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Fire Branch Research

"Cable Response to Live Fire (CAROLFIRE) Testing Program"

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"Fire Safety in Nuclear Power Plants and Installations"
Oshawa, Ontario Canada

August 20 – 22, 2007

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CAROLFIRE Project Objectives

- Two areas of investigation:
  - Resolution of the 'Bin 2' circuit configurations:
    - Regulatory Issue Summary 2004-03, Rev 1 - "Risk-informed Approach For Post-Fire Safe-Shutdown Circuit Inspections"
    - Documents findings from a February 2004 NRC facilitated workshop puts cable/circuit configurations in one of three bins:
      - Bin 1: Configurations that are most likely to fail (e.g., leading to spurious operation
      - Bin 2: Configurations that need more research
      - Bin 3: Configurations that are unlikely or least likely to fail (e.g., leading to spurious operation).
  - Fire Modeling Improvement
    - To reduce uncertainty associated with predictions of fire-induced cable damage

The 'Bin 2' Issues (4)

- The Bin 2 issues:
  A. Spurious actuations caused by Inter-cable shorting for thermoset cables
  B. Spurious actuations caused by Inter-cable shorting between thermoplastic and thermoset cables
  C. Concurrent spurious actuations associated with failures impacting three or more cables
  D. Multiple spurious operations in control circuits with properly sized control power transformers (CPTs)
  E. Fire-induced hot shorts lasting more than 20 minutes
  F. Consideration of spurious actuations for cold shutdown circuits
- CAROLFIRE's goal:
  - Assess Bin 2 items A-E through experiments
  - Make recommendations to NRC/NRR for resolution

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Fire Model Improvement

- RES has separate efforts underway dealing with Verification and Validation of fire models
  - CAROLFIRE compliments these efforts
- Data needed to:
  - Support improved cable thermal response and electrical failure fire modeling tools
  - Reduce modeling uncertainties
- Collaborative partners at NIST and University of Maryland are leading the modeling efforts
- Sandia National Laboratories did the testing
  - Extensive efforts to gather data that correlates thermal response to electrical response
  - Range of exposure conditions from simple to complex
  - Range of cable products

The testing Approach

- Two Scales of testing are being pursued
  - Small-scale radiant heating experiments
  - Intermediate-scale open burn tests
- Testing a broad range of cable products

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Cable types being tested represent wide range of NPP products

Cable Function/Service	Insulation & Jacket Materials (I/J)	Material Type [2]	Cond. Size (AWG)	No. Cond.	Manufacturer	Notes[3]
Power	XLPE/CSPE	TS/TS	8	3	Rockbestos Surprenant	All XLPE cables were selected from the *Firewall III®* product line. All are nuclear qualified. The 16AWG, 2/C cable is shielded, others are un-shielded.
Control	XLPE/CSPE		12	7		
Instrumentation	XLPE/CSPE		16	2		
Instrumentation	XLPE/CSPE		18	12		
Control	*Vita-Link®*	TS/TS	14	7		A "fire-rated" cable based on silicone insulation that ceramifies when exposed to flames.
Control	XLPO/XLPO	TS/TS	12	7		Newer style 'low-smoke, zero halogen' formulation, IEEE-383 qualified.
Control	SR/Aramid Braid	TS/TS	12	7	First Capitol	Industrial grade cable from "sister company" to Rockbestos Surprenant
Control	Tefzel/Tefzel	TP/TP	12	7	Cable USA	Based on Tefzel-280 compound
Control	EPR/CSPE	TS/TS	12	7	General Cable	Industrial grade cable
Control	XLPE/PVC	TS/TP	12	7		Mixed type - thermoset insulated, thermoplastic jacketed
Control	PE/PVC	TP/TP	12	7		Industrial grade cables.
Power	PVC/PVC	TP/TP	8	3		
Control	PVC/PVC		12	7		
Instrumentation	PVC/PVC		16	2		Industrial Grade cable, Shielded
Instrumentation	PVC/PVC		18	12		Industrial Grade cable, Unshielded

Additional Notes:
(1) - XLPE = Cross-linked polyethylene; CSPE = Chloro-sulfanated polyethylene (also known as Hypalon); XLPO = Cross-linked polyolefin; SR = Silicone rubber; EPR = Ethylene-propylene rubber; PVC = Poly-vinyl chloride; PE = Polyethylene (non cross-linked).
(2) - TS = Thermoset; TP = Thermoplastic; shown as: (insulation type)/(jacket type).
(3) - All power and control cables are un-shielded.

