Propulsion Halon Replacement Activity at the FAA WJ Hughes Technical Center

Federal Aviation Administration

Presented to:	5TH Triennial International Fire and Cabin Safety Research Conference
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Date:	30Oct2007

Presentation Overview

- **Discuss the Minimum Performance Standard for Engine Nacelles and APU Compartments (MPSe)**
  - Background
  - Describing the Test Process
- **Review Outcomes from MPSe Testing to Date**
  - HFC-125, CF3I, & FK-5-1-12
  - Noteworthy Observations
- **Identify Pending Challenges to the MPSe**

Discuss the MPSe
Background

- **Who "owns" the MPSe?**
  - FAA International Aircraft Systems Fire Protection Working Group
  - Composed of government and industry representatives
    - International
    - Manufacturer, regulator
    - Civilian, military

Discuss the MPSe
Background

- **Lineage**
  - 1993, FAA , aviation industry, US Department of Defense/tri-service
  - Initial testing planned at Wright-Patterson Air Force Base (WPAFB), OH
    - 3 phase, down-select process resulting in a single halon replacement
    - Culminated in "Aircraft Engine/APU Fire Extinguishing System Design Model (HFC-125)," AFRL-VA-WP-TR-TR-1999-3068
  - 1995, Project started at FAA WJ Hughes Technical Center (FAATC)
    - Civil airplane industry wanted more halon replacement choices
      - 2000, "Options for Aircraft Engine Fire Protection," white paper, http://www.fire.tc.faa.gov/pdf/engine.pdf
      - 1996, "User Preferred Fire Extinguishing Agents for Engine and Auxiliary Power Unit (APU) Compartments," Report No. DOT/FAA/AR-96/80
    - Interests wanted to retain "...X %v/v for 0.5 second..." FAA certification format without design model information

Discuss the MPSe
Describing the Test Process

- **Empirical, full-scale, test process**
- **Considers test process & application constraints**
  - Must be a reliable, repeatable TEST PROCESS
  - Must relate to a wide range of installations found in this APPLICATION
- **Minimizes non-agent fire extinction mechanisms**
- **Limited review**
  - Evaluates fire extinguishment performance only
  - Agent/airplane compatibility issues must be reviewed separately
  - MPSe requires that agent and airplane must be compatible

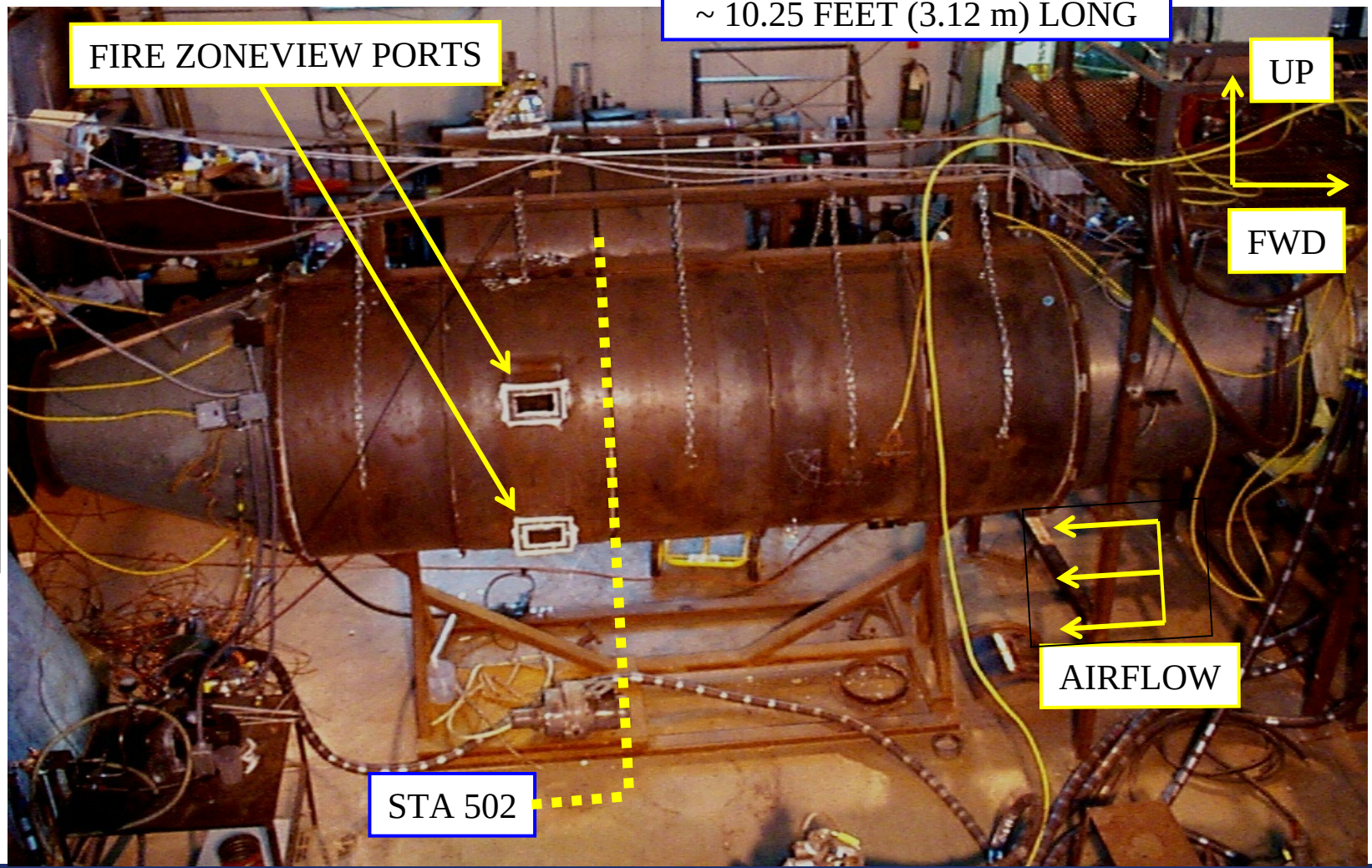
Discuss the MPSe
Describing the Test Process

- **Coupled characterization of Halon 1301 & replacement candidate performances**

- **Four test configurations**
  - 2 ventilation regimes
    - High = 1.2 kg/s @ 38°C (2.7 lbm/s @ T = 100°F)
    - Low = 0.45 kg/s @ 127°C (1.0 lbm/s @ T= 250°F)
  - 2 fire threats, both baffle stabilized with persistent ignition & fuel sources
    - All fuels delivered at 0.95L/min at 66°C (0.25 US gal/min @ 150°F)
    - Spray fire using JP8, lubricating oil, OR hydraulic fluid
    - Pool fire using JP8 alone

