Halon Replacement

Federal Aviation Administration

FK-5-1-12 Fire Extinction Behavior Below Room Temperature in a Forced Flow

Presented to: Seventh Triennial International Fire & Cabin Safety Research Conference

By: Doug Ingerson, Testing Engineer

Date: 5 December 2013

Presentation Overview

- **Purpose & Basis**

- **Test Article Description**
  …test article, fire extinguishing system, telemetry

- **Test Conditions**
  …global test conditions

- **Test Results**
  …average values, observations, outcomes

Purpose & Basis

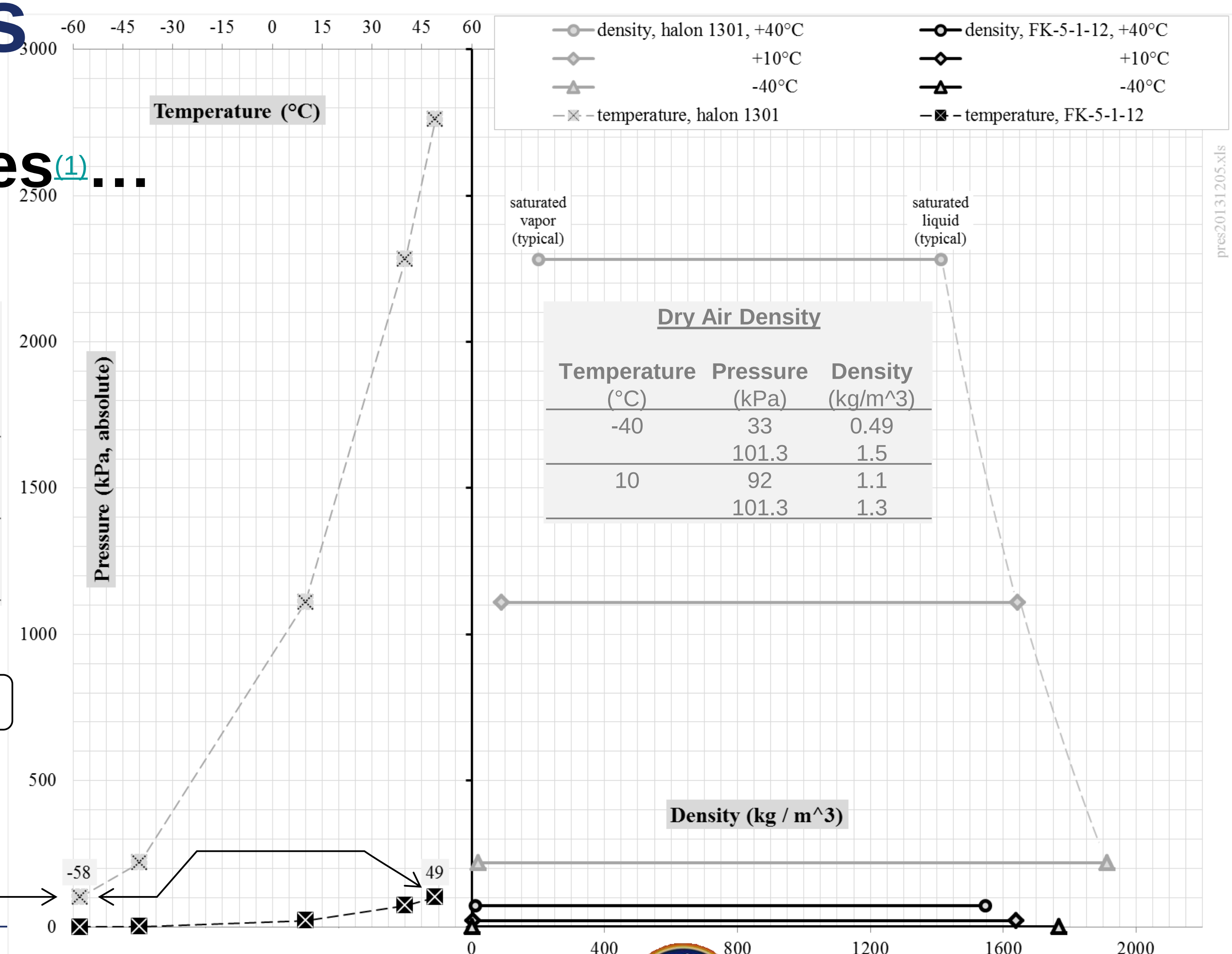
- **To investigate the <u>fire extinguishment</u> behavior of FK-5-1-12 in a forced flow at :**
  - full-scale
  - less than room temperature
    - “cool” ventilation
    - ”cold”/”cool” boundaries
    - “cold”/”cool” FK-5-1-12
- **The basis…**
  - FK-5-1-12 & halon 1301 are notably different
  - A witnessed temperature-associated phenomena…

Purpose & Basis

Differences[(1)]…

Reported Experimental Extinguishment Concentrations[(2)]

Parameter (%v/v)	Firex Agent FK-5-1-12	halon 1301
Cup Burner (n-Heptane)	4.5	3.3
Peak Inerting (propane)	8.1	6.1



Dry Air Density

Temperature (°C)	Pressure (kPa)	Density (kg/m^3)
-40	33	0.49
	101.3	1.5
10	92	1.1
	101.3	1.3

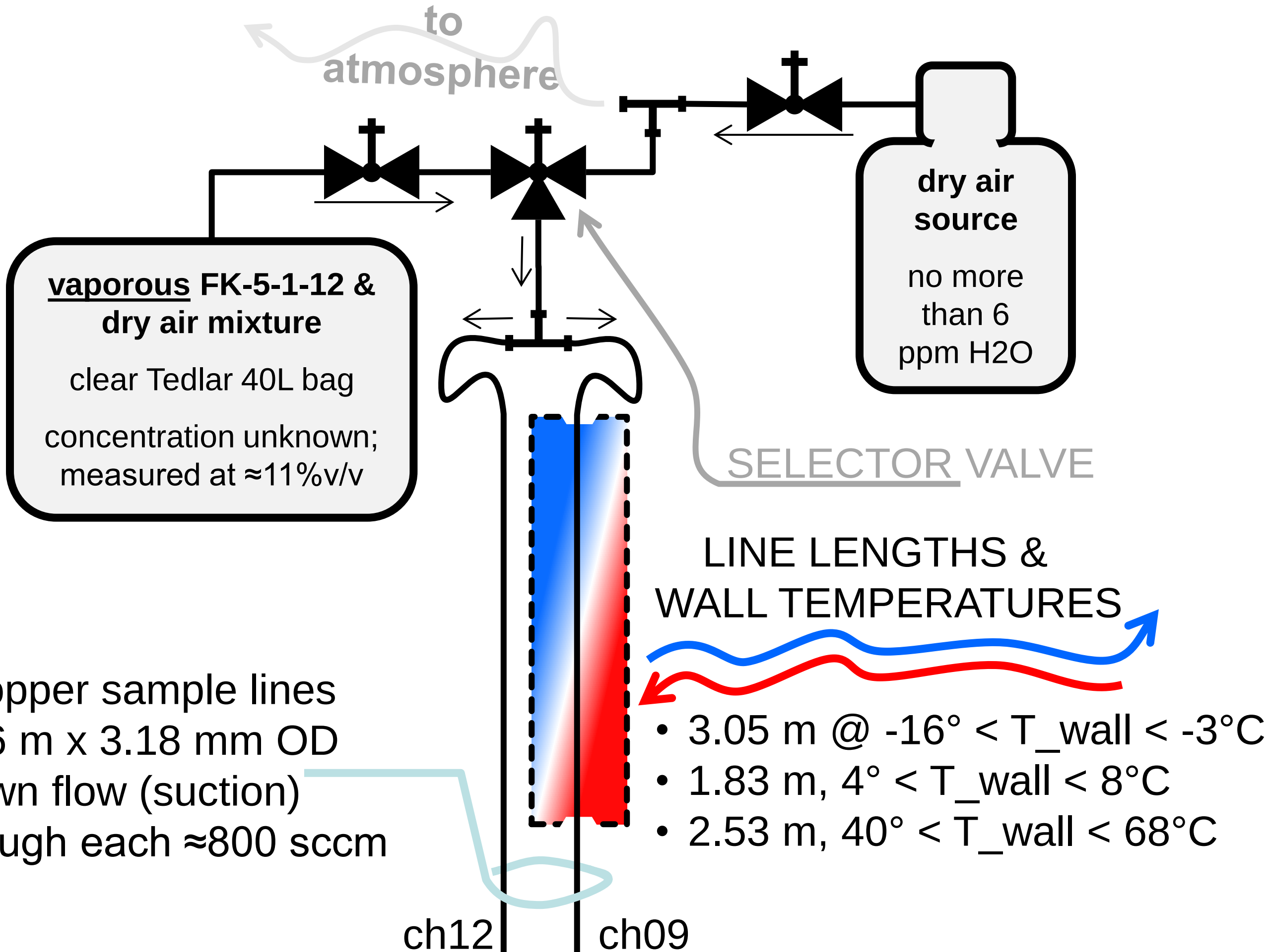
Purpose & Basis

A witnessed phenomena (2006)…

- **Test configuration & conditions**
- **Behaviors & observations**

Purpose & Basis

Configuration & conditions



- 2 copper sample lines
- 3.66 m x 3.18 mm OD
- drawn flow (suction) through each ≈800 sccm

FAA-owned, MSSI/Pacific Scientific Halonyzer II Sensors

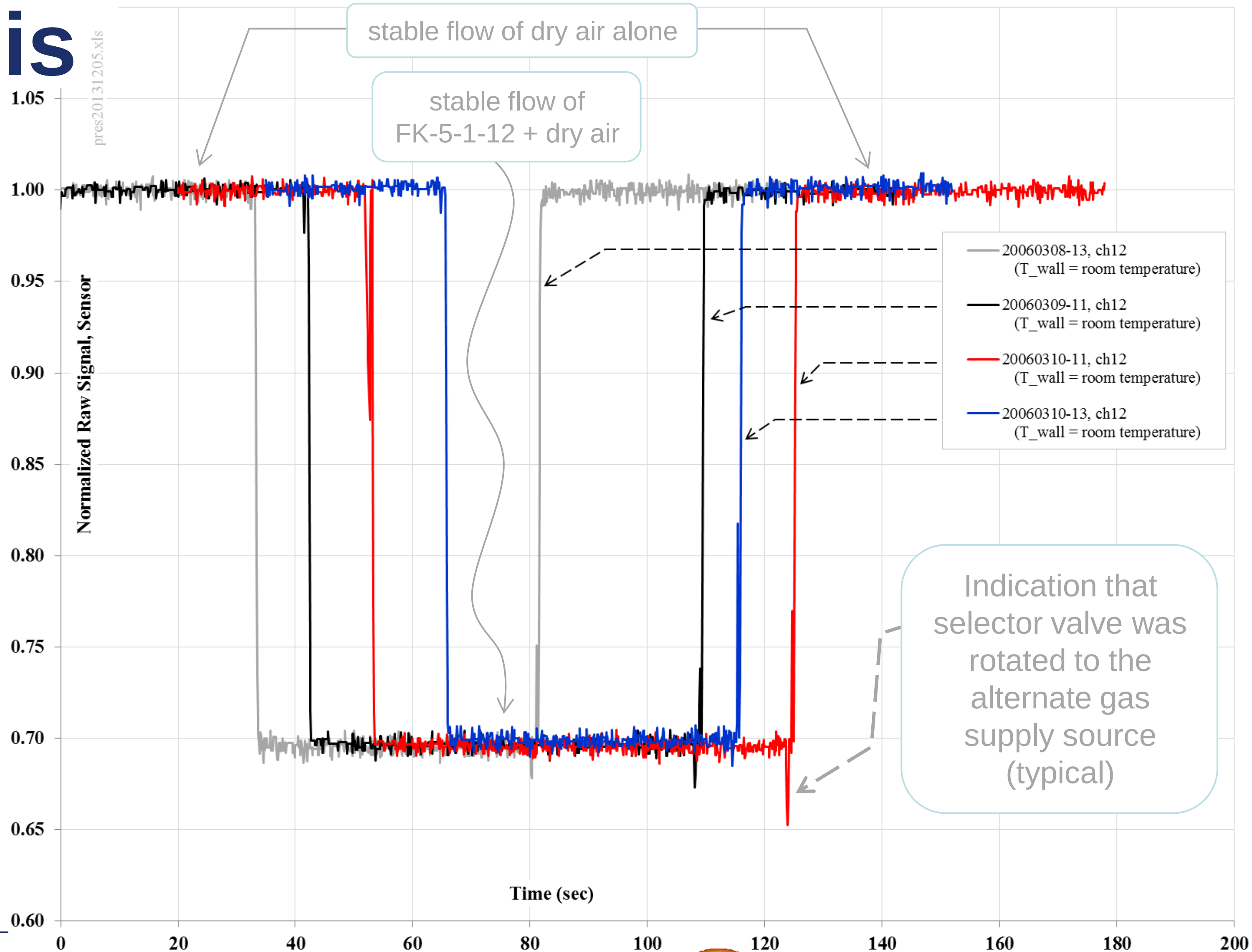
ch = channel, as in a channel number
MSSI = Meggitt Safety Systems Inc.
OD = outside diameter
T_wall = wall temperature of copper sample line

Purpose & Basis

Comparing channel **12** behaviors…

…all looks reasonable…

…concentration calculated at 11.2%v/v



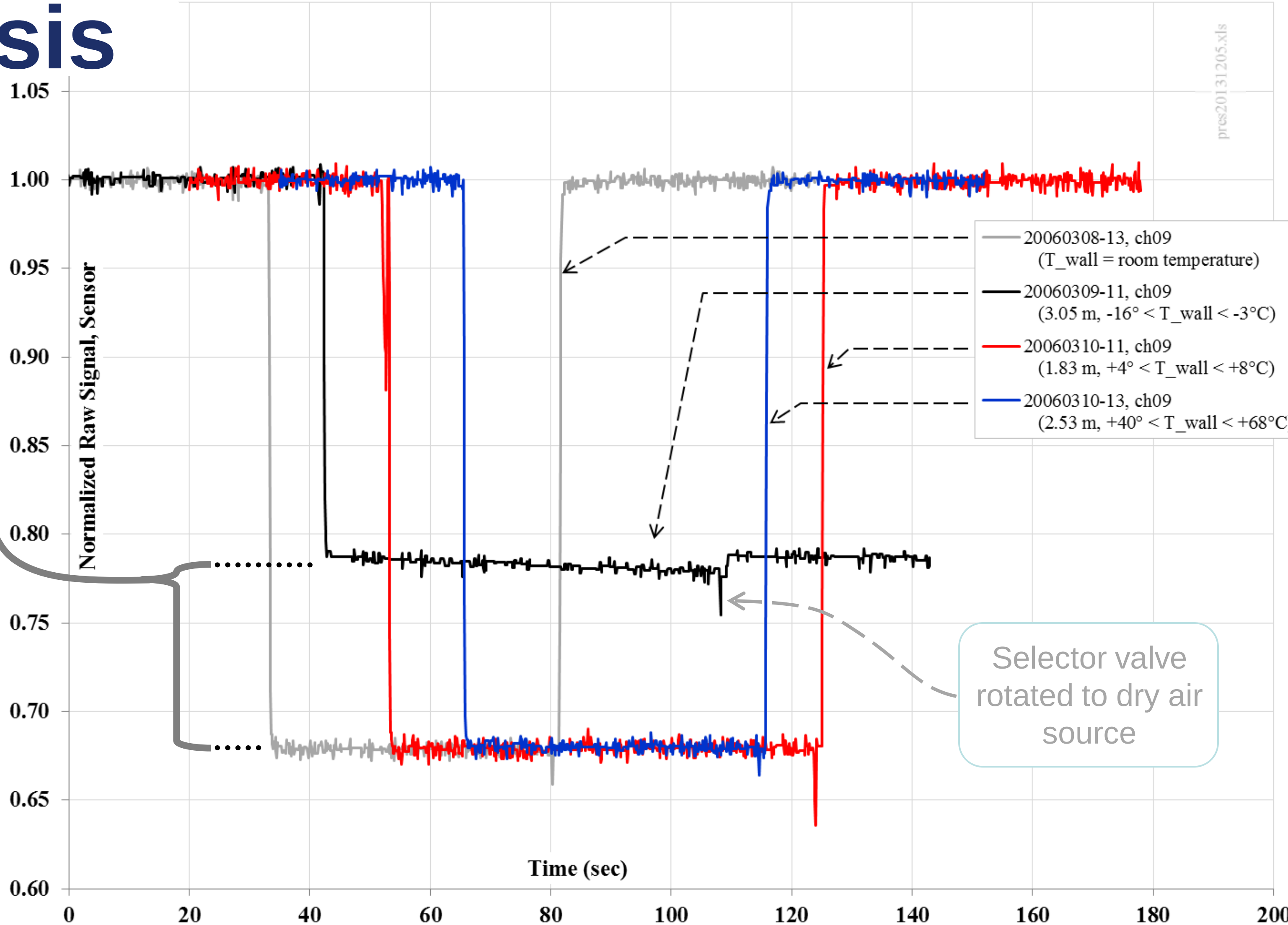
Purpose & Basis

Comparing channel **09** behaviors…

…roughly a 33% reduction in RAW signal…

…<u>initially-“warm” mass lost from vapor phase to “cool” wall</u>…

…concentration calculated at 5.8%v/v; roughly a 48% loss in indicated concentration



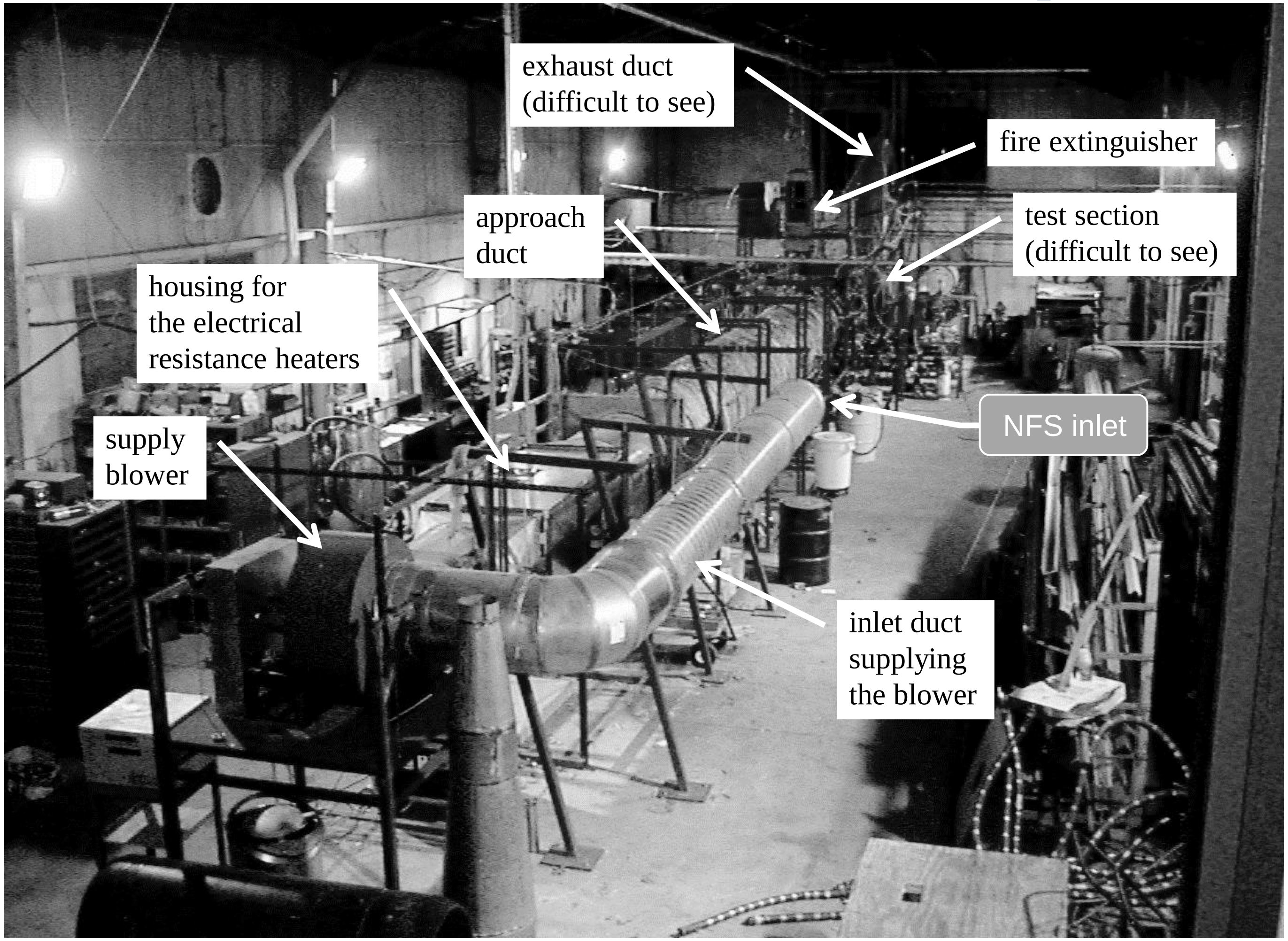
Test Article Description

Details of the full-scale testing (2011)

- Nacelle fire simulator (NFS) global orientation
- Making things "cold"
- Test telemetry package

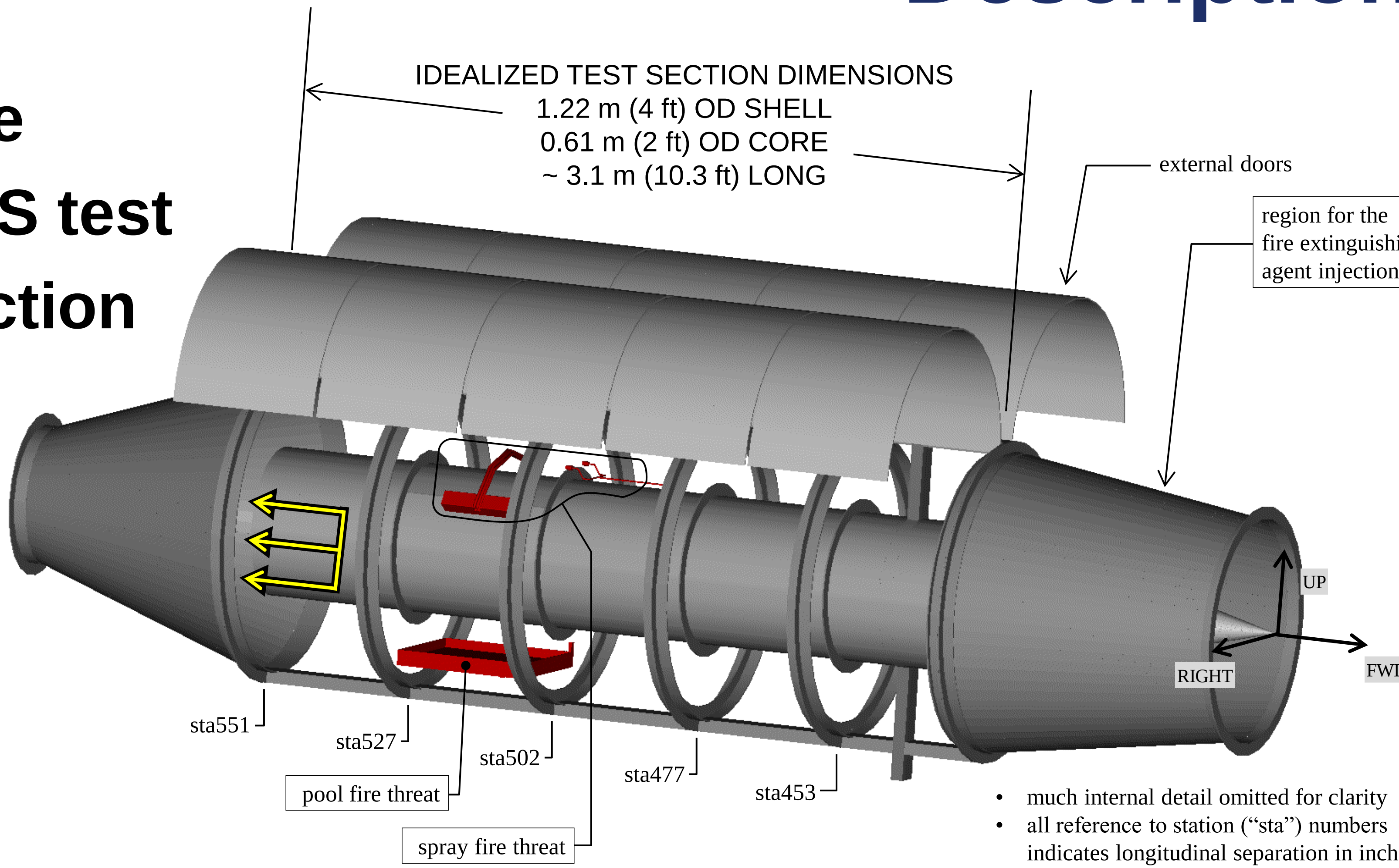
Test Article Description

The complete NFS



Test Article Description

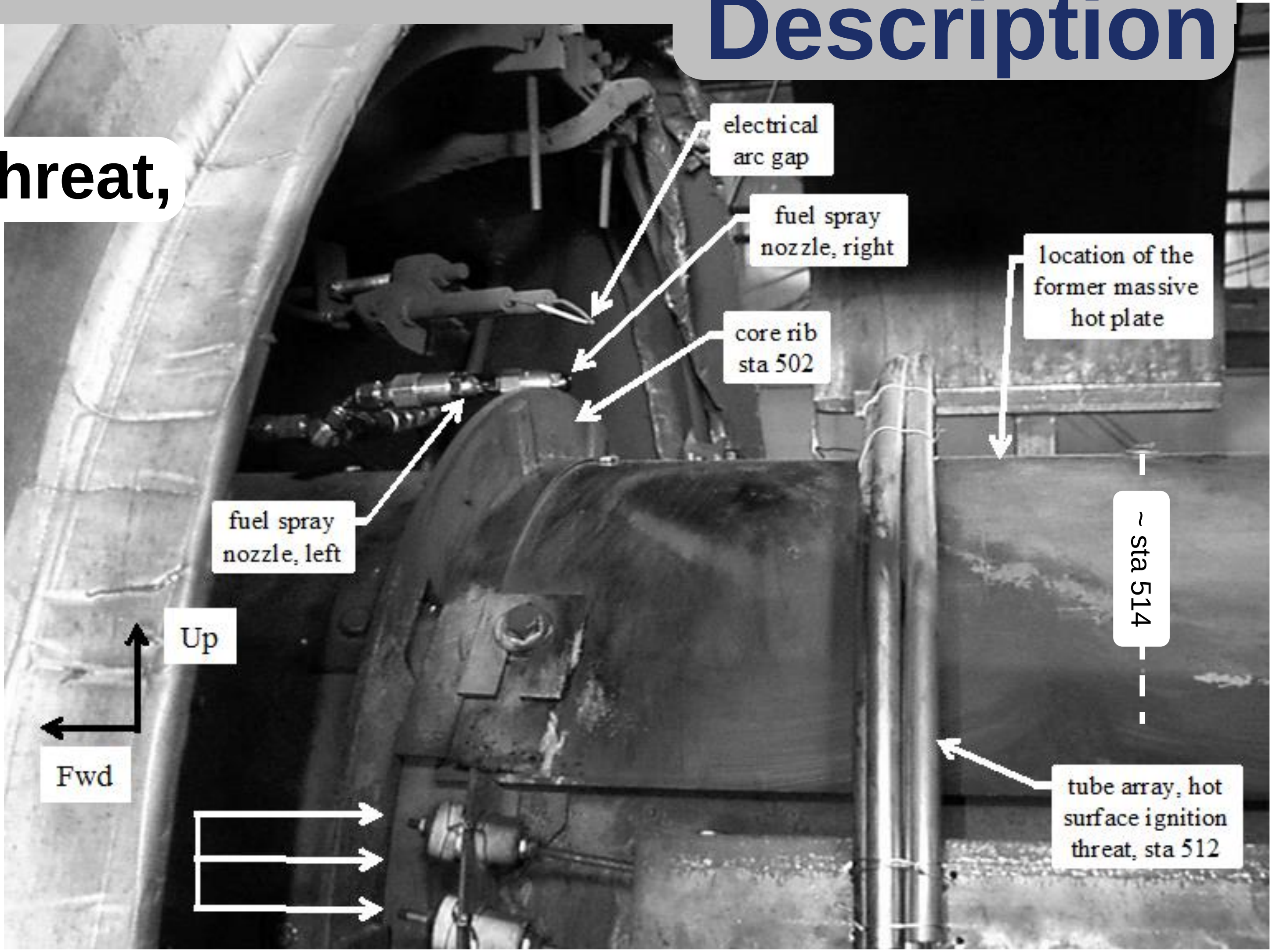
The NFS test section



- much internal detail omitted for clarity
- all reference to station ("sta") numbers indicates longitudinal separation in inches

