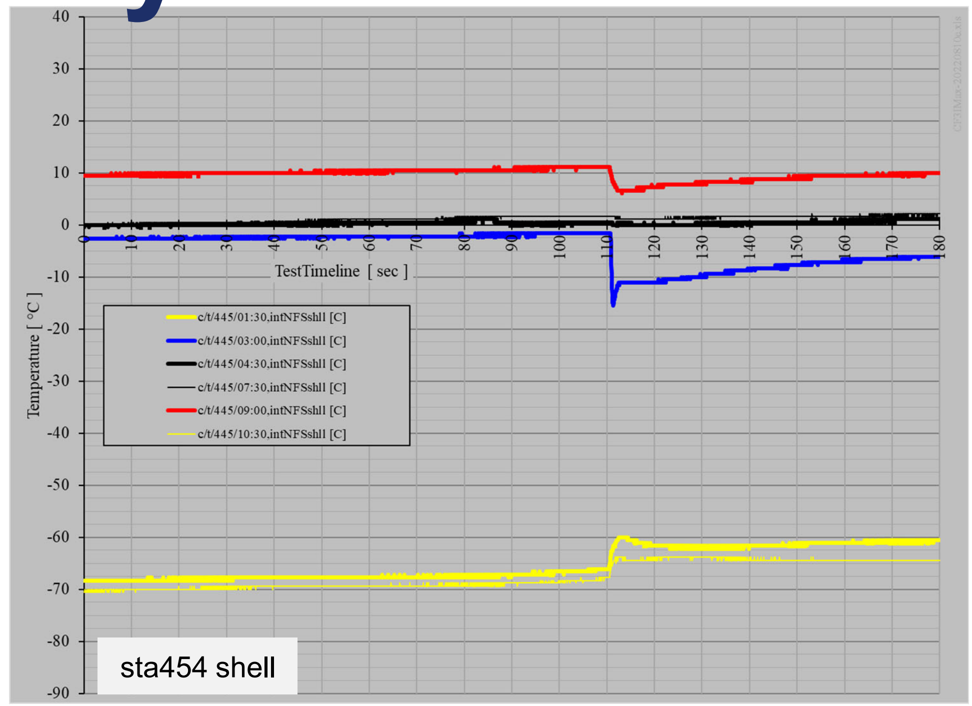
CF3I Testing, Ancillary

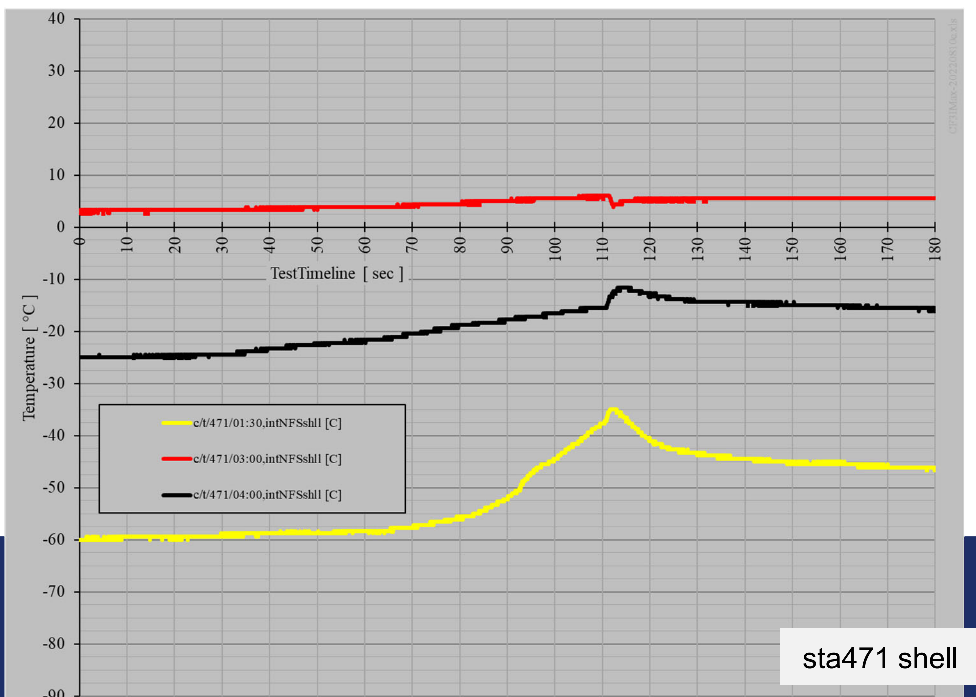


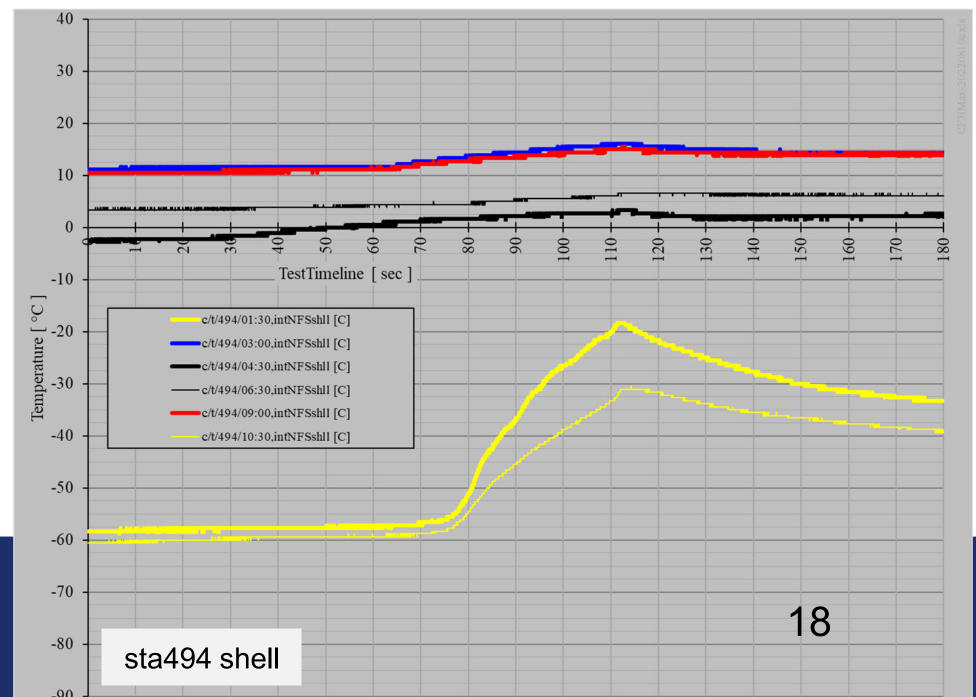
Volume concentration data recorded & provided by Parker-Meggitt

