Very Early Warning Fire Detection of Incipient Sources in Nuclear Power Plant Applications

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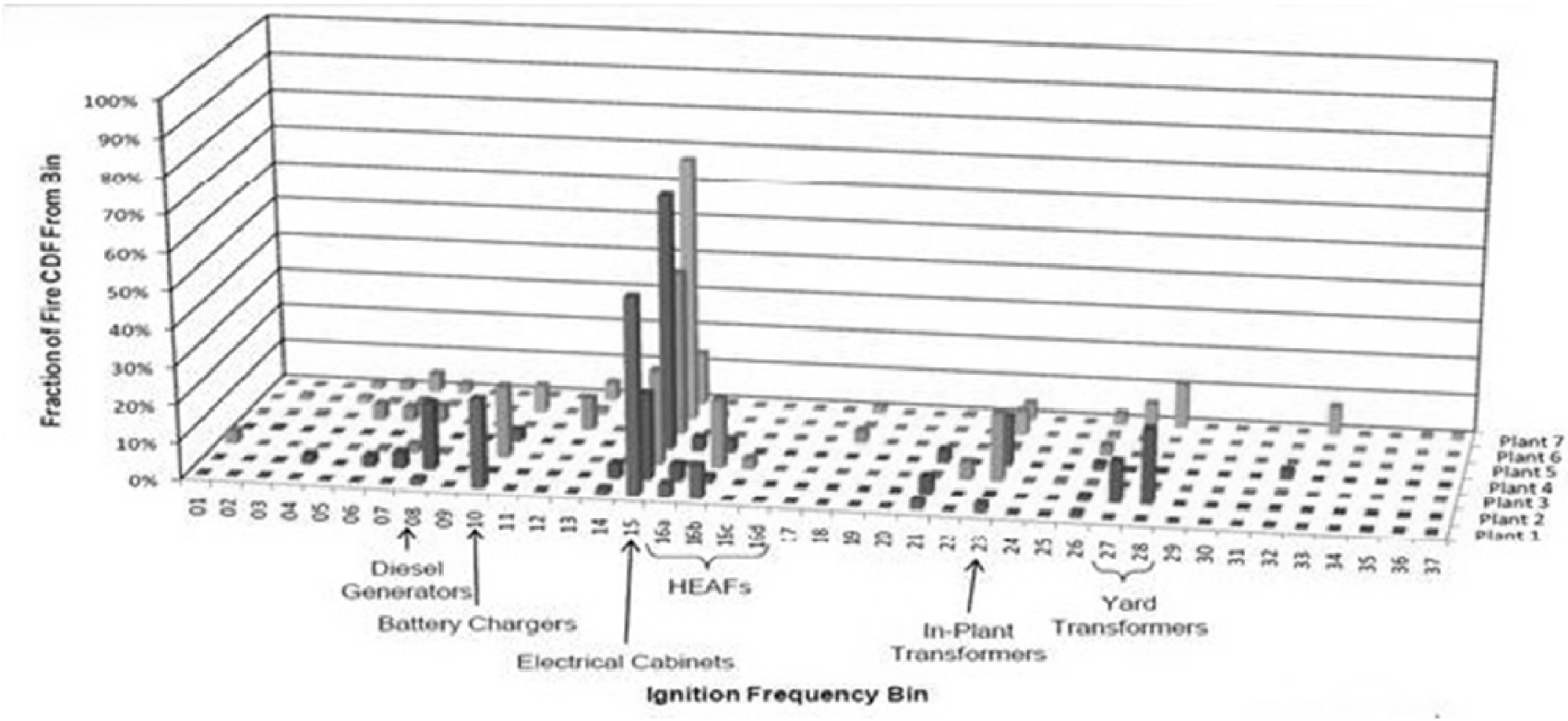
Very Early Warning Fire Detection of Incipient Sources in Nuclear Power Plant Applications

- Outline
  - Background on test program
  - Experimental design of test program
  - How measurements were made
  - Results of test program
  - Conclusions
  - Path Forward

Background

- NRC encourage the use of risk information in regulatory decision making process
  - US Nuclear Regulatory Commission (NRC) Policy Statement on the Use of Probabilistic Risk Assessment (PRA) Methods in Regulatory Activities (60 FR 42622)
  - Complements the NRC's Deterministic Approaches
- Fire Protection Defense-in-Depth
  - Prevent fires from starting
  - Rapidly detect and suppress fires that do occur
  - Protect critical systems to ensure fires that are not suppressed will prevent essential plant safety functions

Background – Fire Contributors



Note: Graphic from 2010 EPRI slide presented during an NRC Advisory Committee on Reactor Safeguards Meeting (NRC ADAMS Accession No. ML110050249)

Background

- In telecommunications facilities, very early warning fire detection (VEWFD) has proven to be very effective in detecting fires in the incipient stage.
- A challenge in accepting the wide scale use of these technologies for use in nuclear power plant (NPP) applications is the lack of data related to these systems performance and reliability
- NIST and the NRC are collaborating on assessing the performance of VEWFD systems in detecting incipient fire scenarios as applied to NPP in-cabinet and area-wide installations

Objectives

- Evaluate the *effectiveness* of various smoke detection systems to detect incipient fire sources
- Provide performance *comparisons* between VEWFD and conventional spot-type detectors
- Evaluate smoke detection system *response* to common products of combustion
- Evaluate the electrical enclosure *layout and design attributes* that affect performance.