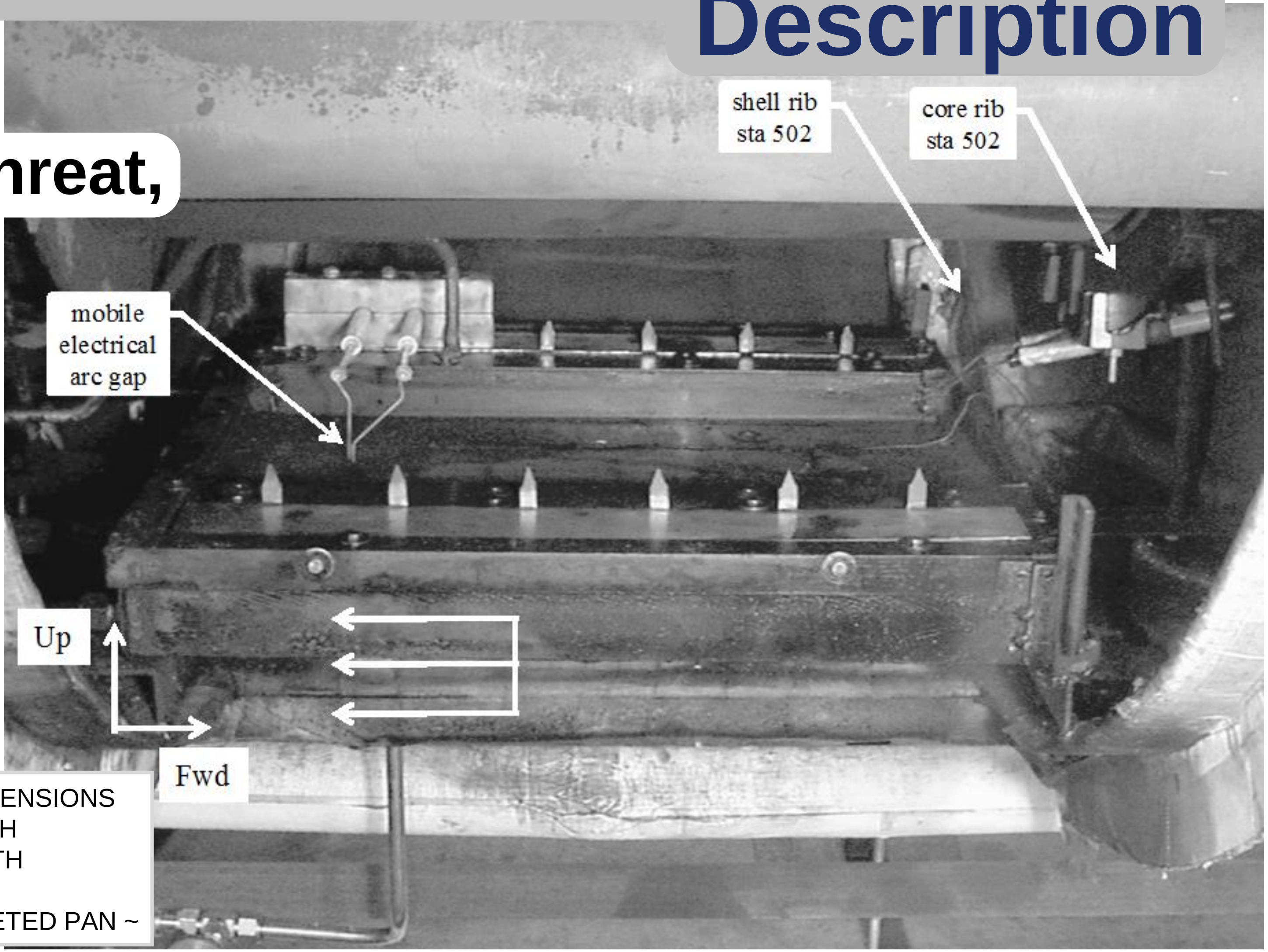
Test Article Description

NFS fire threat, spray



Test Article Description

NFS fire threat, pool

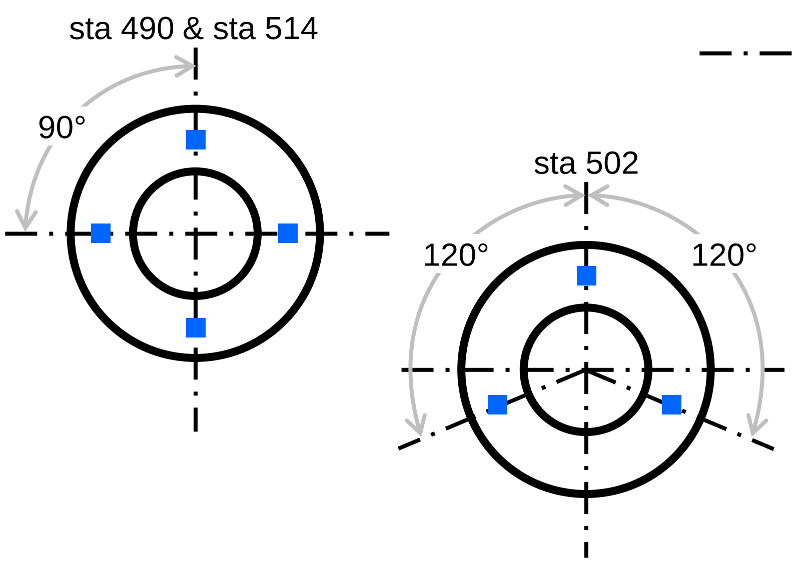


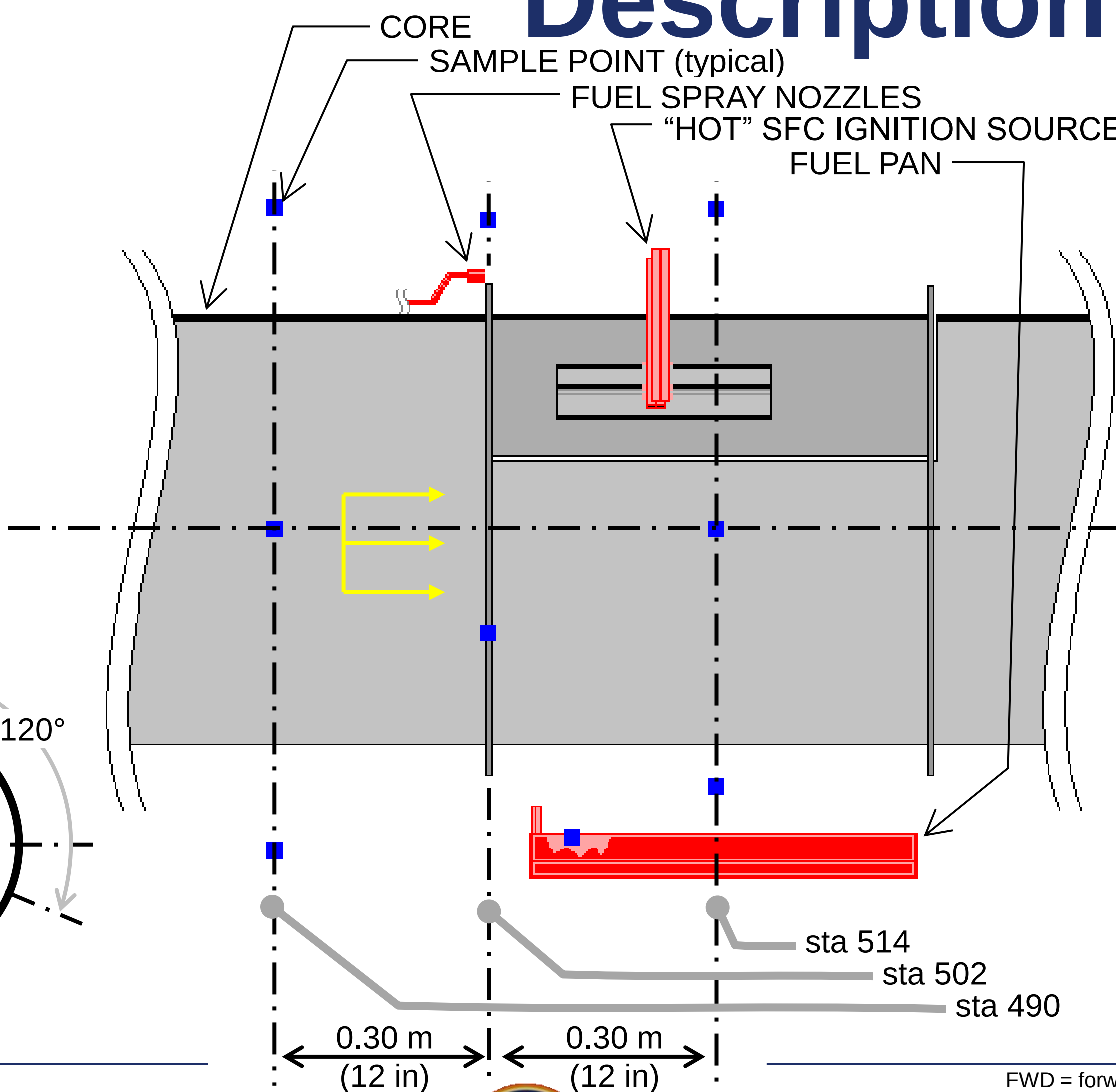
IDEALIZED FUEL PUDDLE DIMENSIONS
27.4 cm (10.8 in) WIDTH
52.8 cm (20.8 in) LENGTH
13 mm (0.5 in) DEPTH
~ FUEL SITS IN A WATER-JACKETED PAN ~

- CONCENTRIC CORE & SHELL, 0.61 m (2 ft) OD CORE, 1.2 m (4 ft) OD SHELL
- 11 SAMPLE POINTS IN "FREE" STREAM (roughly 0.15 m off core sfc)
- 12TH SAMPLE POINT IS IN THE WAKE REGION OF THE FUEL PAN FWD LIP
- "PROTECTED" VOLUME ≈ 0.61 m LONG x 0.61 m ID x 1.2 m OD

Test Article Description

Defining the Fire Extinguishment System

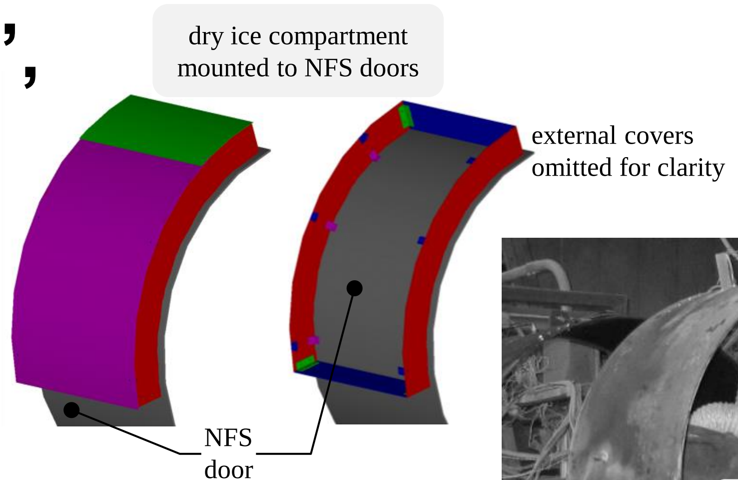


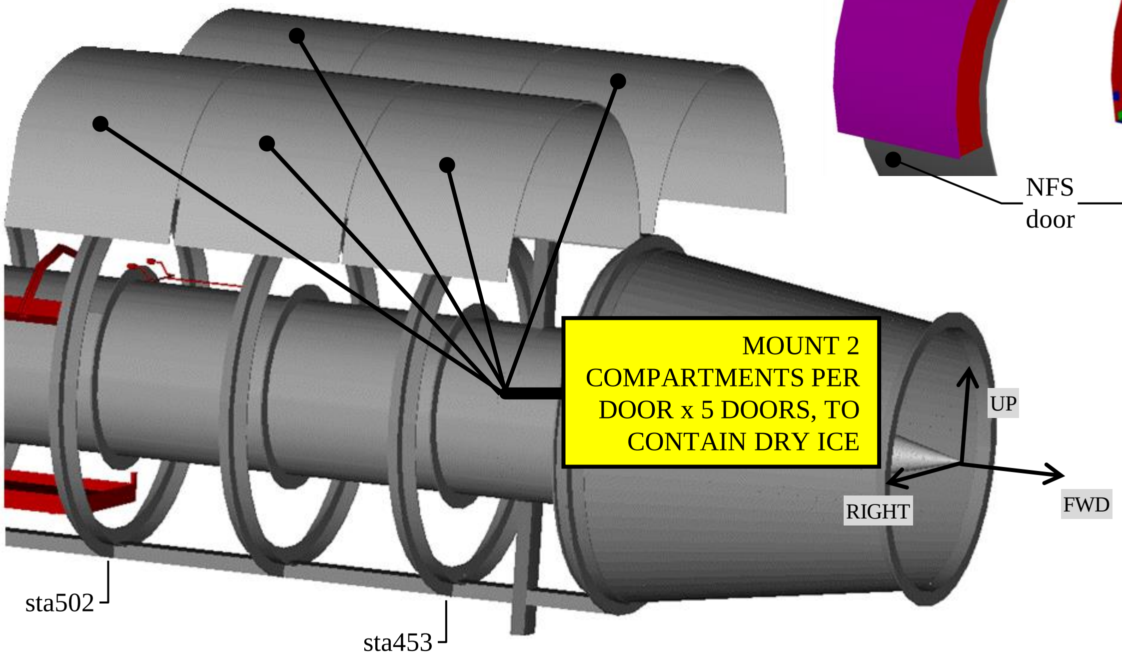


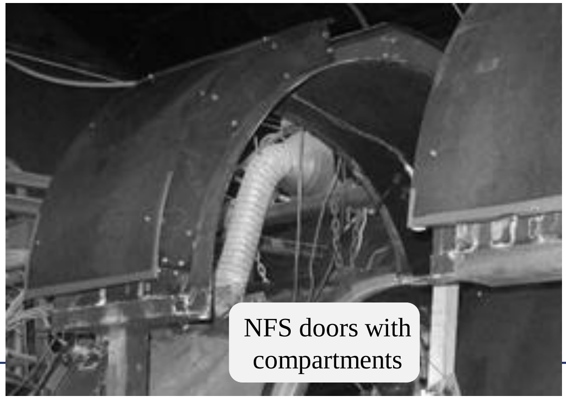
FWD = forward
SFC = surface

Test Article Description

Making things "cold",
the NFS walls…







Test Article Description

Making things "cold",

the FK-5-1-12…

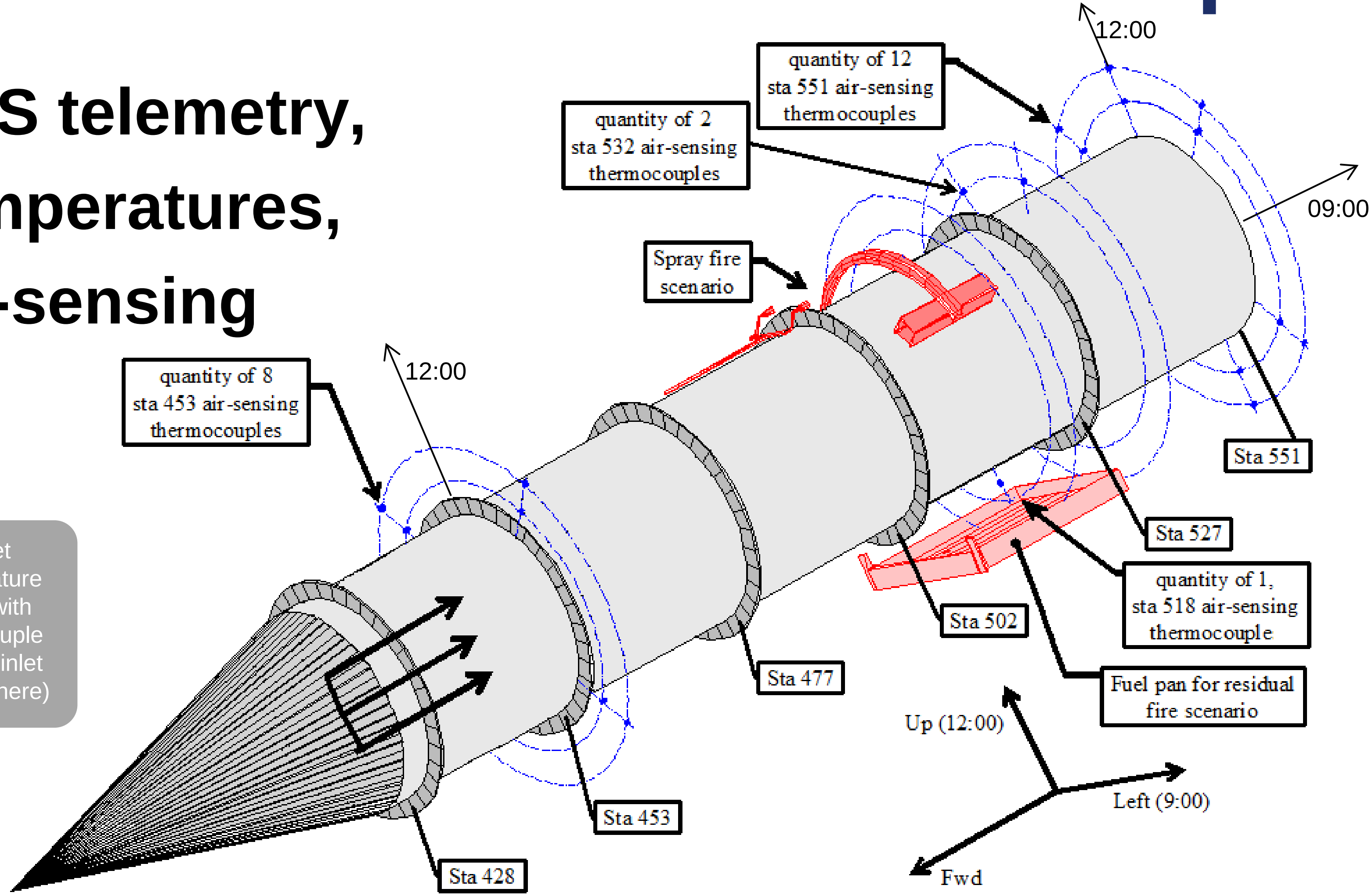
dry ice
(solid carbon dioxide)

MSSI/Pacific Scientific fire extinguisher
bottle and valve assemblies
containing FK-5-1-12 & nitrogen gas

MSSI = Meggitt Safety Systems Inc.

Test Article Description

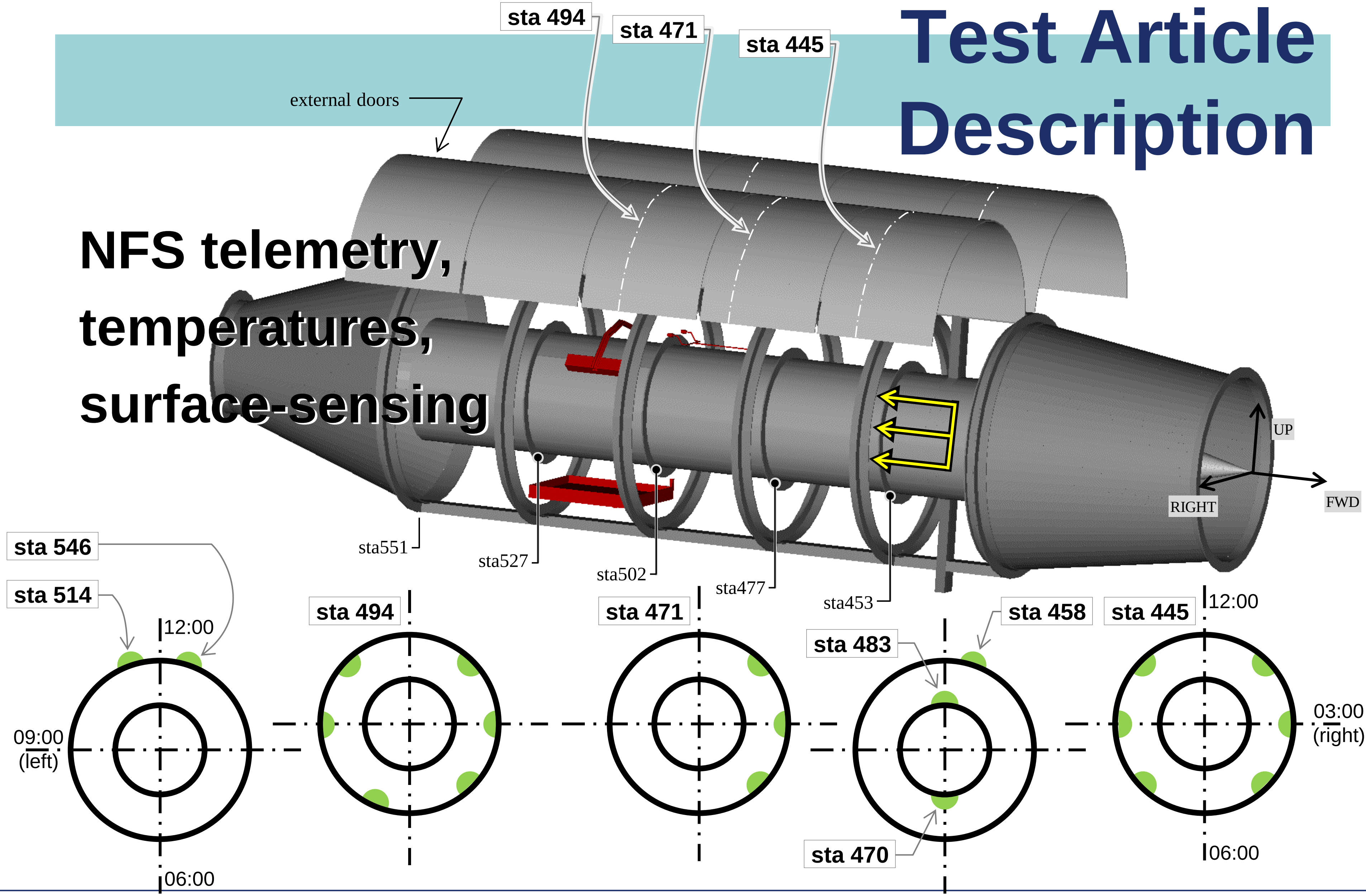
NFS telemetry, temperatures, air-sensing



NFS inlet air temperature captured with 1 thermocouple at the NFS inlet (not shown here)

Test Article Description

NFS telemetry, temperatures, surface-sensing



Test Article Description

NFS telemetry, fire extinguisher temperature & pressure

PRESSURE TRANSDUCER

SURFACE-MOUNTED THERMOCOUPLE (frx btl shell)