CF3I Testing, Ancillary

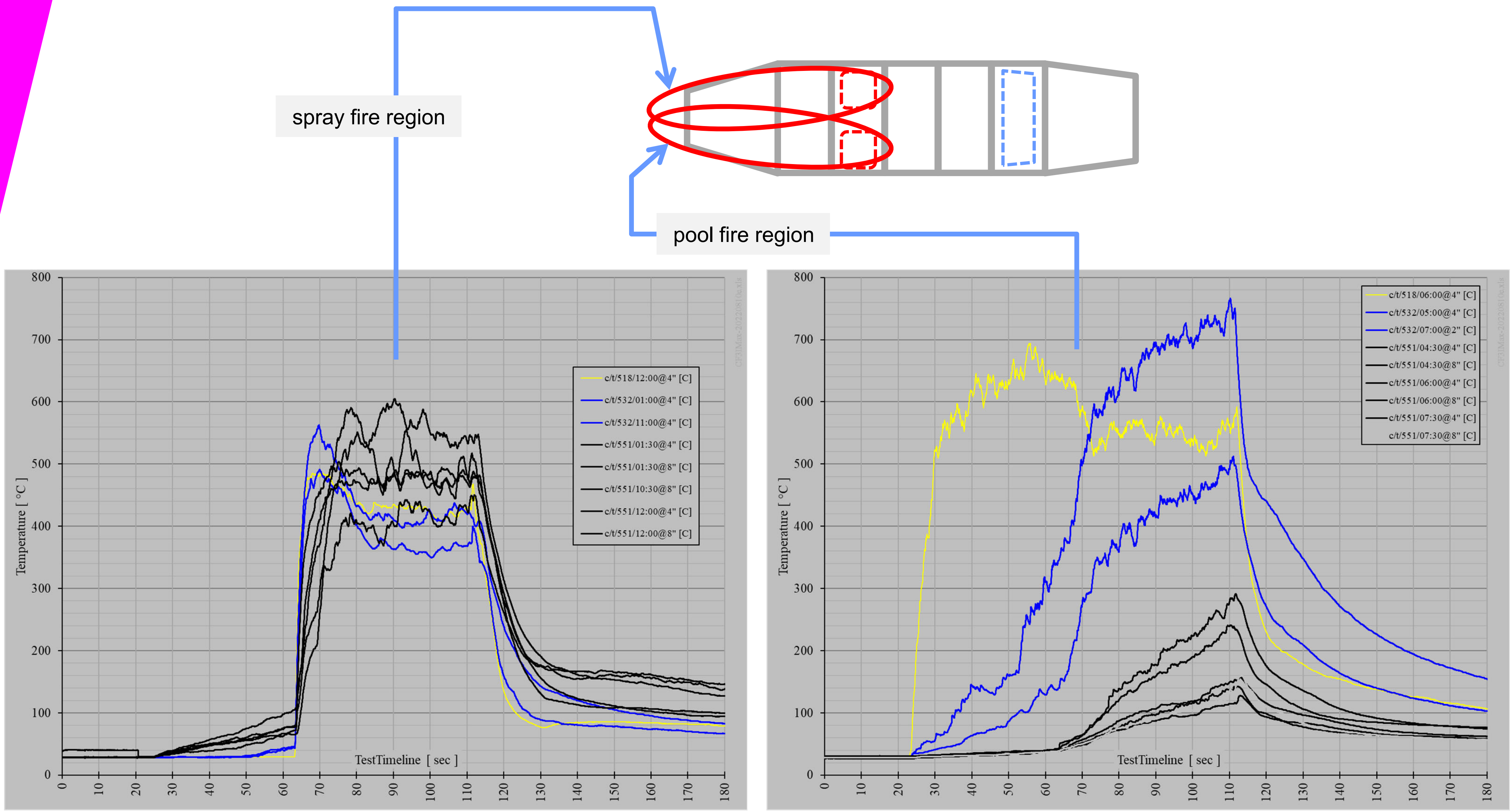








CF3I Testing, Ancillary



Project Acknowledgements

- **FAA Technical Center, Fire Safety Branch :**

  Mr. Ed Sica, Diakon Solutions

  Mr. Mark Materio, Diakon Solutions

  Mr. Tim Smith

- **Parker-Meggitt**

  Dr. Samir Tambe

APPENDIX SLIDES

Appendix

References in order of mention; line numbers may be missing here.

[1] Ingerson, D., 2010, "Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments, revision 04", draft/working document, United States Department of Transportation, Federal Aviation Administration, W.J. Hughes, Technical Center, Atlantic City, NJ. AIChtEEtEEpEs://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf

[2] Advisory Circular 20-100, 1977, "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments," United States Department of Transportation, Federal Aviation Administration, Washington, D.C. http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC20-100.pdf

[3] Demaree, J.E., and Dierdorf, P.R., 1959, "Aircraft Installation and Operation of an Extinguishing Agent Recorder", Technical Development Report No. 403, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ.

[5] Chamberlain, G., 1970, "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Recorder", Report No. FAA-DS-70-3, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ.

[6] Purdue University, 1950, "Final Report on Fire Extinguishing Agents for the period 1Sep1947 to 30June1950 covering research conducted by the Purdue Research Foundation and Department of Chemistry".

[7] Bennett, J.M., Bennett, M.V., 1999, "Aircraft Engine/APU Fire Extinguishing System Design Model (HFC-125)", Report No. AFRL-VA-WP-TR-1999-3068, Air Force Research Laboratory and Booz, Allen, and Hamilton, Incorporated, Wright Patterson Air Force Base, OH.

[15] National Fire Protection Association, 2007, "NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems," 2008 Edition, Quincy, MA.

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Appendix

Brief History of 6%v/v CF3Br

AC NO: 20-100 AC 44D 001413

DATE: 9/21/77

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: GENERAL GUIDELINES FOR MEASURING FIRE-EXTINGUISHING AGENT CONCENTRATIONS IN POWERPLANT COMPARTMENTS

1. PURPOSE. The purpose of this Advisory Circular is to describe the installation and use of a model GA-2A fire extinguisher agent concentration recorder in determining the distribution and concentration of fire-extinguishing agents when discharged in an aircraft powerplant compartment.

2. REFERENCE.

a. Report No. FAA-DS-70-3, "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Concentration Recorder," is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151, under Accession No. AD 712 191.

b. FAR Sections 25.1195(b), 29.1195(b), and 29.1195(c).

c. FAR 21.21(b)(2) as it affects powerplant fire-extinguisher installations accomplished on an optional basis.