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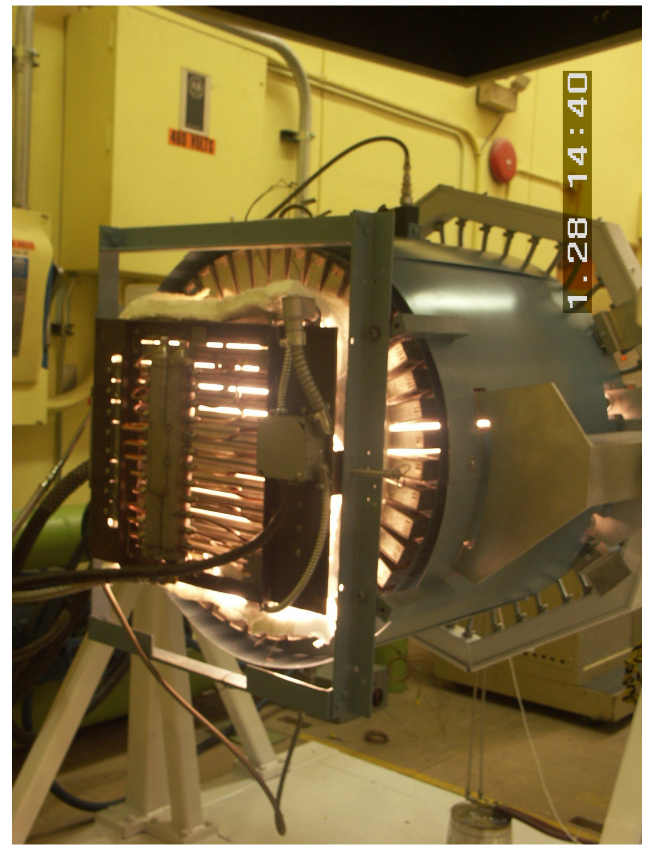
Small Scale Tests

- ***Penlight*** heats target cables via grey-body radiation from a heated shroud
- Well controlled, well instrumented tests
- Allows for many experiments in a short time
- Thermal response and failure for single cables and small cable bundles (up to six cables)
- Cable trays, air drops, conduits