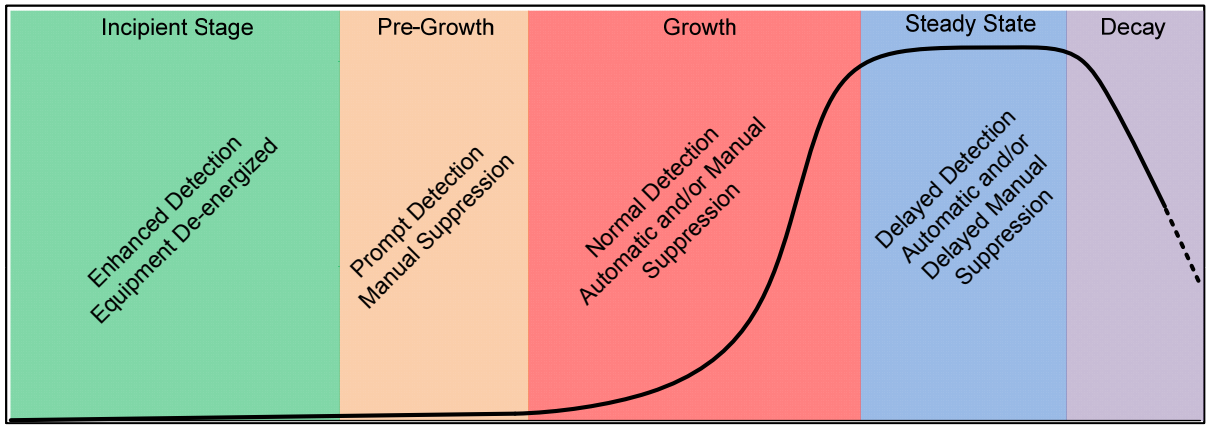
Experimental Design

- Incipient Smoke Source
  - Mimics slowly-developing incipient fire stage
- Multiple Detectors Examined
  - VEWFD ~ nominal 0.2 %/ft obsc.
    - Air Sampling Detectors (3 vendors, 5 models)
    - Sensitive spot laser photodetector (1 vendor)
  - Conventional ~ 1-2%/ft obsc.
    - Ionization and Photoelectric detectors
- Multiple test scales
  - 4 cabinet sizes
  - 2 room sizes
- Variations
  - Ventilation, smoke source location, materials

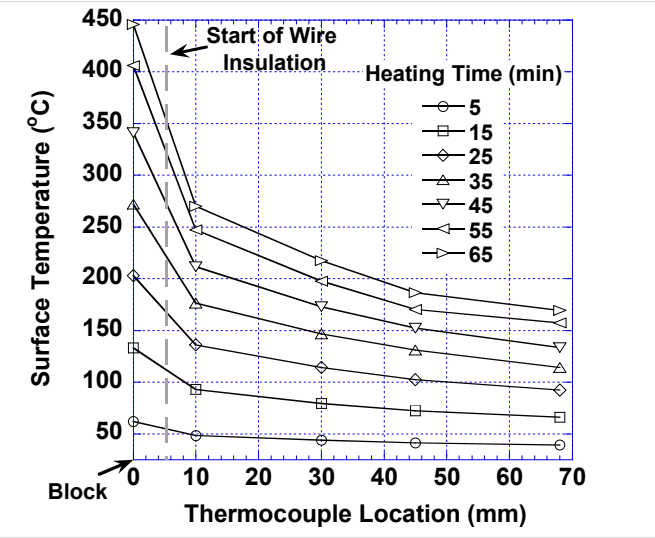
Test Series	Cabinet Dimensions
Laboratory Scale – small	0.56 m by 0.61 m by 1.32 m tall
Laboratory Scale – large	0.61 m by 0.61 m by 2.13 m tall
Small Room	0.61 m by 0.61 m by 1.78 m tall Single, 4- and 5-cabinet banks
Large Room	0.74 m by 0.91 m by 2.11 m tall Single and 3-cabinet banks

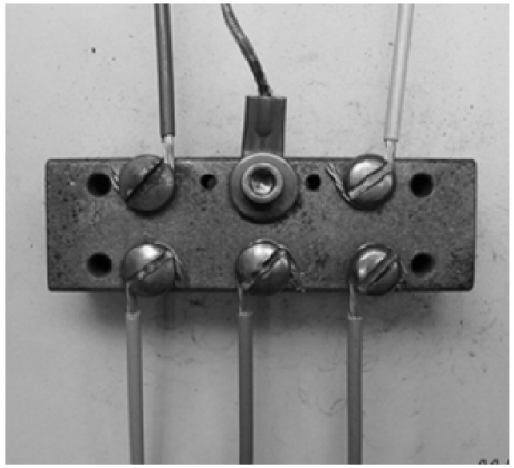
Incipient Smoke Source

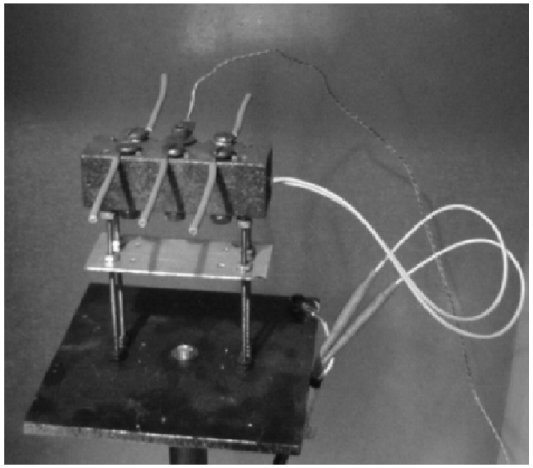
- 500 Watt cylindrical electric cartridge heater inside copper bus bar block
- Smoke source materials attached to block
- Thermocouple control block external surface temperature heating ramp period (HRP) profile
- Three HRPs selected: 15-minutes, 1-hr, 4-hr
- Block temperature raises source materials to piloted ignition temperatures. No pilot source present in test