3. BACKGROUND. From 1959 to 1968, the Federal Aviation Administration (FAA) was actively engaged in the evaluation of aircraft powerplant fire-extinguishing systems. During this period, the FAA provided, without charge, specialized fire-extinguishing agent concentration recorder equipment and knowledgeable personnel to organizations requesting assistance in the evaluation of aircraft fire-extinguishing systems. Testing was conducted and data was obtained for STOL, VTOL, helicopters, large transport category aircraft, military aircraft, executive aircraft, turbojet, turbopropellers, and reciprocating engine-powered aircraft. This evaluation program provided information helpful in establishing criteria for the installation and utilization of the fire-extinguishing agent concentration recorder. The FAA no longer makes evaluations. This type of work is now being performed by private companies for a fee. The FAA

Initiated by: AFS-140

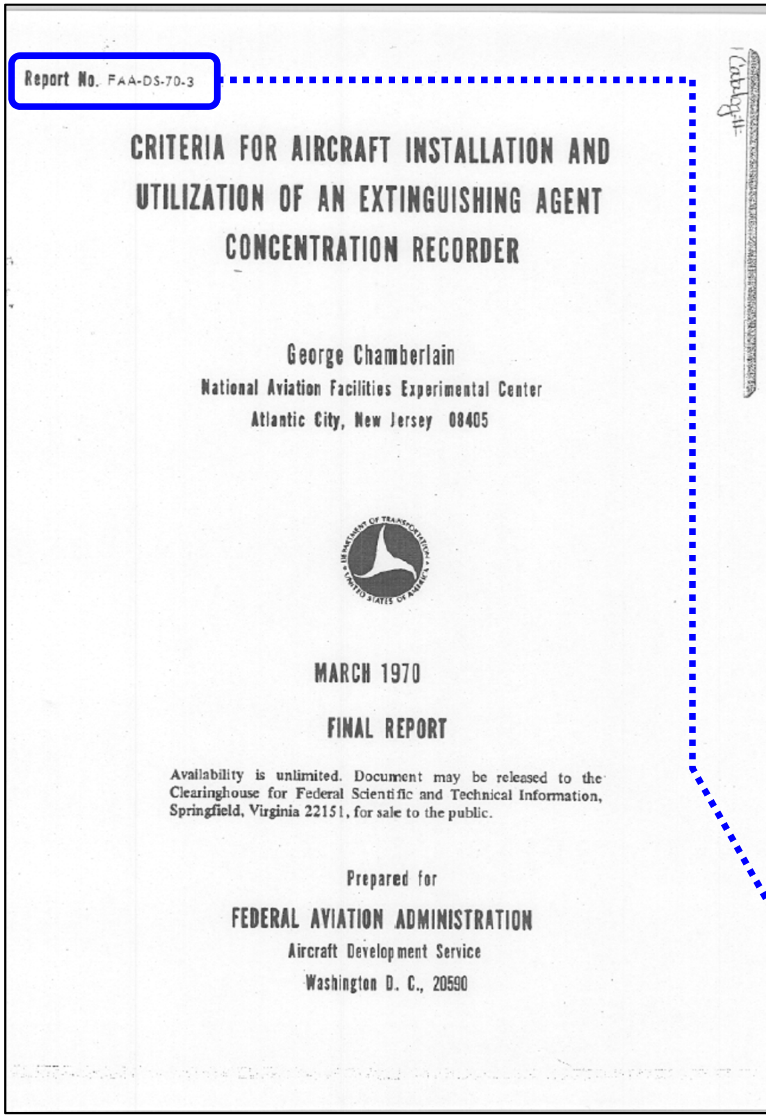
Examples of minimum concentrations sufficient to extinguish fire and prevent its recurrence are as follows:

AGENT	CONCENTRATION BY WEIGHT	IN PERCENT BY VOLUME	RELATIVE CONCENTRATION PERCENT
CO_2	49	37	40
CH_3Br	30	11	15
CH_2BRCl	36	11	25
CF_2Br_2	26.5	5	15
CF_3Br	22	6	15

**FAA AC 20-100, halon 1301 certification concentration criterion => 6%v/v CF3Br
...refers to report FAA-DS-70-3**

Appendix

Brief History of 6%v/v CF3Br



Report No. FAA-DS-70-3

CRITERIA FOR AIRCRAFT INSTALLATION AND UTILIZATION OF AN EXTINGUISHING AGENT CONCENTRATION RECORDER

George Chamberlain
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

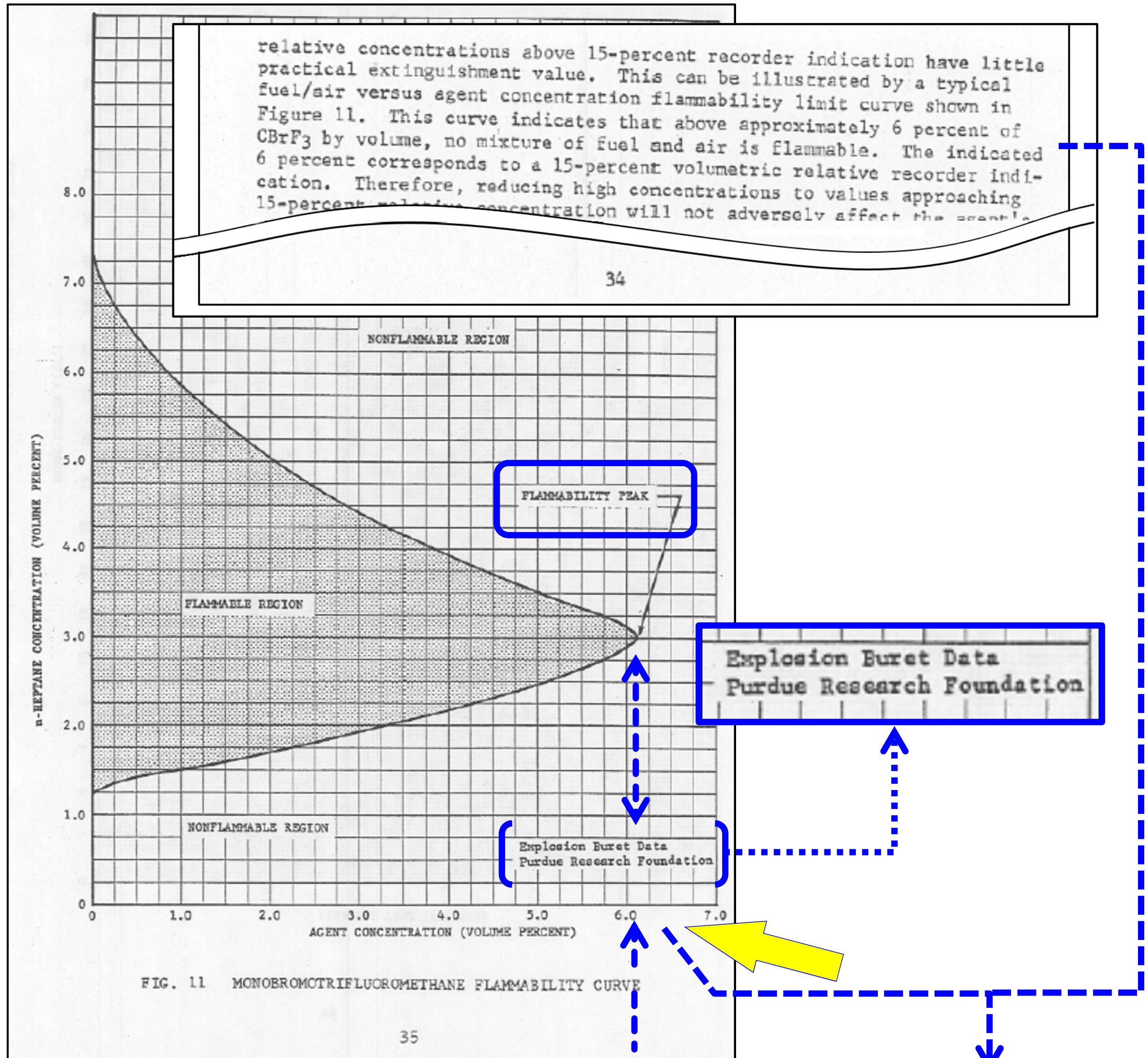
MARCH 1970

FINAL REPORT

Availability is unlimited. Document may be released to the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151, for sale to the public.