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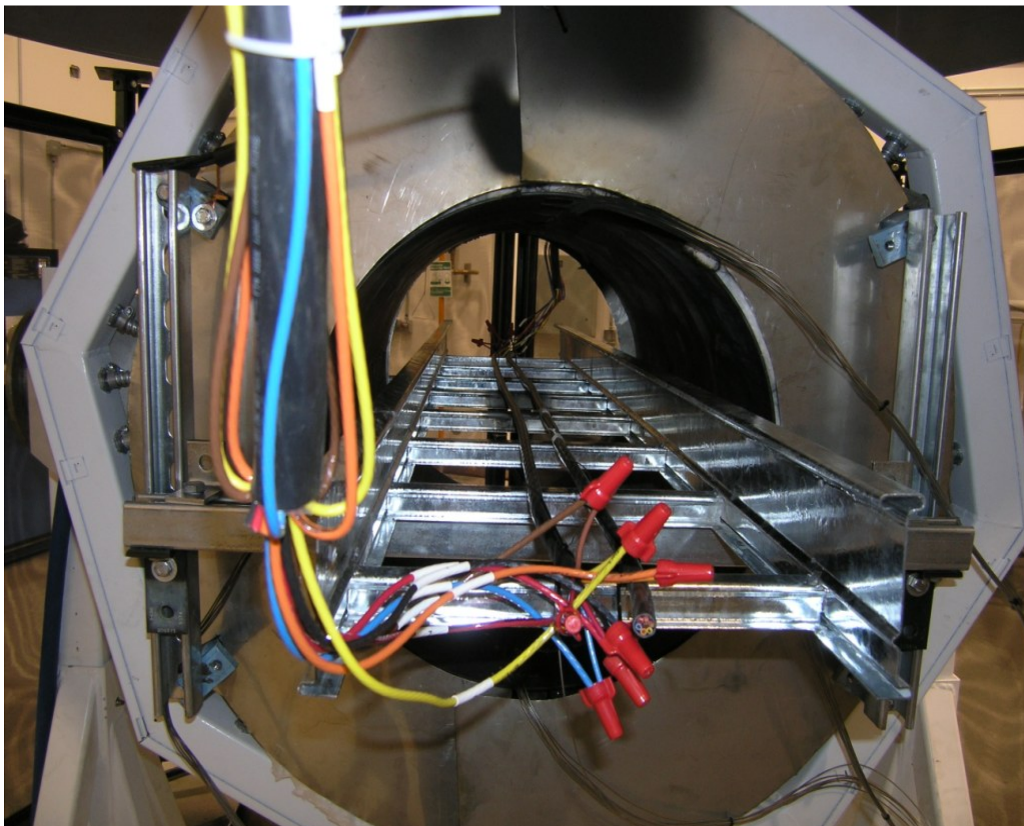
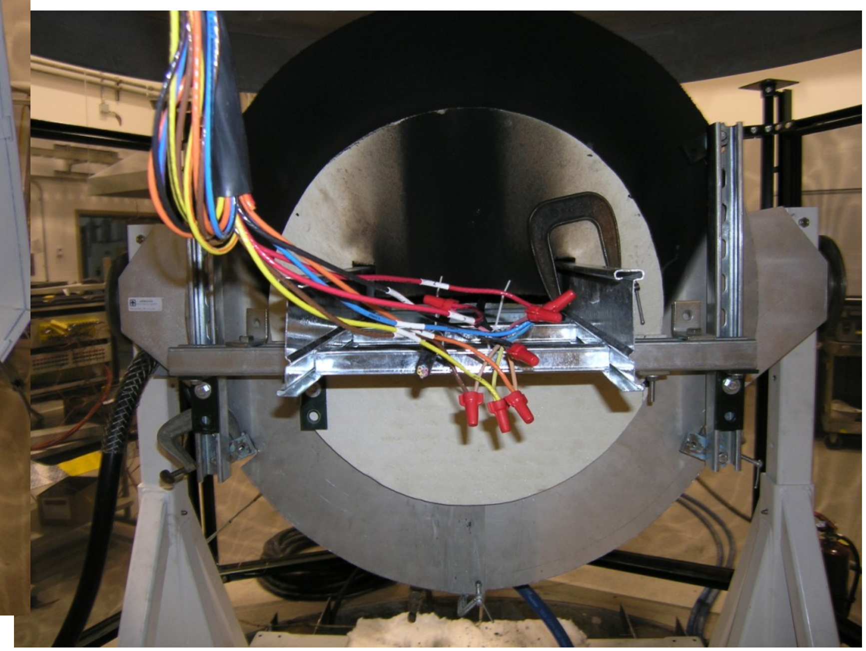
Typical Penlight setup