Discuss the MPSe

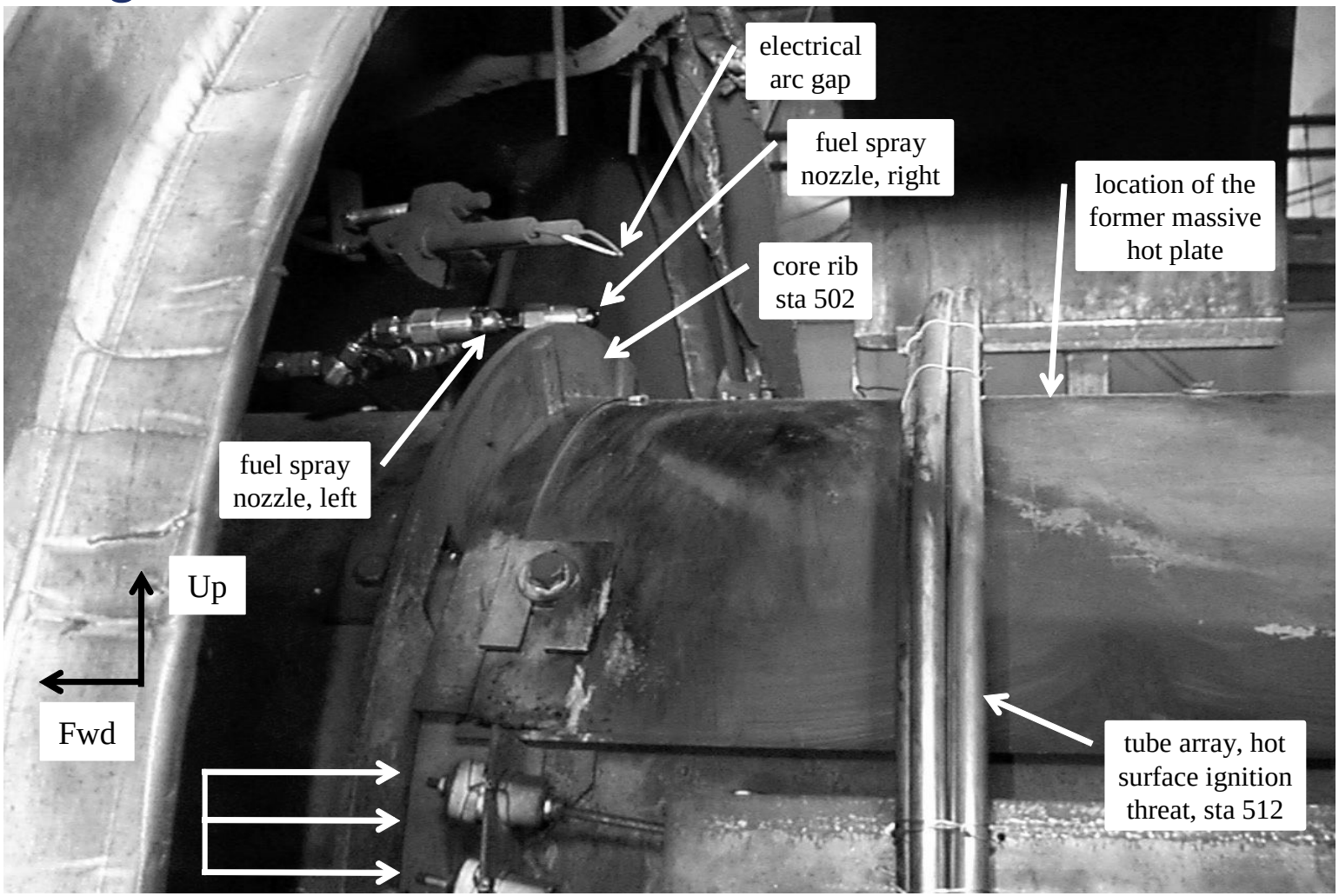
Describing the Test Process



Discuss the MPSe

Describing the Test Process

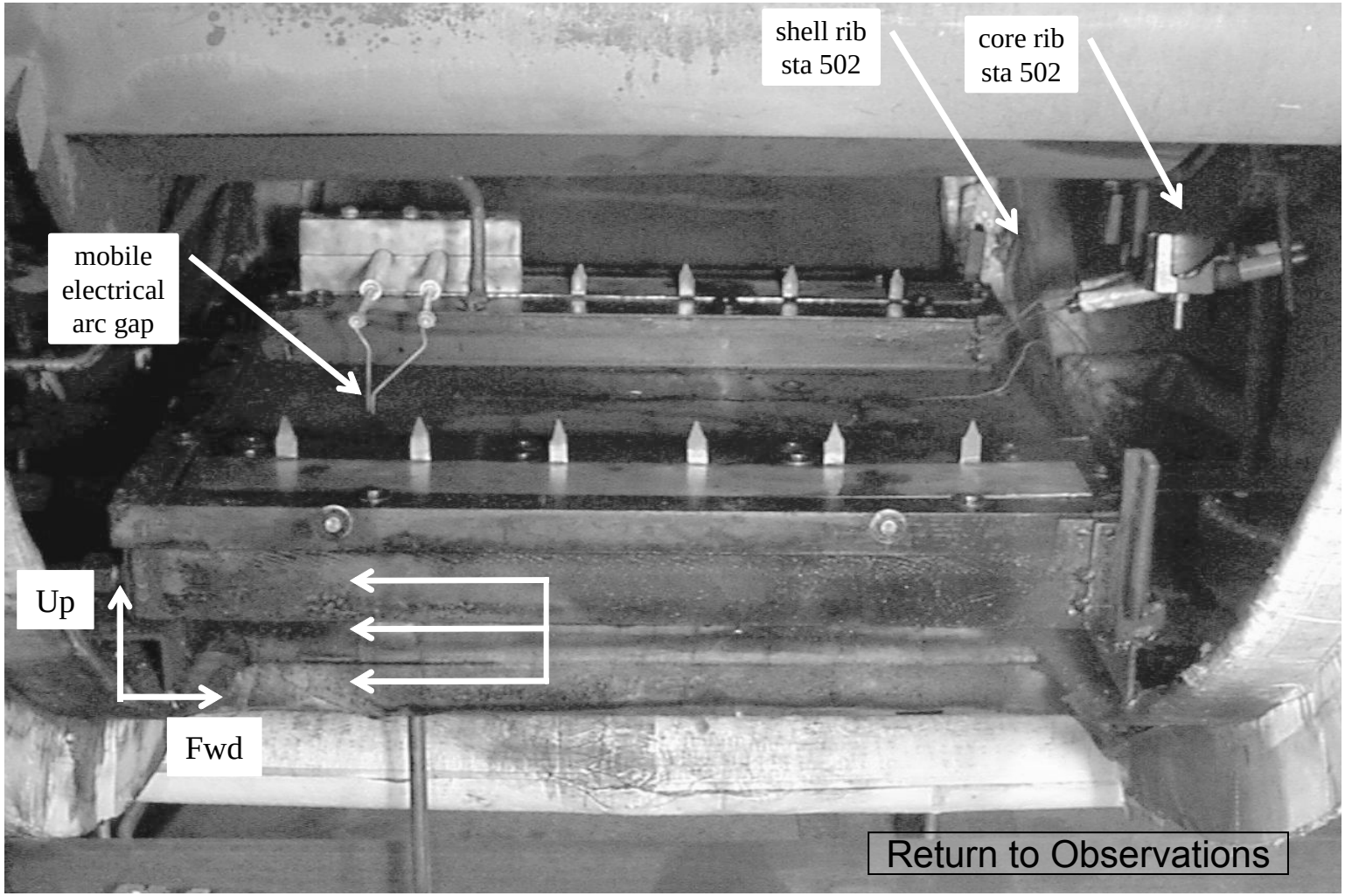
Spray Fire Threat



Discuss the MPSe

Describing the Test Process

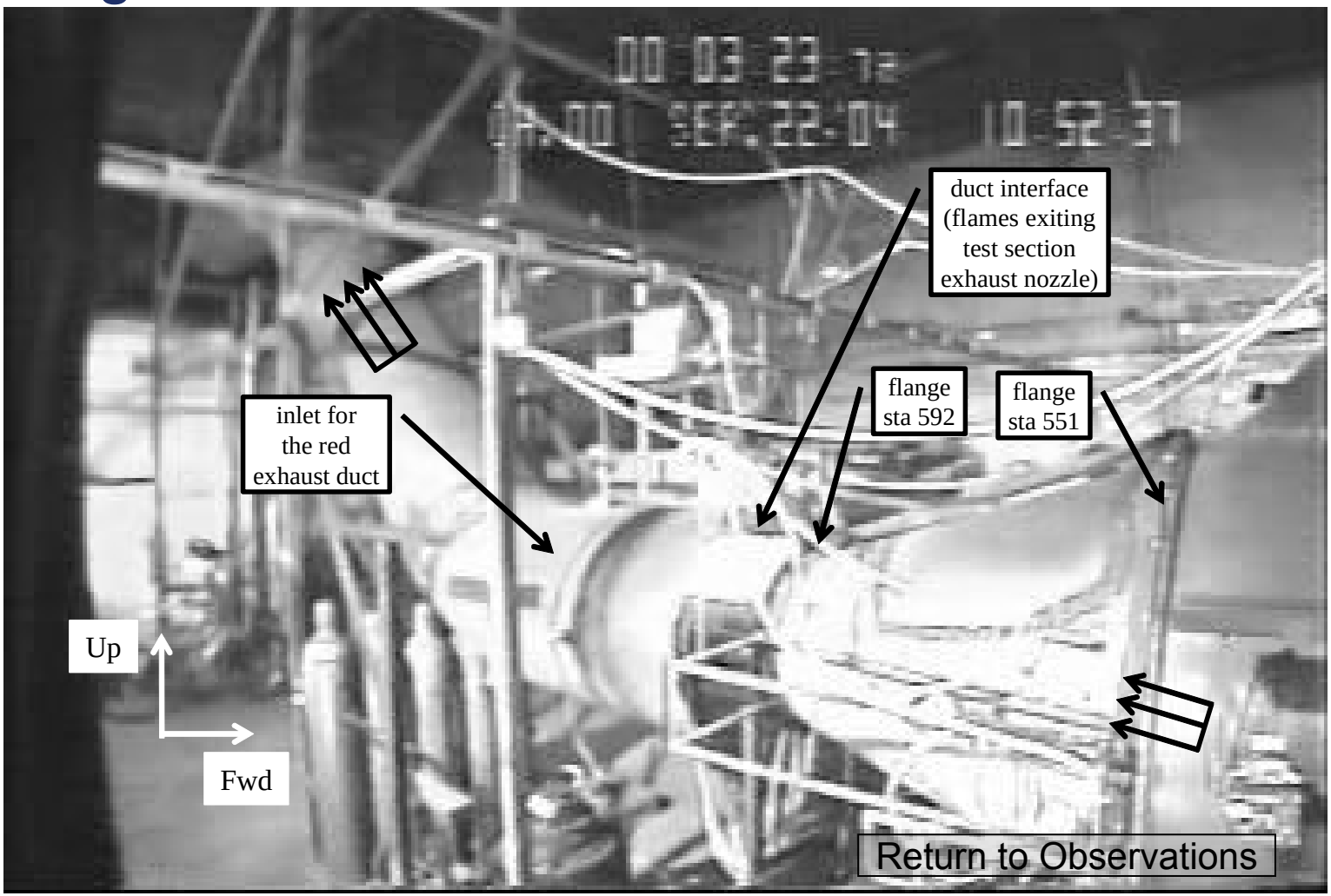
Pool Fire Threat



Discuss the MPSe

Describing the Test Process

Duct Interface



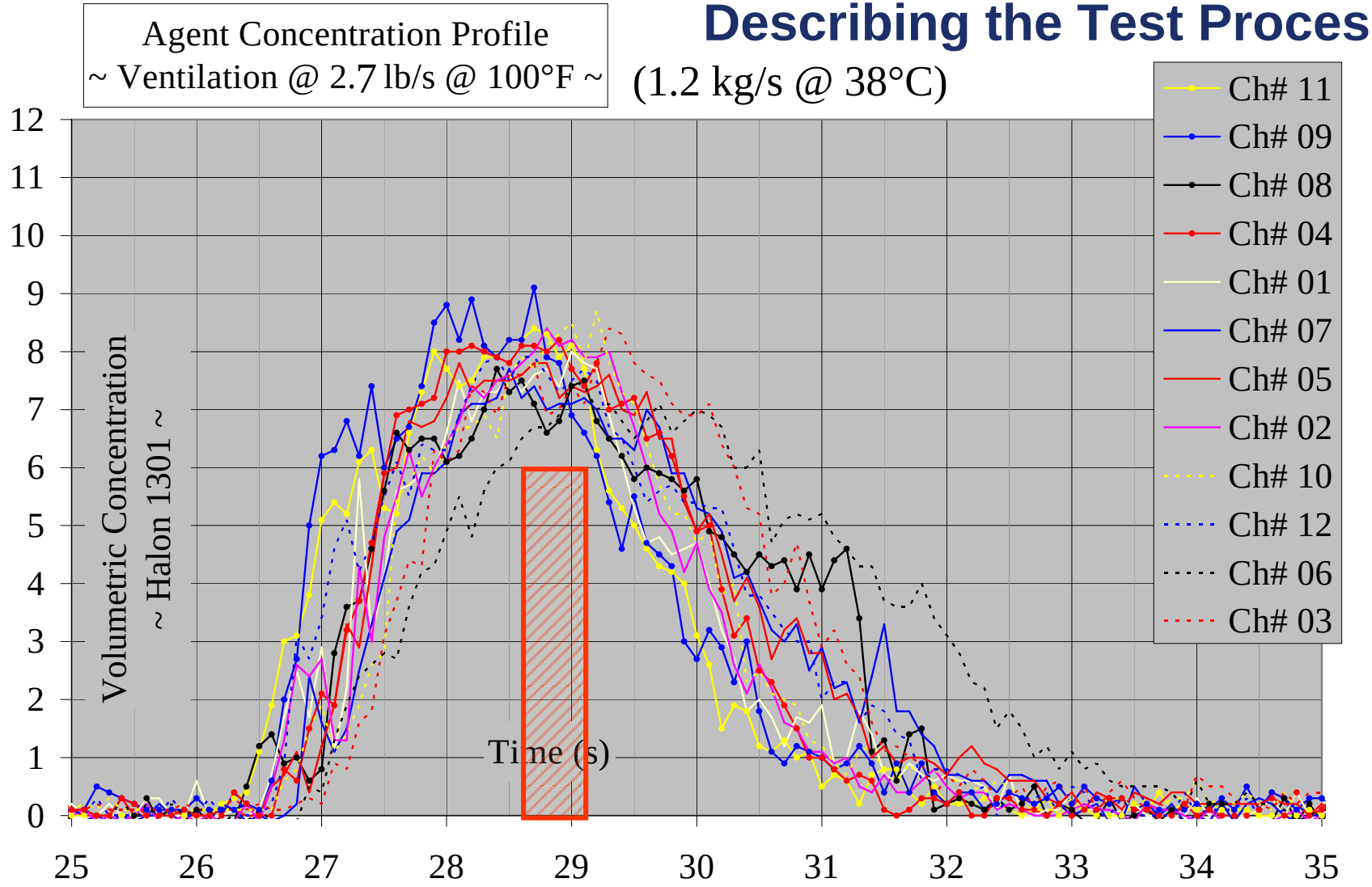
Discuss the MPSe
Describing the Test Process

- **Demonstrating Halon 1301 Equivalence**
  - Fire extinction
    - Direct observation
    - Based on an average of 5 repeated fire tests
    - Verified against other fuels based on an average of 3 repeated fire tests
  - Agent concentration
    - Direct observation + mathematical manipulation
    - Based on 3 repeated non-fire tests
- **Halon 1301 delivered to test fixture meeting the intent of FAA certification**
  - Measured by Statham-derivative gas analyzer, 12 sampling points
  - 3 ring sampling arrangement, middle ring centered at flame front