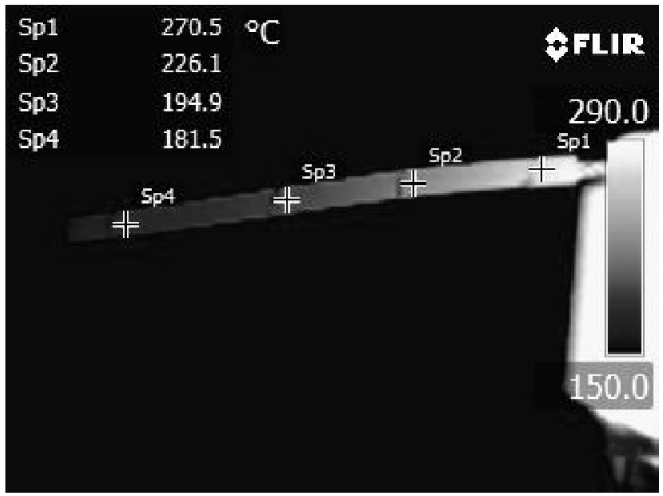


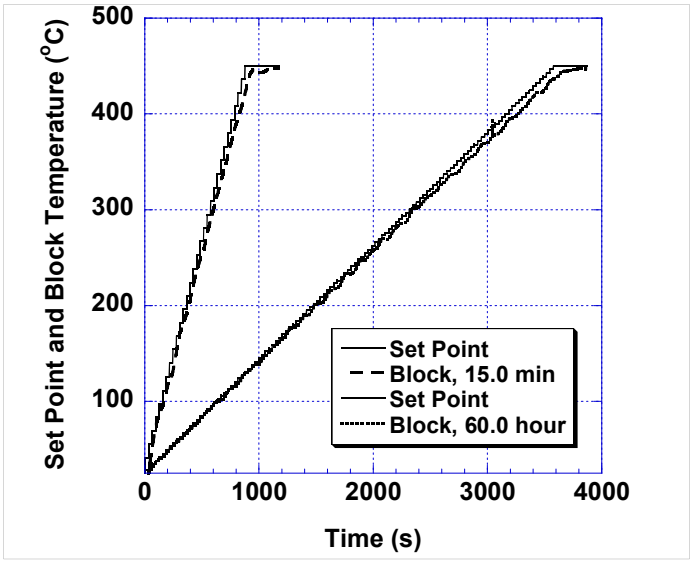
Incipient Smoke Source







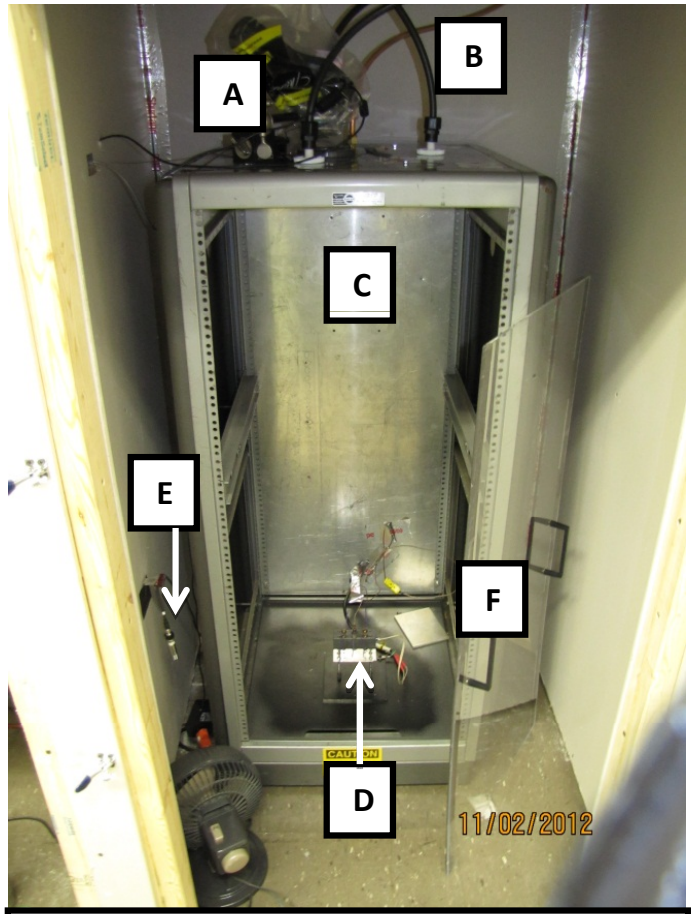




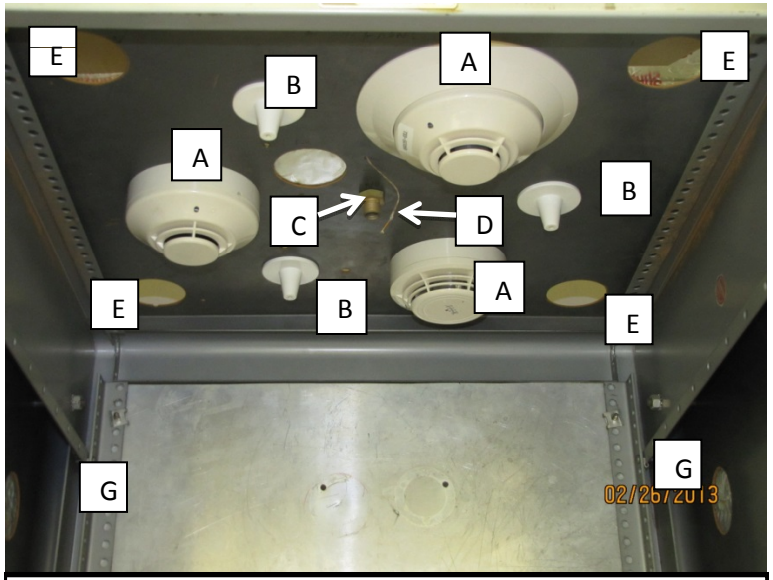
Smoke Source Materials

ID #	Name	Description of Material
1	PVC wire (1)	Polyvinyl chloride insulated, 18 AWG wire
2	PVC wire (2)	Polyvinyl chloride insulated, 14 AWG wire
3	Silicone wire	Silicone insulated , 18 AWG wire
4	PTFE wire	Polytetrafluoroethylene insulated, 14 AWG wire
5	XLPO wire (1)	Cross-linked polyolefin insulated, 12 AWG wire
6	XLPO wire (2)	Cross-linked polyolefin insulated, 12 AWG wire
7	XLPE wire	Cross-linked polyethylene insulated, 12 AWG wire.
8	CSPE wire	Chlorosulfonated polyethylene insulated, 10 AWG wire
9	Epoxy PCB	FR4, glass-reinforced epoxy laminate circuit board
10	Phenolic TB	Phenolic barrier terminal block