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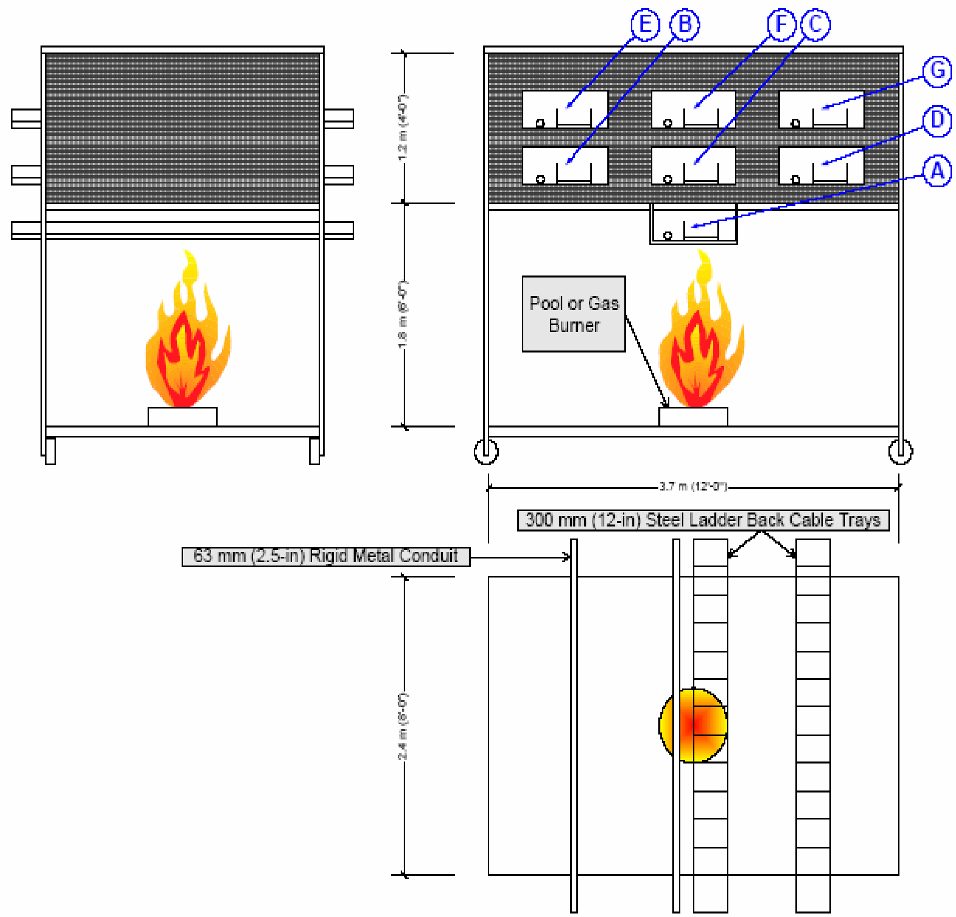
Intermediate-Scale Tests

Layout of the intermediate-scale test structure.

Structure was located within a larger test facility.



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Intermediate-Scale Tests

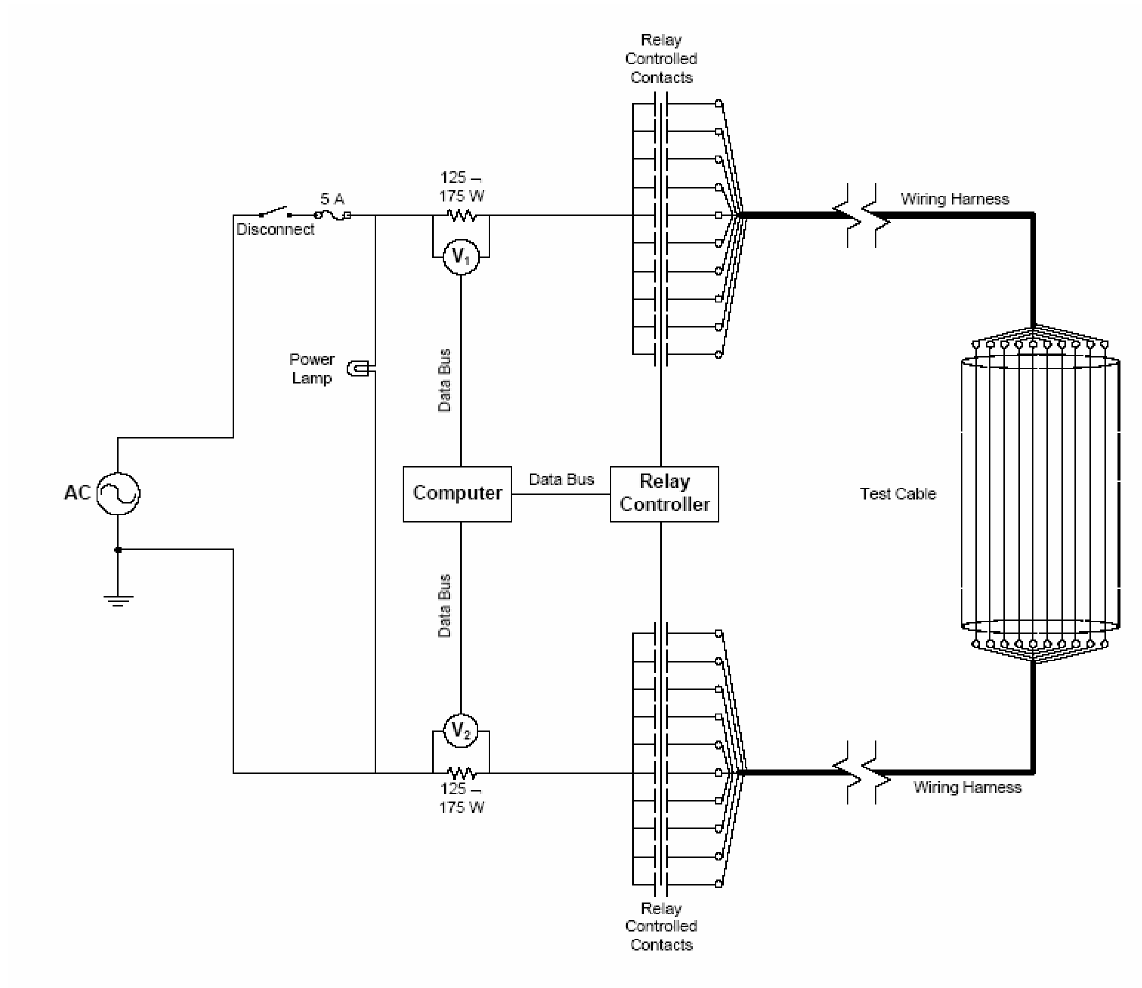
- Less controlled, but a more realistic testing scale
- Hood is roughly the size of a typical ASTM E603 type room fire test facility (more open to allow for ready access)
- Propene (Propylene) burner fire source (200 kW typical)
- Cables in trays, conduits and air drop