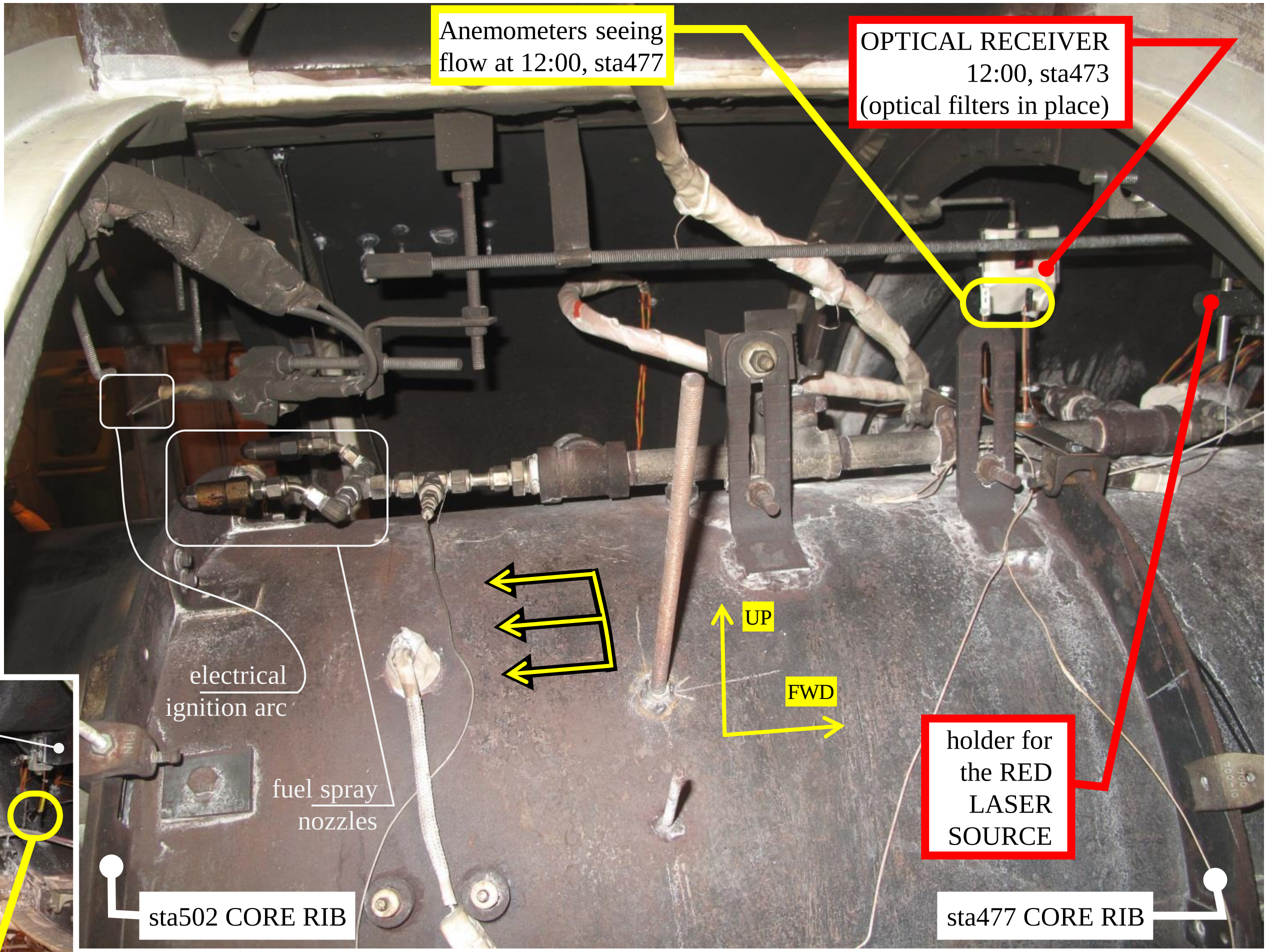
PLUMBING ASSEMBLY USED TO SENSE INTERNAL TEMPERATURE & PRESSURE

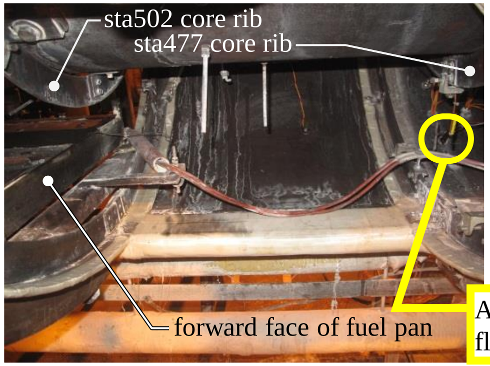
TAP FOR PRESSURE TRANSDUCER

THERMOCOUPLE TIP for internal temperature measurement (frx btl interior)

Test Article Description

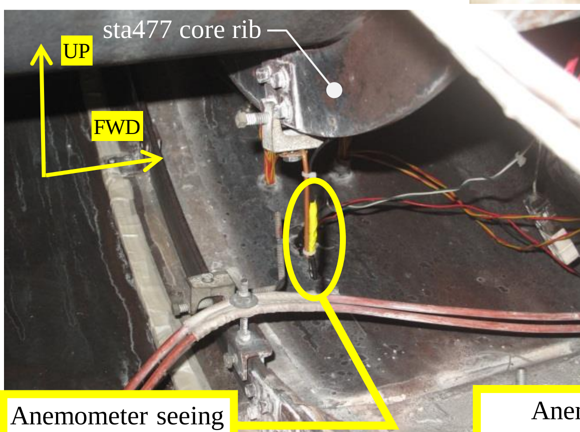
NFS telemetry, global view, optics & anemometry, <u>spray</u> fire region

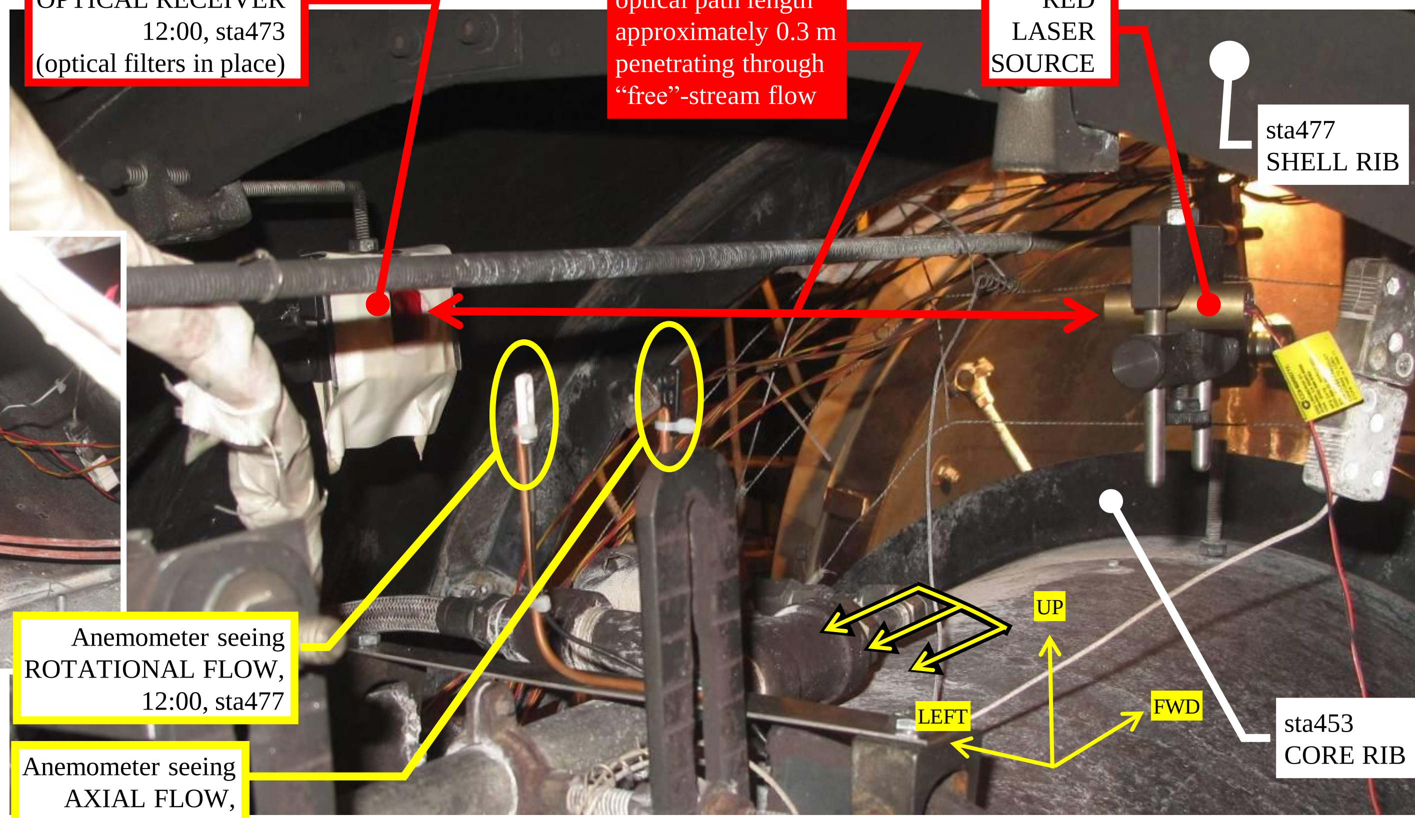




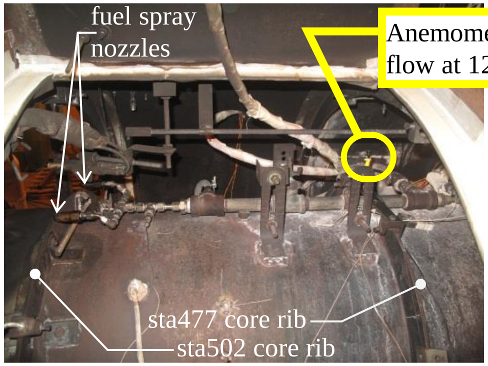
Test Article Description

NFS telemetry, optics & anemometry, spray fire region

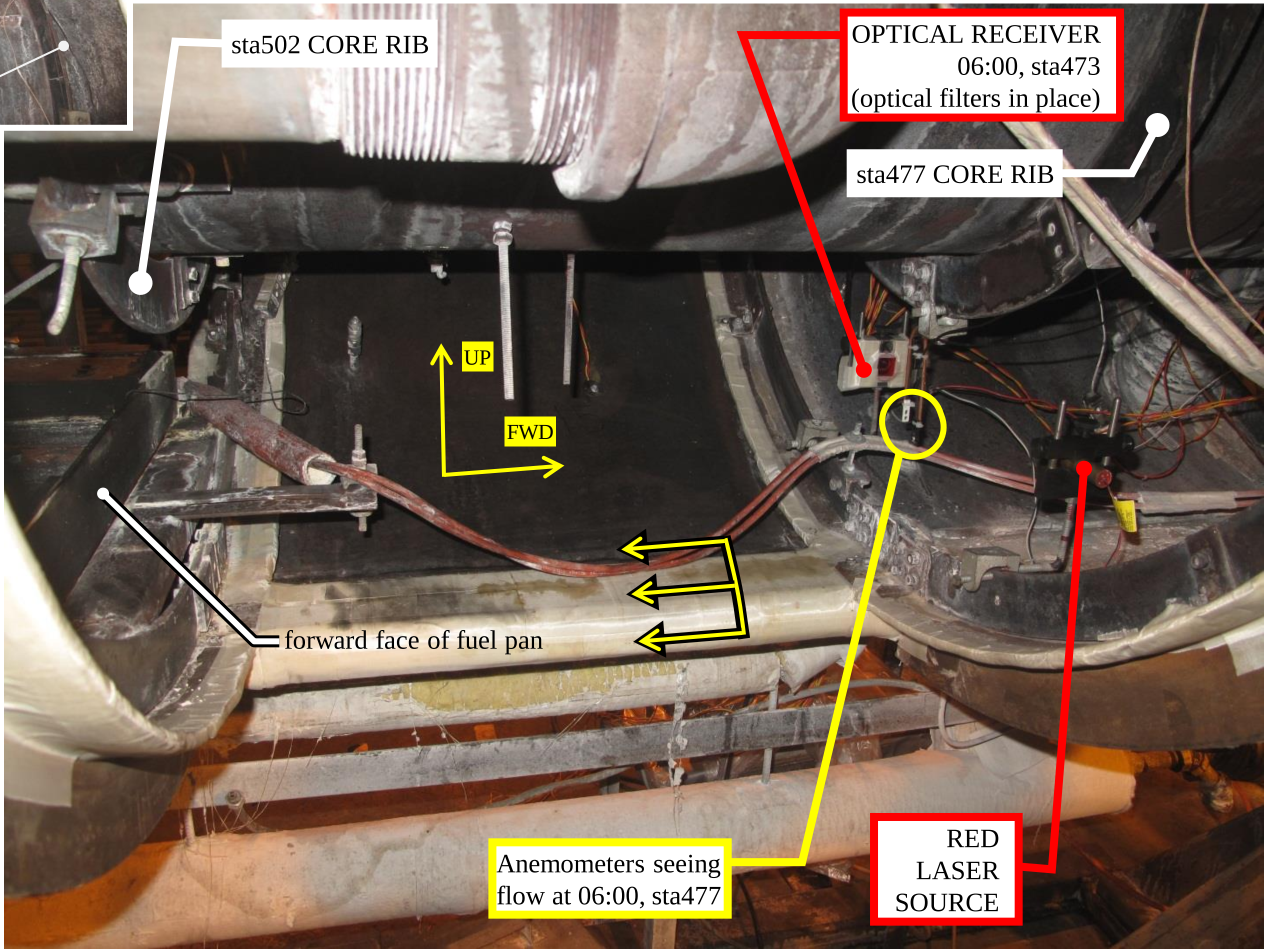




Test Article Description

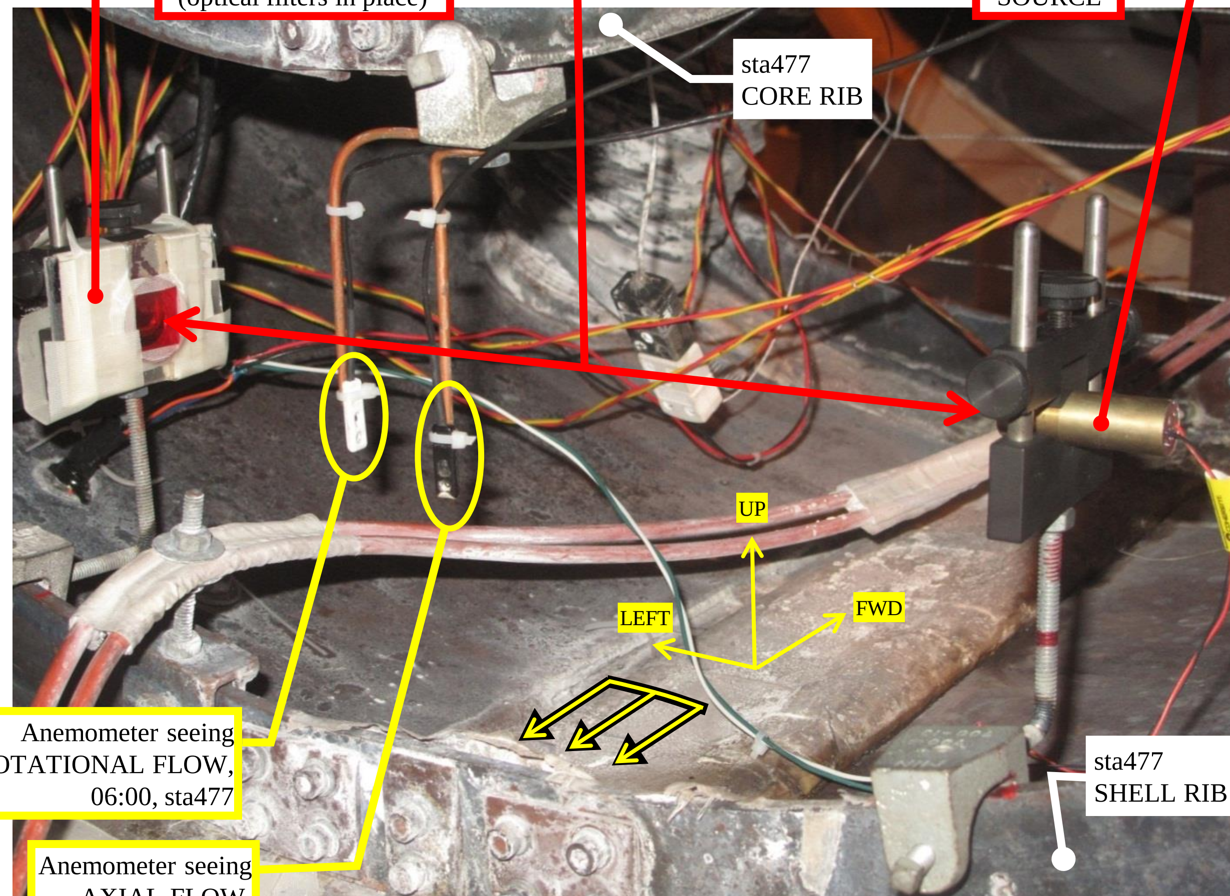


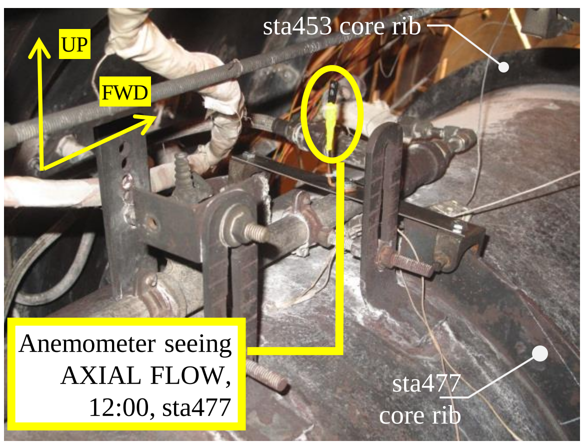
NFS telemetry, global view, optics & anemometry, <u>pool</u> fire region



Test Article Description

NFS telemetry, optics & anemometry, pool fire region

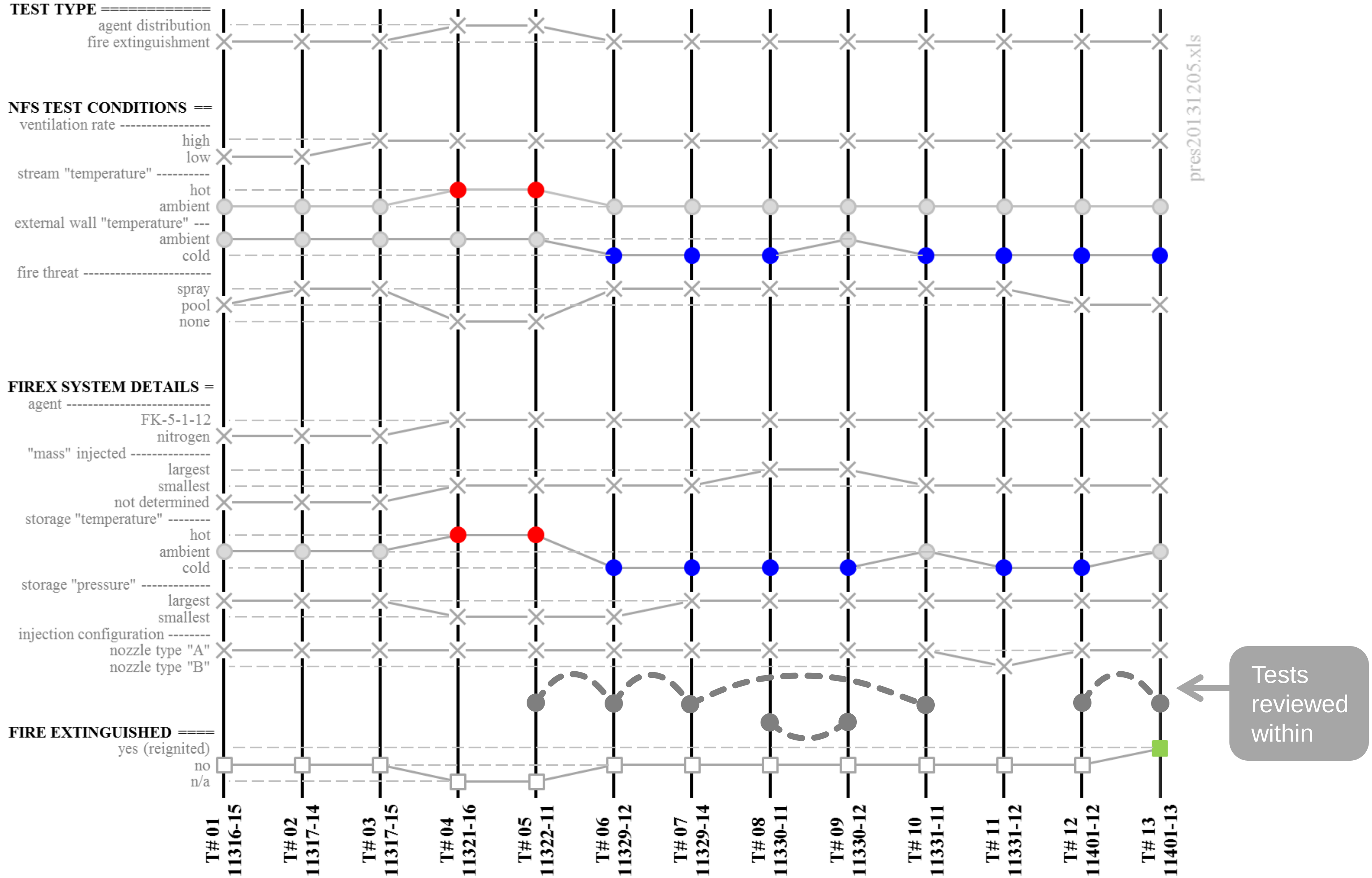




Test Conditions

- **General global conditions**
  – NFS air mass flow ≈ 1.4 kg/s @ 1 atm, T≈8° or 47°C
  – injected FK-5-1-12 masses of 4.3 or 6.4 kg
- **Limited comparative review accomplished here**
  – 13 total tests completed
  – 8 tests reviewed here to assess FK-5-1-12 behavior
    - 6 tests related to a spray fire
      – 4 tests usefully group; tied to the lineage of the pool fire testing
      – 2 other tests usefully group; of their own lineage
    - 2 tests related to a pool fire

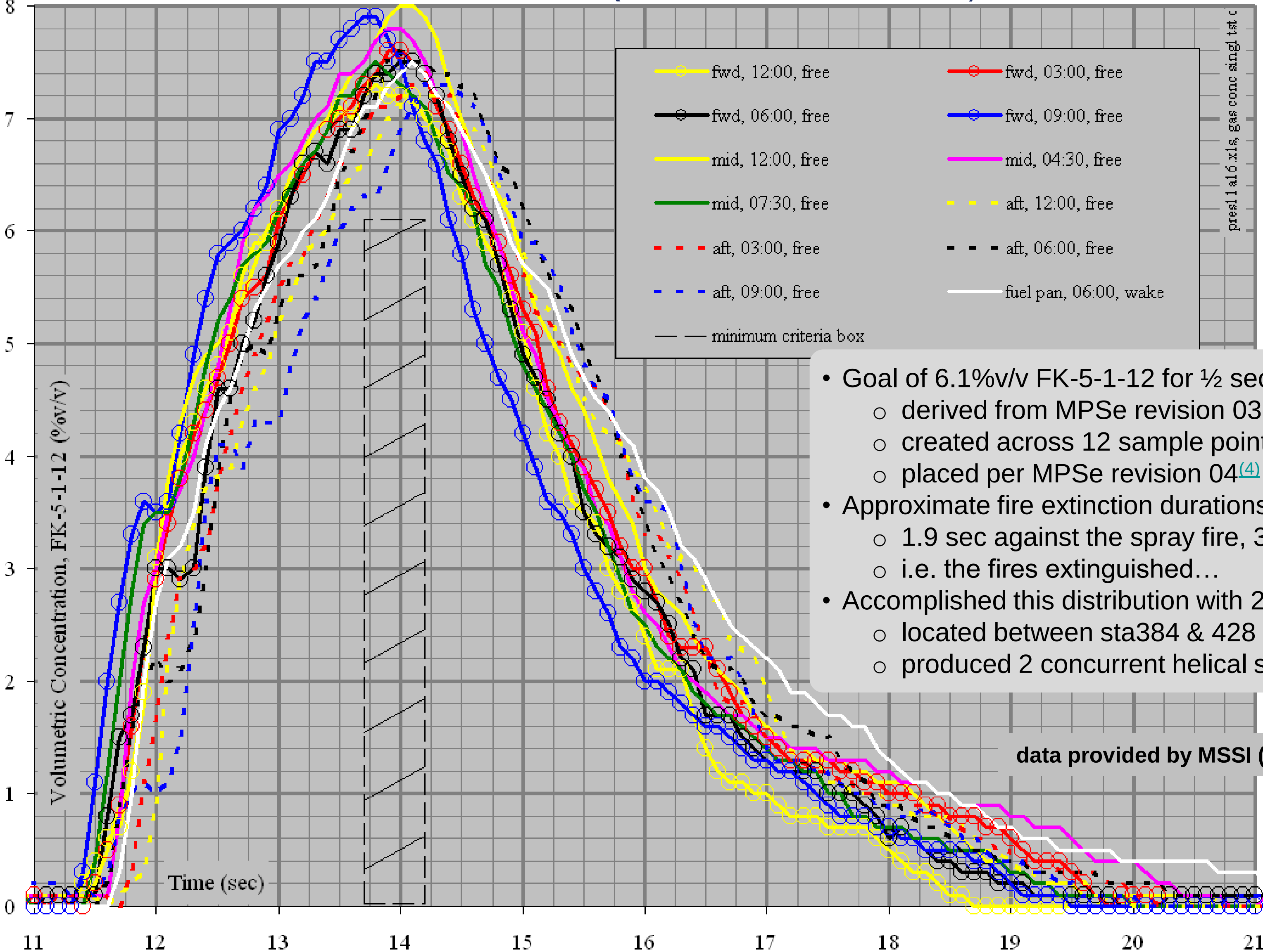
Test Conditions



Test Results (graphical & tabular data)

- **Looking at select tests**
  - illustrating some behaviors
    - FK-5-1-12 distribution in the flow when all “hot”/ambient
    - injection plume insults on the environment :
      - thermally via type-K thermocouples
      - flow speeds via hot-wire anemometry
    - aerosol existence via light obscuration
  - explaining the bases of calculated single-point values
  - collectively review these values for global comparisons