Prepared for

FEDERAL AVIATION ADMINISTRATION
Aircraft Development Service
Washington D. C., 20590



FAA-DS-70-3, halon 1301 certification concentration criterion ≈ 6%v/v CF3Br
...refers to the Purdue Research Foundation

Appendix

Brief History of 6%v/v CF3Br

AD-654322

Final Report

on

Fire Extinguishing Agents

for the period

September l, 1947 to June 30, 1950

covering research conducted by

Purdue Research Foundation and Department of Chemistry

Purdue University

under contract
W44-009-eng-5057
with
Army Engineers Research and Development Laboratories

Fort Belvoir

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Purdue Research Foundation, foundation of this value...

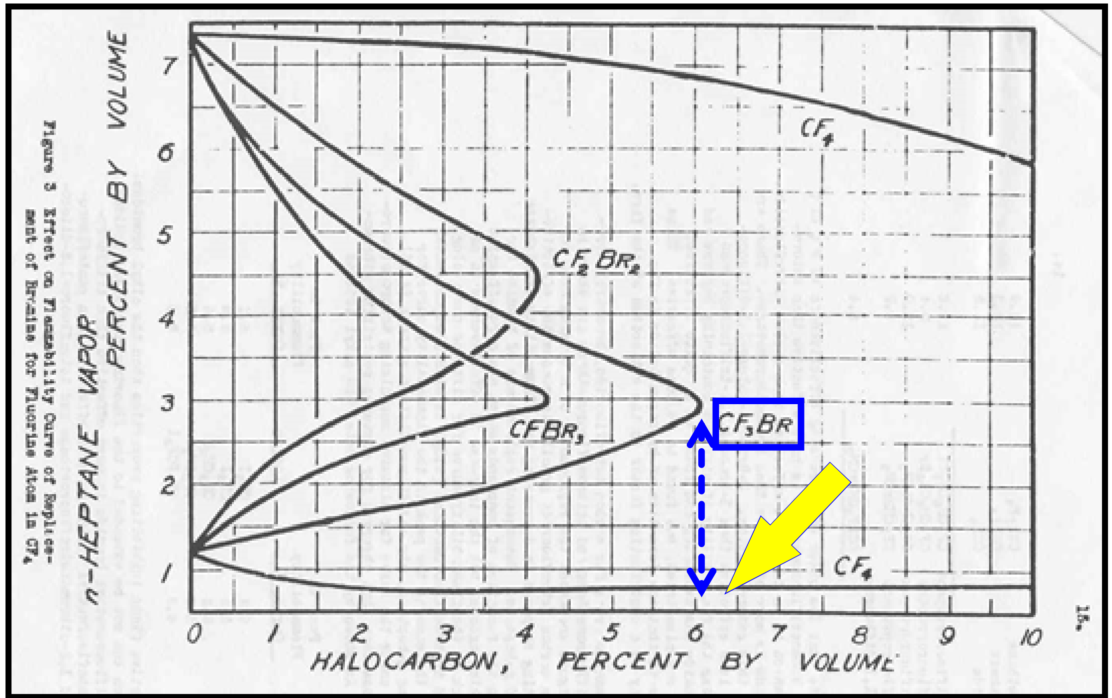

Table 12

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND BROMOTRIFLUOROMETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg $n-C_7H_{16}$	Pressure, mm. Hg $CBrF_3$	Volume, % $n-C_7H_{16}$	Volume, % $CBrF_3$	Result
5.0	0.0	1.3	0.0	-
6.0	0.0	1.5	0.0	+
28.0	0.0	7.0	0.0	+
29.0	0.0	7.3	0.0	-
11.[illegible]	[illegible]	2.8	[illegible]	-
13.0	2[illegible].0	3.3	6.0	-
6.0	8.0	1.5	2.0	-
7.0	8.0	1.8	2.0	+
8.0	16.0	2.0	4.0	-
9.0	16.0	2.3	4.0	+
20.0	[illegible]	5.0	2.0	-
16.0	16.0	4.0	4.0	-
12.0	24.0	3.0	6.0	+
12.0	25.0	3.0	6.3	-
10.0	20.0	2.5	5.0	+
13.0	23.0	3.3	5.8	-
9.0	20.0	2.3	5.0	-
15.0	16.0	3.8	4.0	+
19.0	8.0	4.8	2.0	+
14.0	20.0	3.5	5.0	+
24.0	4.0	6.0	1.0	-

- from Purdue [1950]
- [n-heptane = $n-C_7H_{16}$]

[a "+" means the mixture ignited & flame propagated through the detonation tube; "-" means the mixture did not ignite or did ignite but did not propagate]

Federal Aviation Administration

Appendix

Brief History of CF3I

AD-654322

Final Report

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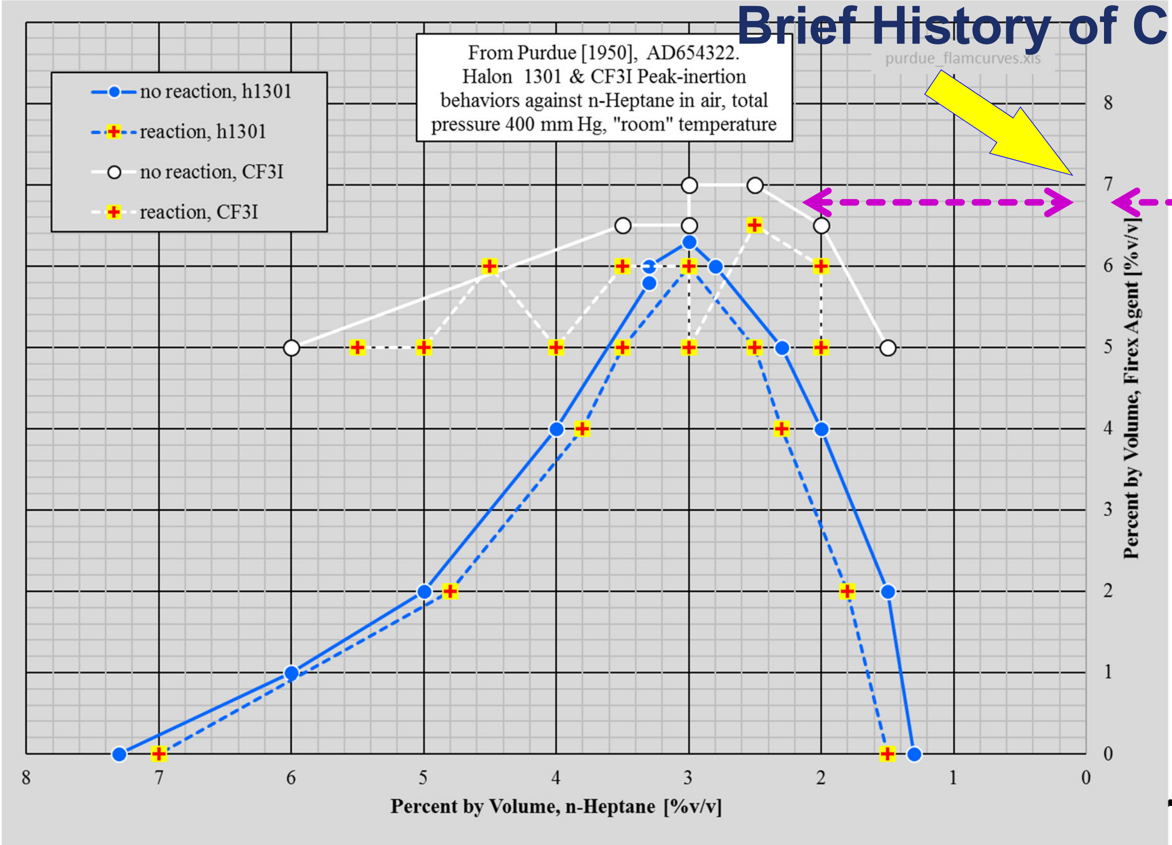