Instrumentation

- Cable thermal response (surface and interior)
- Raceway surface temperature
- Exposure environment
- Cable electrical Response via two monitoring systems
  - The SNL Insulation Resistance Measurement System
  - Surrogate Circuit Diagnostic Units (circuit simulators)

Instrumentation (2)

- All tests – SNL Insulation Resistance Measurement System
- Continuous measurement of cable degradation and functionality



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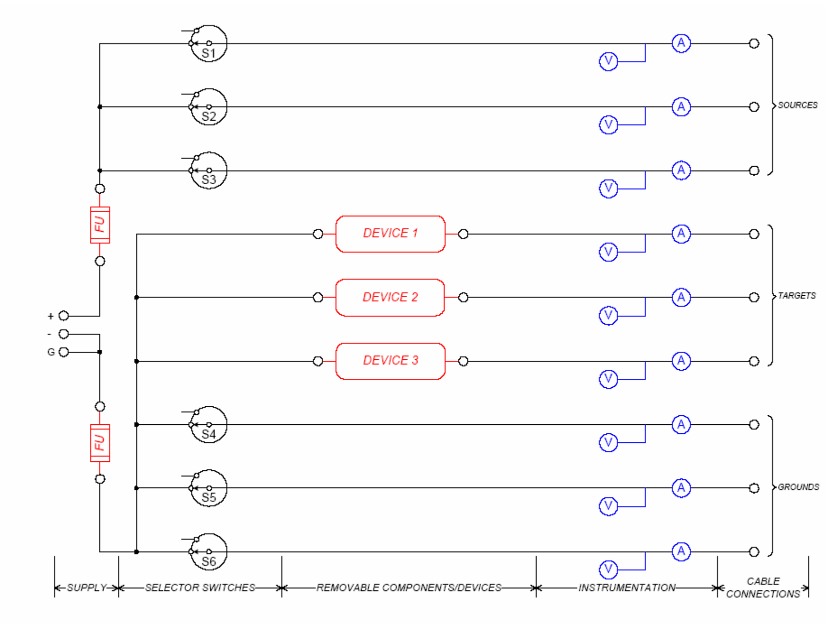
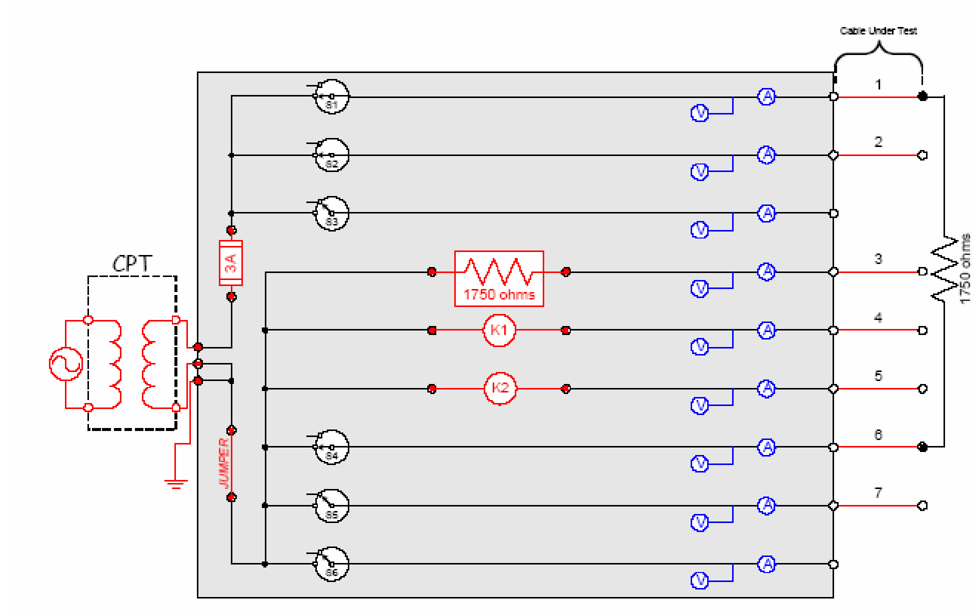
Instrumentation (3)

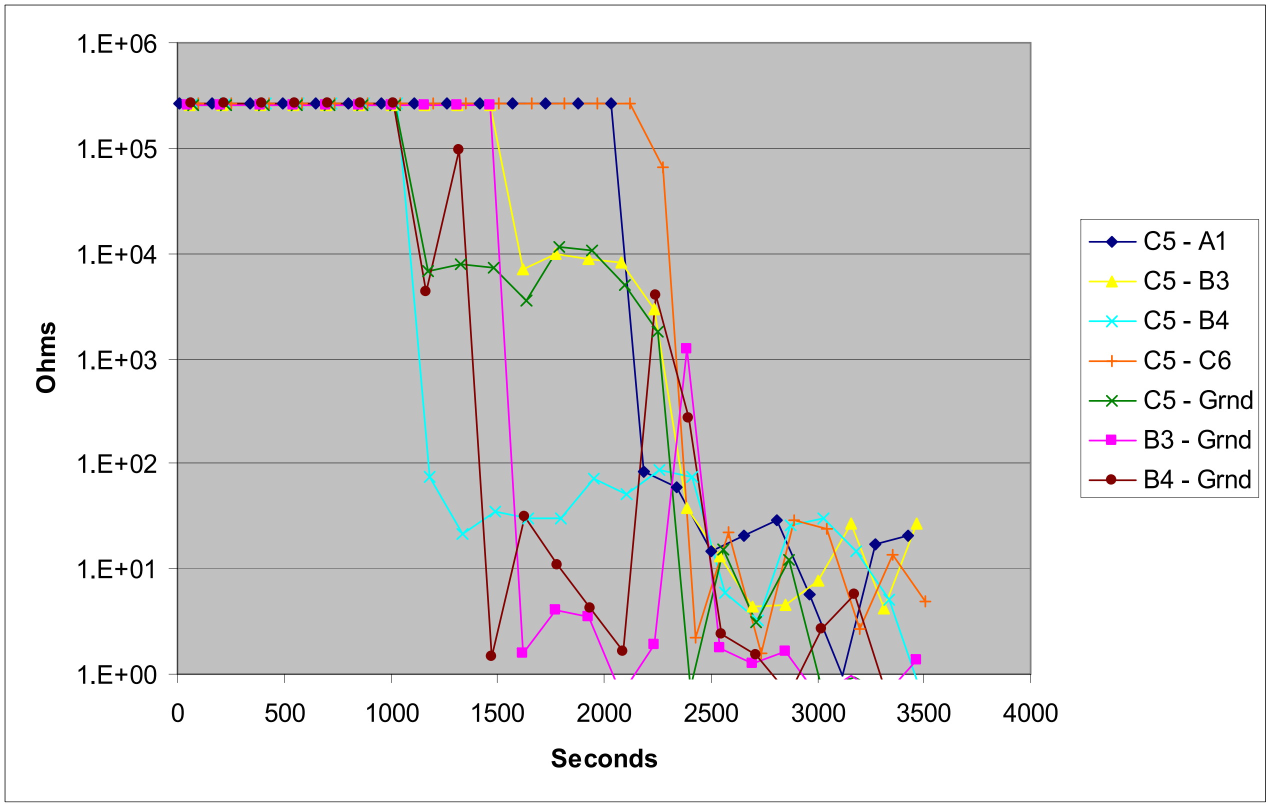
- Intermediate-scale: control circuit simulators allow for testing of various circuit configurations
- Base configuration is the typical MOV control circuit
  - Same as that used in all previous testing by industry