Discuss the MPSe

Describing the Test Process

Meeting Intent of FAA Certification

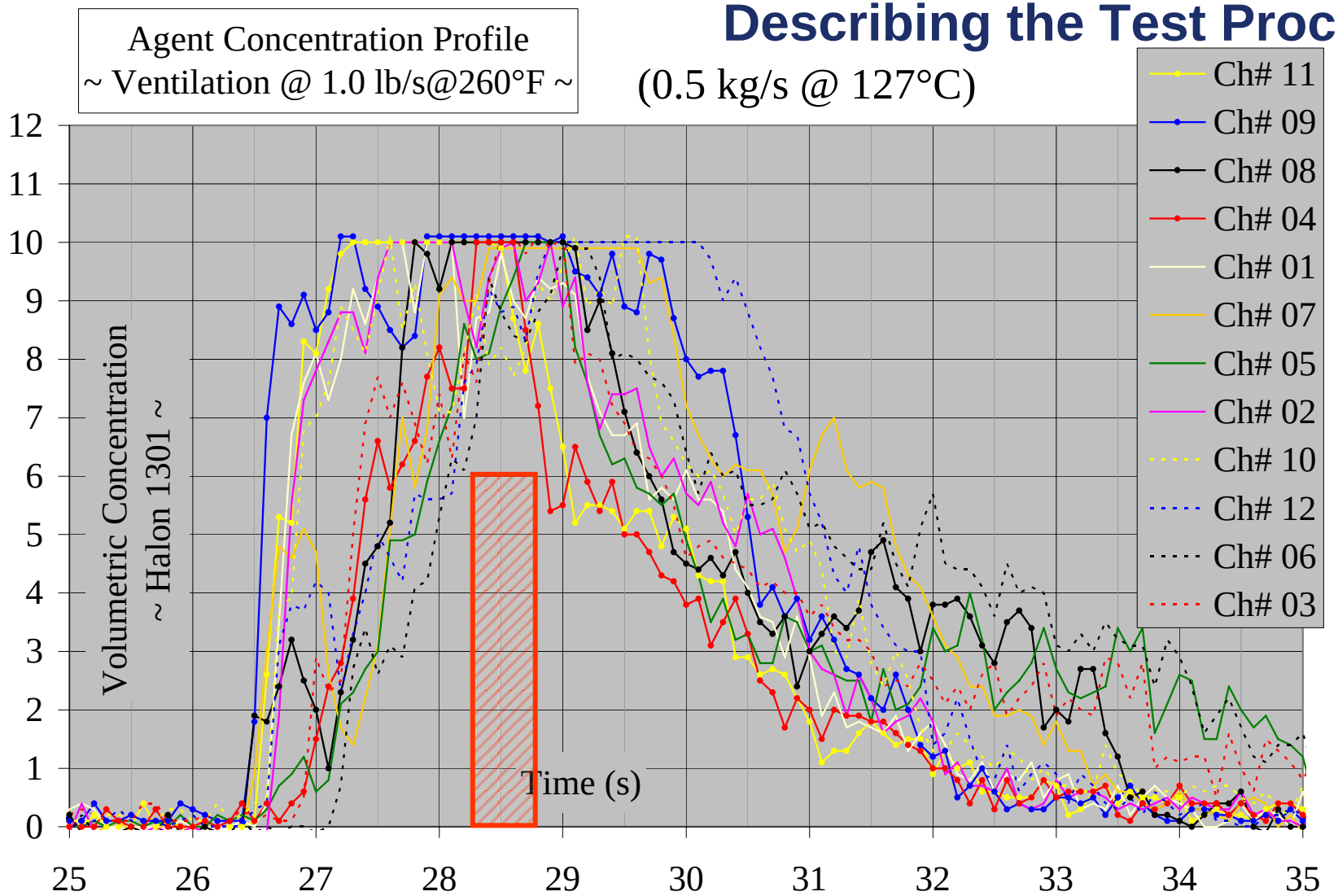


Return to Equivalent Concentration

Discuss the MPSe

Describing the Test Process

Meeting Intent of FAA Certification

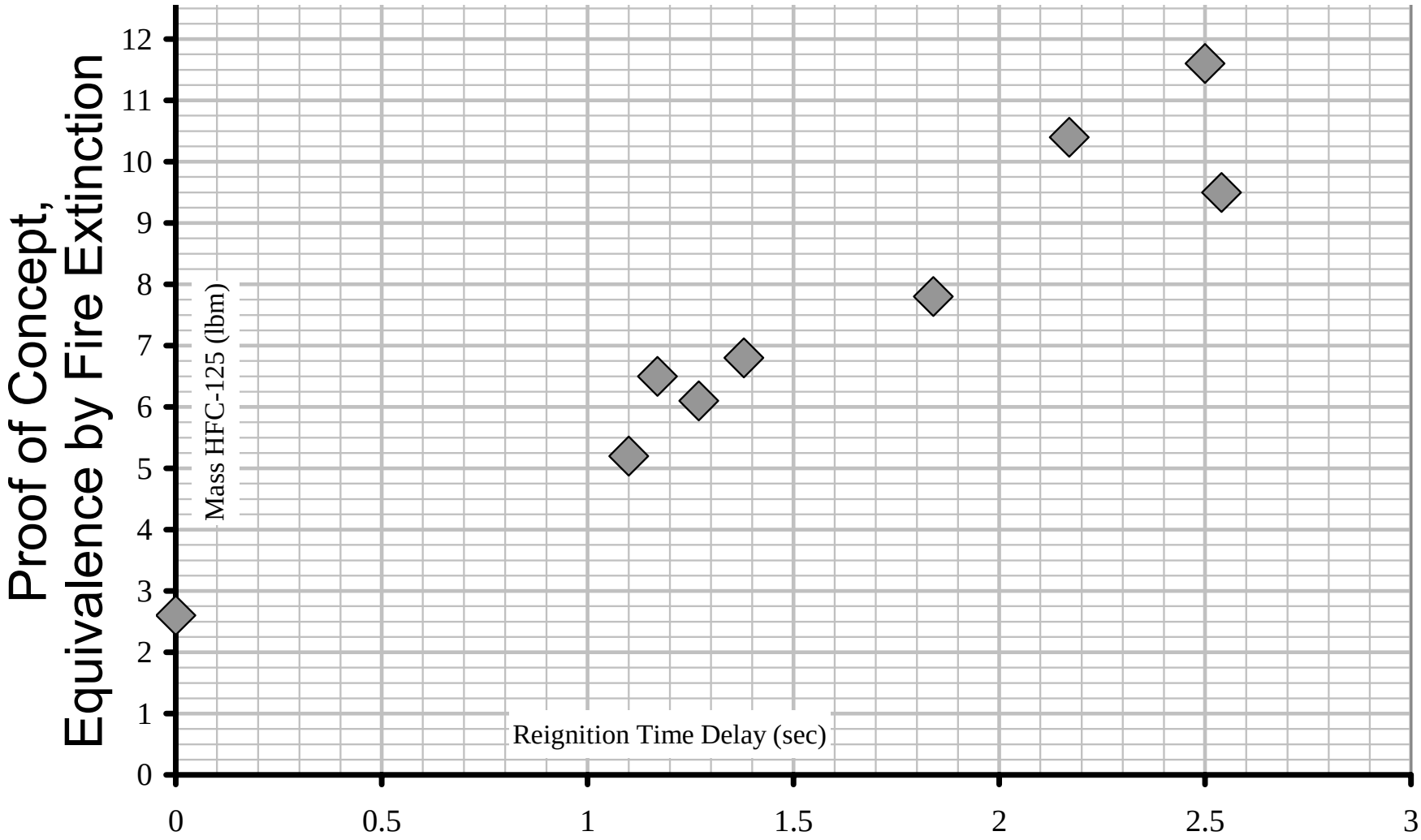


Discuss the MPSe
Describing the Test Process

- **Explaining equivalence by "fire extinction"**
  - Reignition Time Delay (RTD)
    - A visually observed duration of suppressed combustion
    - Occurs during the presence of forced ventilation, a transient agent pulse, and persistent ignition/fuel sources
    - $RTD = t_{FIRE\,REIGNITION} - t_{FIRE\,EXTINCTION}$
  - Desired conditions :
    - $\overline{RTD}(\text{Replacement quantity 01}) \geq \overline{RTD}(\text{H1301})$
    - $\sigma(\text{Replacement quantity 01}) \approx \sigma(\text{H1301})$

Discuss the MPSe

Describing the Test Process

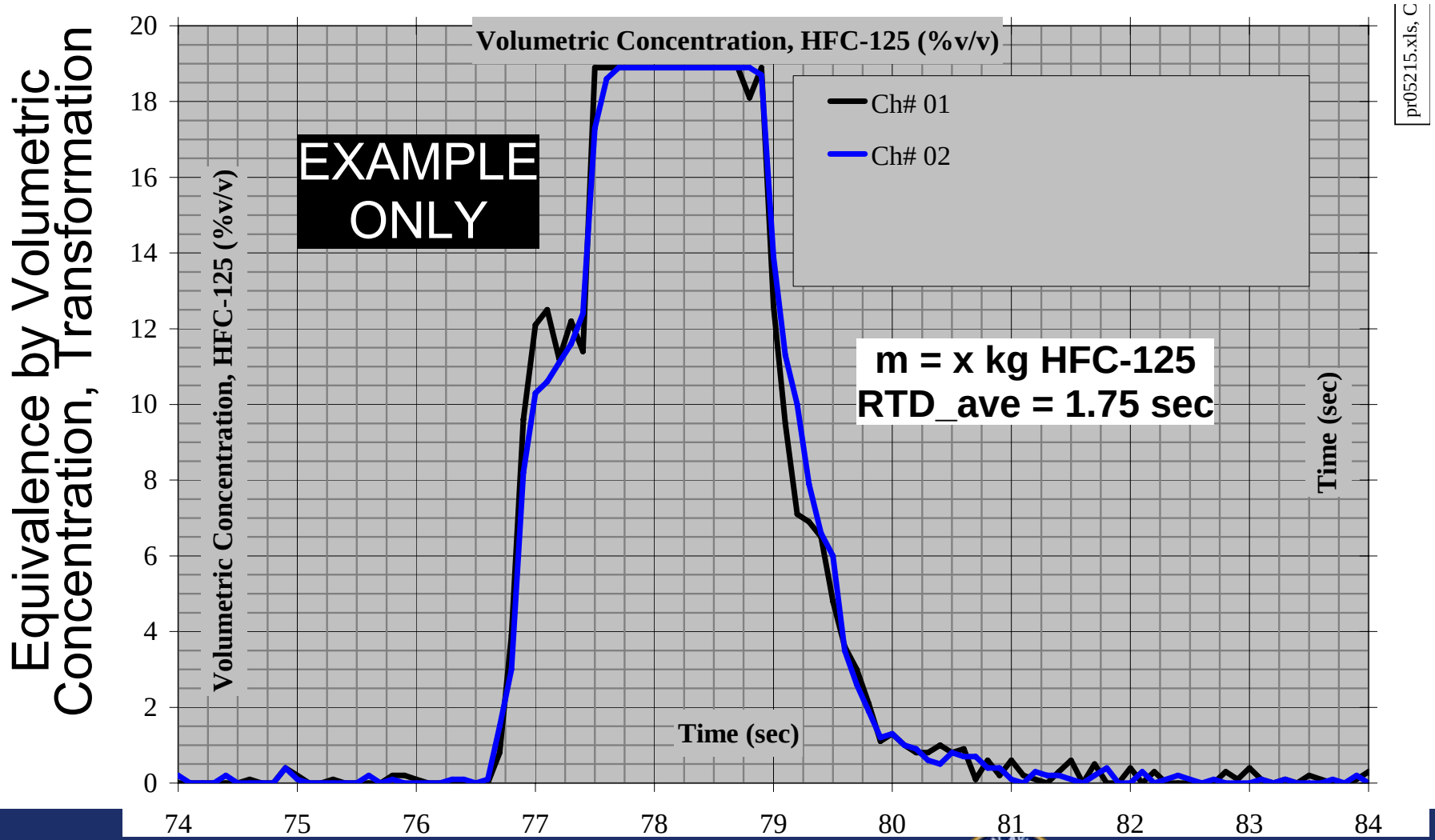


Discuss the MPSe
Describing the Test Process

- **Explaining equivalence by "concentration"**
  - Fire testing ceases; equivalence by fire extinction is established
  - Agent distribution captured for the established agent delivery
  - Data pool composed of recorded concentration behavior :
    - 2 flame front locations
    - 3 repeated tests
  - Data pool is transformed :
    - From elapsed/historical time to durational behavior
    - Described by a best-fit least squares polynomial
  - Equivalence by concentration is calculated by :
    - Using the related average RTD in the best-fit relationship
    - Solving for a volumetric concentration