• from Purdue [1950]

• [n-heptane = n-C_7H_{16}]

Purdue [1950] : 6.8 %v/v CF3I, in air & vaporous n-heptane

[a "+" means the mixture ignited & flame propagated through the detonation tube; "-" means the mixture did not ignite or did ignite but did not propagate]

156.

Table 22

FLAMMABILITY OF MIXTURES OF N-HEPTANE, AIR AND TRIFLUORO-IODOMETHANE
(Total Pressure = 400 mm. Hg.)

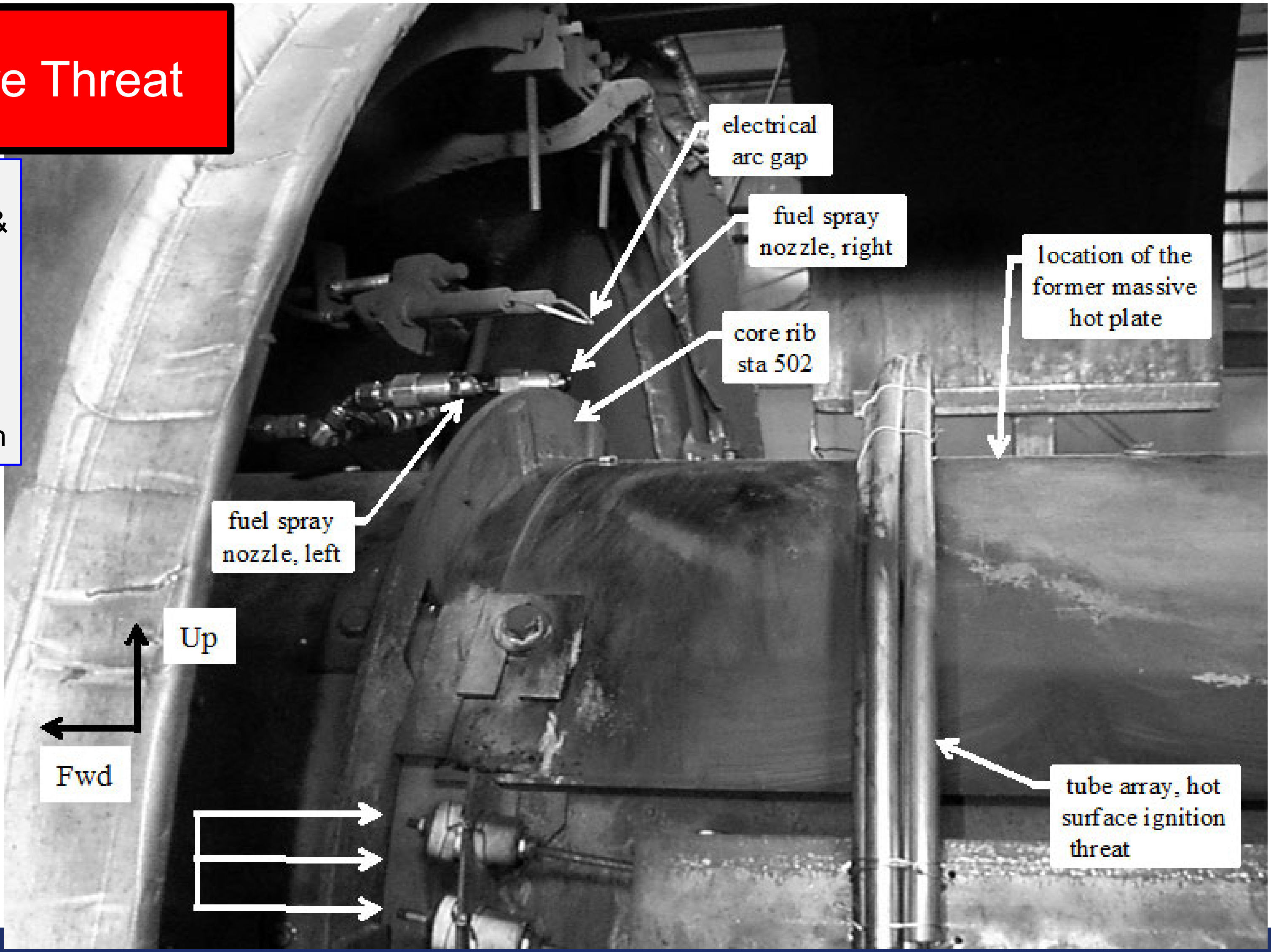
Pressure, mm. Hg.		Volume %		Result
C_7H_{16}	CF_3I	C_7H_{16}	CF_3I	
12.0	20.0	3.0	5.0	+
12.0	28.0	3.0	7.0	-
12.0	24.0	3.0	6.0	+
12.0	26.0	3.0	6.5	-
10.0	26.0	2.5	6.5	+
14.0	26.0	3.5	6.5	-
10.0	28.0	2.5	7.0	-
16.0	20.0	4.0	5.0	+
8.0	26.0	2.0	6.5	-
8.0	20.0	2.0	5.0	+
20.0	20.0	5.0	5.0	+
6.0	20.0	1.5	5.0	-
24.0	20.0	6.0	5.0	-
8.0	24.0	2.0	6.0	+
22.0	20.0	5.5	5.0	+
14.0	24.0	3.5	6.0	+
18.0	24.0	4.5	6.0	+