Item A – Thermoset-to-Thermoset

- One solid case of inter-cable shorting as primary failure mode observed on IRMS
- Several cases where inter-cable shorting was secondary or tertiary failure mode on IRMS
- No spurious actuations on the SCDUs



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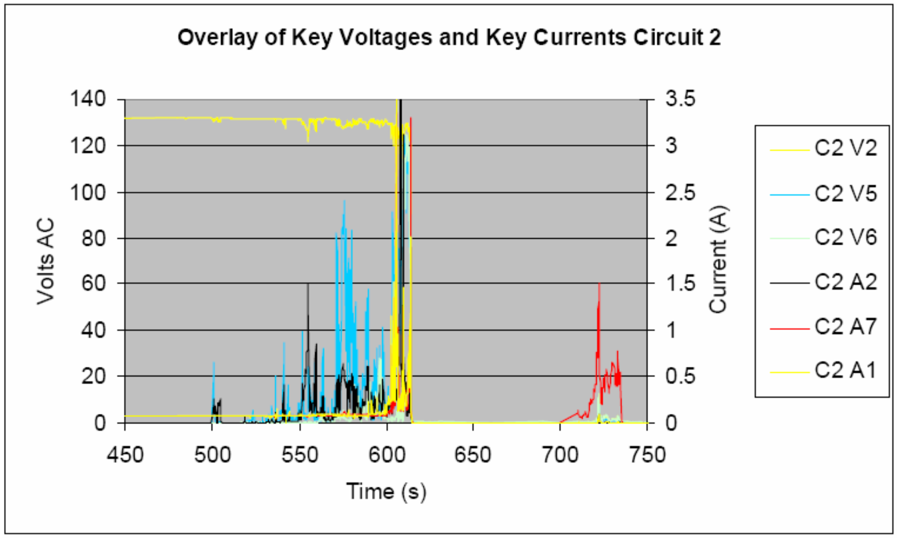
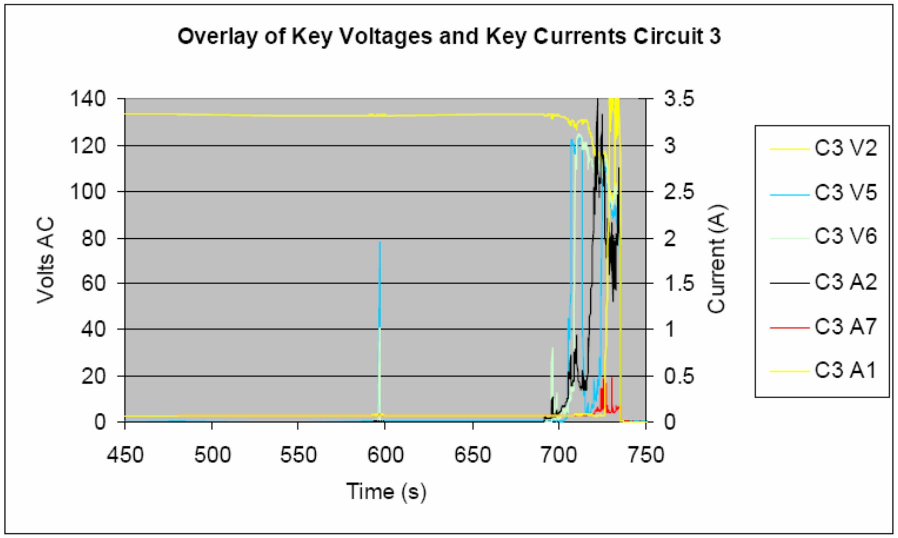
Item B – Thermoset-to-Thermoplastic