Discuss the MPSe

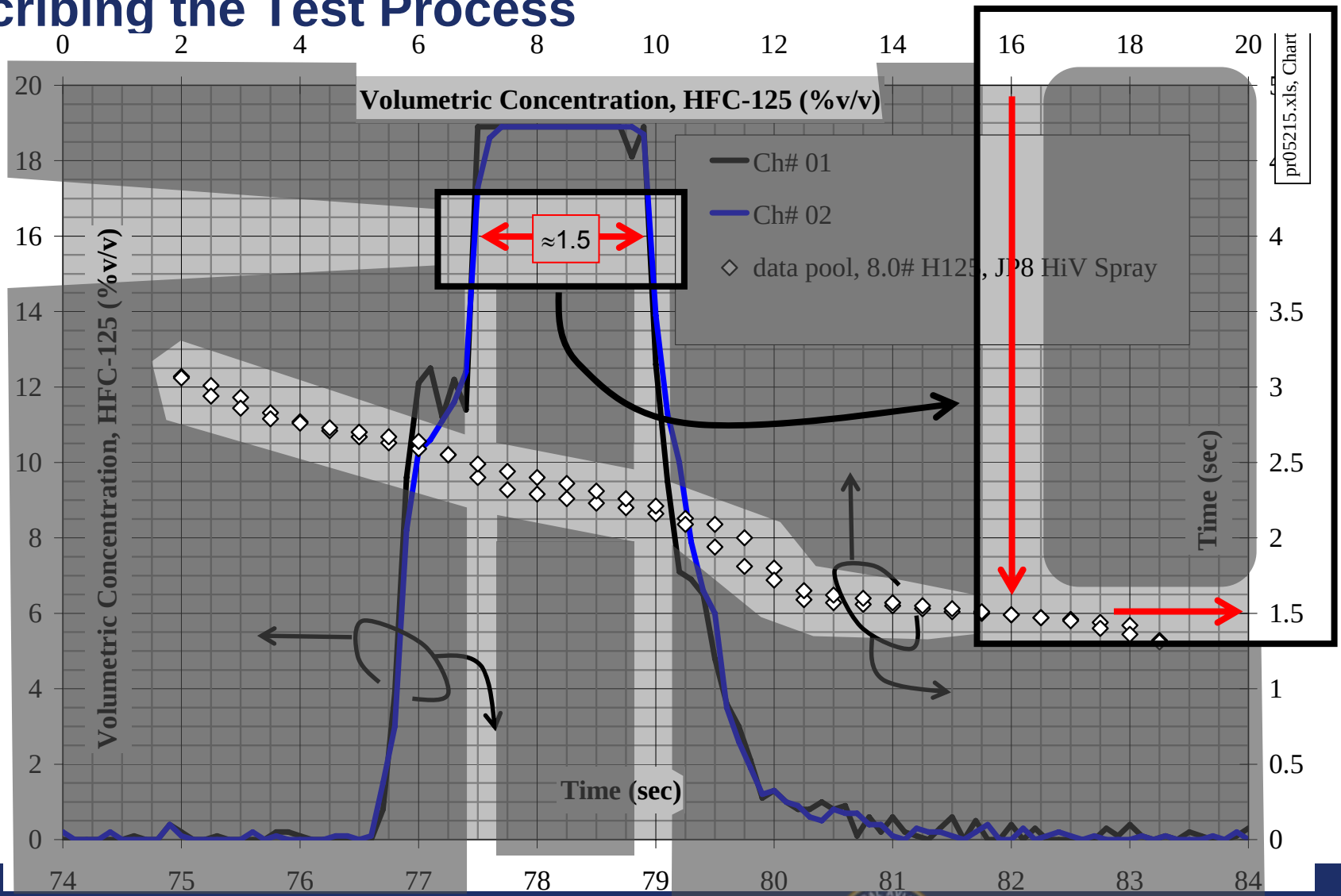
Describing the Test Process



Discuss the MPSe

Describing the Test Process

Equivalence by Volumetric Concentration, Transformation



Discuss the MPSe

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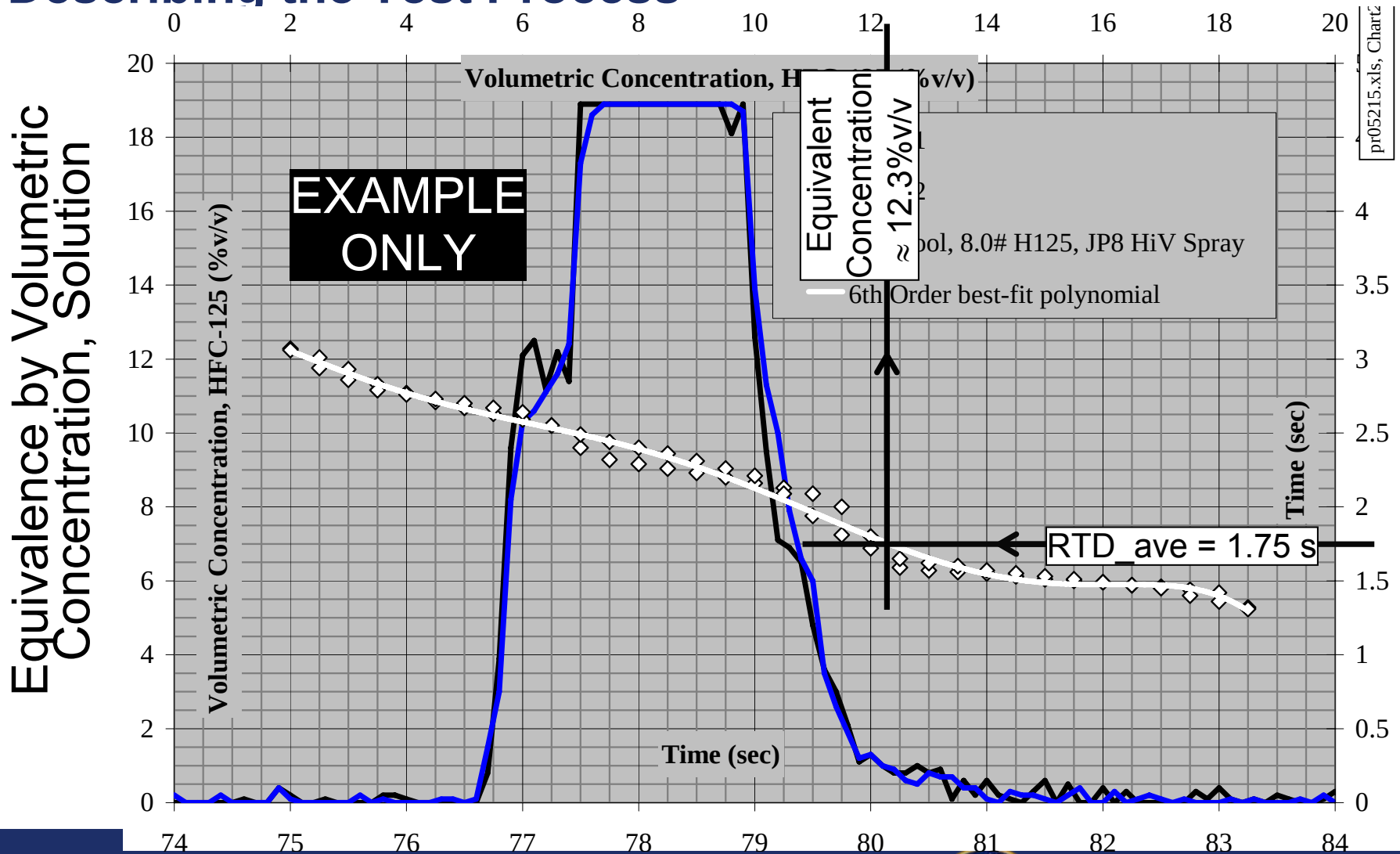


Discuss the MPSe
Describing the Test Process

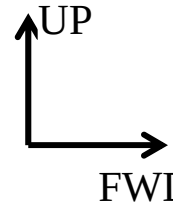
- **Outputs from the MPSe test process**
  - Equivalences
    - minimum of 4 based on fire extinction performance (mass-based)
    - 4 based on agent distribution (volumetric concentration)
  - Recommendation for a certification value is the largest of the 4 equivalent concentrations
    - for a gas, X %v/v simultaneously for 1/2 sec throughout the fire zone
    - for something else, ?

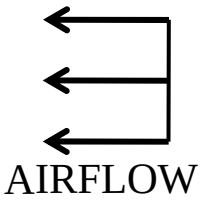
- **Mass-based equivalence is NOT cited**
  - Inefficient agent delivery systems can demonstrate parity with halon

Discuss the MPSe

Describing the Test Process

HALON 1301 VERSUS
HiVent JP8 SPRAY FIRE
(video plays at 1/2 speed)