Appendix

Generic Nacelle Fire Simulator, Spray Fire Threat

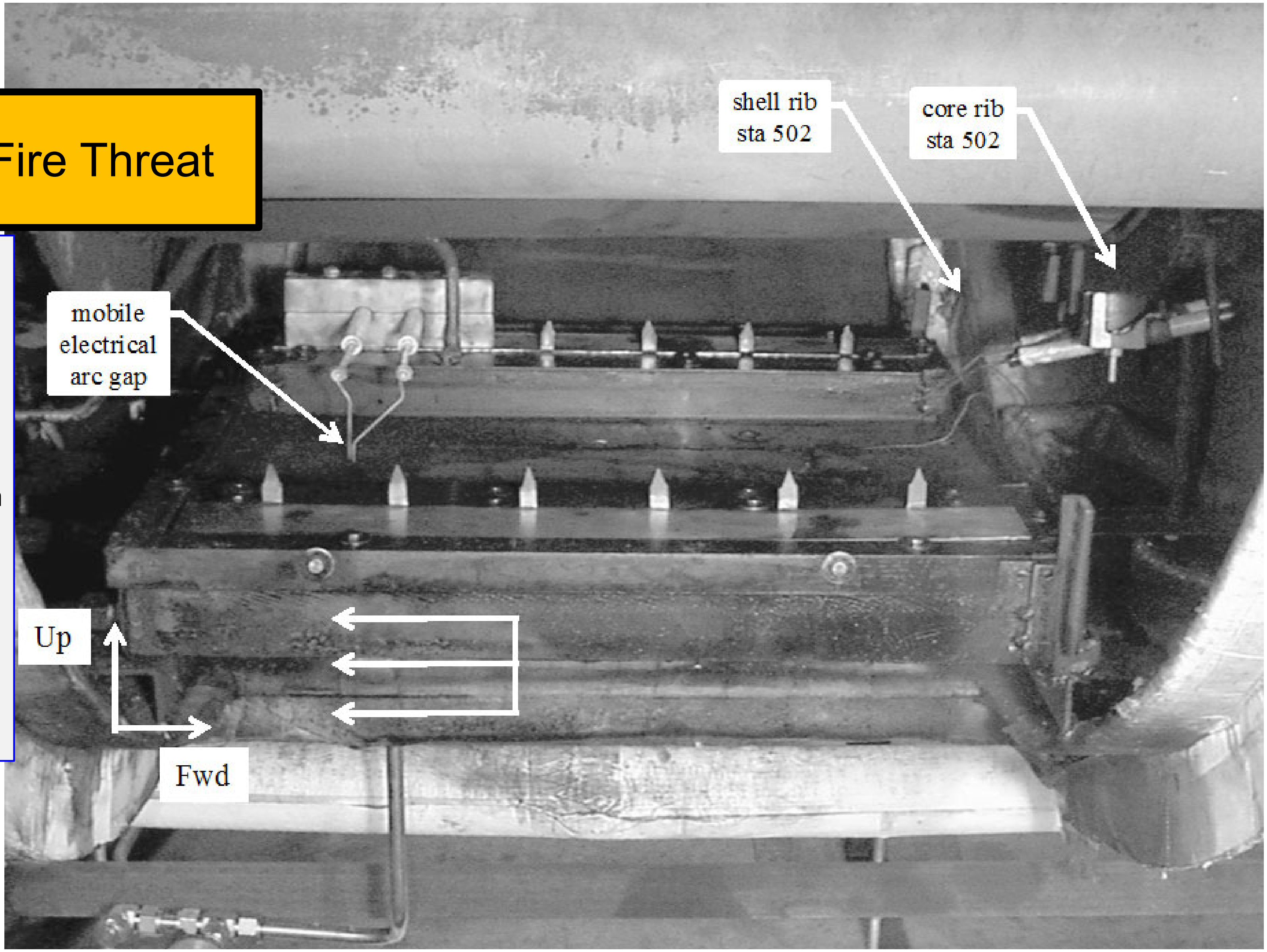
Spray Fire Threat

- Fuel flow ≈ 1 L/min @ 67°C
- Fuel flow, electrical ignition arc, & "hot" surface are present during the migration of the fire-extinguishing agent pulse through the test section
- Looking at/using the duration the fire is suppressed for comparison



Appendix

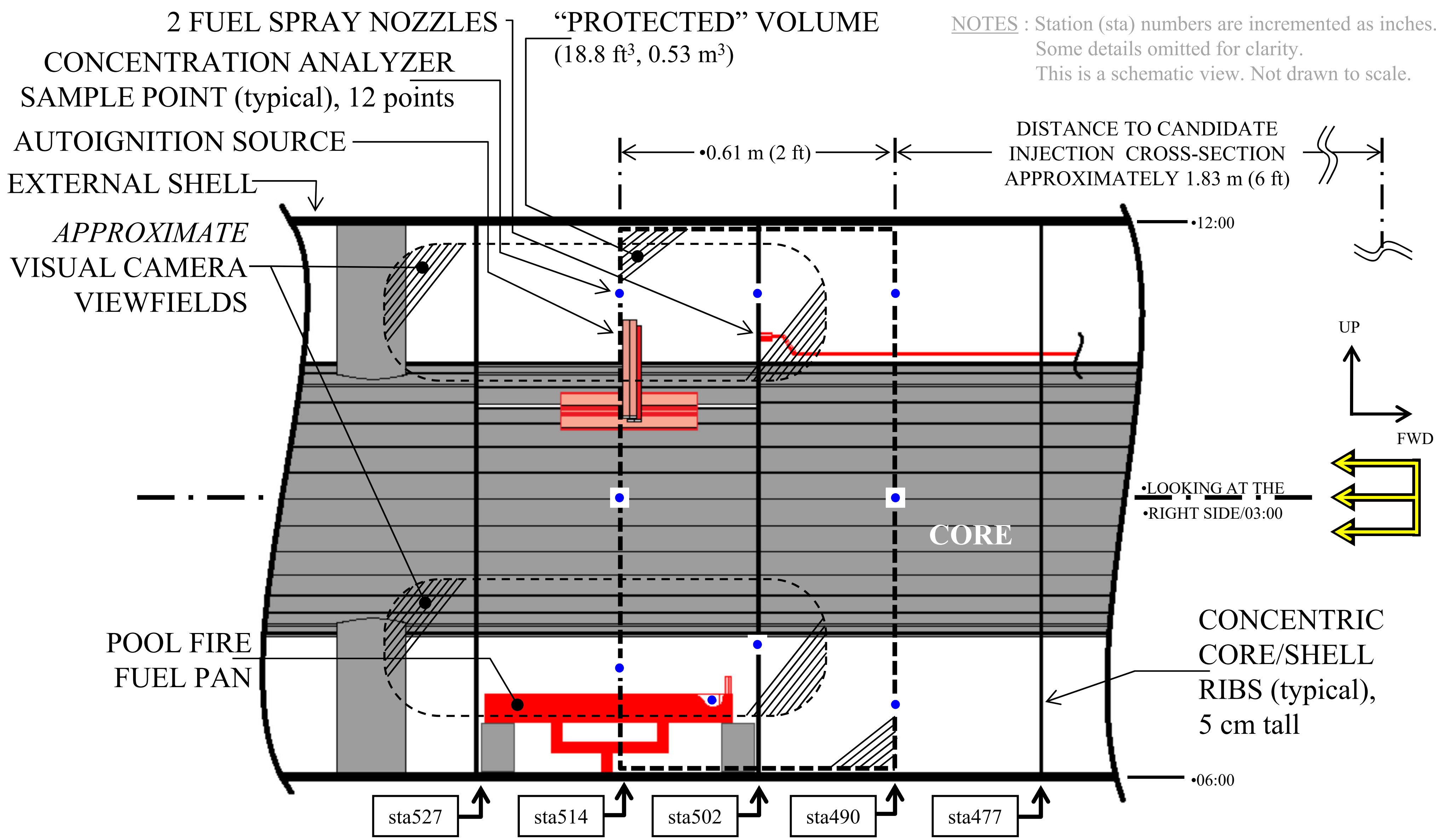
Generic Nacelle Fire Simulator, Pool Fire Threat