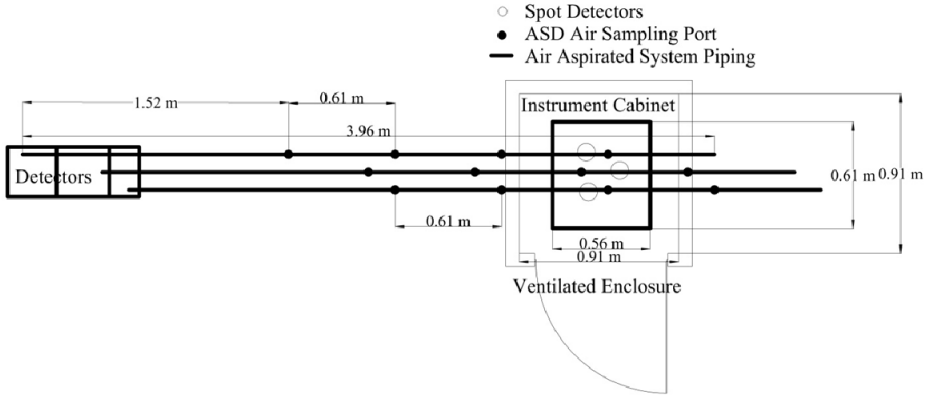
Experimental Setup Laboratory – Small Scale



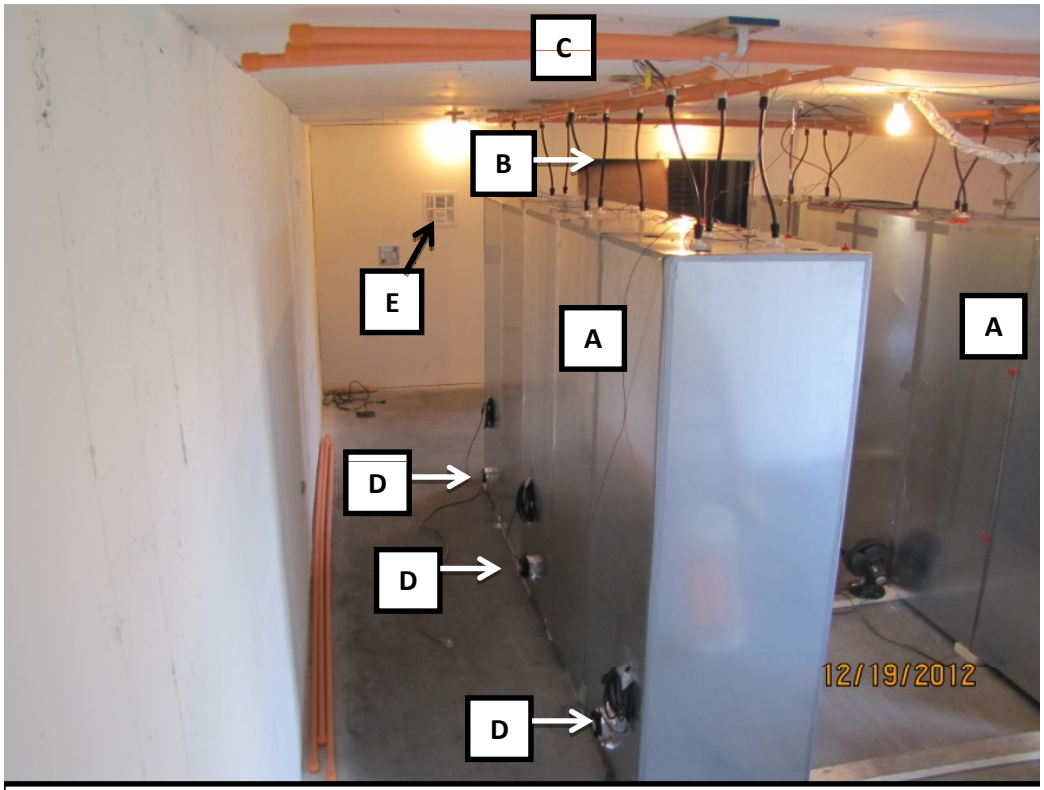
A: IR camera
B: Sampling tubes
C: Instrument cabinet
D: Source location
E: Humidity probe
F: Cabinet door



A: Spot detectors
B: ASD sampling ports
C: Aerosol sampling port
D: Thermocouple
E: Top vent holes
F: IR camera view port
G: Side vent holes