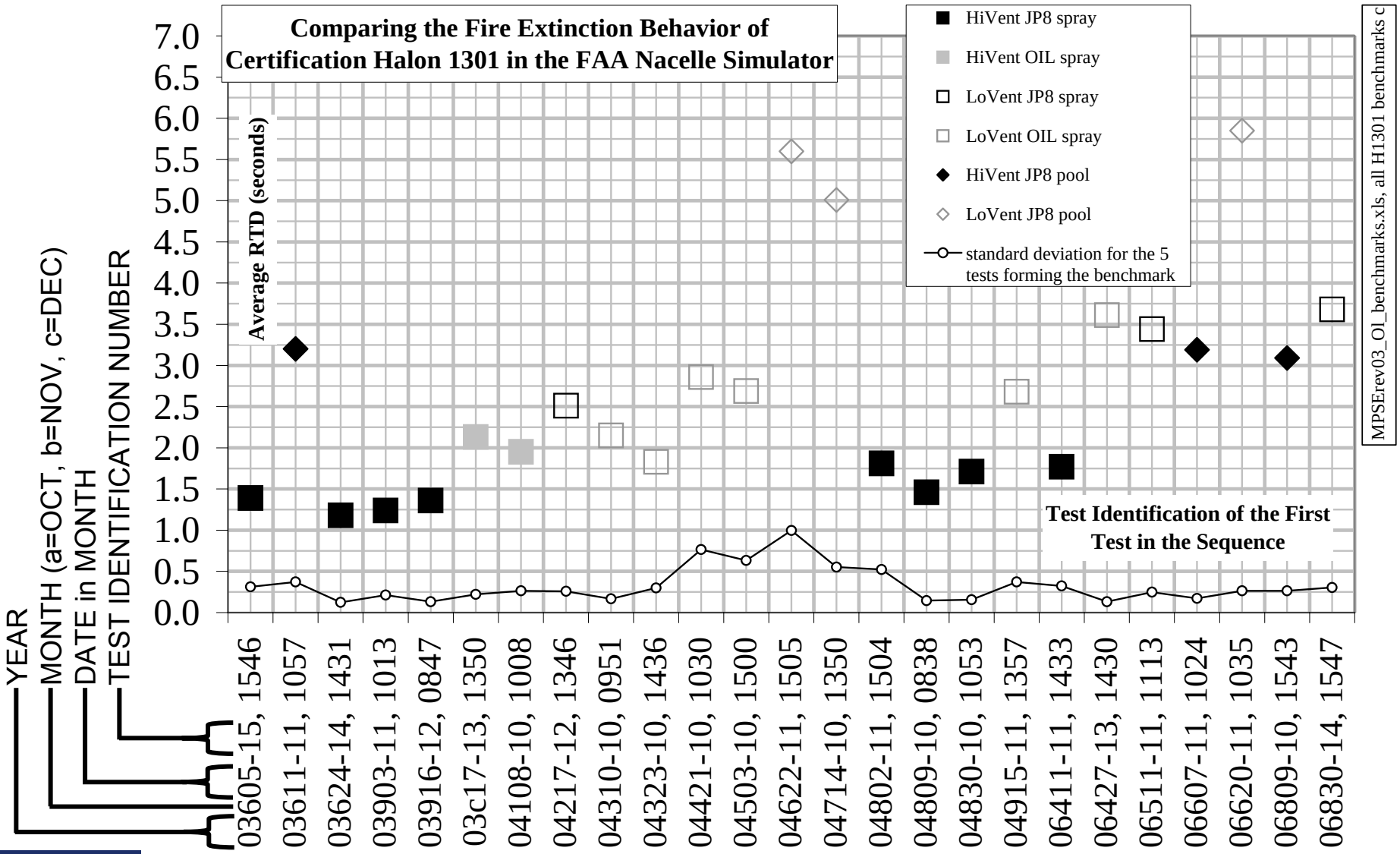




Outcomes from MPSe Testing to Date
Noteworthy Observations

- **Test histories include Halon 1301, HFC-125, CF_3I, 2-bromotrifluoropropene (2-BTP), & FK-5-1-12**
- **Variation in test process & environment**
  - If all is operating normally, test outcome is reasonably consistent
  - Anomalous behavior indicates fault
- **Have determined equivalent concentrations for HFC-125, CF_3I, FK-5-1-12**
  - Relative relationship of equivalent concentrations are reasonable
  - Compare reasonably with reported inerting and cup burner data

Outcomes from MPSe Testing to Date



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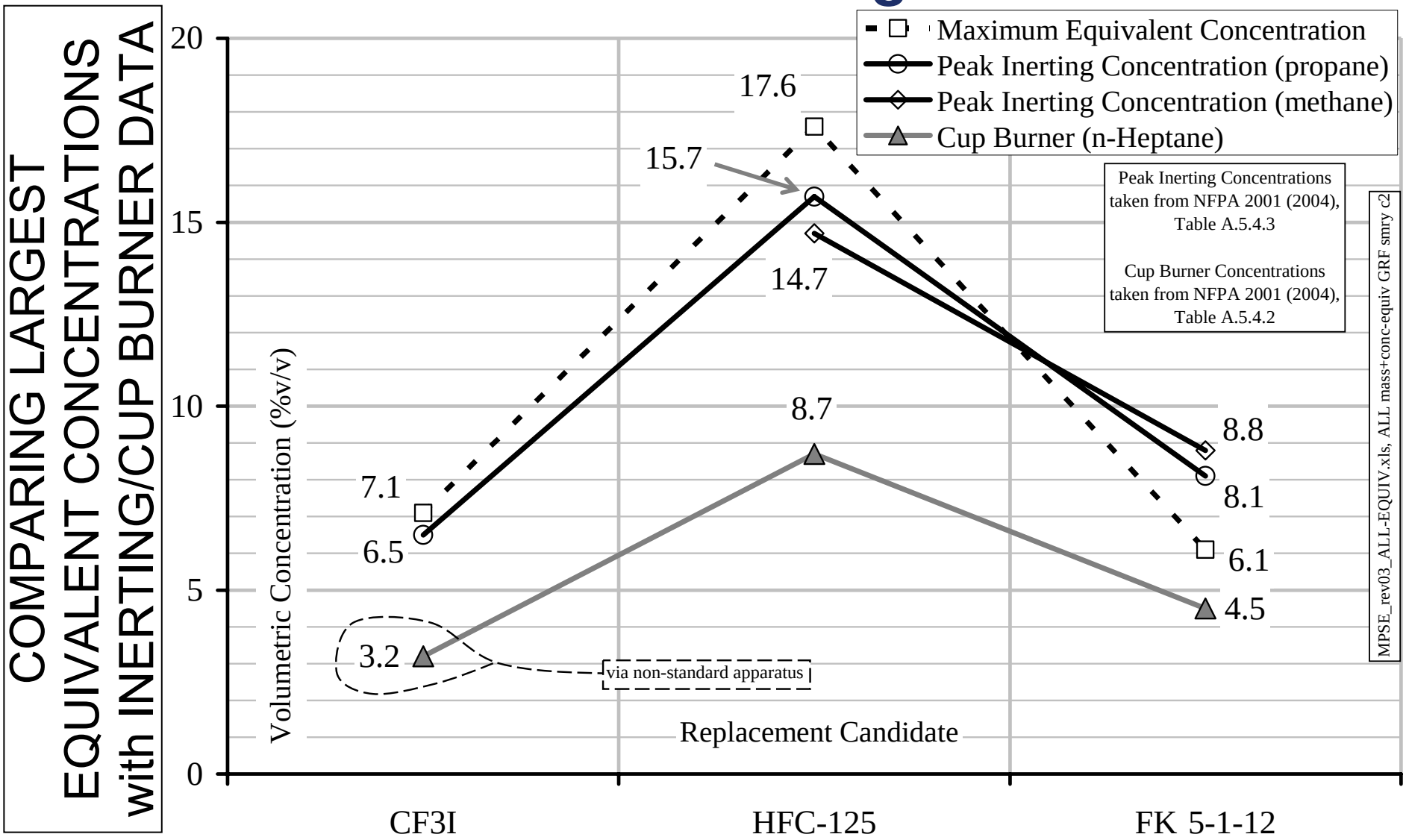


Outcomes from MPSe Testing to Date
Noteworthy Observations

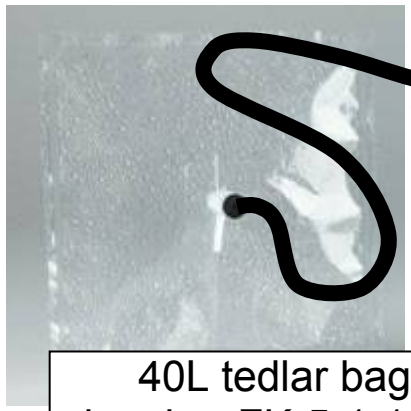
- **Observations at the duct interface**
  - Initially not suspected as a region of interest
  - 2004, 2-BTP observed to be reactive
  - Temperature, pressure, & optical instrumentation added after 2004 testing
  - H1301 & candidates demonstrate different behaviors during reignition
    - H1301 does not force any visible smoke into test bay
    - ALL successful replacement candidates forced visible smoke (NOT fire) into the test bay in some configuration

Refresh memories about duct interface

- **Observations associated with normal boiling point (BP)**
  - FK-5-1-12 condensed in analyzer sample lines during bench scale investigations
  - Flame attachment more evident with increasing normal BP (CF3I, FK-5-1-12)
    - anecdotal observations during pool fire testing
    - photoconductive photodiodes

Outcomes from MPSe Testing to Date

COMPARING SAMPLE LINE TEMPERATURE & ANALYZER SIGNAL BEHAVIORS



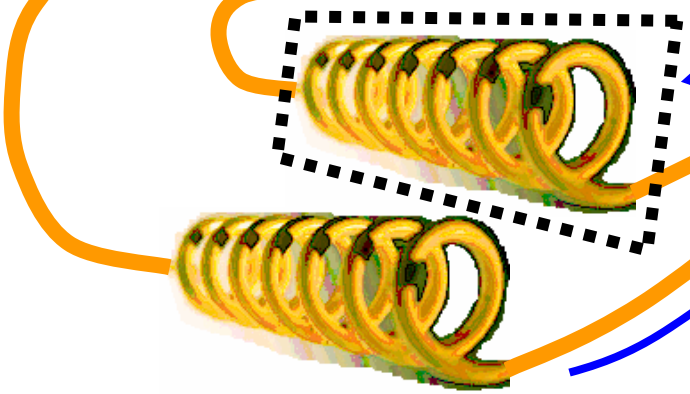
40L tedlar bag
dry air + FK-5-1-12(v)

vent to atmosphere

dry air
% < 6 ppm H2O

$\dot{Q}$

Line length &
wall temperature
10 ft @ 4°F<T<26°F
6 ft @ 40<T<47
8.3 ft @ 104<T<155