- Idealized fuel puddle dimensions are :
  - 27.4 cm (10.8 in) wide
  - 52.8 cm (20.8 in) long
  - 13 mm (0.5 in) deep
- Fuel puddle sits in/atop water-jacketed pan
- Fuel flow & electrical ignition arc are present during the migration of the fire-extinguishing agent pulse through the section
- Again, looking at/using the duration the fire is suppressed for comparison

Appendix

Generic Nacelle Fire Simulator, *MPSHRe/rev04* Concentration Sampling Geometry



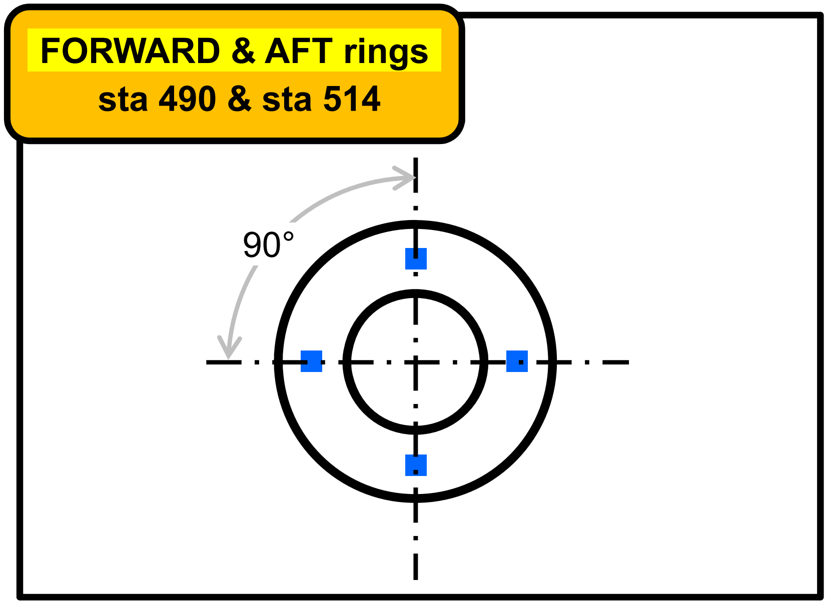
- 11 SAMPLE POINTS IN "FREE" STREAM APPROXIMATELY 0.15 m OFF THE CORE SURFACE
- 12TH SAMPLE POINT IS IN THE FWD WAKE REGION OF THE FUEL PAN
- "PROTECTED" VOLUME : ≈ 0.61 m LONG x 0.61 m ID x 1.2 m OD

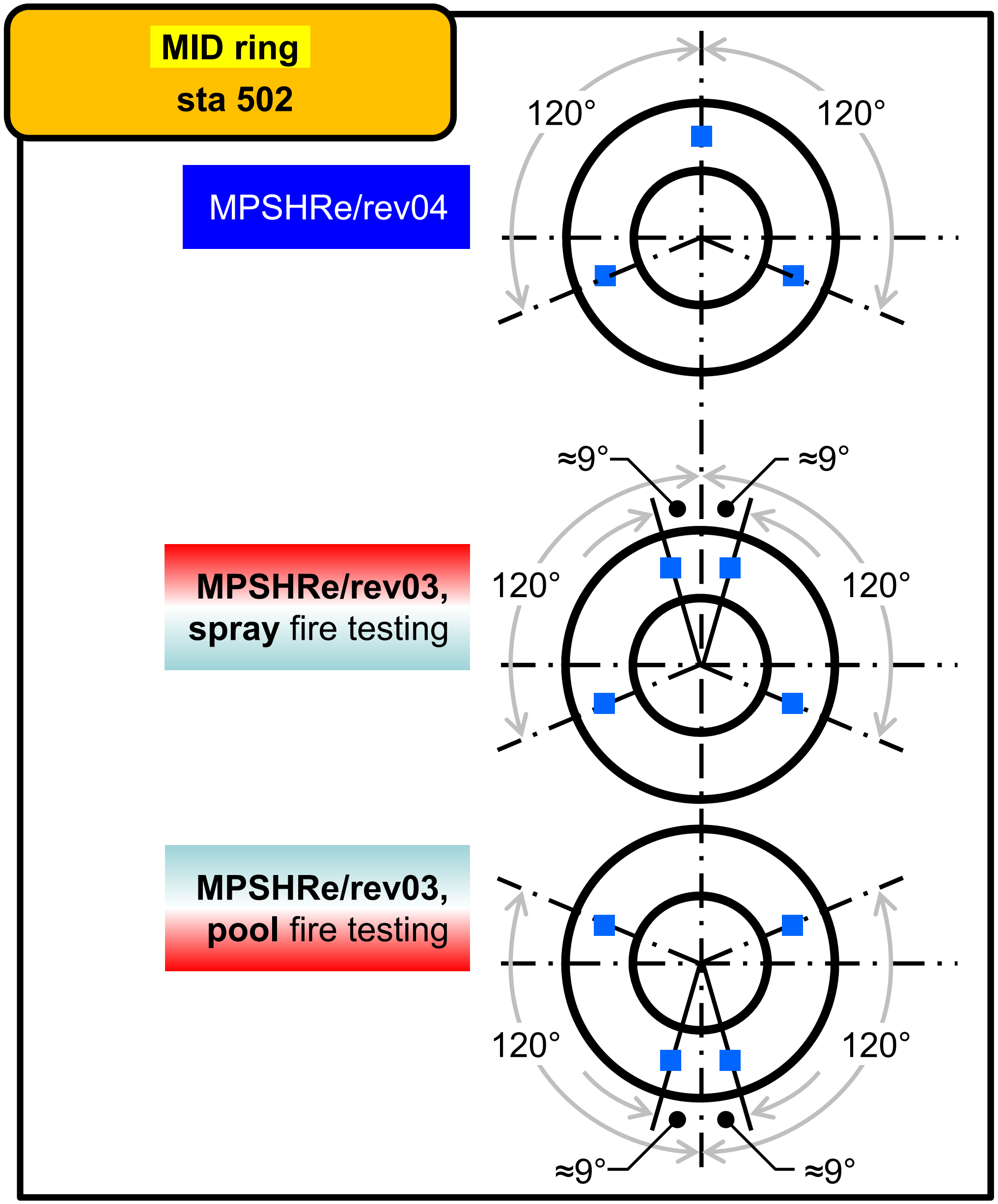
Appendix

Generic Nacelle Fire Simulator, Concentration Sampling Geometry, rev04 Versus rev03

NOTES :

1. Sample-point geometry on the forward [sta490] & aft [sta514] sample rings remained consistent for both MPSHRe revisions; 12:00, 03:00, 06:00, & 09:00.
2. MPSHRe/rev04's wake-region sample point nonexistent for MPSHRe/rev03 testing; point is aft of & below the fuel pan's forward lip
3. Sample points on the mid ring [sta502] changed between MPSHRe/rev04 & /rev03, & during MPSHRe/rev03 testing, this ring's orientation related to the type of fire threat present when testing.