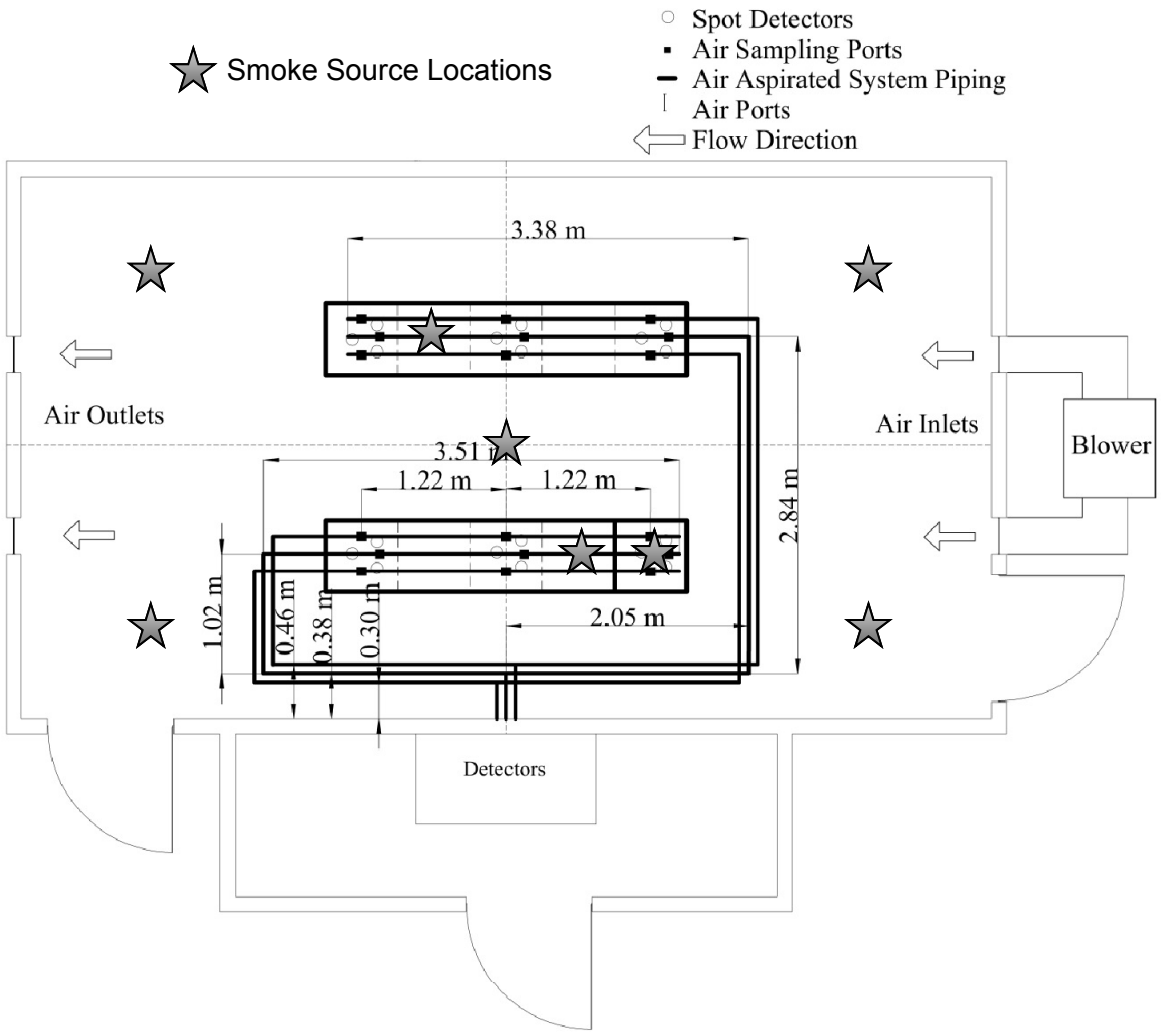
Experimental Setup
Small Room



A: Cabinet mock-ups
B: Sampling tubes
C: ASD pipes
D: Cabinet ventilation fans
E: Room ventilation air inlet

Experimental Setup - Small Room

Room Size
8.2 m x 4.6 m



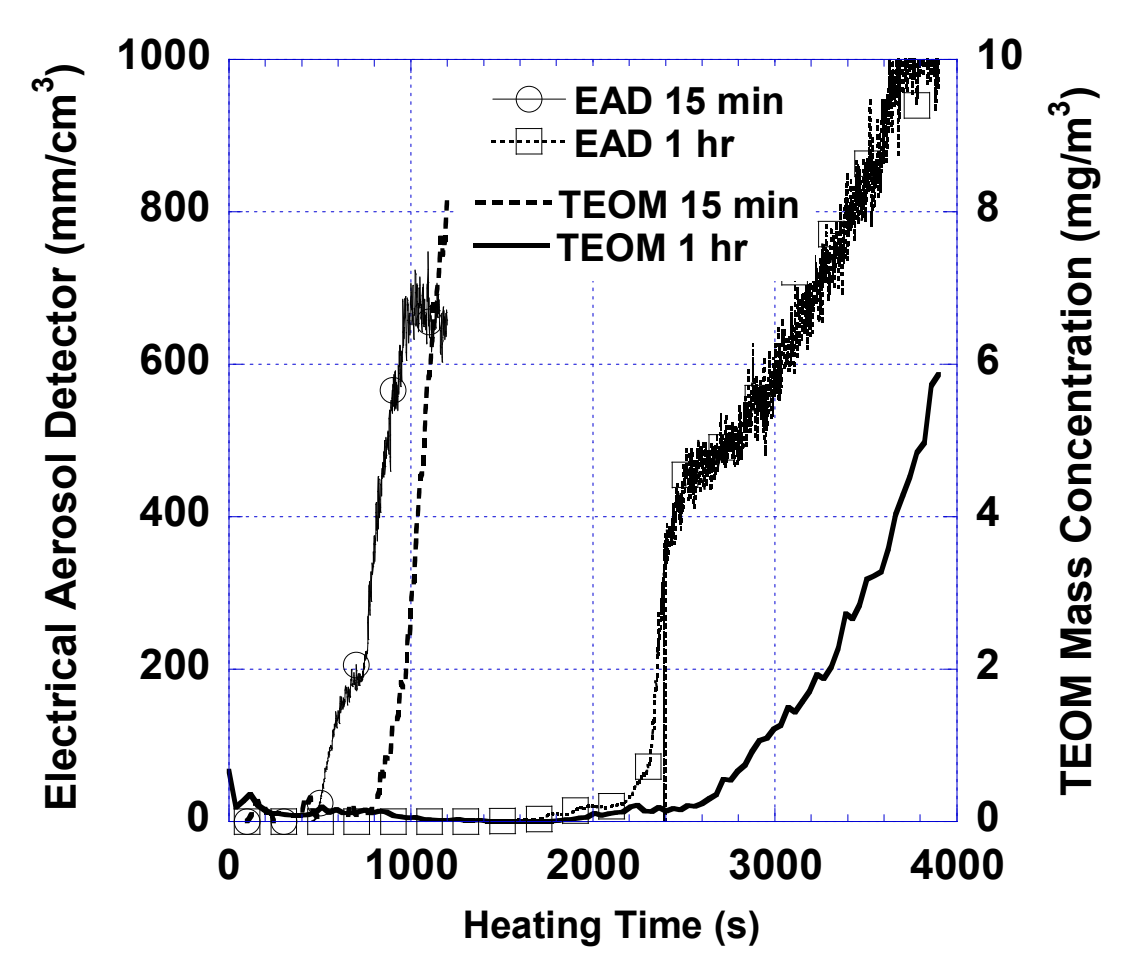
Smoke Source Measurements

- Electrical low pressure impactor results – arithmetic mean diameter (AMD) and mass mean diameter (MMD) averaged over the 5 min soak time for 15 min heating rate period tests. Highlighted samples selected for follow-on experiments.