gas sample flow

ch12

ch09

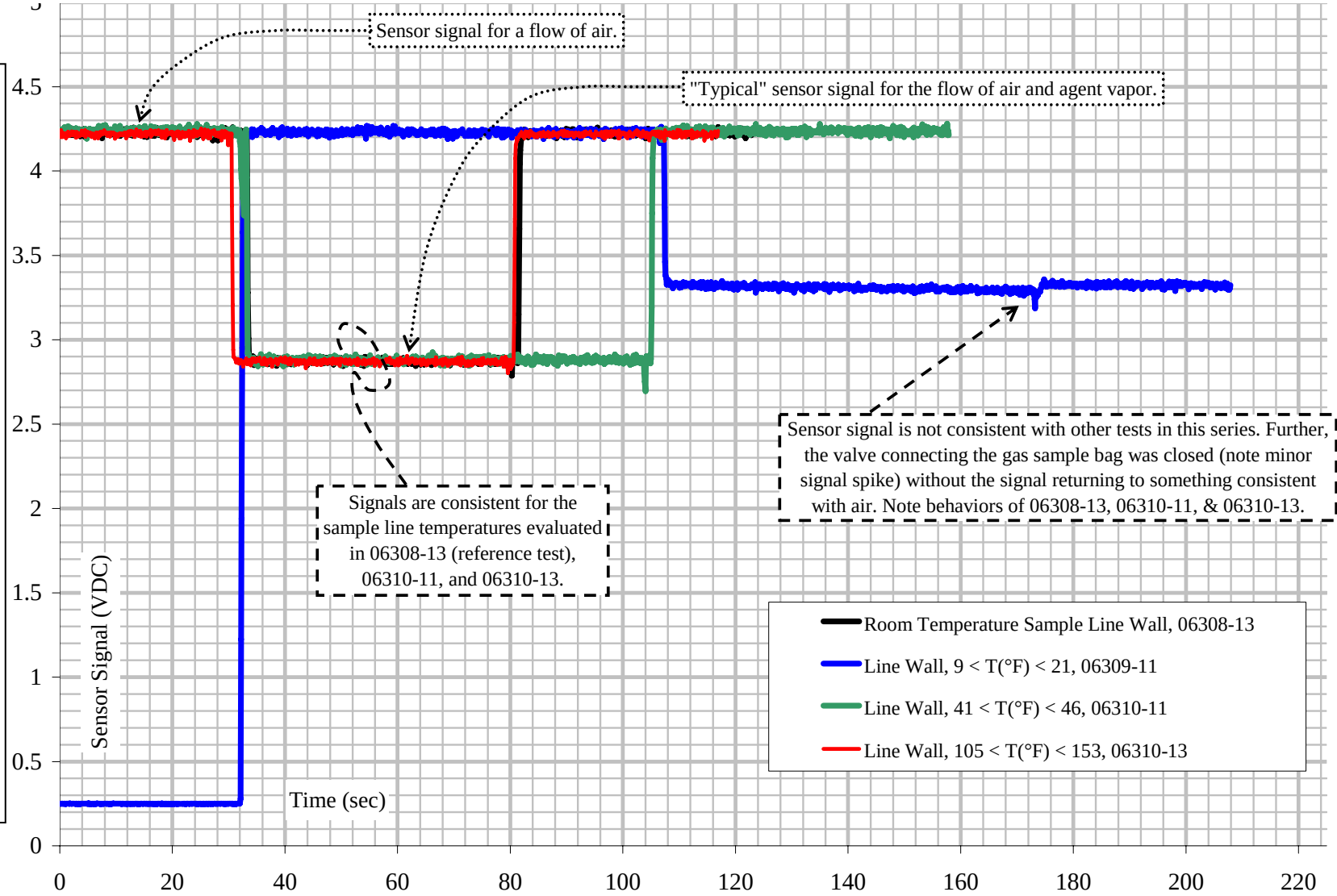
Pacific Scientific
Halonyzer II Quad

12 in = 1 ft = 0.34 m
°C = 5/9*(°F-32)

12 ft x 0.125 in OD Cu
gas analyzer sample lines
flow through each line ≈ 800 scc/min