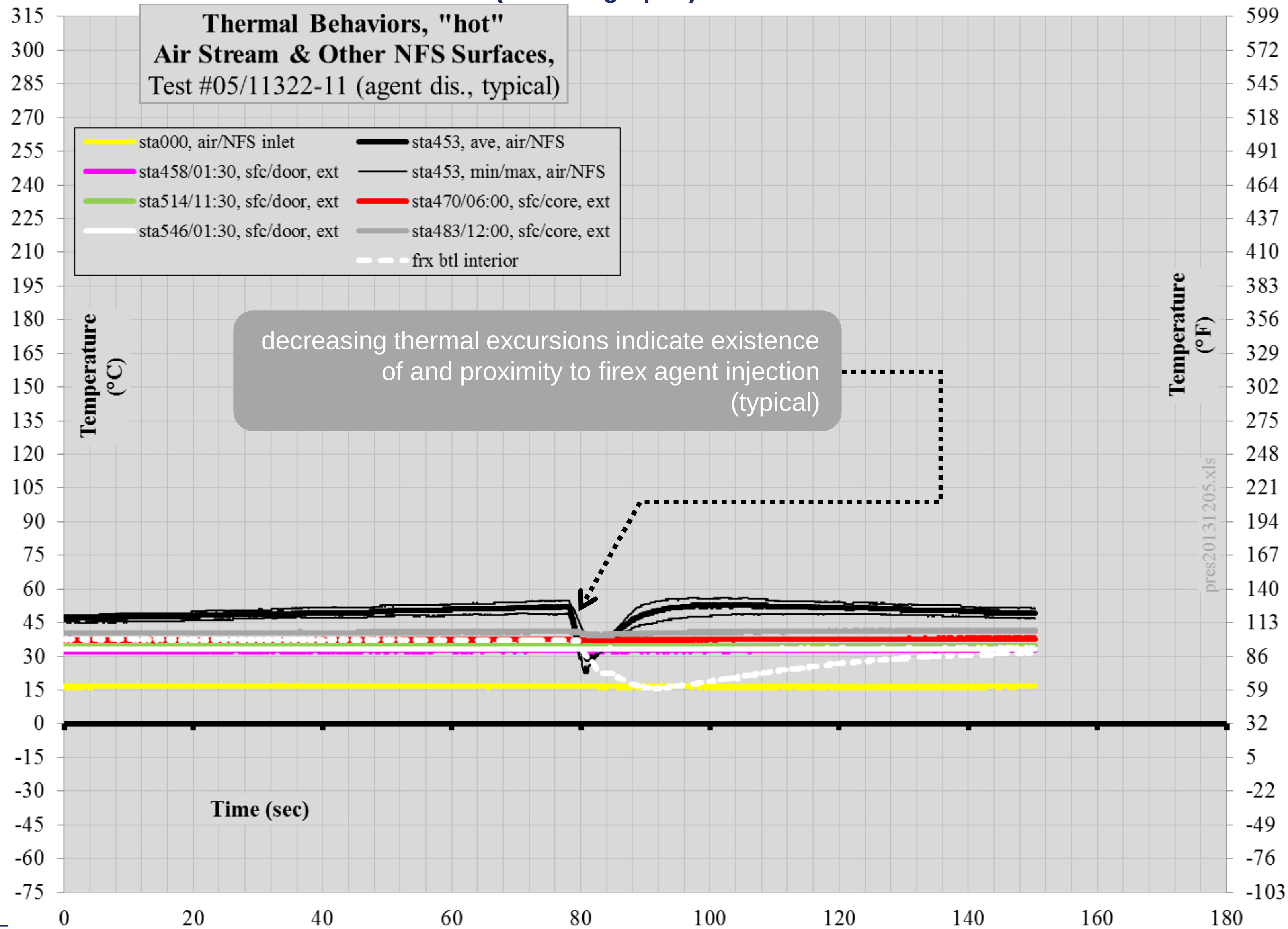
Test Results (FK-5-1-12 “hot” distribution)



- Goal of 6.1%v/v FK-5-1-12 for ½ second
  - derived from MPSe revision 03 testing[3]
  - created across 12 sample points in the NFS
  - placed per MPSe revision 04[4]
- Approximate fire extinction durations from MPSe revision 03
  - 1.9 sec against the spray fire, 3.4 sec against the pool
  - i.e. the fires extinguished…
- Accomplished this distribution with 2 injection nozzles
  - located between sta384 & 428
  - produced 2 concurrent helical swirls

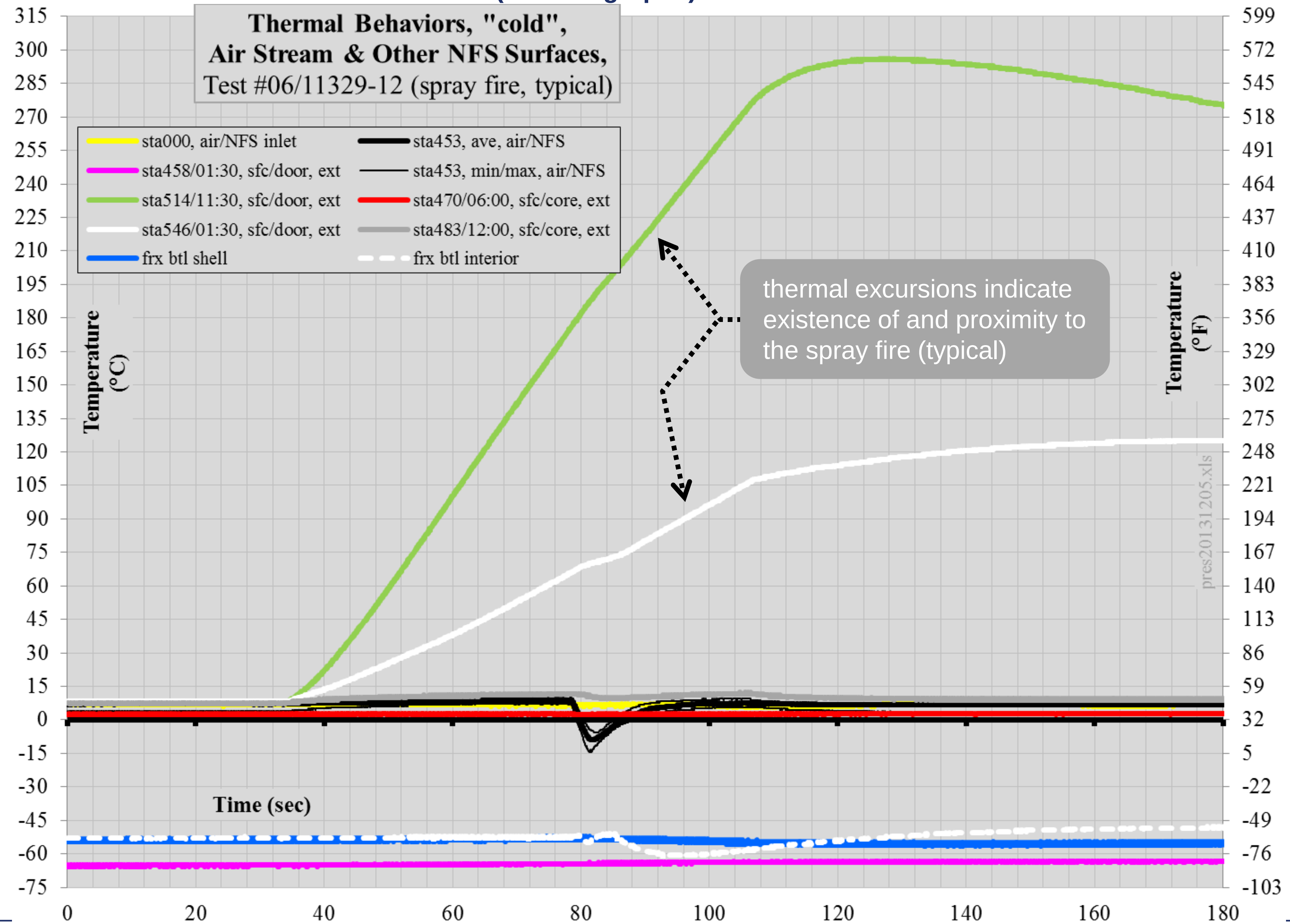
review slide 14 for telemetry details

Test Results (thermal graphs)

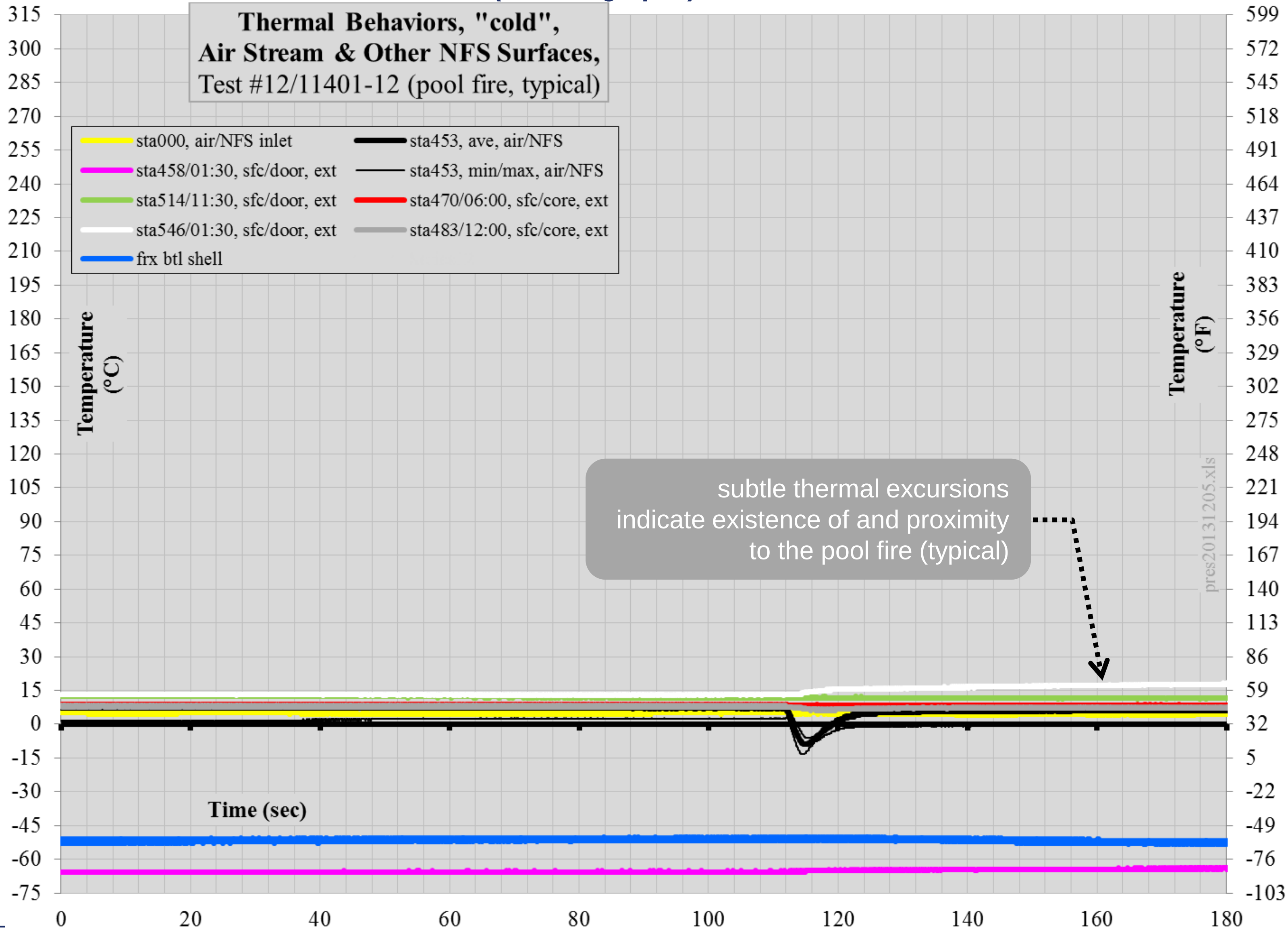


review slides 17-19 for telemetry details

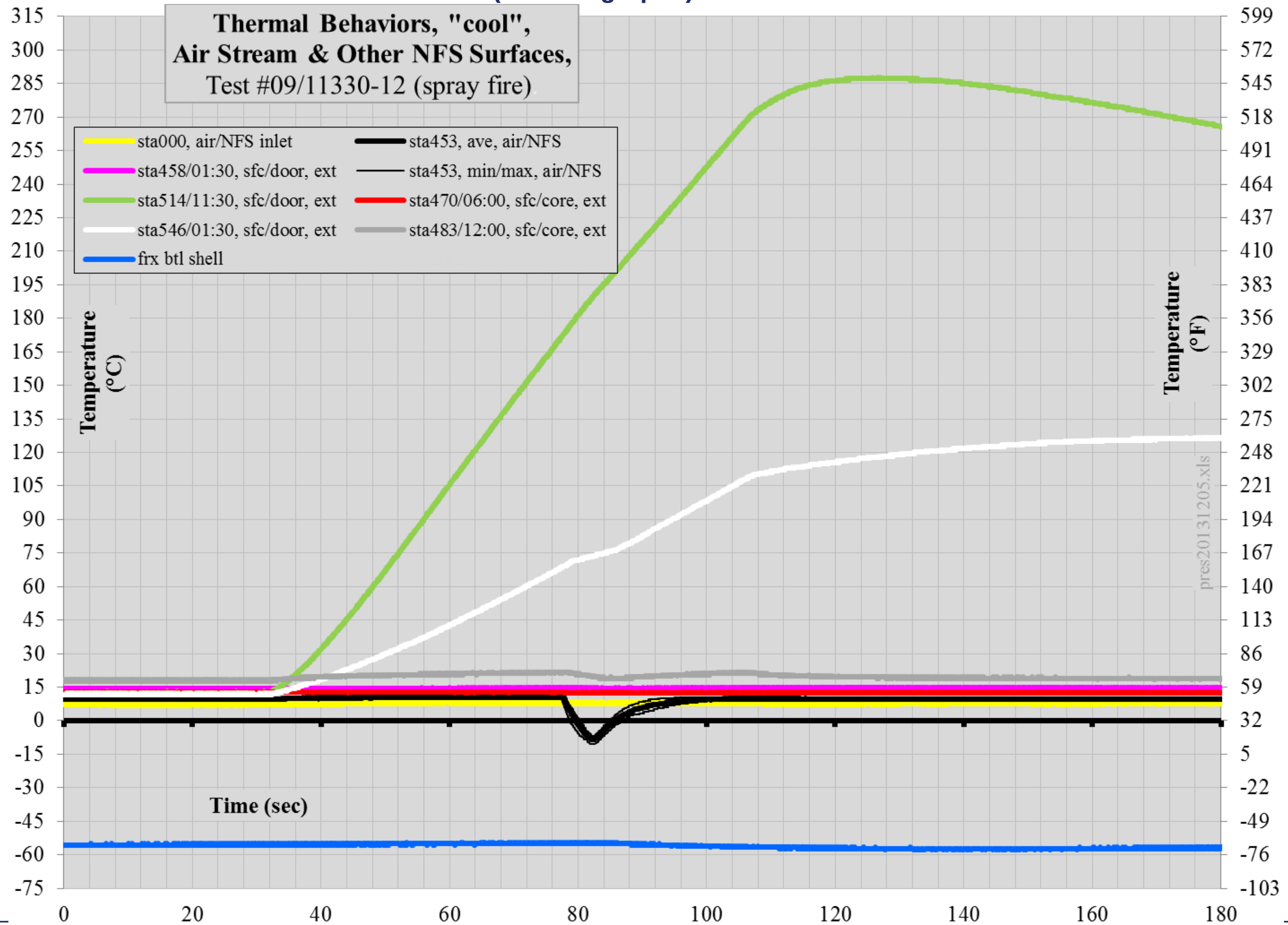
Test Results (thermal graphs)



Test Results (thermal graphs)



Test Results (thermal graphs)



Test Results (thermal descriptors)

Average Ambient Air (NFS Inlet), NFS Ventilation Air, & FK-5-1-12 Temperatures
(T_{air} , T_{NFS}, T_{agent})

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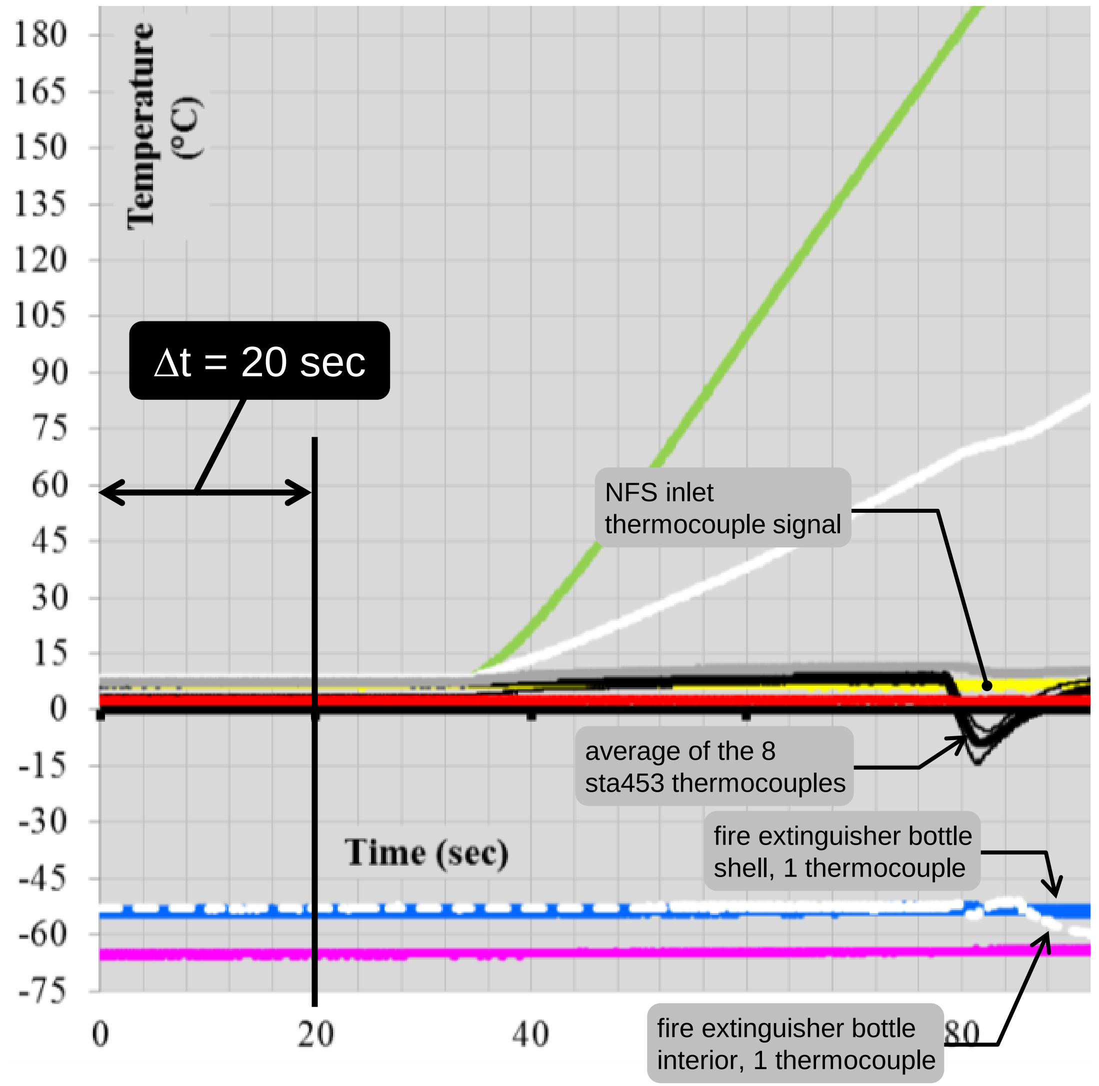
all are averages of the first 20 seconds in the test

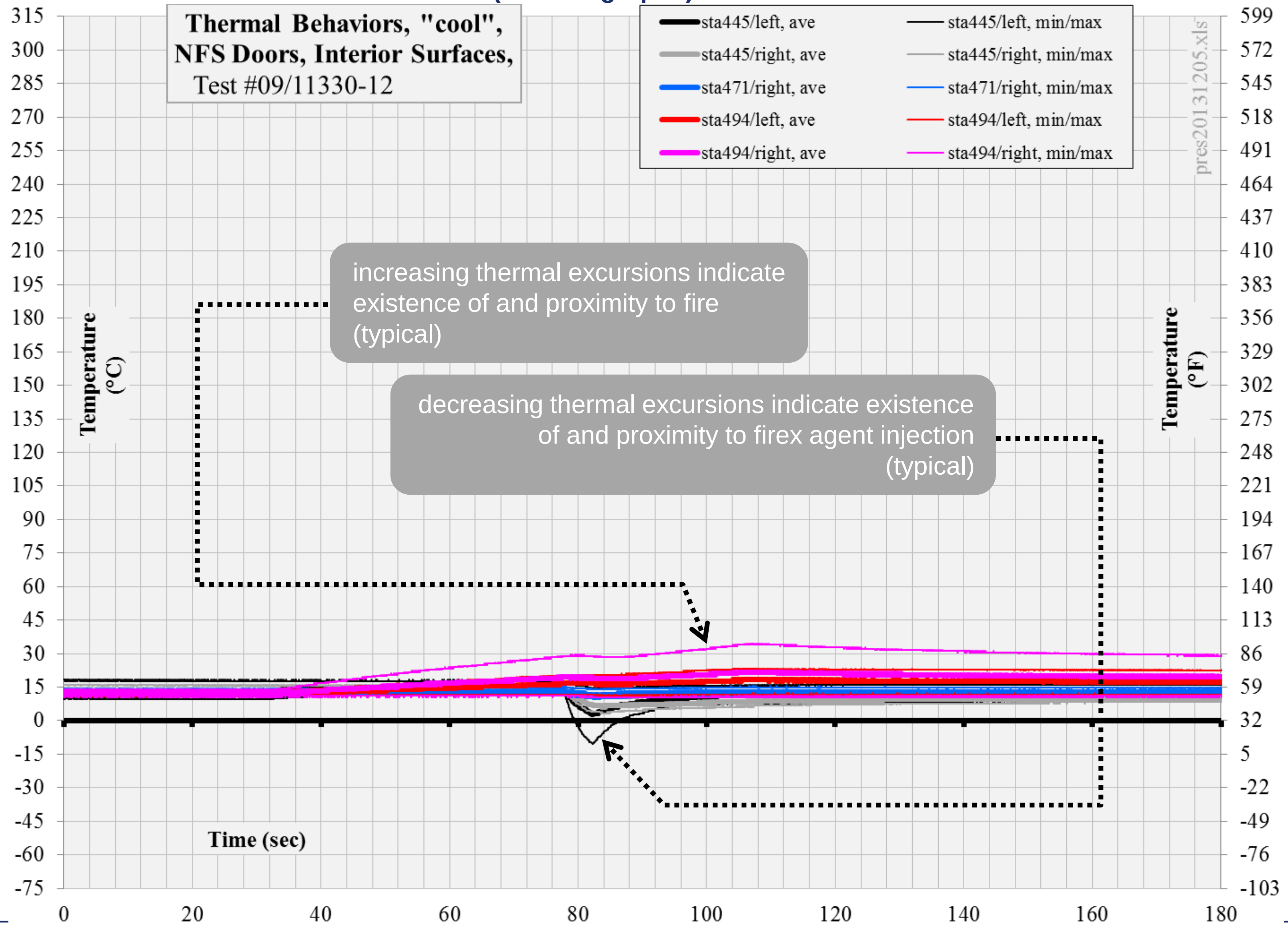
T_{air} = ambient air temperature (NFS inlet), average of NFS inlet thermocouple signal

T_{NFS} = NFS ventilation stream temperature, average of the eight sta453 thermocouple signals

T_{agent} = FK-5-1-12 temperature, average of thermocouple signal for either the interior or the shell of the fire extinguisher bottle

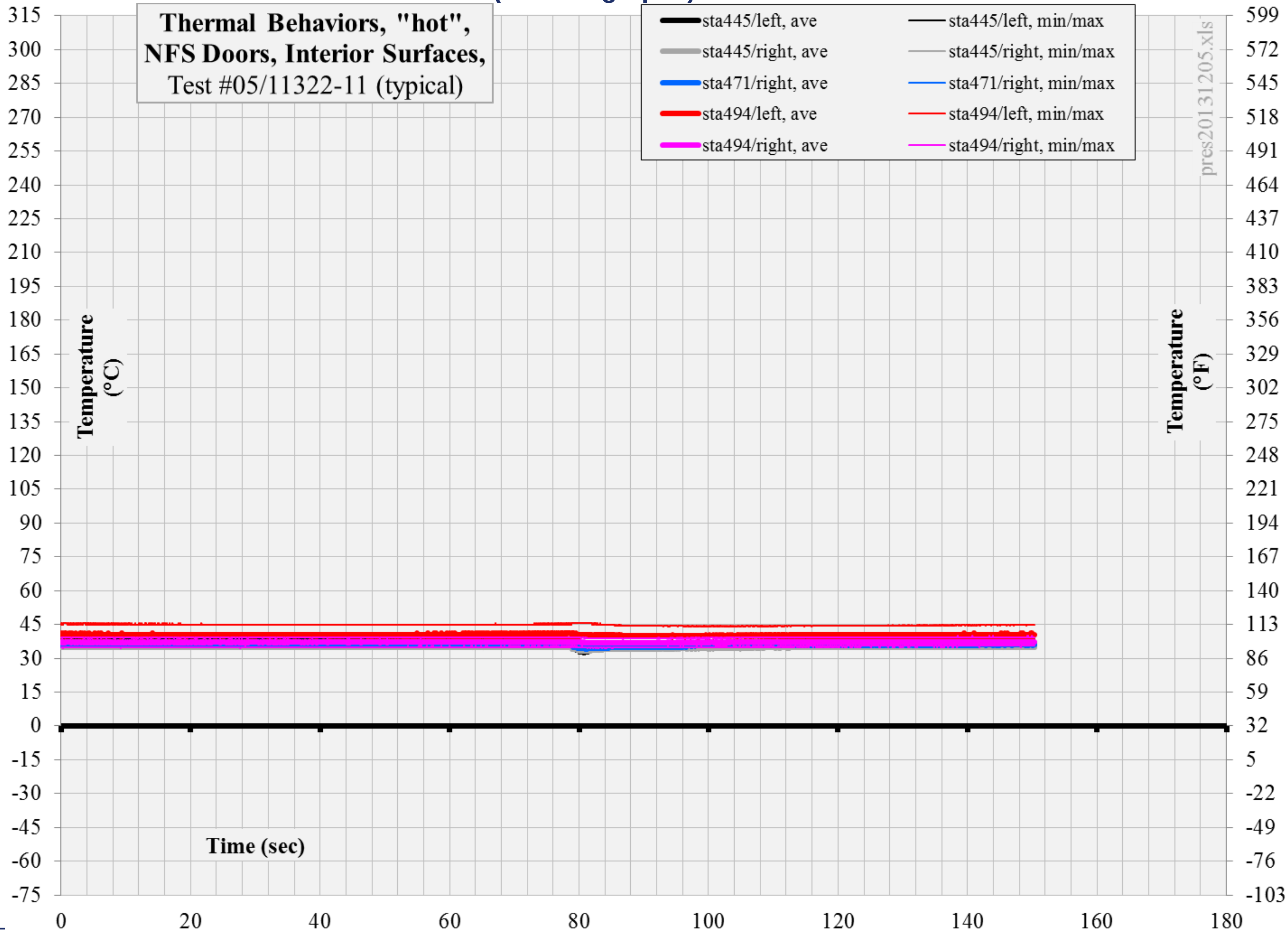


Test Results (thermal graphs)