ID #	Name	AMD (μm)	MMD (mm)
1	PVC wire (1)	0.12	0.27
2	PVC wire (2)	0.11	0.26
3	Silicone wire	0.14	0.23
4	PTFE wire	0.10	0.21
5	XLPO wire (1)	0.13	0.21
6	XLPO wire (2)	0.23	0.45
7	XLPE wire	0.20	0.33
8	CSPE wire	0.33	0.64

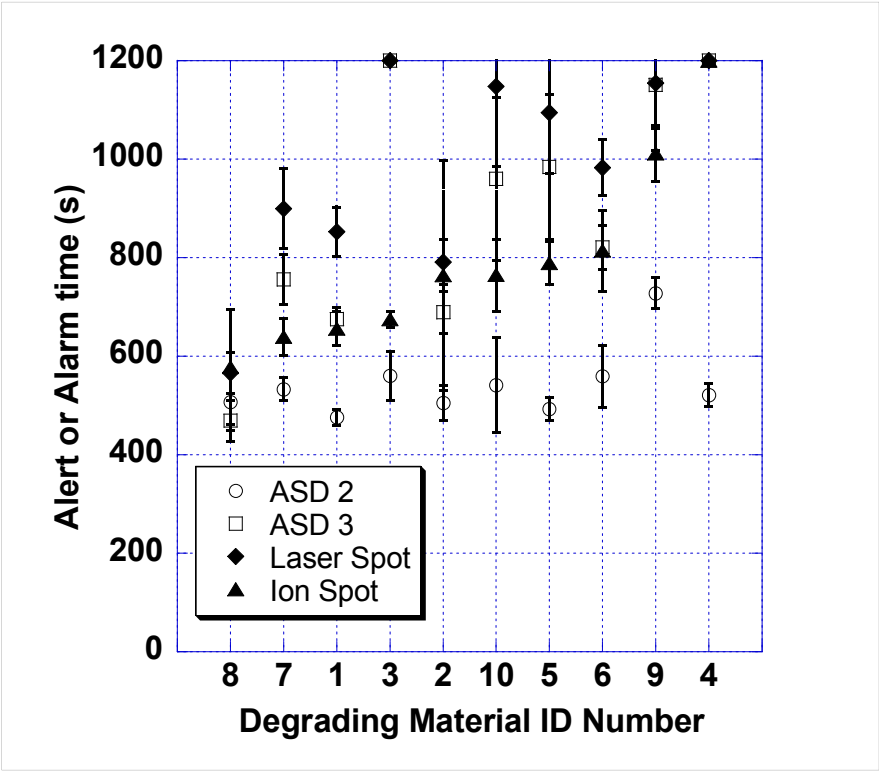
Smoke Concentration Measurements

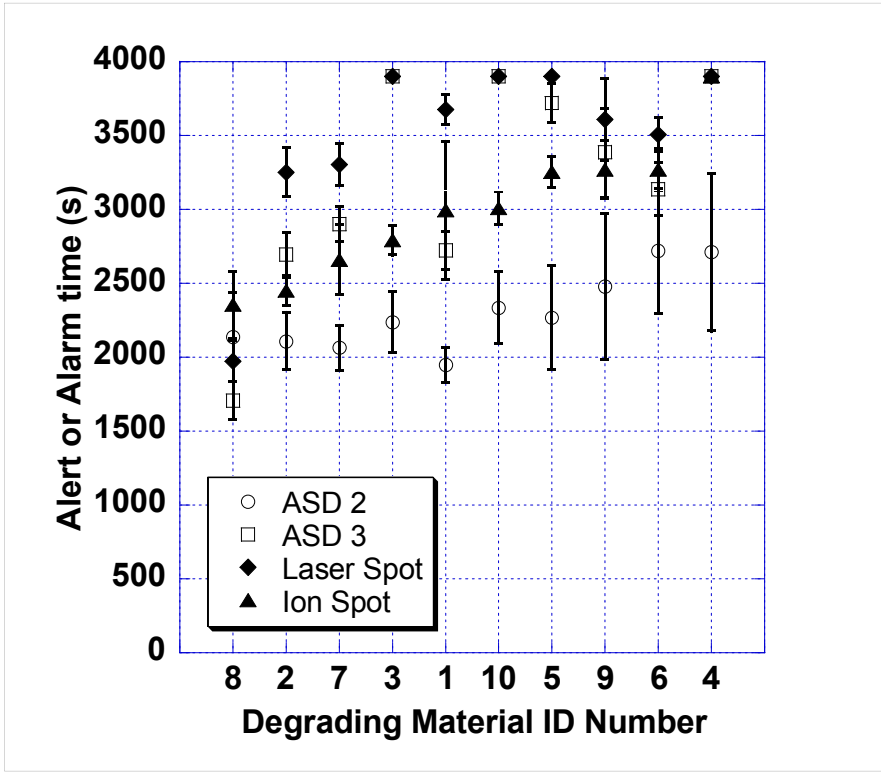
- Smoke concentration for XLPE insulated conductor experiments



Results

Average Alert or Alarm time for repeated small cabinet experiments





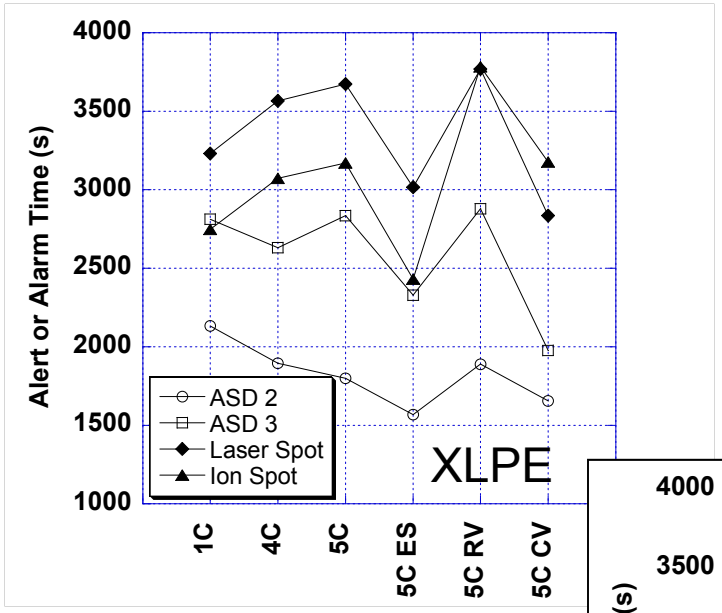
ASD 2 – Cloud Chamber
ASD 3 – Light Scattering