Appendix

MPSHRe/rev04, test results, 4th condition

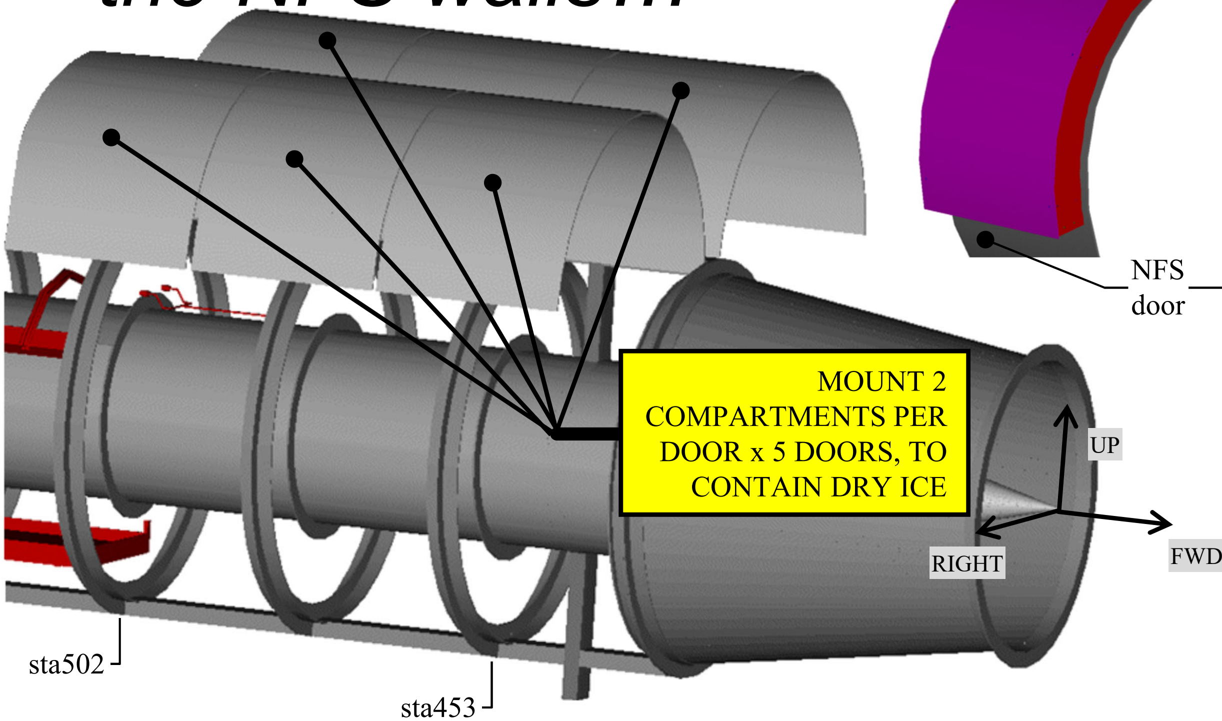
	3.1 lbf CF3I, 6.6%v/v average HSRVC CF3I	h1301 threshold, Low-vent/pool-fire	3.6 lbf CF3I, 7.0%v/v average HSRVC CF3I
HSRVC 01 :	7.5	n/a	6.8
02 :	6.8	n/a	7.4
03 :	5.9	n/a	6.7
04 :	6.3	n/a	none
average, HSRVC :	6.6	n/a	7.0
standard deviation :	0.69	n/a	0.38
RTD 01 :	4.87	n/a	5.47
02 :	5.67	n/a	6.11
03 :	5.08	n/a	7.24
04 :	5.50	n/a	5.63
05 :	5.53	n/a	5.10
average, RTD :	5.33	5.48	5.91
standard deviation :	0.339	0.725	0.827

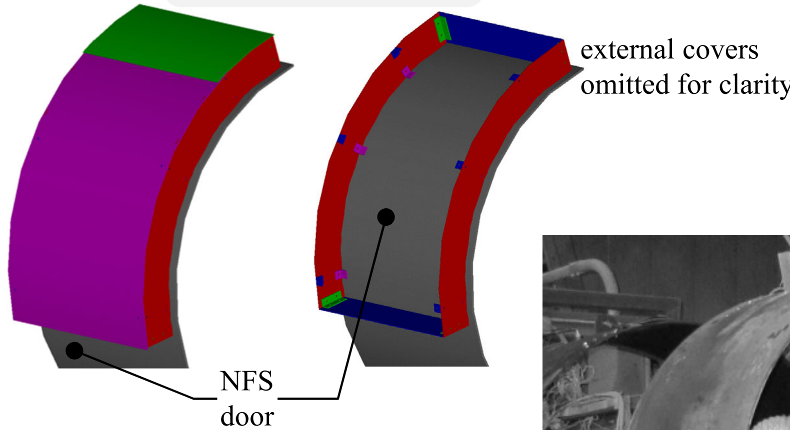
from : CF3IMax2022-BoeingDataPkg-FullSpectrumMPSHRe_rev04Results.xlsx

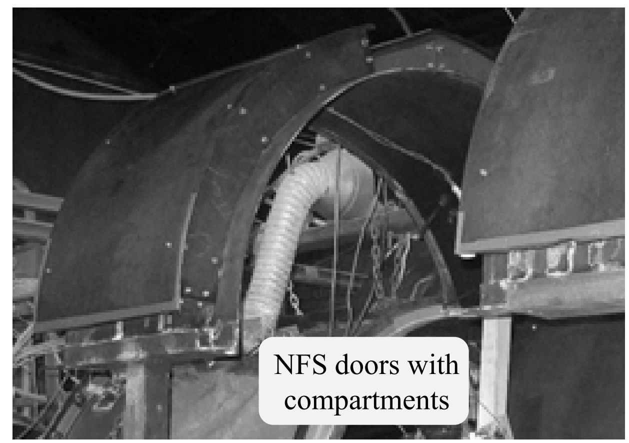
Appendix

Making things “cold”

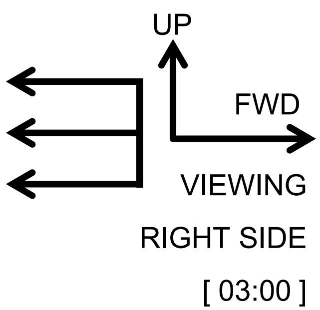
the NFS walls…







Dry-ice compartments loaded with dry ice already having chilled the FAATC gNFS shell; this is long after the test [typical]



Appendix

NFS telemetry, temperatures, surface-sensing