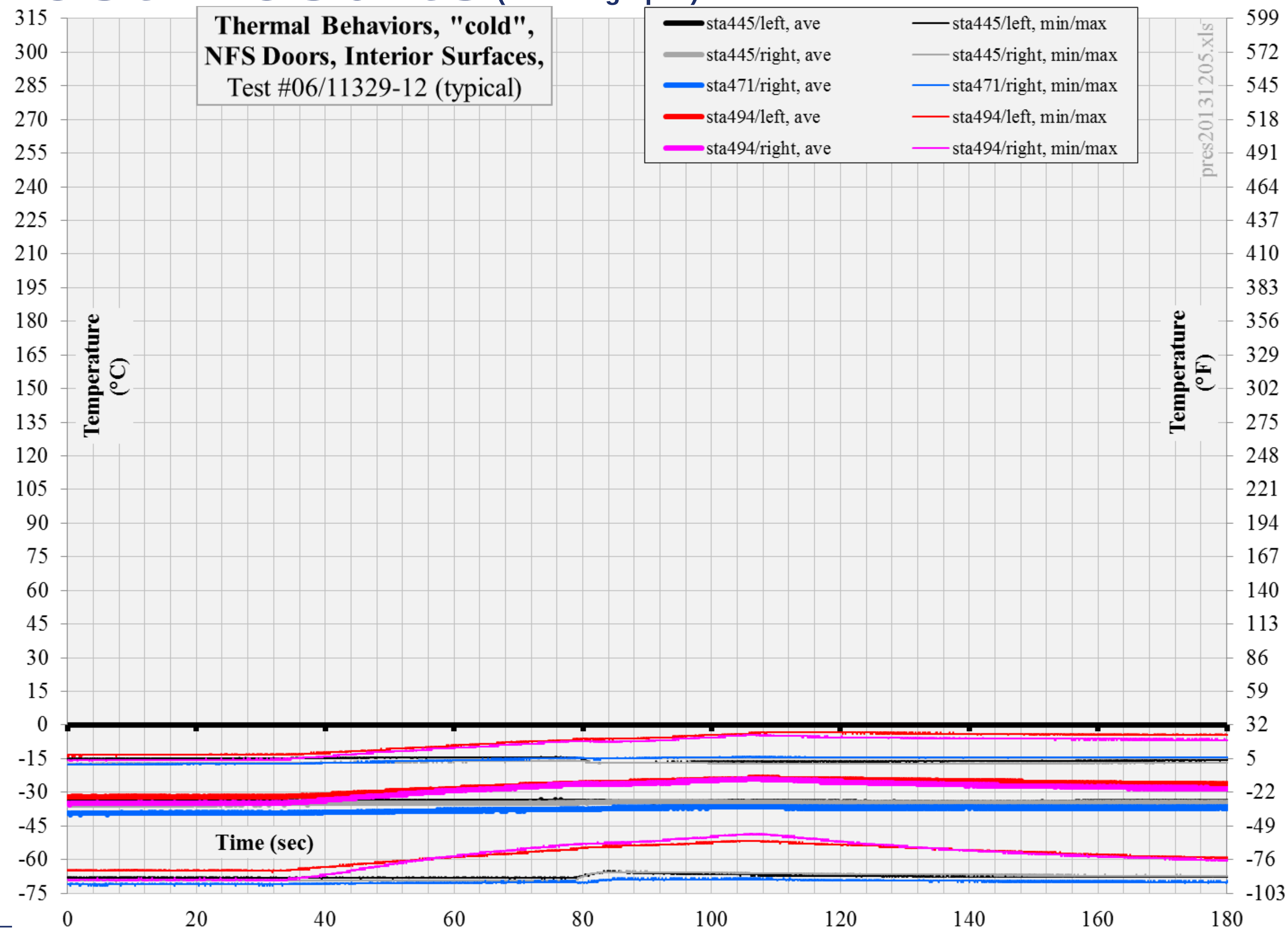


review slide 18 for telemetry details

Test Results (thermal graphs)



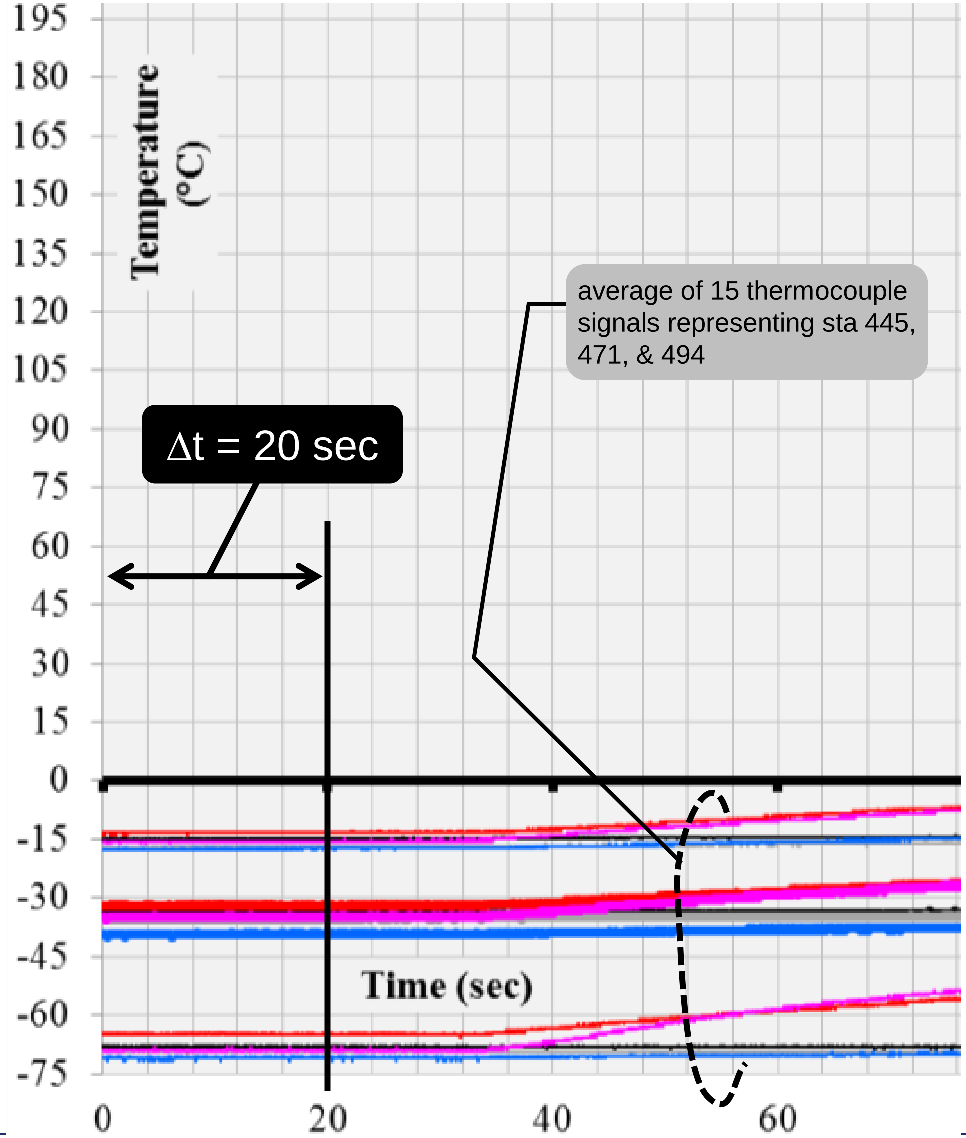
Test Results (thermal graphs)



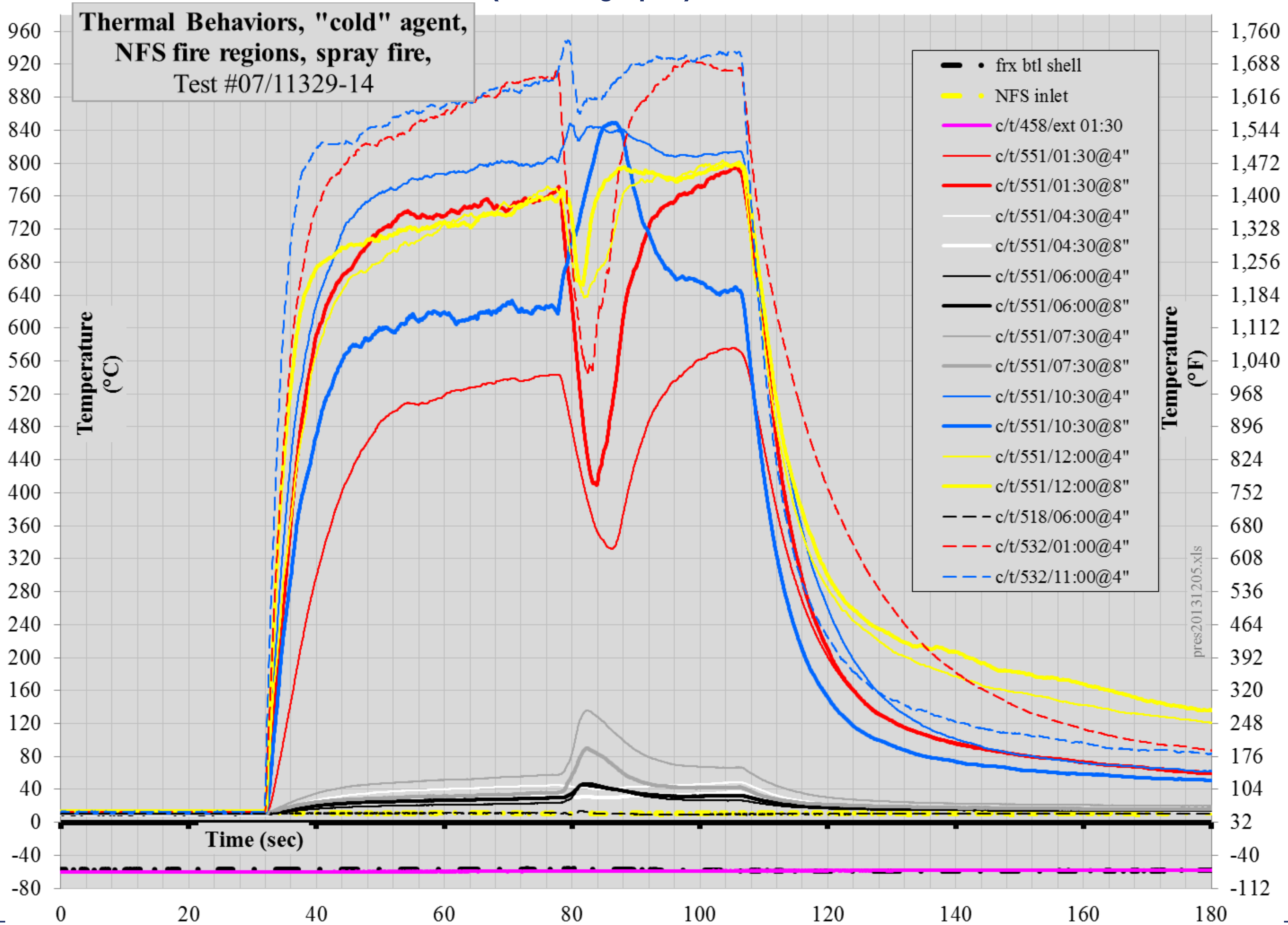
Test Results (thermal descriptors)

Average NFS Shell Temperature (T_{shell})

T_{shell} = average of sta445, 471, & 494 thermocouple signals in the first 20 seconds of the test

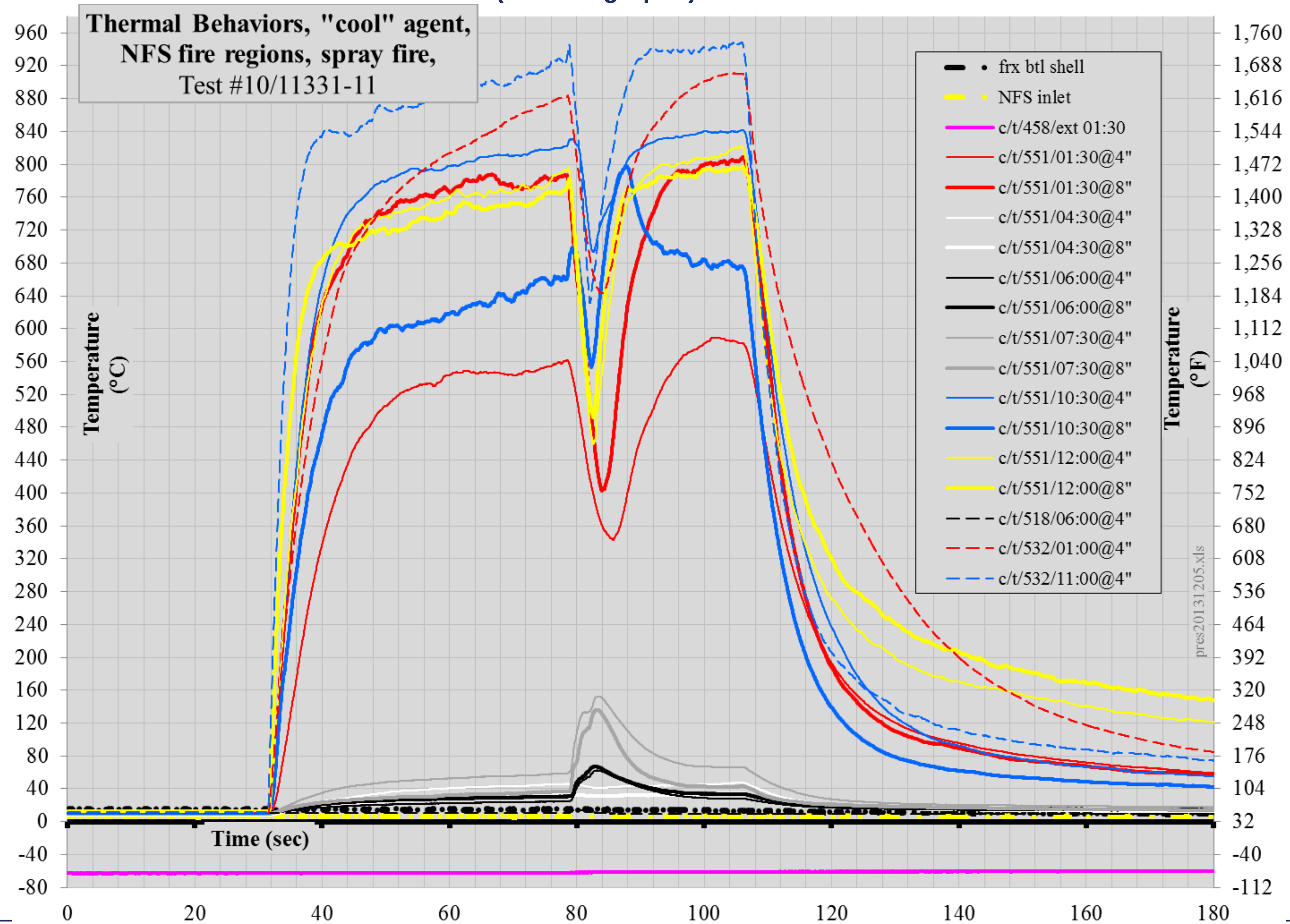


Test Results (thermal graphs)

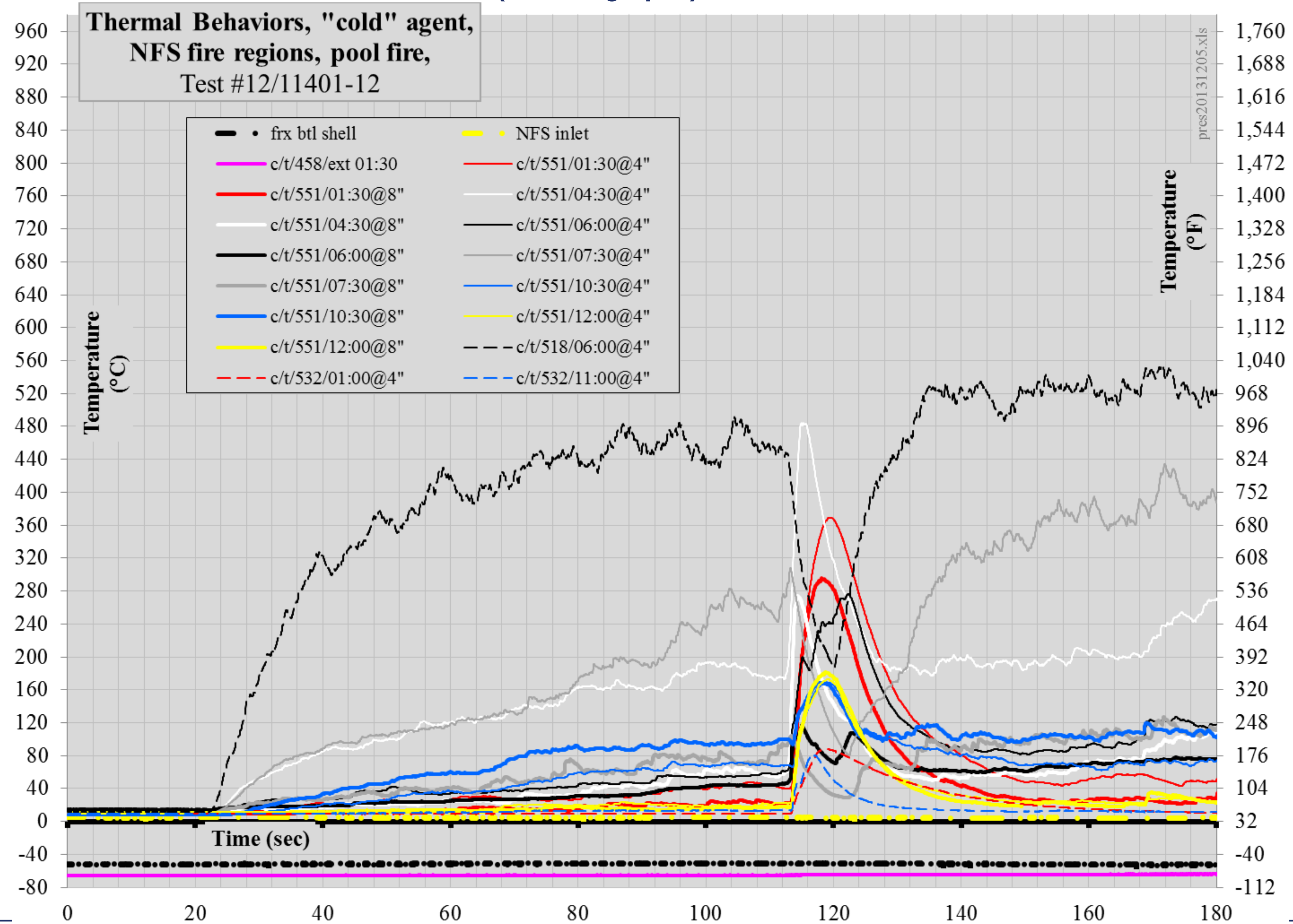


review slides 17-19 for telemetry details

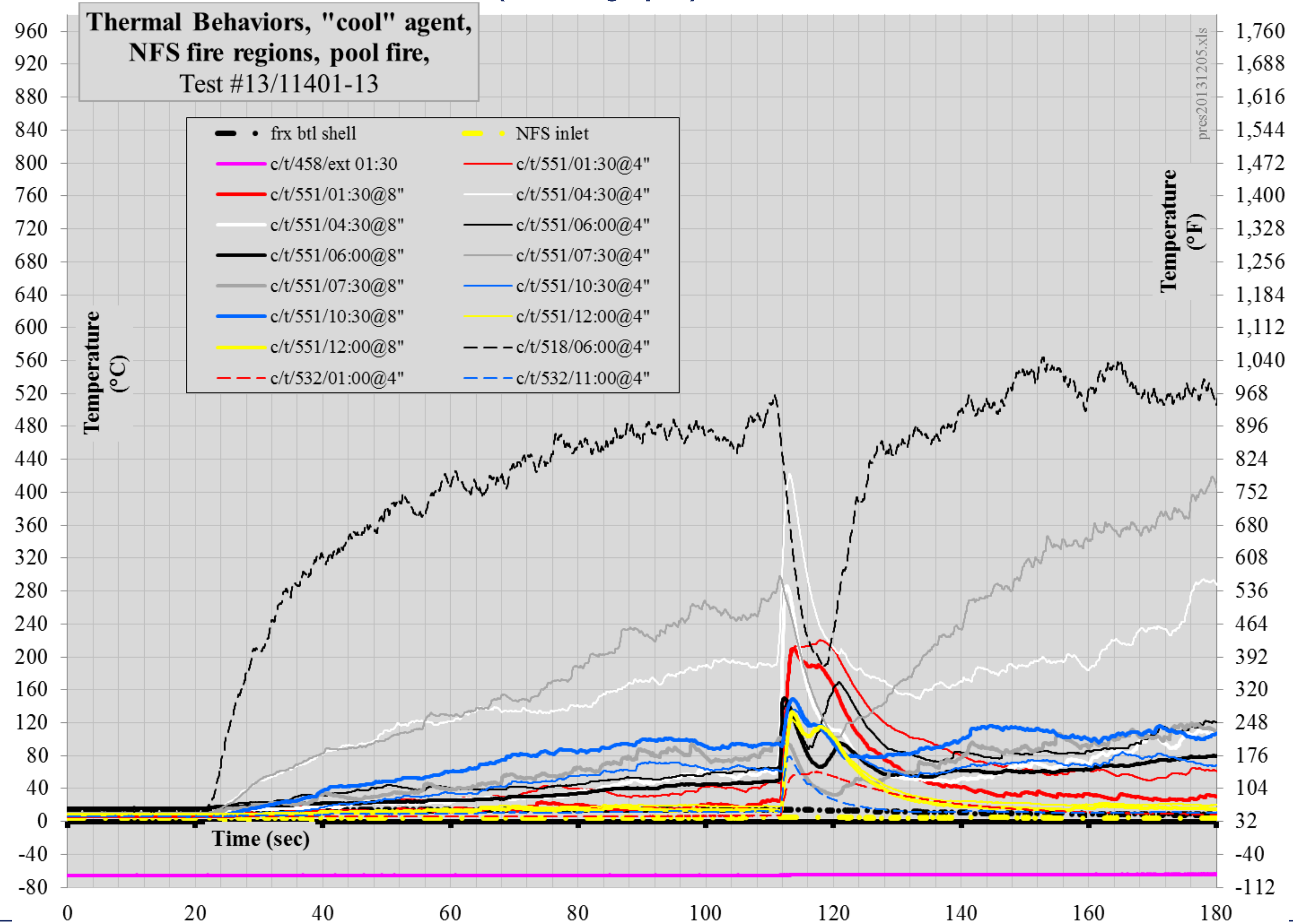
Test Results (thermal graphs)