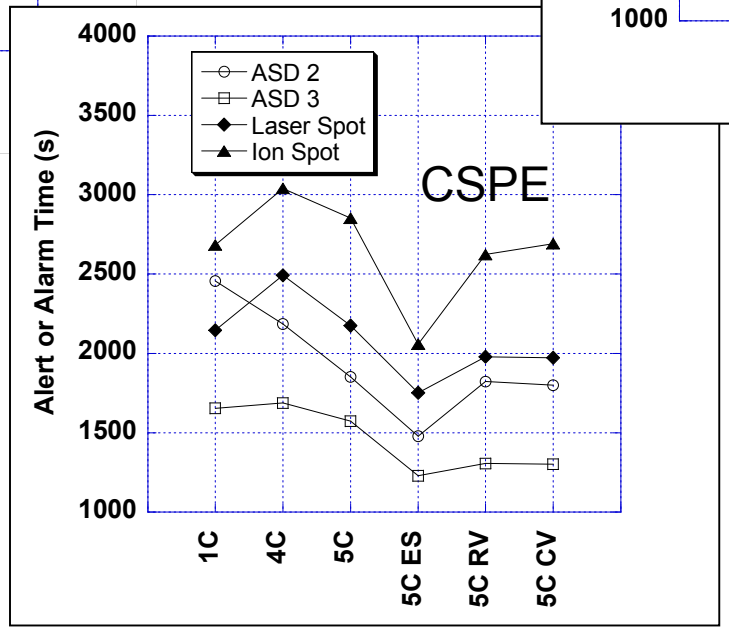
Source Elevation

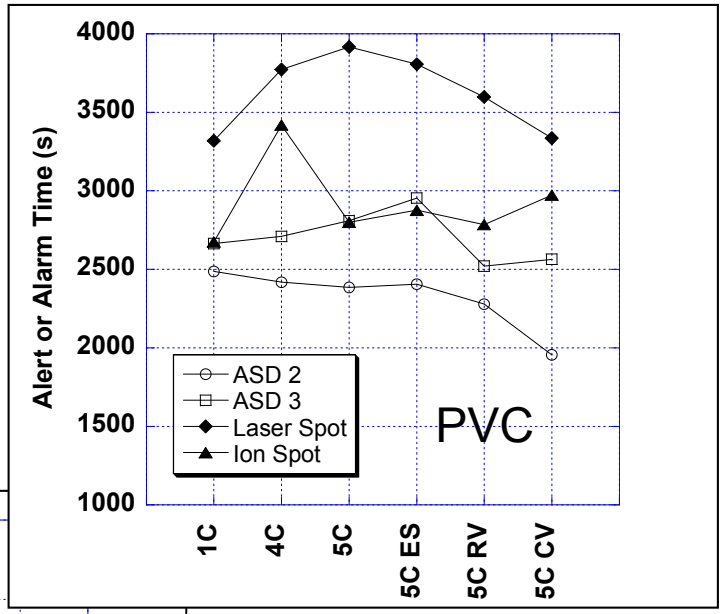
- **Small room cabinet mockup experiments**
  - **Source located in isolated single cabinet (1C)**
  - **Source located in open four cabinet space (4C)**
  - **Source located in open five cabinet space (5C)**
  - **Source elevated off floor 2/3 cabinet height (5C ES)**
  - **Room ventilation on 9 air changes per hour**
  - **Cabinet ventilation on 8 air changes per hour**

Results

Alert or alarm times for various full-scale one hour heating ramp experiments







Note performance difference for ASD2/3 and ION/PHOTO between CSPE and other materials (XLPE, PVC)

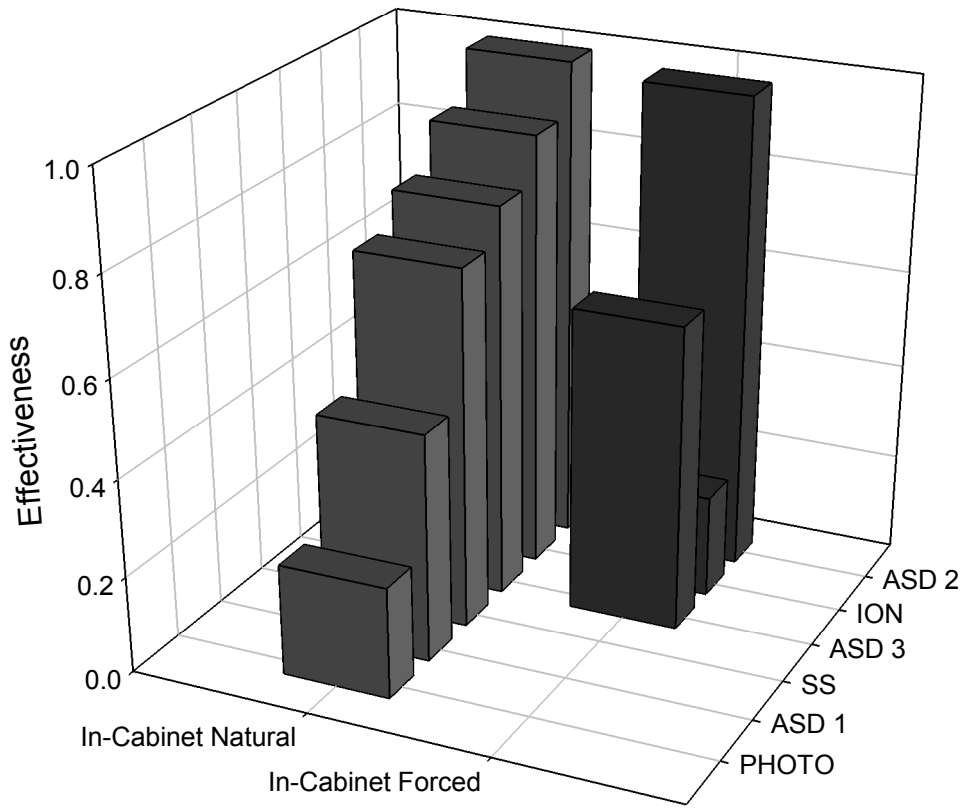
System Effectiveness – In-Cabinet

Column plot represents the fraction of tests where the detector responded.