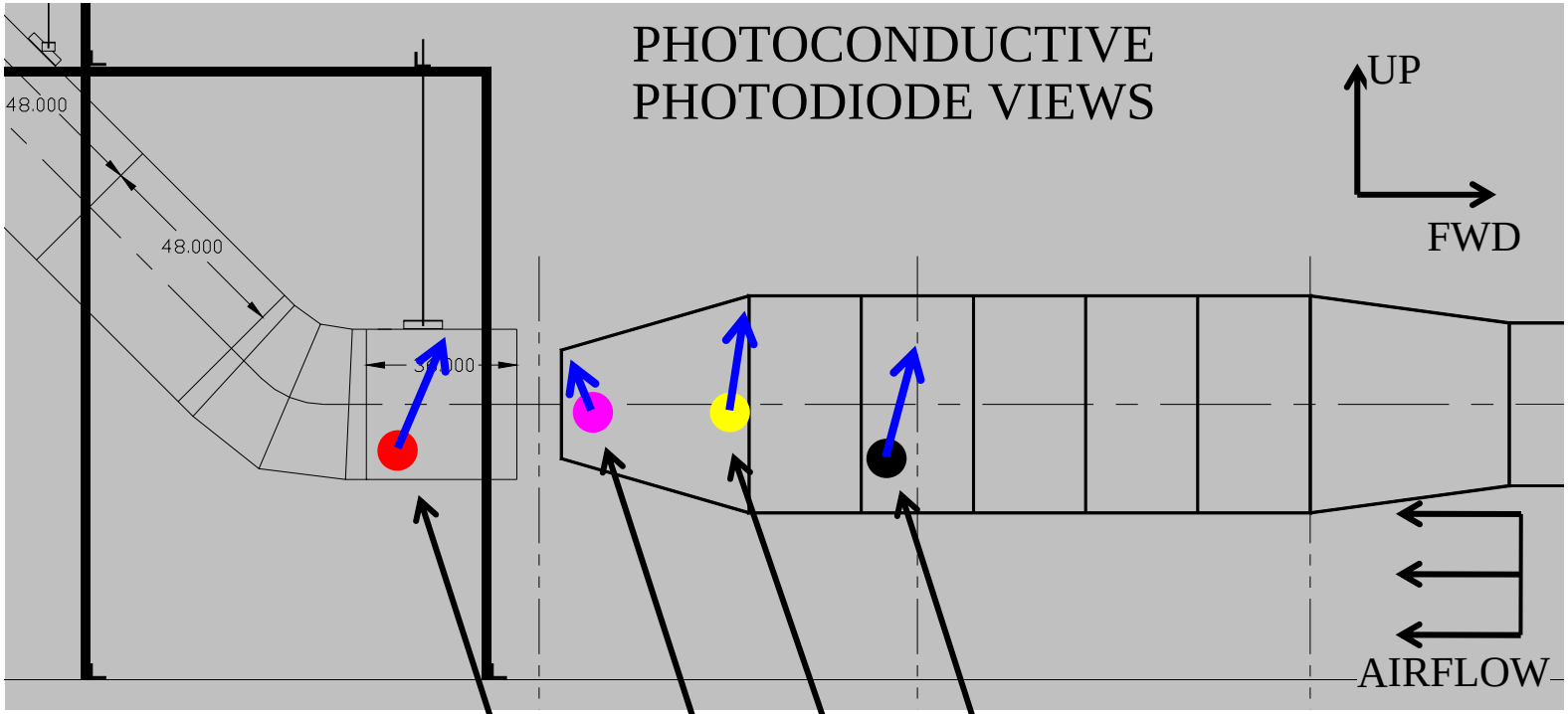
Outcomes from MPSe Testing to Date

COMPARING SAMPLE LINE TEMPERATURE & ANALYZER SIGNAL BEHAVIORS



Outcomes from MPSe Testing to Date

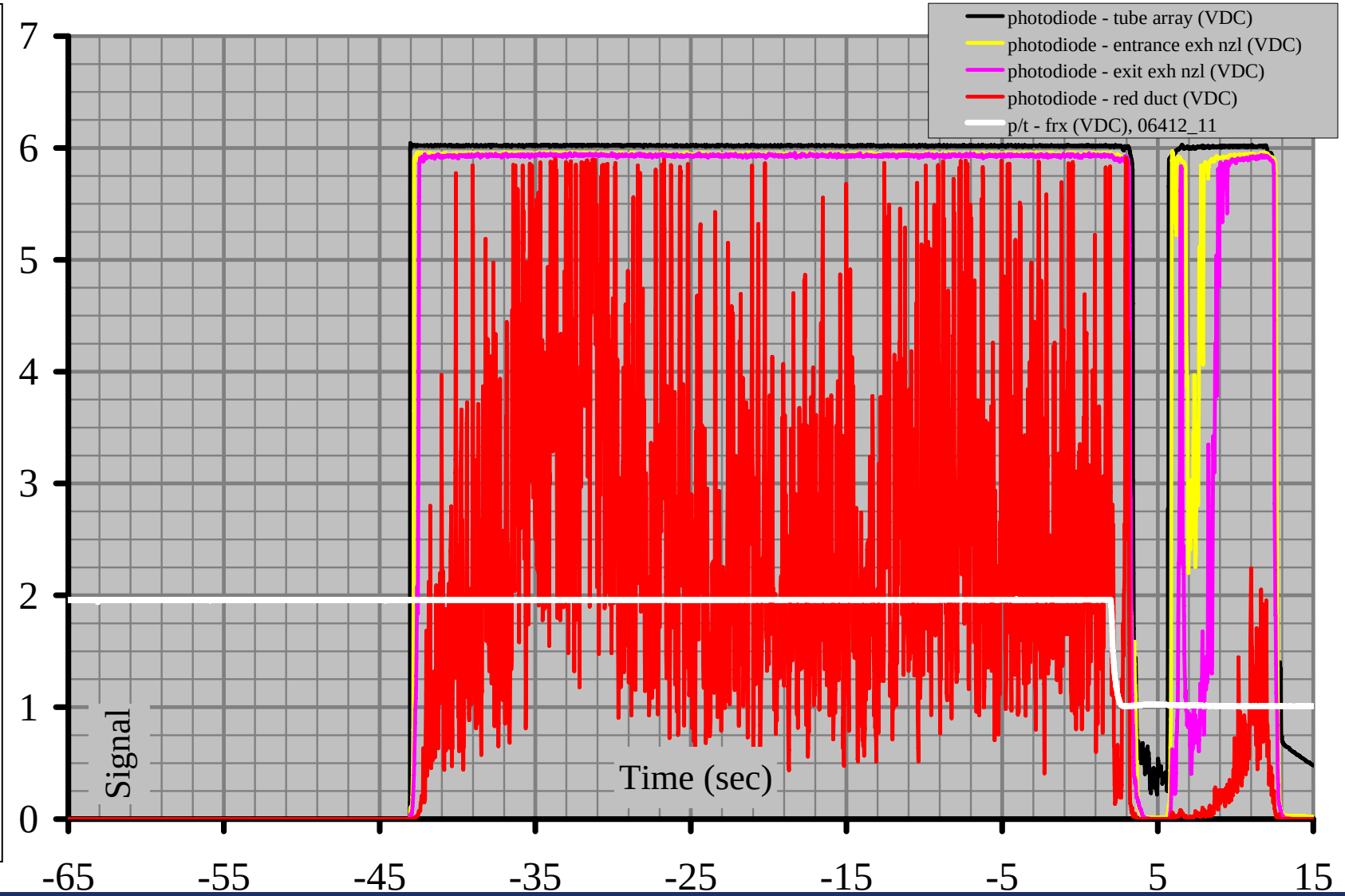
OBSERVING FLAME ATTACHMENT BEHAVIOR DOWNSTREAM FROM FIRE ZONE



Illustrate anecdotal behavior in the Pool Fire Image

Outcomes from MPSe Testing to Date

OBSERVING FLAME ATTACHMENT BEHAVIOR DOWNSTREAM FROM FIRE ZONE



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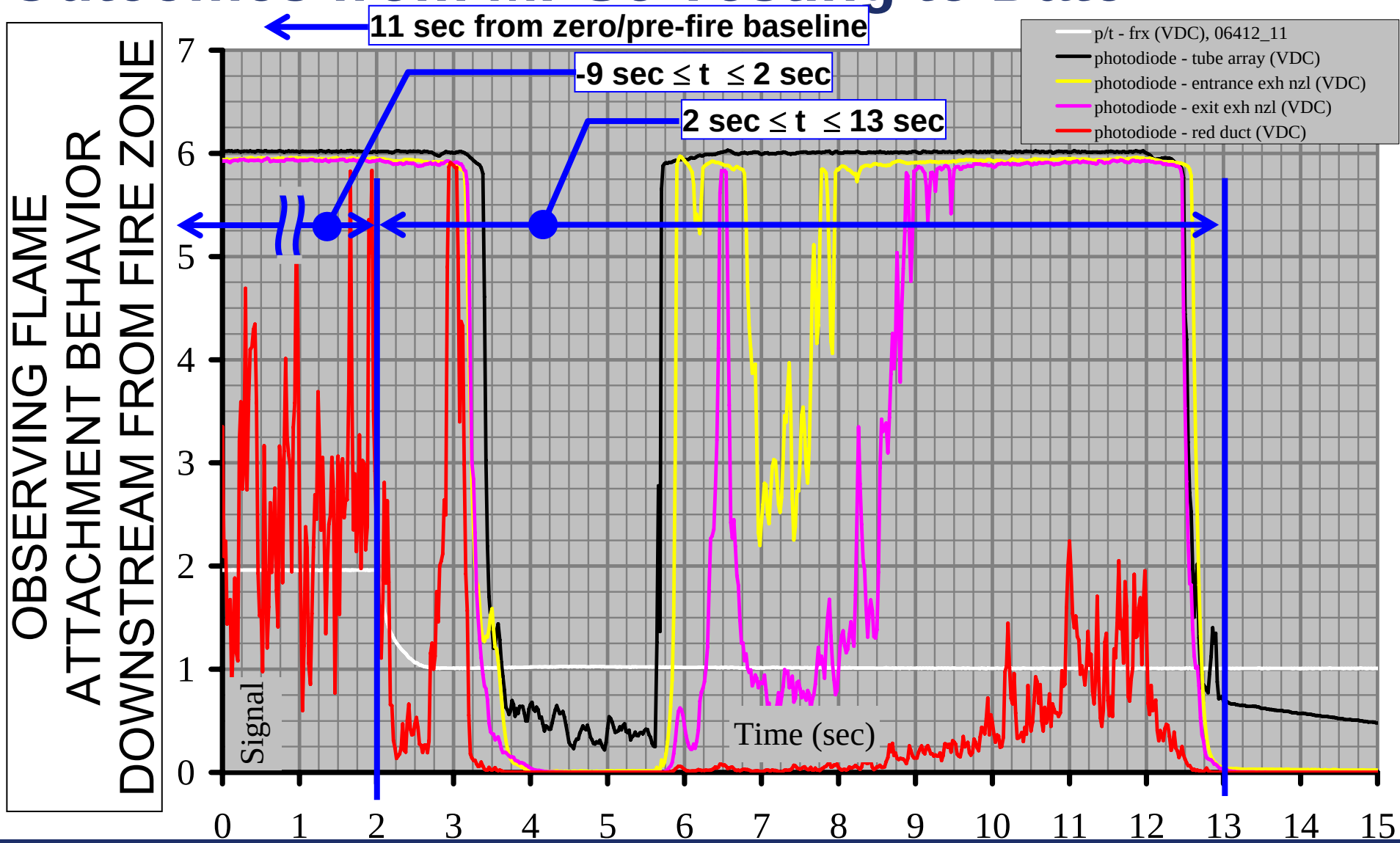

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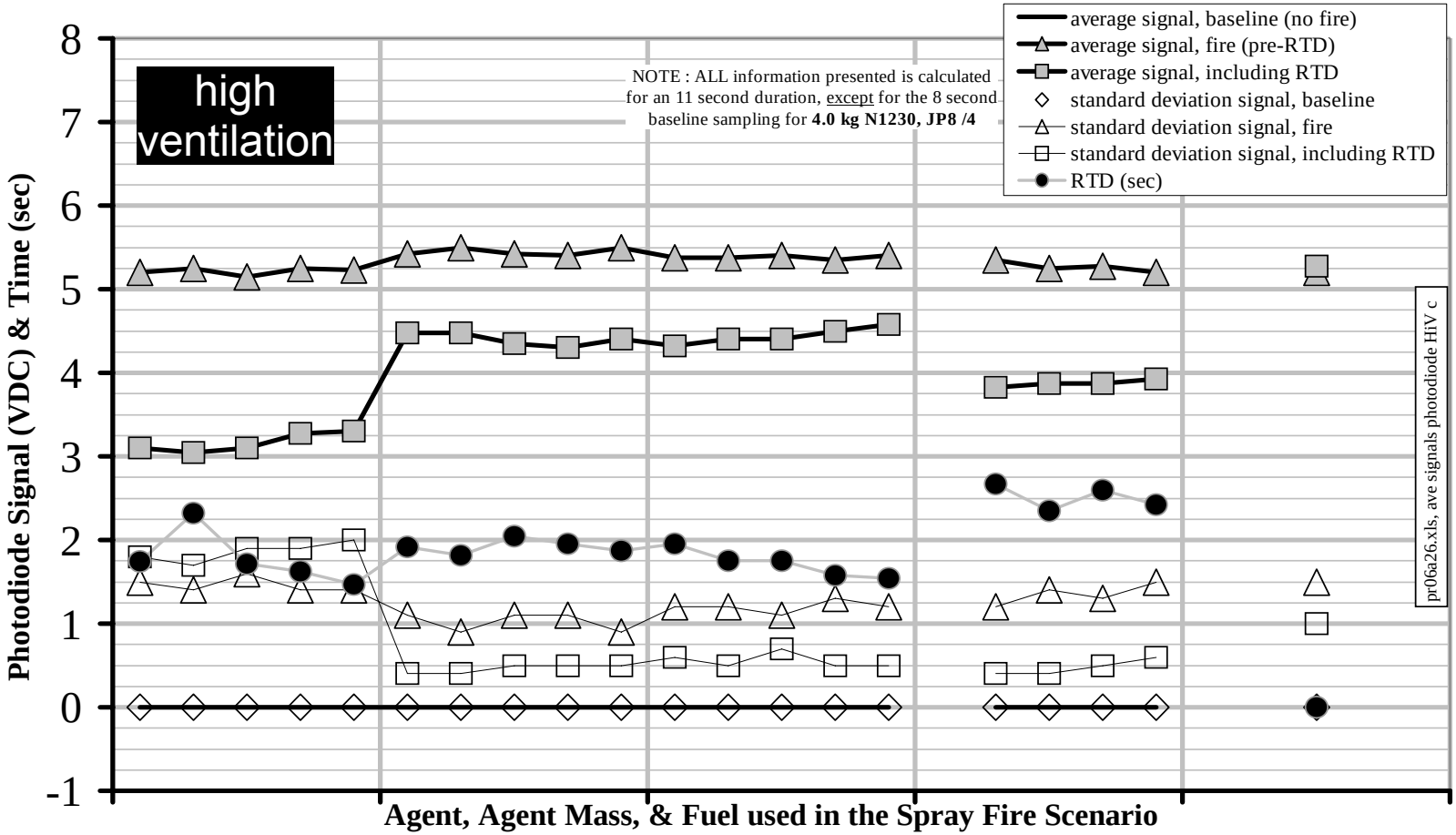

Identify Pending Challenges to the MPSe

- **Need to move away from a H1301 benchmark**
- **Currently working with a solid aerosol, i.e. NOT a gaseous agent**
- **Sensitivity of the calculated equivalent concentration to the shape of the concentration history**

Concluding Summary

- **Equivalent concentrations**
  - HFC-125 = 17.6%v/v
  - CF3I = 7.1%v/v
  - FK-5-1-12 = 6.1%v/v
- **Observations indicate considerations must be made for agents as they depart from behavior similar to Halon 1301**
- **Additional issues exist which may impact the MPSe**