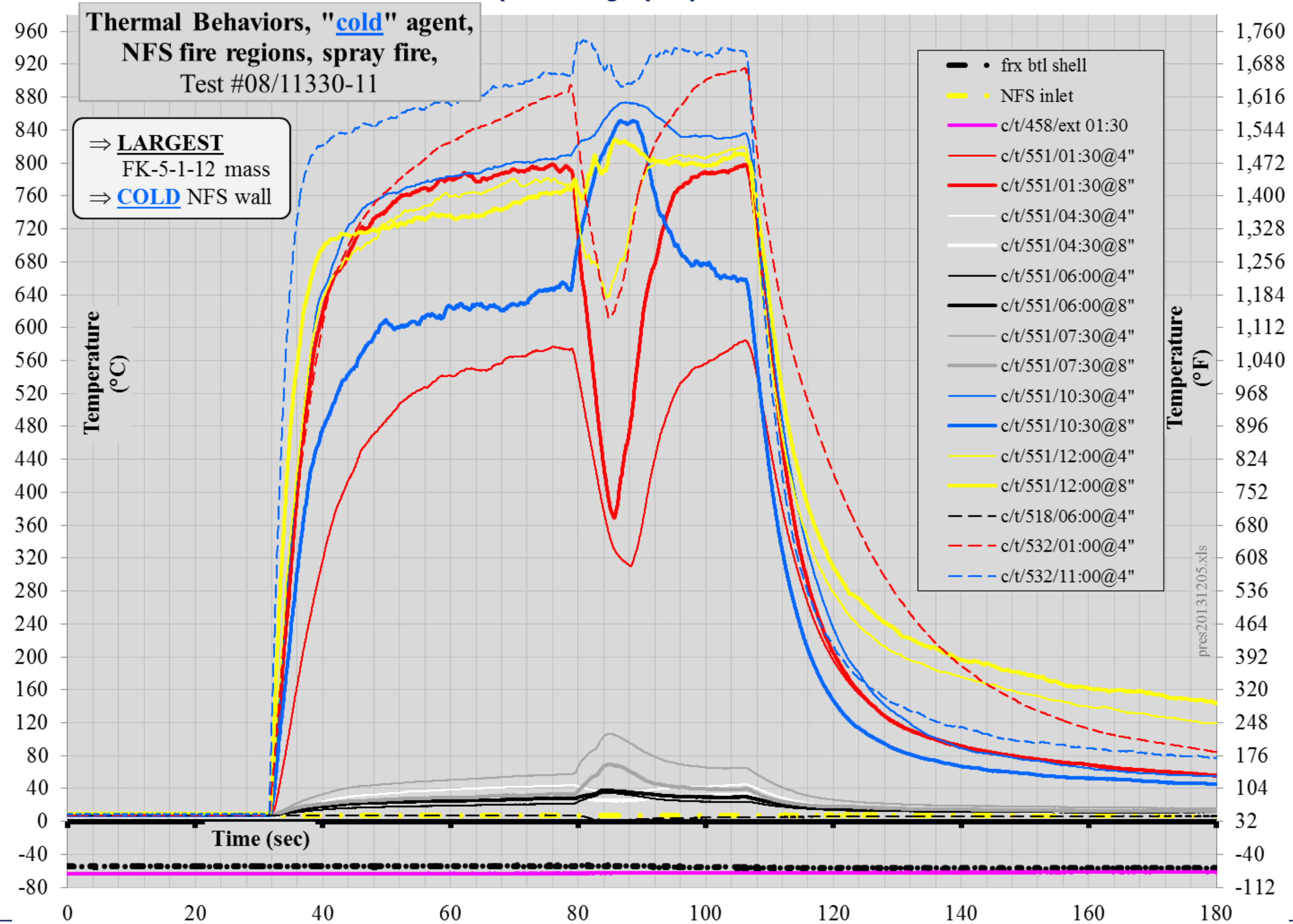
Test Results (thermal graphs)



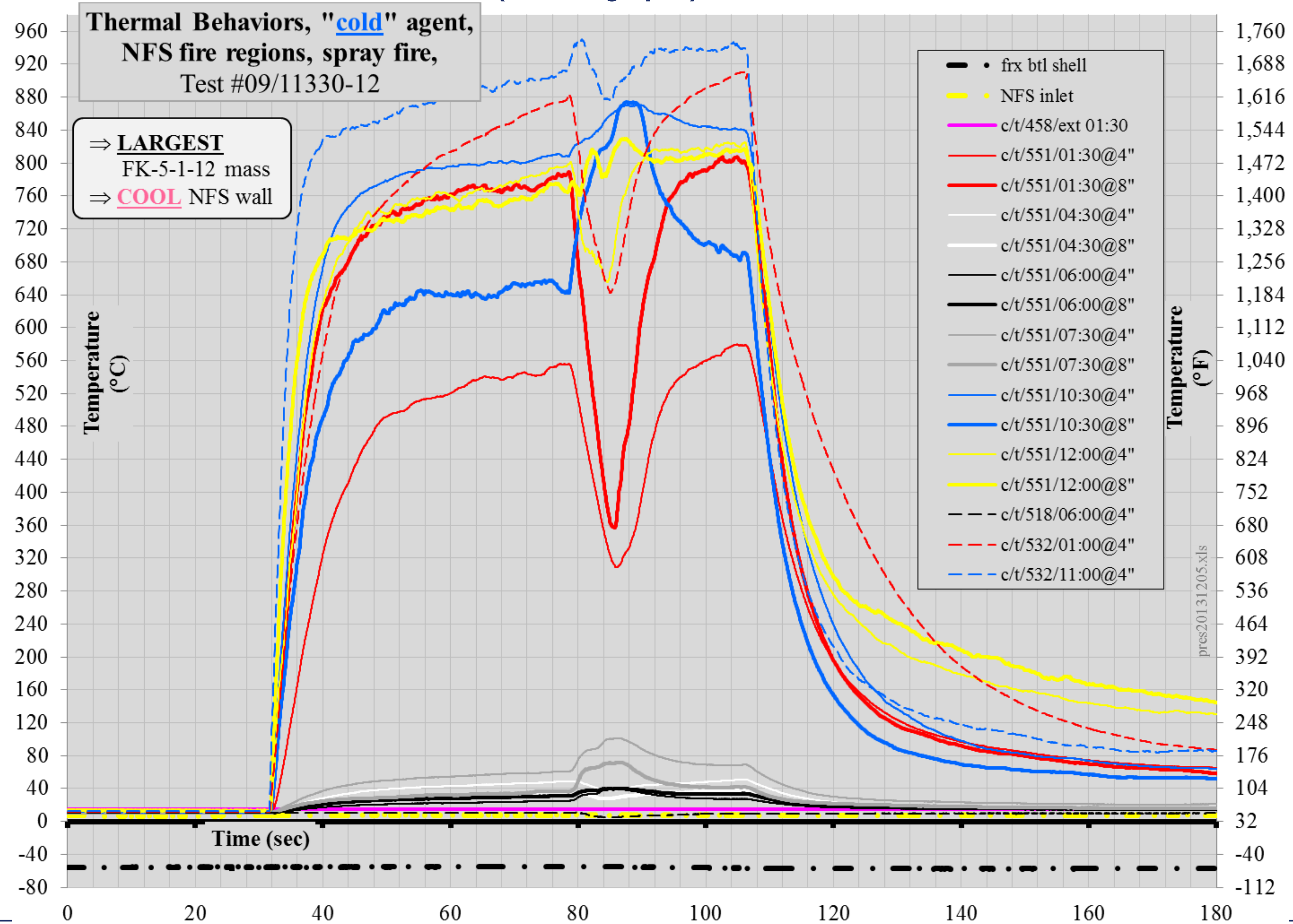
Test Results (thermal graphs)



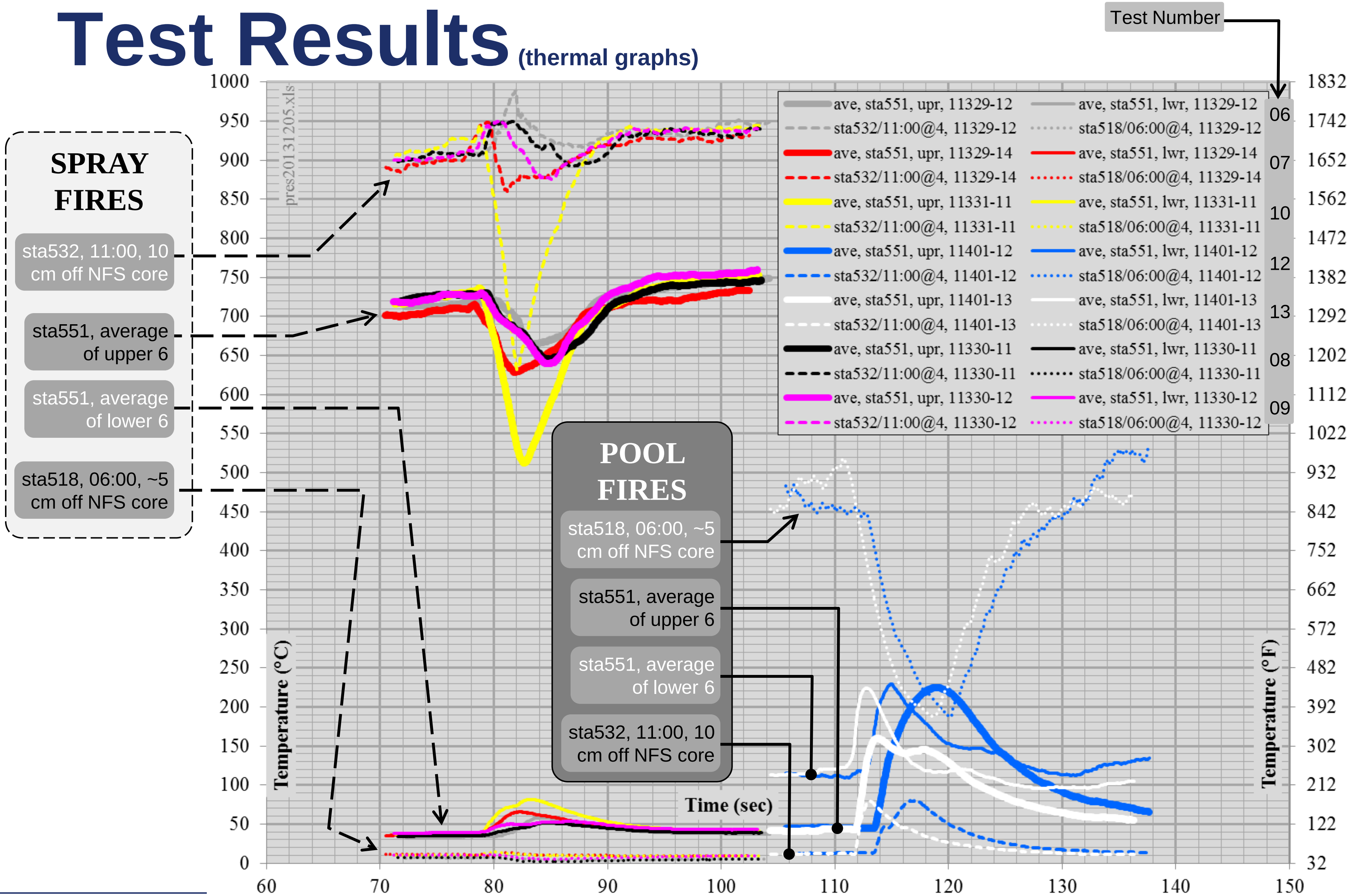
Test Results (thermal graphs)



Test Results (thermal graphs)



Test Results (thermal graphs)



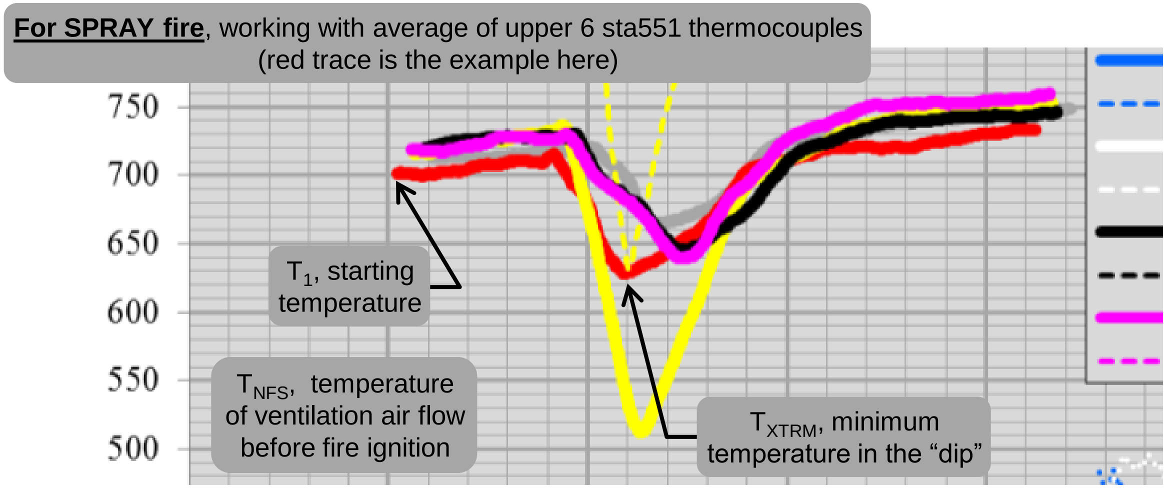
Test Results (thermal descriptors)

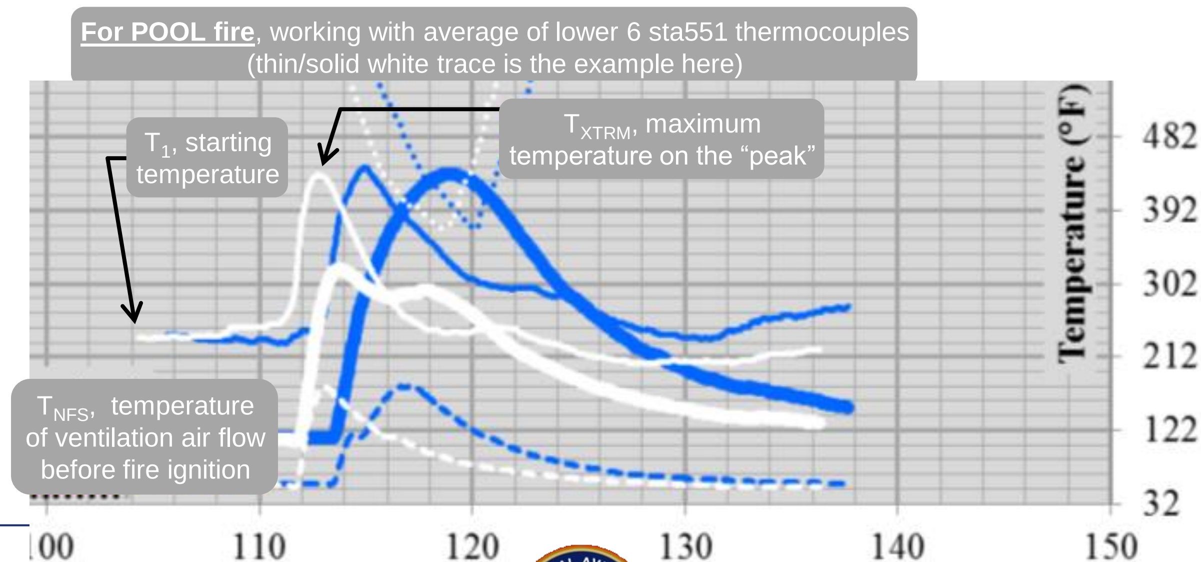
Temperature Ratio, sta551
($K_{j\ sta551}$)

(for each average temperature history of j = the lower or upper 6 sta551 thermocouples)

$$K_{j\ sta551} = (T_{XTRM} - T_{NFS}) / (T_1 - T_{NFS})$$

- duration is the same & its location adjusted according to the FK-5-1-12 injection initiation signal
- <u>with</u> fire extinction,
  - ✓ $T_{XTRM} \approx T_{NFS}$
  - ✓ $K_{j\ sta551} = 0$
- *<u>without</u>* fire extinction,
  - ✓ $T_{XTRM} > T_{NFS}$
  - ✓ if $0 < K_{j\ sta551} < 1$, fire diminishing
  - ✓ if $K_{j\ sta551} \approx 1$, fire unaffected
  - ✓ if $K_{j\ sta551} > 1$, fire relocating and/or intensity increasing; improved fuel/air mixing resulting from agitation by fire extinguishing agent injection plume; agent is not defeating the fire as fast as the fire is burning





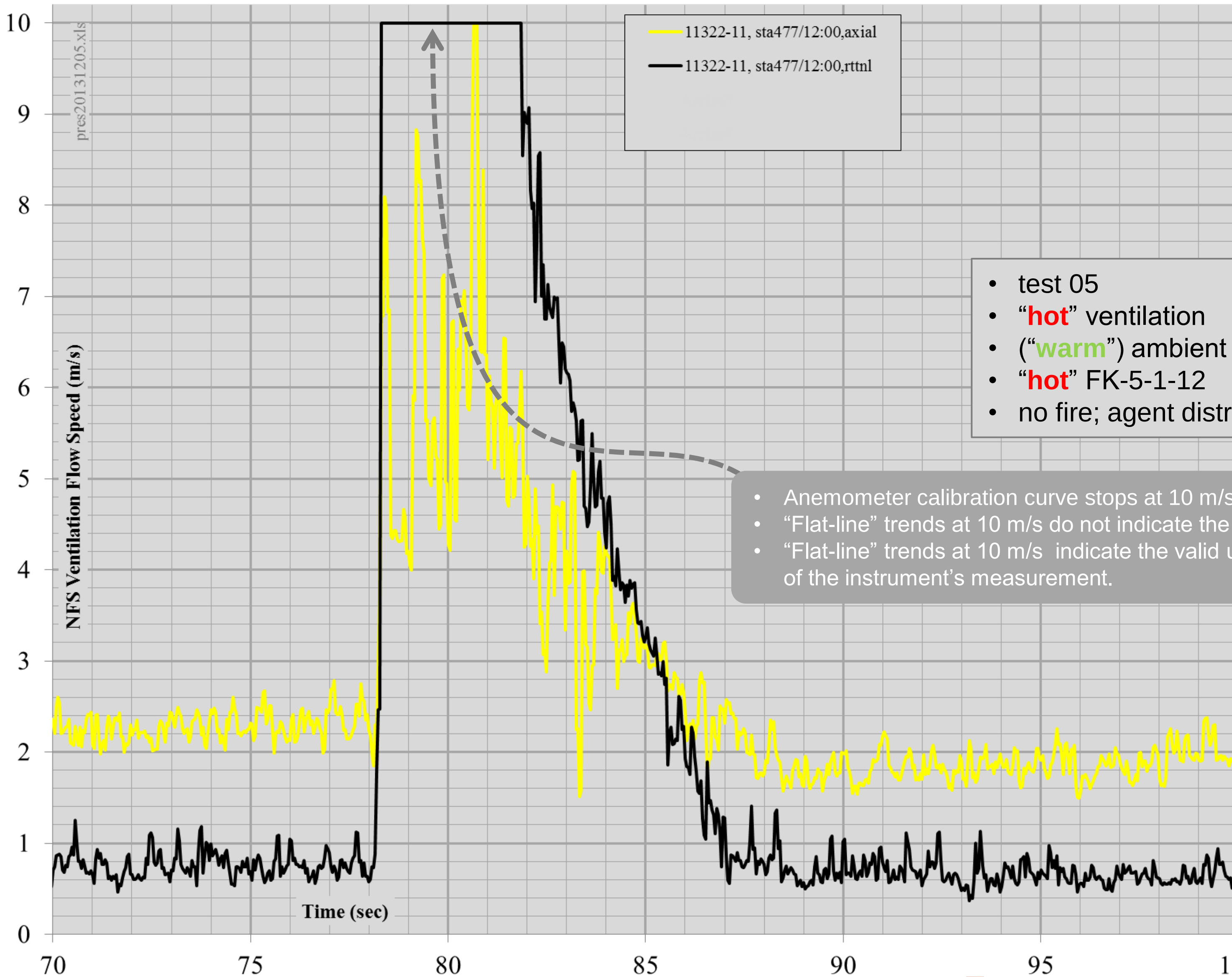
Test Results (anemometry graphs)

Substance	C_P (kJ/(kg K))
FK-5-1-12, liquid	1.103
FK-5-1-12, vapor	0.891
air	1.003
water vapor	1.8723
water	4.184

Specific Heats (T=25°C, 1 atm)

- **Hot-wire anemometry trends are interesting**
- **Limitations apply to the flow speed indications**
  - – anemometer calibration : dry air, 1 atm, 25° & 40°C
  - – NFS ventilation stream differs from calibration basis :
    - atmospheric moisture present ≠ dry air
    - most flow temperatures ≠ 25°C
  - – anemometers exposed to migrating FK-5-1-12 pulse in the ventilation stream; heat capacity of gas flow changes
  - – H_2O & FK-5-1-12 existence is multi-phased (vapor, liquid, solid)
  - – indications likely reasonable before FK-5-1-12 migration

Test Results (anemometry graphs)

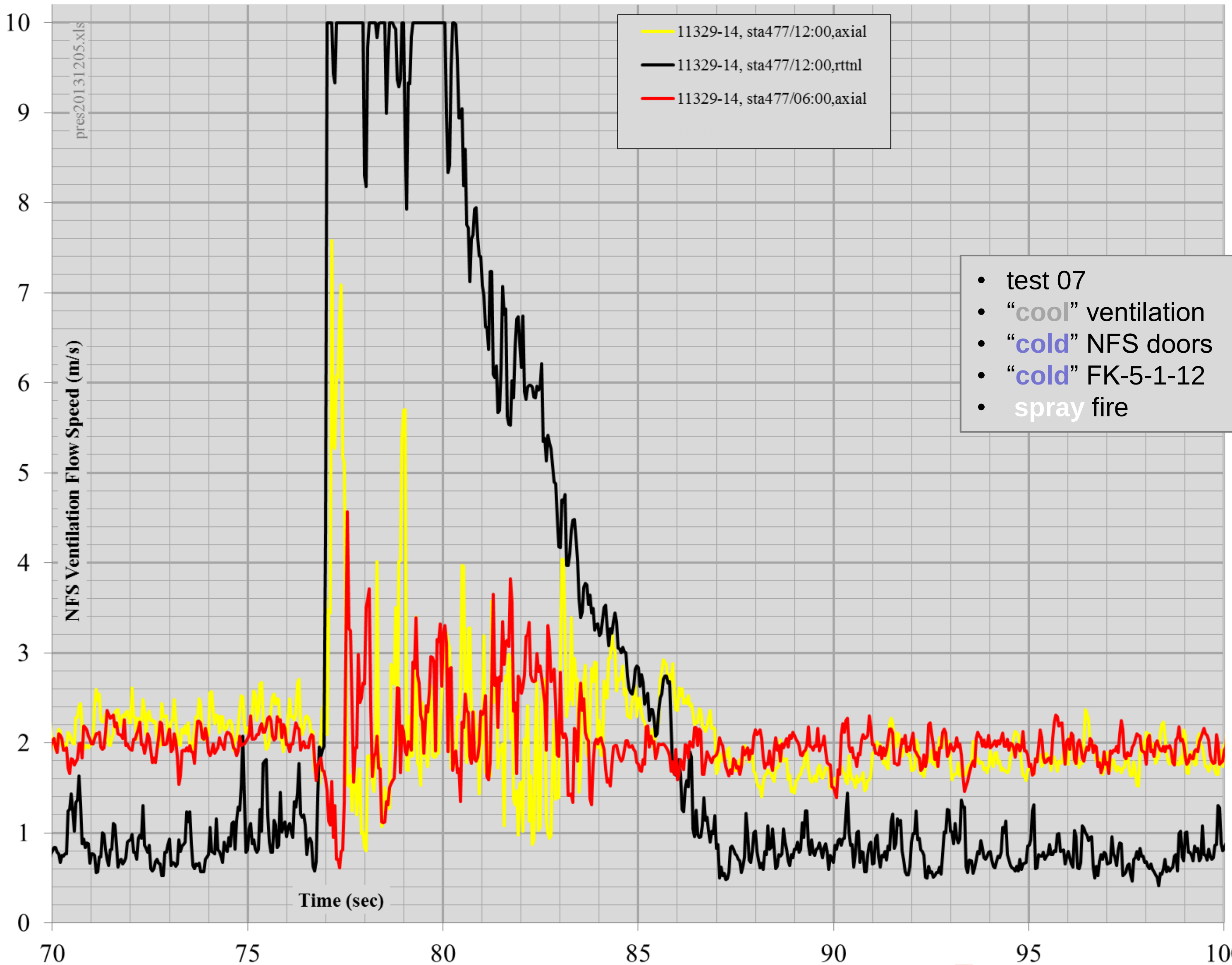


- test 05
- "hot" ventilation
- ("warm") ambient NFS doors
- "hot" FK-5-1-12
- no fire; agent distribution test

- Anemometer calibration curve stops at 10 m/s.
- "Flat-line" trends at 10 m/s do not indicate the flow speed.
- "Flat-line" trends at 10 m/s indicate the valid upper bound of the instrument's measurement.