End of test is assumed to be end of the incipient stage.

Effectiveness decreases as ventilation rate and/or distance between source and detector (sampling point) increase

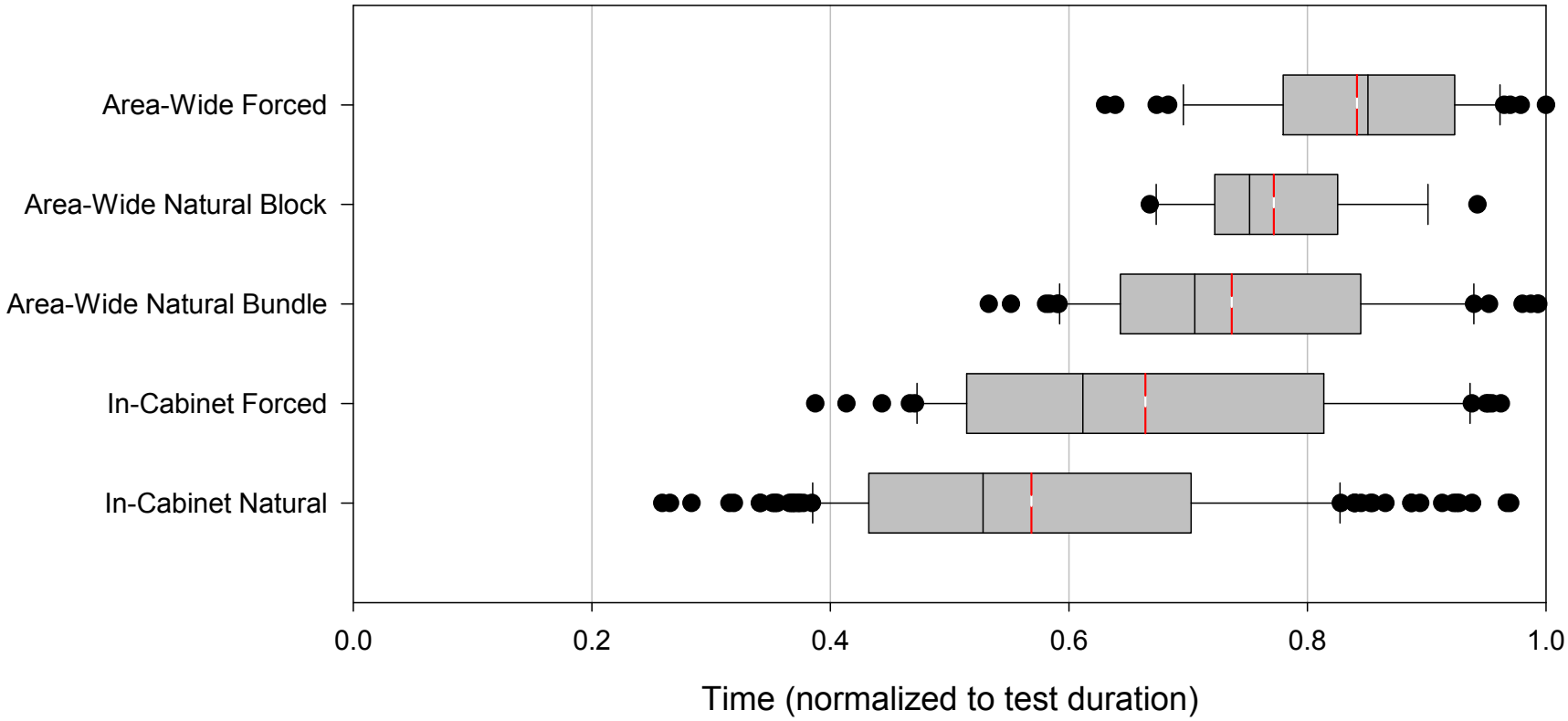
Complements “time to detection” (next slide)



Forced ~ 300 ACH

Time to Detection

ASD VEWFD system time to detection (~ 0.2 %/ft obsc.)
Data from all three HRP tests normalized to respective test duration
Mean value shown as red/white line
Complements “system effectiveness” (previous slide)



Conclusions – Smoke Source

- A smoke source that mimics the slow overheat conditions during degradation of polymeric electrical insulating materials was developed. The source was sufficiently repeatable to use in follow-on system performance testing
- Insulated electrical conductors, with insulation material thought likely to be representative of a range of chemical compositions of materials producing smoke during incipient fires in nuclear power plants, were examined and results showed:
  - Both the AMD and MMD vary by a factor of 3 from PFTE to CSPE insulation
  - PVC wire (2), XLPE wire, and CSPE wire materials were selected to (1) cover the observed (relatively) small, medium and large mean particle sizes, and (2) to have the ability produce sufficient smoke to activate the detectors being studied in the various experimental configurations
- The trend between the 15 min and 1 hour heating ramps for ASD 2 and ASD 3 was consistent for all three materials, but in opposite directions. ASD 2 activated at higher block temperatures when the heating ramp time was increased, while ASD 3 activated at lower block temperatures

Conclusions

- It was observed that material, heating rate, sample location, cabinet and air sampling port configuration, cabinet ventilation and room ventilation factor into the order of alert or alarm times for the various detectors examined
- In experiments conducted in the instrument cabinet, some wire samples did not produce enough smoke to initiate alerts or alarms in some of the detectors
- ASD 2 alerted first to all materials except CSPE, where ASD 3 alerted first
- In the full-scale experiments, the two ASD's tended to outperform the ION spot alarm with ASD 2 typically alerting several hundred seconds before the ION spot alarm
- The laser spot pre-alarmed after the ION spot with XLPE and PVC (2) wire samples, but before the ION spot with CSPE wire samples

Path Forward

- Use test results and NPP operating experience to inform parameter estimates for risk scoping study
- Issue Draft NUREG report for public comment
  - Encourage comment from smoke detection industry
- Resolve public comment, Issue final report
- Update interim staff guidance