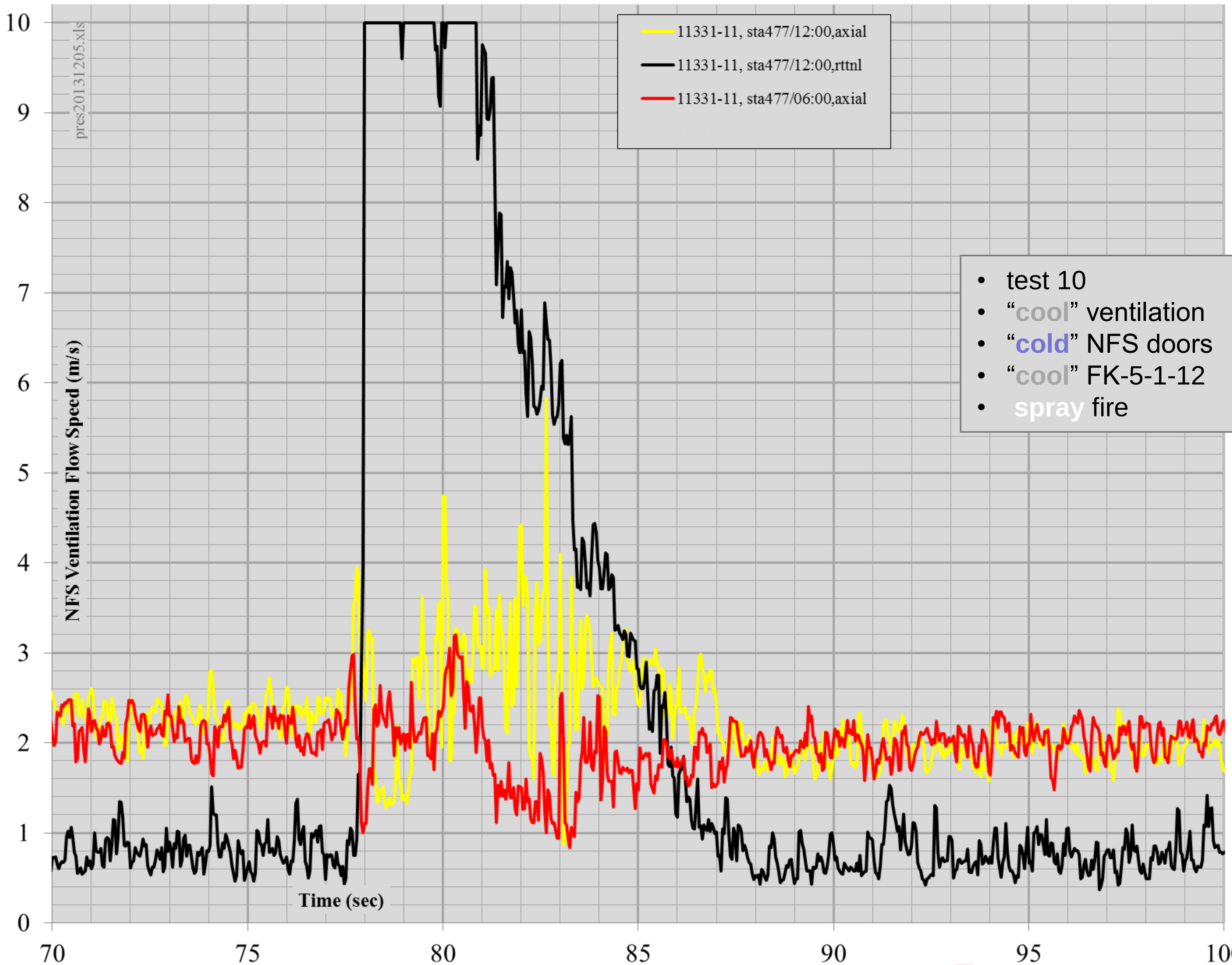
review slides 20-23 for telemetry details

Test Results (anemometry graphs)



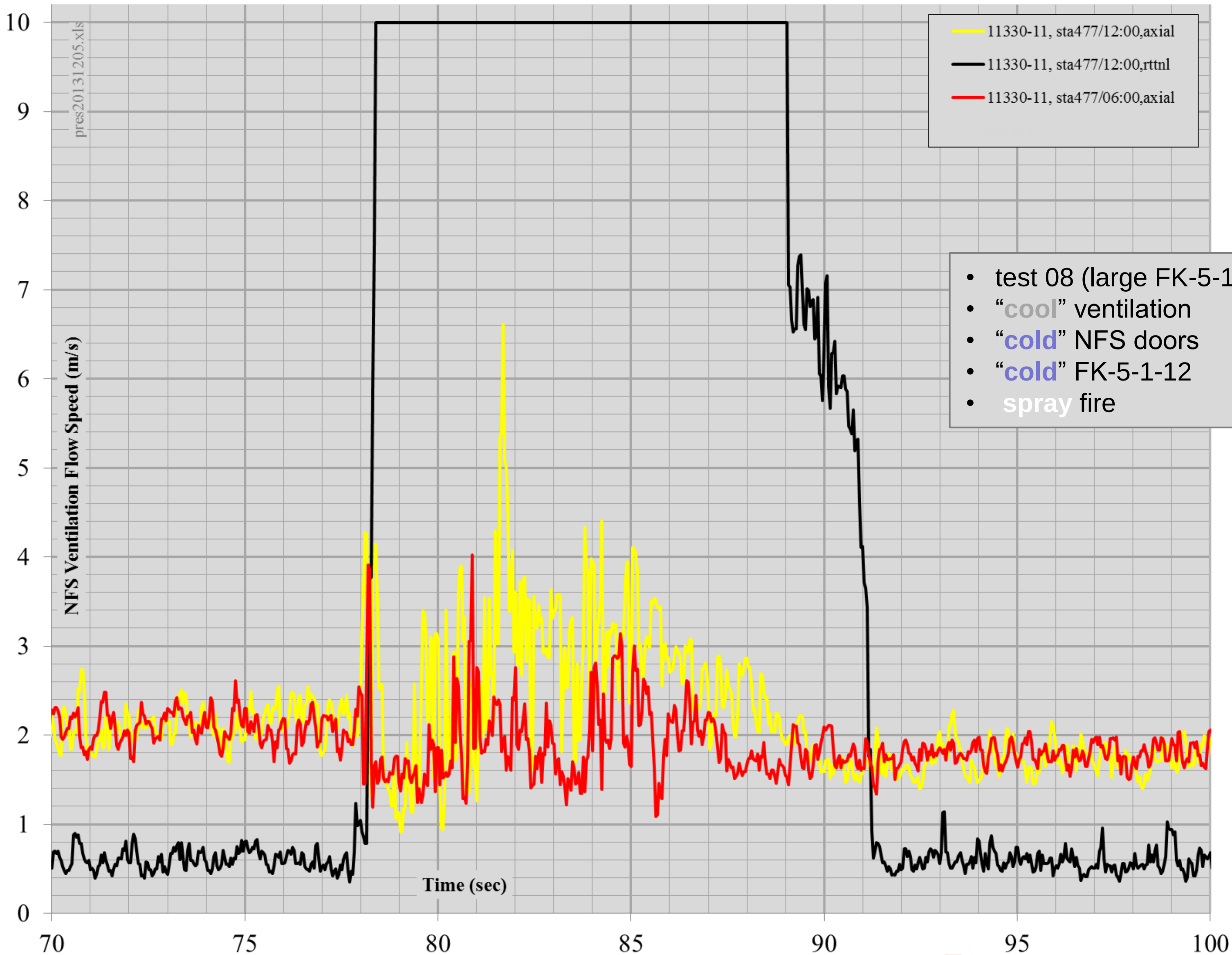
- test 07
- "cool" ventilation
- "cold" NFS doors
- "cold" FK-5-1-12
- spray fire

Test Results (anemometry graphs)



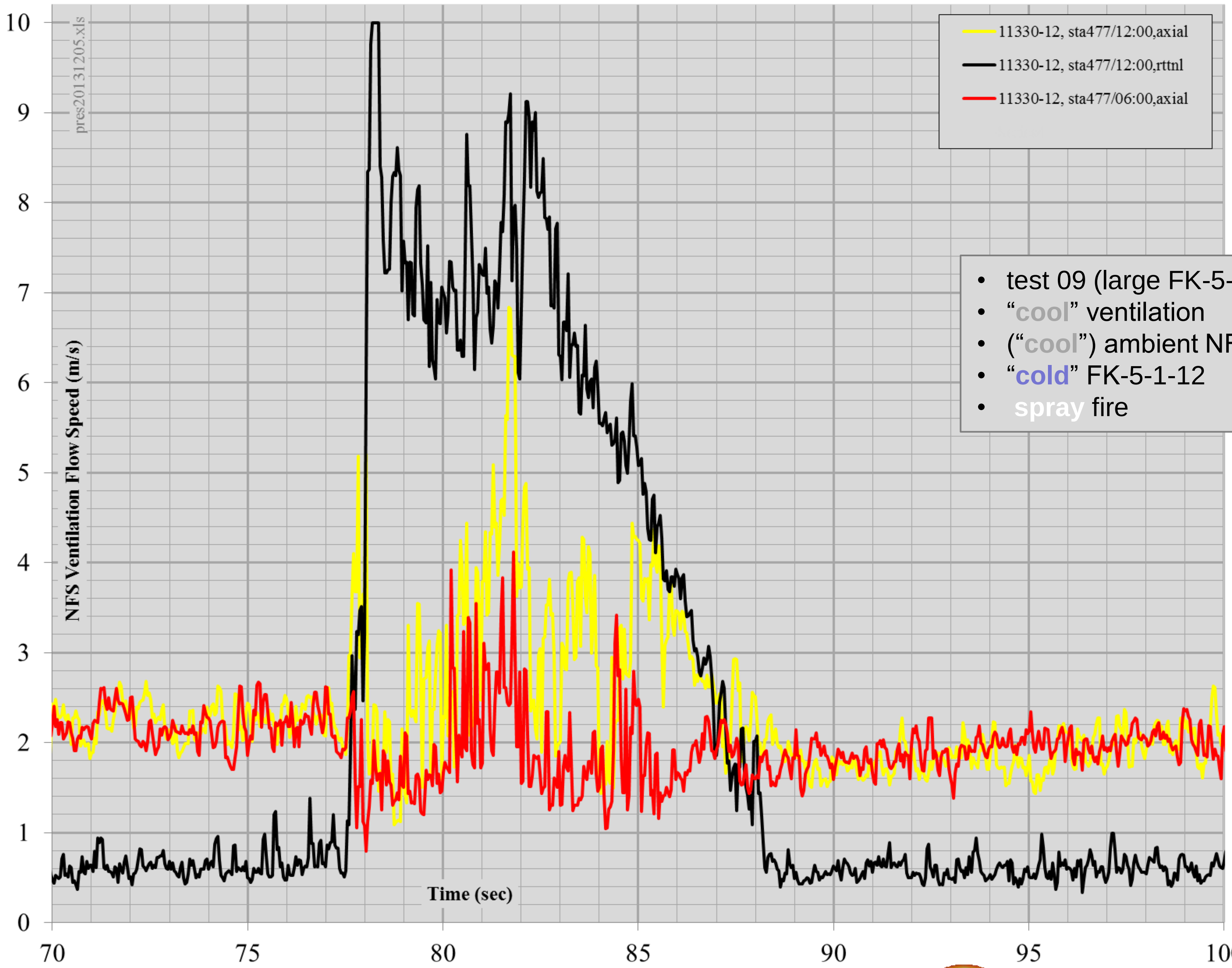
- test 10
- "cool" ventilation
- "cold" NFS doors
- "cool" FK-5-1-12
- spray fire

Test Results (anemometry graphs)



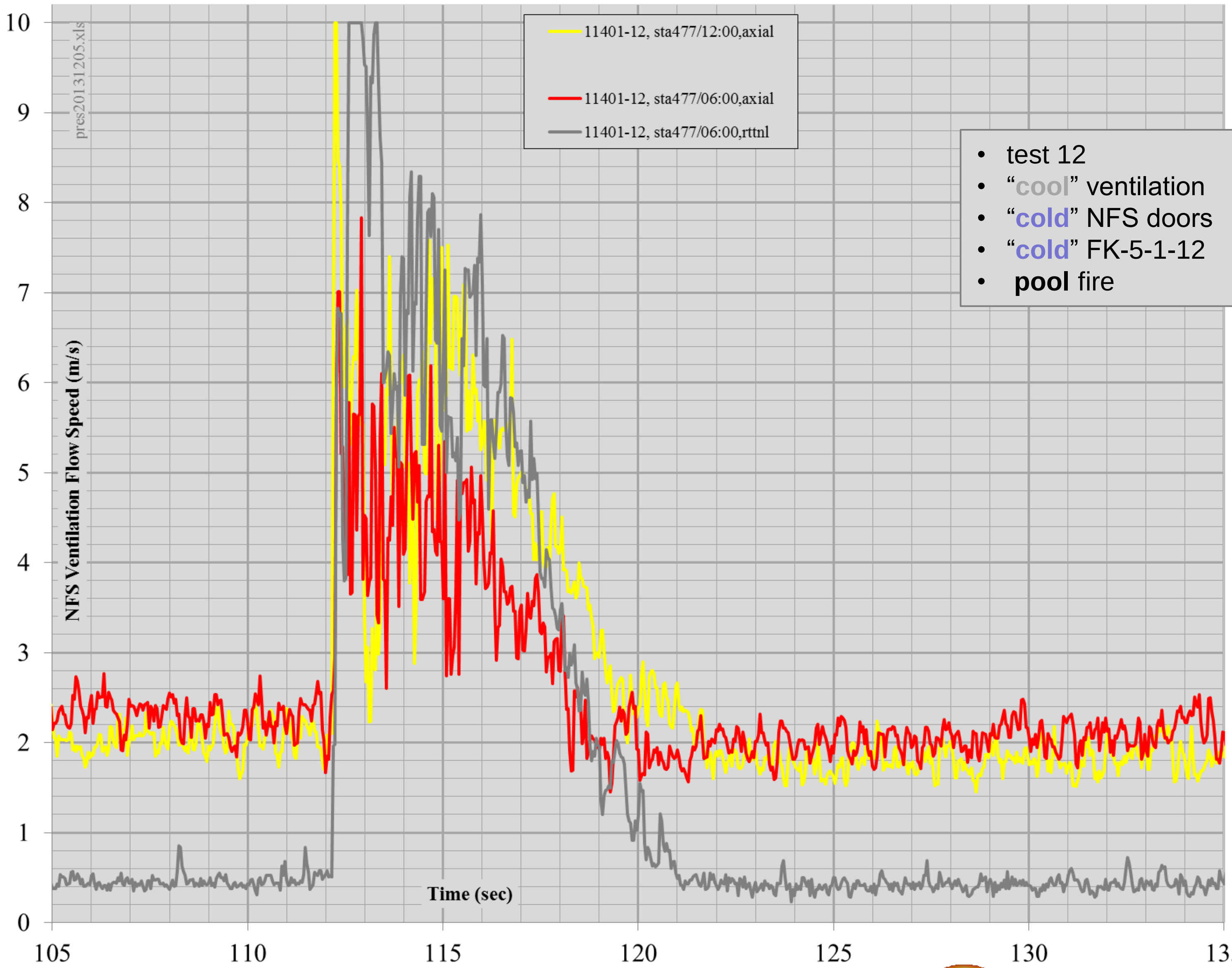
- test 08 (large FK-5-1-12 mass)
- "cool" ventilation
- "cold" NFS doors
- "cold" FK-5-1-12
- spray fire

Test Results (anemometry graphs)



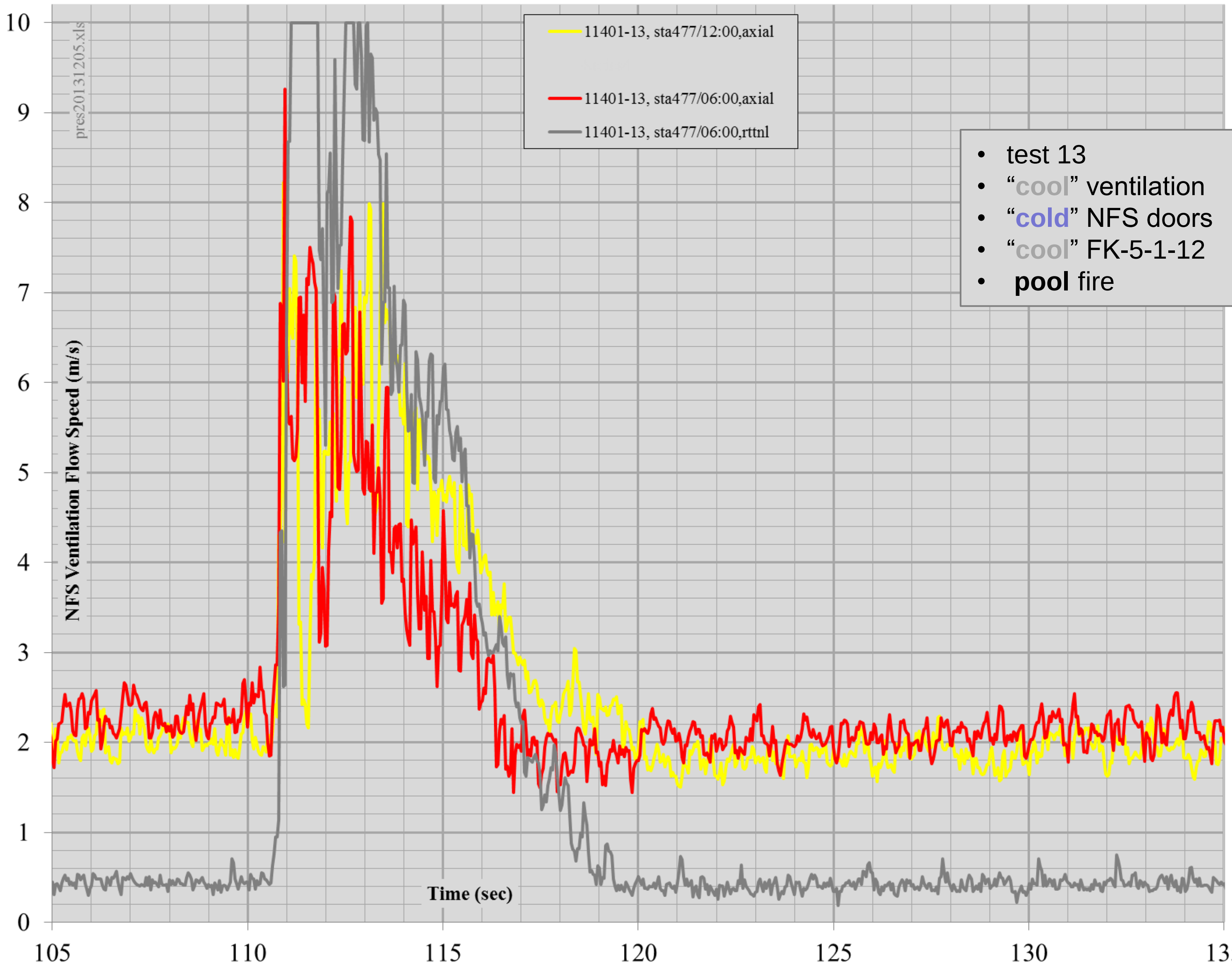
- test 09 (large FK-5-1-12 mass)
- "cool" ventilation
- ("cool") ambient NFS doors
- "cold" FK-5-1-12
- spray fire

Test Results (anemometry graphs)



- test 12
- "cool" ventilation
- "cold" NFS doors
- "cold" FK-5-1-12
- **pool** fire

Test Results (anemometry graphs)



- test 13
- "cool" ventilation
- "cold" NFS doors
- "cool" FK-5-1-12
- **pool** fire

Test Results (anemometry descriptors)

Characterizing the Anemometry
(x'_{jk} , $A_{jk\ mig}$ / $A_{jk\ prinj}$, $A_{j\theta\ mig}$ / $A_{jL\ mig}$)

(for each anemometer history at j = 12:00 or 06:00 & k = axial or rotational flow orientation)

---

x'_{jk} : average flow speed
15 sec duration, before FK-5-1-12 injection (pre-injection)

A, area under flow speed curves

jk prinj : 15 sec duration, pre-injection
$A_{jk\ prinj}$ = 15 sec * x'_j

jk mig : 15 sec duration, includes FK-5-1-12 migration (migration)

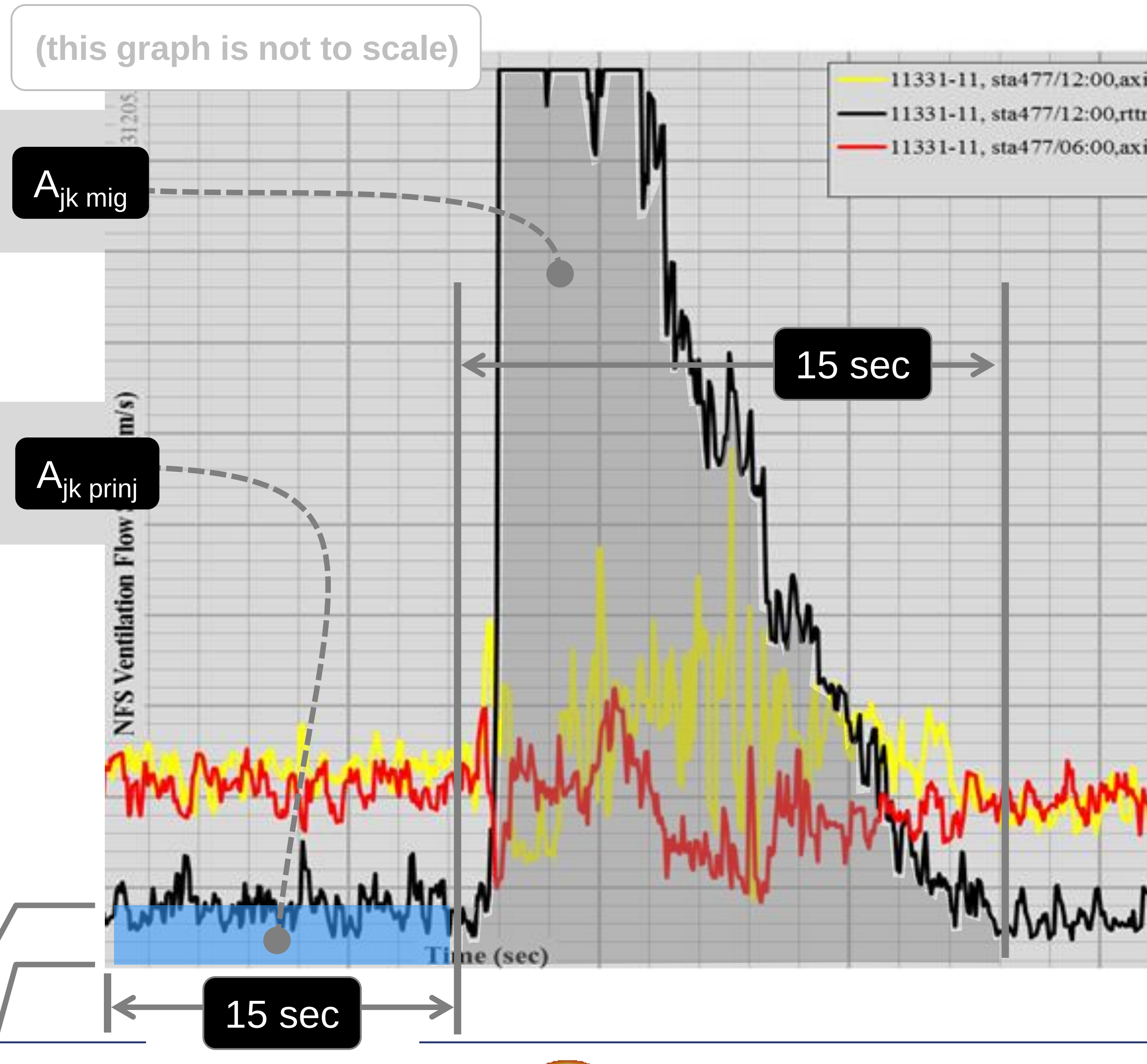
jθ mig : 15 sec duration, rotating flow

jL mig : 15 sec duration, axial flow

Area Ratios

$A_{jk\ mig}$ / $A_{jk\ prinj}$ used to differentiate magnitudes & durations of the flow speeds during pre-injection & migration, at the same location

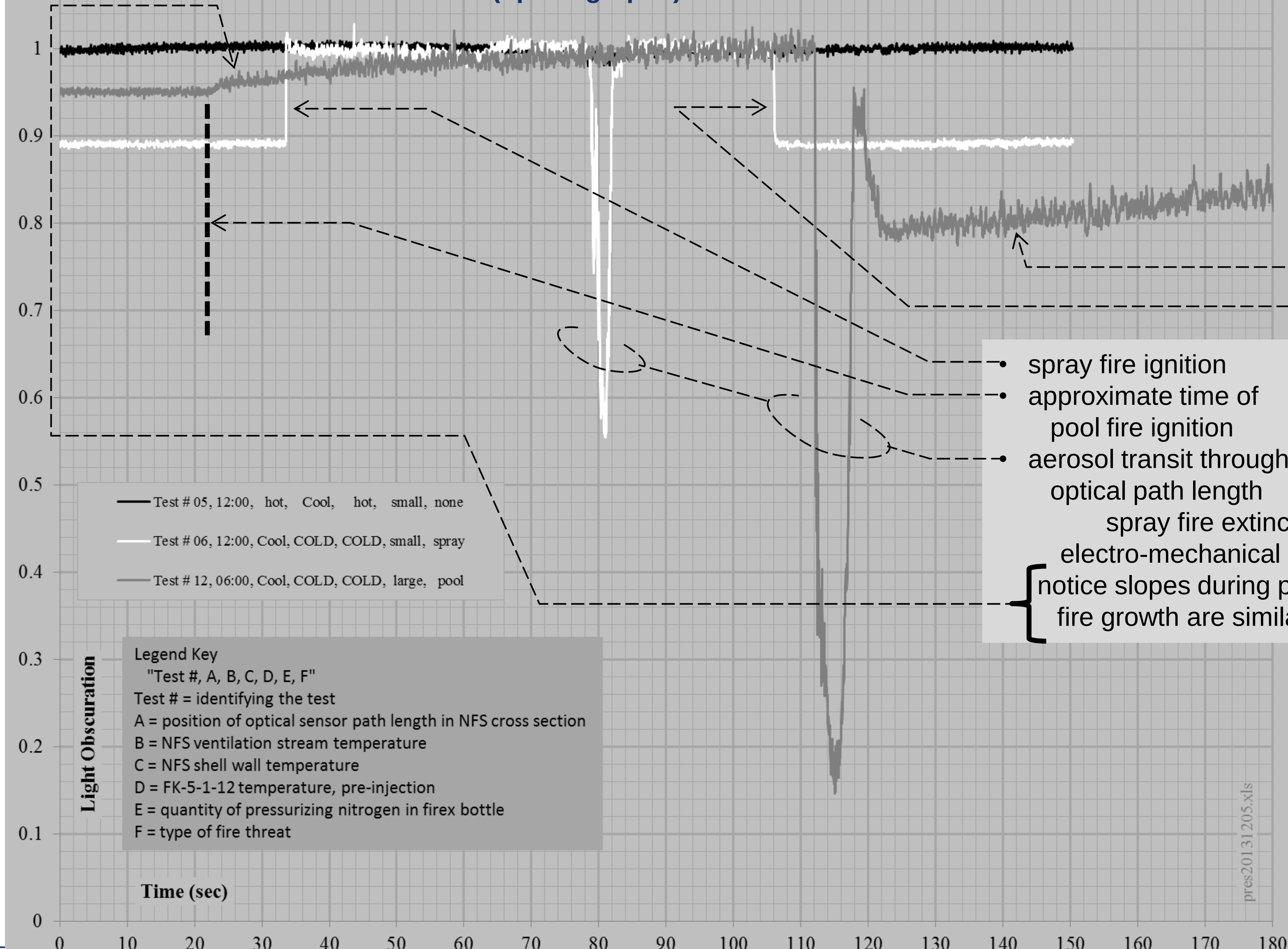
$A_{j\theta\ mig}$ / $A_{jL\ mig}$ used to differentiate magnitudes & durations of the flow speeds during migration for rotating & axial directions, at the same location



Test Results (optics graphs)

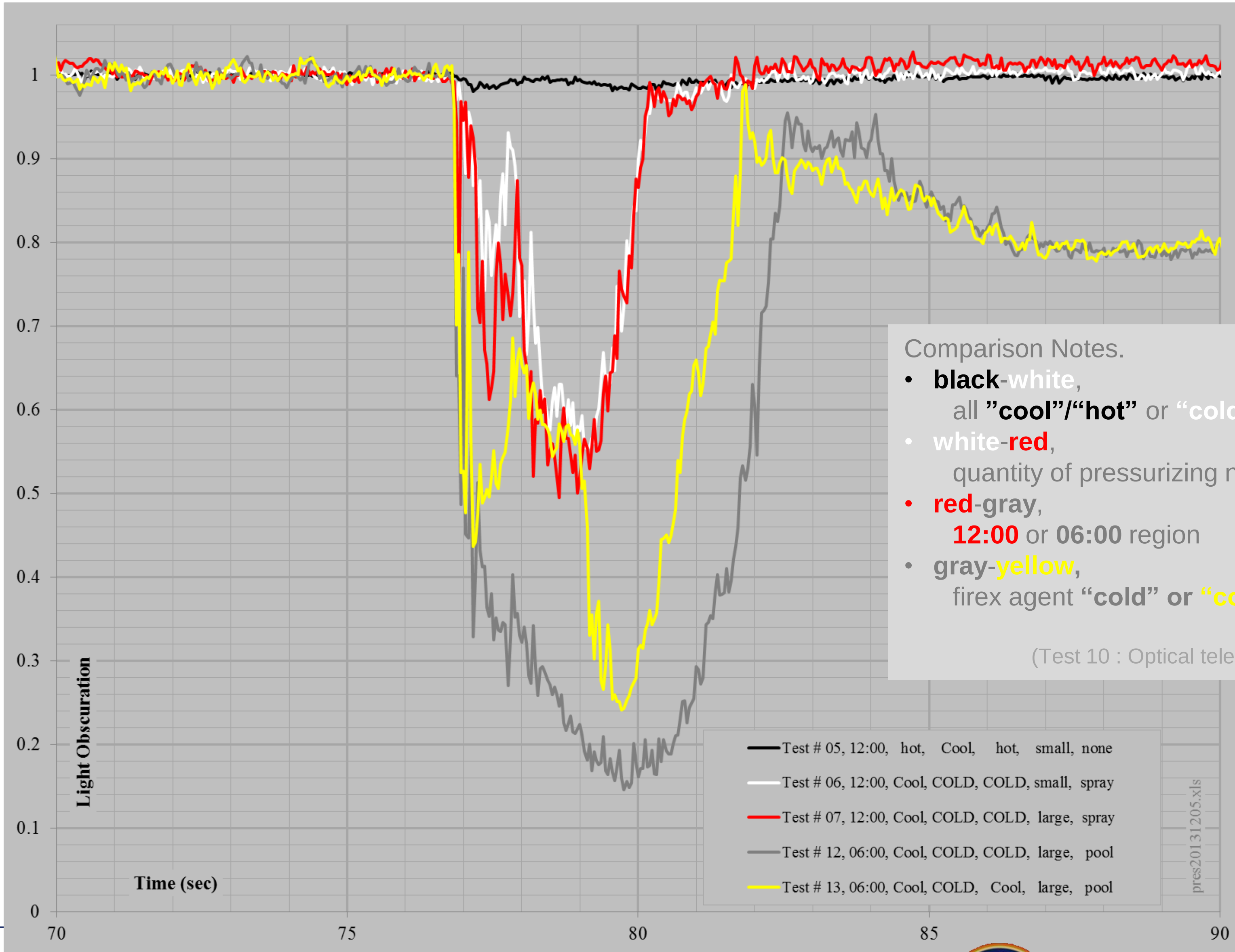
- **Light obscuration (L/O) is significant indicator**
- **Can <u>not</u> make simple calculations to characterize the FK-5-1-12 aerosol**
  - FK-5-1-12 absorption/scattering properties?
  - "cold" FK-5-1-12 injection reduced local temperatures below water dew point in the moist-air ventilation stream; did a water aerosol (fog) form? yes…
  - while pre-test, hoar frost coated NFS door interiors; did frost suspend in the air flow with injection? yes…
- **Timelines in L/O graphs are artificially aligned**

Test Results (optics graphs)



review slides 20-23 for telemetry details

Test Results (optics graphs)

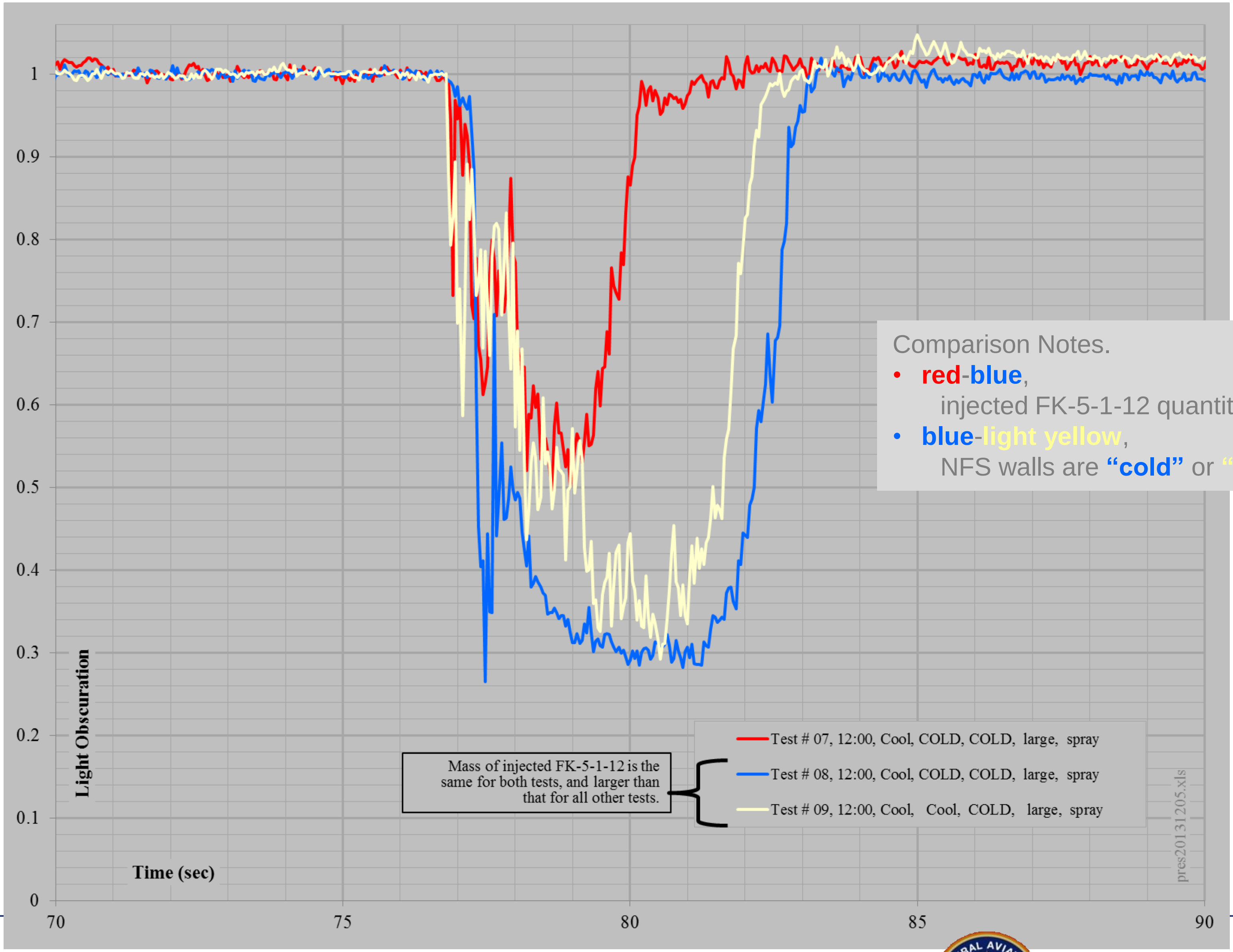


Comparison Notes.

- **black**-**white**,
  all **"cool"/"hot"** or **"cold"/"cool"**
- **white**-**red**,
  quantity of pressurizing nitrogen **small or large**
- **red**-**gray**,
  12:00 or **06:00** region
- **gray**-**yellow**,
  firex agent **"cold" or "cool"**

(Test 10 : Optical telemetry faulted.)

Test Results (optics graphs)



Comparison Notes.

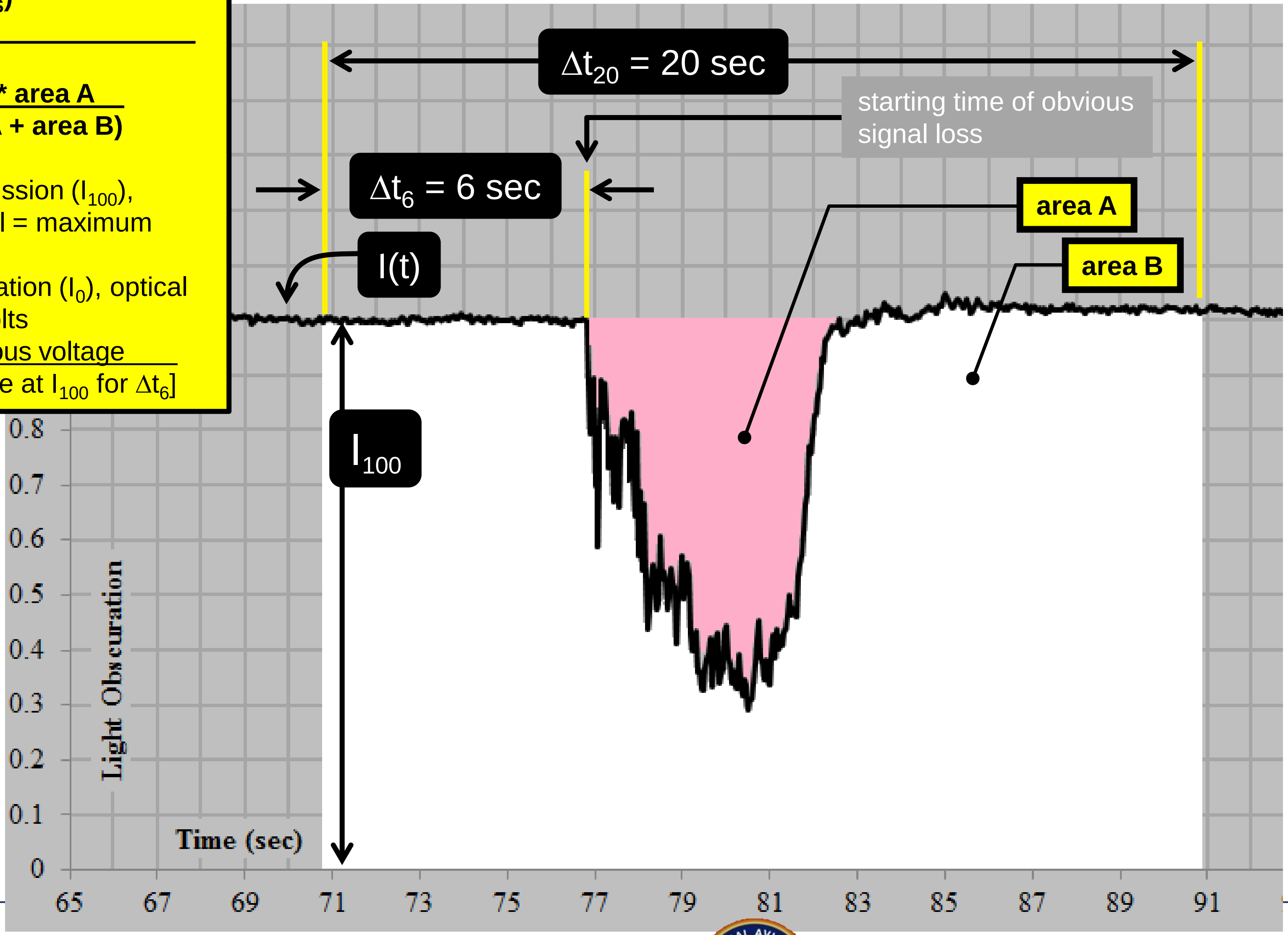
- **red-blue**,
  injected FK-5-1-12 quantity is **small** or **large**
- **blue-light yellow**,
  NFS walls are **"cold"** or **"cool"**

Test Results (optics descriptor)

% Light Obscuration
(% I_{OBS})

$$\% I_{OBS} = \frac{100 * \text{area A}}{(\text{area A} + \text{area B})}$$

- At 100% light transmission (I_{100}), optical receiver signal = maximum voltage
- At 100% light obscuration (I_0), optical receiver signal = 0 volts
- $I(t) = \dfrac{\text{instantaneous voltage}}{[\text{average voltage at } I_{100} \text{ for } \Delta t_6]}$



Test Results (tabular summary)

Test Identification	05	06	07	10	12	13	08	09
test # / test date & run #	11322-11	11329-12	11329-14	11331-11	11401-12	11401-13	11330-11	11330-13
Type of test	agent distribution	fire ext, spray fire	fire ext, spray fire	fire ext, spray fire	fire ext, pool fire	fire ext, pool fire	fire ext, spray fire	fire ext, spray fire
Did the fire extingiush (assessed by visual inspection) ?	-	no	no	no	no	yes/reignited	no	no
Temperature Indications air/KACY (°C)	13	6	11	5	3	4	7	7
H2O dew point in air/KACY (°C)	1	-11	-10	3	2	2	-5	-1
air/NFS inlet (°C)	17	7	11	7	5	4	7	7
air/NFS sta453 average (°C)	47	7	12	9	7	5	7	9
FK-5-1-12 (°C)	38	-54	-57	14	-52	14	-54	-56
shell/average of interior NFS door surfaces, sta 445, 471, & 494 (°C)	37	-35	-32	-33	-34	-33	-36	13
upper sta551 average, pre-injection (°C)	50	713	702	717	45	42	719	718
lower sta551 average, pre-injection (°C)	45	33	36	37	115	113	34	38
difference, upper sta551, deviation due to injection (°C)	-	-49	-73	-205	+180	+117	-74	-79
difference, lower sta551, deviation due to injection (°C)	-	+25	+30	+45	+114	+111	+18	+15
temperature ratio, upper sta 551	-	0.93	0.89	0.71	5.5	4.08	0.9	0.89
temperature ratio, lower sta 551	-	1.96	2.2	2.5	2.04	2.02	1.67	1.48
Anemometry Indications	average speeds, pre-injection							
sta477, 12:00 axial (m/s)	2.3	2.2	2.2	2.3	2	2	2.1	2.2
sta477, 12:00 rotational (m/s)	0.8	0.8	0.9	0.8	-	-	0.6	0.6
sta477, 06:00 axial (m/s)	-	2.1	2	2.1	2.2	2.2	2.1	2.2
sta477, 06:00 rotational (m/s)	-	-	-	-	0.4	0.4	-	-
	ratio, areas under flow speed curves (FK-5-1-12 migration) / (pre-injection)							
sta477, 12:00 axial	1.5	1.1	1	1.1	1.7	1.6	1.2	1.2
sta477, 12:00 rotational	5.2	4.9	4.8	5	-	-	12.9	7
sta477, 06:00 axial	-	1	1	0.9	1.3	1.3	0.9	0.9
sta477, 06:00 rotational	-	-	-	-	7.5	7.7	-	-
	ratios, areas under flow speed curves, FK-5-1-12 migration (rotational / axial)							
12:00	3.5	4.5	4.8	4.5	-	-	10.8	5.8
06:00	-	-	-	-	5.8	5.9	-	-
Percent Light Obscuration Indications sta473, 12:00 axial	0.42	4.39	4.73	sensing failed	-	-	16.9	11.7
sta473, 06:00 axial	-	-	-	-	25.62	19.38	-	-

Changes in Light Obscuration from Test to Test (for select test pairs)

Proportional change in light obscuration		Percent change in light obscuration (positive number signifies increasing obscuration)	
Test #5 to #6 (#6 / #5)	10.452	Test #5 to #6 ([#6 - #5] / #5)	945.2
Test #6 to #7 (#7 / #6)	1.077	Test #6 to #7 ([#7 - #6] / #6)	7.7
Test #7 to #12 (#12 / #7)	5.416	Test #7 to #12 ([#12 - #7] / #7)	441.6
Test #7 to #8 (#8 / #7)	3.573	Test #7 to #8 ([#8 - #7] / #7)	257.3
Test #12 to #13 (#13 / #12)	0.756	Test #12 to #13 ([#13 - #12] / #12)	-24.4
Test #8 to #9 (#8 / #9)	0.692	Test #8 to #9 ([#9 - #8] / #8)	-30.8

Test Results (observations & outcomes)

- <u>**Fire extinguishment not observed**</u>
  - notable behavior occurred 1X against a pool fire (13)
  - fire pushed from pool, but regained it (not extinguished)
  - why this behavior?
    - pool combustion not as thermally effective as spray combustion
      - "large"- versus "small"-surface fuel diffusion; spray versus pool; with increasing diffusion, combustion likely improves
      - *steady global conditions more critical to pool fire stability*
    - loss of liquid FK-5-1-12 from ventilation stream
    - "protected" & flame volumes not concurrent
    - rate of local FK-5-1-12 transformation into useful state/form lacked compared to that of air & fuel in the combustion process

Test Results (observations & outcomes)

- **Comparing other observations**
  - "cold" condition observably affected FK-5-1-12 injection
    - compare tests {"hot" & no fire} / {"cold" & spray fire} (5/6)
    - reviewing L/O behaviors
      - L/O increased 0.4% / 4.4% (respectively); magnitudinally larger; +945%
      - FK-5-1-12 end-state <u>not</u> all vaporous in 6 (%L/O notably ≠ 0)
    - reviewing anemometry behaviors
      - 6's rotational/axial ratio fractionally larger; flows less alike than in 5
      - reduction in axial flows is notable & greater than that for rotation
      - larger reduction in axial flow indicating less migratory expansion
    - L/O is the basis for the statement; anemometry tentative, yet, trends lend support

Test Results (observations & outcomes)

- **Comparing other observations…**
  - global “cold” FK-5-1-12 distribution behavior in the NFS
    - FK-5-1-12 favored NFS lower lobe, even with rotating injection
      - compare & blend {12:00 spray fire} / {06:00 pool fire} (7/12)
      - L/O increased 4.7% / 25.6%; multiply larger at 06:00; +442%
      - with larger L/O in lower lobe, more FK-5-1-12 resident
    - FK-5-1-12 injection plumes captured rotating around core
      - notable spike observed in L/O histories; 6-9 & 13; 2 spikes in 9?
      - spike separates 2 durations of more aerosol-laden flow
      - oscillating signal expected at fixed point subject to rotating plumes
      - plausible given injection plumbing created rotation during injection
      - spike & L/O excursion durations & proportionalities dissimilar; indicating some transition?

Test Results (observations & outcomes)

- **Comparing other observations…**
  - outcome not significant for increasing FK-5-1-12 mass
    - review small/large injected masses (7/8); both “cold” FK-5-1-12
    - L/O increased from 4.7% to 16.9%; multiply larger; +253%
    - reviewing anemometry behaviors
      - indicates significant rotational flow in 8; a “wet” hot-wire ?
      - axial flow perturbations roughly 1-2 seconds longer in 8
    - reviewing sta551 behaviors
      - comparable thermal excursions in upper lobe; -73° ≈ -74°C
      - observable decrease in lower lobe excursions
        - » +30°C > +18°C
        - » due to more “cold” FK-5-1-12, with minimal effect on fire?
      - thermal degradation faster during 7

Test Results (observations & outcomes)

- **Comparing other observations…**
  - what affects FK-5-1-12 more? “cold” FK-5-1-12 or walls
    - confounding issues
      - optical history not captured for test 10 due to telemetry fault
      - pool fire test configuration (12/13) versus spray fire (8/9, 7/10)
      - 2 different FK-5-1-12 masses injected (8=9 > 7=10=12=13)
    - L/O suggests “cold” walls affected FK-5-1-12 more
      - compare “cold”/”cool” agent (12/13) & “cold”/”cool” walls (8/9)
      - L/O decreased 24% (12/13) & 31% (8/9)
        - » 12/13 : L/O decreased from 25.62 to 19.38% (7 at 4.7%)
        - » 8/9 : L/O decreased from 16.9 to 11.7%
      - larger change in aerosol quantity for “cold”/“cool” walls
      - pool/spray? 2 masses? large mass more fog? warm wall no frost?

Test Results (observations & outcomes)

- **Comparing other observations…**
  - what affects FK-5-1-12 more? “cold” FK-5-1-12 or walls
    - anemometry suggests “cold” walls affected FK-5-1-12 more
      - compare “cold”/”cool” FK-5-1-12 (7/10 & 12/13) against “cold”/”cool” walls (8/9)
      - NFS walls played an observable role
        - » isolate & look at each test pair for its behavioral change due to its conditional change, then compare the sizes of changes
          - 8/9 differ from others due to larger FK-5-1-12 injection
          - others differ from 12/13 due to anemometer location
        - » largest difference is that of rotational flow seen between 8/9; due to notable change in *rotational* flow behavior
      - largest change between tests in each test pair is for the rotational flow between 8/9

Test Results (observations & outcomes)

Thermal Excursions at sta551

Tests	sta551 Sample Position	Variable	Condition of Variable	Temperature Excursions (°C)
7/10	upper	FK-5-1-12	“cold”/”cool”	-73/-205
	lower	(small mass)		+30/+45
12/13	upper	FK-5-1-12	“cold”/”cool”	+180/+117
	lower	(small mass)		+114/+111
8/9	upper	NFS walls	“cold”/”cool”	-74/-79
	lower	(large mass)		+18/+15

- **Comparing other observations…**
  - what affects FK-5-1-12 more? “cold” FK-5-1-12 or walls
    - consider temperature behaviors at NFS sta551
      - still comparing tests for varied FK-5-1-12/NFS wall temperatures…
      - (7/10), (12/13), & (8/9)
      - sta551 pre-injection values show fires behaved consistently
      - thermal excursions are largest for “cold”/“cool” FK-5-1-12
        - » largest decrease for “cool” FK-5-1-12/”cold” NFS walls (10)
        - » related excursions decrease or are similar for 12/13
        - » related excursions are similar for “cold”/”cool” NFS walls (8/9)
    - *increasing FK-5-1-12 temperature better improved its ability*

Test Results (observations & outcomes)

- **Comparing other observations…**
  - what affects FK-5-1-12 more? “cold” FK-5-1-12 or walls
    - why a conflict in the means of observation/comparison?
      - L/O & anemometry suggest “cold” walls are more significant
      - sta551 trends suggests storage temperature is more significant
      - conflict relates to the question “…what affects FK-5-1-12 more…”
        - » affecting how? as defined by use for this application…
        - » state of FK-5-1-12 after injection? relates to migratory state; indicated by L/O & anemometry trends…
        - » FK-5-1-12 ability to extinguish fire? relates to fire extinction; indicated by sta551 trends…
      - does FK-5-1-12 mist/spray work like FK-5-1-12 vapor? based on that seen here, no…

Test Results (conclusions & considerations)

- **Concluding**
  - no fires were extinguished in 13 tests
  - test 10 & 13 provided most interesting observations
  - while maintaining the same injection plumbing…
    - storage & environmental temperatures notably affected the state & dispersion of FK-5-1-12
    - “cold” FK-5-1-12 settled low in the NFS (all tests run at similar air mass flow rate)
    - “cold” boundaries notably affected the injection plumes
    - increasing the “cold” mass negligibly changed fire suppression
    - increasing storage temperature improved fire suppression

Test Results (conclusions & considerations)

- **Considerations**
  - witnessed phenomena (slides 6-8) ≠ full-scale testing (slides 10-68)
    - witnessed phenomena : initially-“warm” vapor mass lost to boundary by condensation, at reduced temperature *& pressure*
    - full-scale testing : reduced boundary & FK-5-1-12 temperatures did not extinguish fire at atmospheric pressure
  - substance trends moving to less-energetic materials
  - with aerosol existence in a “protected” volume :
    - use of a Statham-derivative gas analyzer is questionable
    - does FAA A.C. 20-100[5] concentration framework remain valid?
      - volumetric concentration?
      - ½ second residence time remain unchanged?

Recognition of Contributions by Others

We miss you Bandit

Please recognize additional contributions to this body of work from the following individuals :

- Mr. Stephane Pugliese, Airbus Industries, Toulouse, France
- Mr. James Mavricos, Meggitt Safety Systems Incorporated, Duarte, CA, USA
- Mr. Dick Hill, Mr. Jason Fleming, Mr. Mark Materio, Mr. Tom Carmen, FAA Technical Center, Atlantic City International Airport, NJ, USA
- Mr. Stephen Happenny, FAA Northwest Mountain Region, Renton, WA, USA

Referable Information

1. Thermodynamic data provided by :
   - DuPont “Thermodynamic Properties DuPont Halon 1301 Fire Extinguishant,” Bulletin T-1301, E.I. Du Pont De Nemours & Co, Inc, Wilmington, DE, USA, Feb, 1966.
   - personal communication, Paul Rivers, 2006.
2. FK-5-1-12 & halon 1301 cup-burner & peak-inerting experimental concentrations
   - Hamins, et al., 1994, “Flame Suppression Effectiveness,” NIST Special Publication 861, National Institute of Standards & Technology, Building and Fire Research Laboratory, Gaithersburg, MD.
   - National Fire Protection Association, 2007, “NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems,” 2008 Edition, Quincy, MA.
   - National Fire Protection Association, 1989, “NFPA 12A Standard on Halon 1301 Fire Extinguishing Systems,” 1989 Edition, Quincy, MA.
   - FK-5-1-12 cup-burner & peak inerting concentration values

     cup-burner : NFPA, 2007, Tables A.5.4.2(a) & A.5.4.2(b), p.50.

     peak inerting : NFPA, 2007, Table A.5.4.3, p.55.
   - halon 1301 cup-burner & peak inerting concentration values

     cup-burner : Hamins, 1994, table 5, p.395.

     peak inerting : NFPA, 1989, derived from table A-2-3.2.1, p.15.
3. Presentation on Outcomes from MPSe Revision 03 Testing, found at :

   http://www.fire.tc.faa.gov/pdf/systems/Oct06Meeting/Ingerson-1006-HalonReplacement.pdf
4. Working Copy of Draft MPSe Revision 04, found at

   http://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf
5. 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, DC, http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/list/AC%2020-100/$FILE/AC20-100.pdf