- No cases of spurious actuation on SCDUs
- One case of a hot short from a TS to a TP cable
- No cases where inter-cable shorting was primary failure mode for both cables
- One case where inter-cable shorting was secondary mode for one cable, primary for second cable
- Several cases involving secondary/secondary or tertiary failures





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Item C: Concurrent for three or more cables

- Every test program conducted to date has seen as many as four out of four simulated control circuits spuriously actuate, CAROLFIRE included

- CAROLFIRE did explore different exposure locations and conditions and this does impact timing significantly

Item D: Concurrent spurious actuations given properly sized CPT

- CAROLFIRE could not confirm NEI/EPRI results relative to CPTs
  - Testing of larger CPTs
  - No apparent affect on spurious actuations
  - No cases where voltage collapse was thought to have prevented spurious actuation
- What is meant by 'properly sized' is a key question
  - Relay coil pick-up current NOT in-rush
  - May be issue with interpreting manufacturer specs.

Item E: Hot shorts lasting more than 20 min.

- CAROLFIRE saw no hot shorts lasting greater than 7.6 minutes
- NEI/EPRI saw max duration of 11.3 minutes
- All data appears to indicate that once cable degradation begins, it will cascade through all modes within a relatively short time

Summary

- CAROLFIRE is addressing need areas
  - Resolution of deferred spurious actuation circuit configurations
  - Improving the fire modeling of cable response and failure
- Status:
  - All testing has been completed
  - Final reports in publication process:
    - Volume 1, on the Bin 2 items, and Volume 2, on fire modeling improvement have just completed 60 day public comment period
    - Scheduled to be submitted to NRC publication office for printing Winter 2007

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"Development of a Cable Response Model and Fire Model Verification and Validation"

Kevin McGrattan, Ph.D.
National Institute of Standards and Technology

Tuesday March 13, 2007

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"Development of a Cable Response Model and Fire Model Verification and Validation"

- Modeling Cable Failure
- Incorporating such a model into a practical fire model

Simple Response Models in Fire

$$\frac{dT_l}{dt} = \frac{\sqrt{|\mathbf{u}|}}{\mathrm{RTI}}(T_g - T_l)$$

Solve for link temperature using velocity **u** and gas temperature from Fire Model. The RTI (Response Time Index) is unique to each sprinkler.
Source: Gunnar Heskestad, Factory Mutual

$$\frac{dY_c}{dt} = \frac{Y_e(t) - Y_c(t)}{L/\mathbf{u}}$$

Solve for smoke chamber concentration using external smoke concentration and velocity **u** from Fire Model. L is a length scale unique to each detector.

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Surely, you're joking…

There must be more to sprinklers and smoke detectors than just these simple equations!

Absolutely, but consider the fire models in which these sub-models are embedded…

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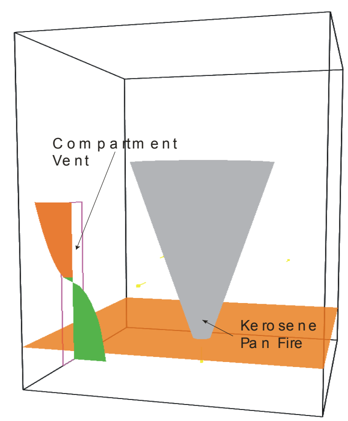
Three Classes of Fire Models

Hand Calculations

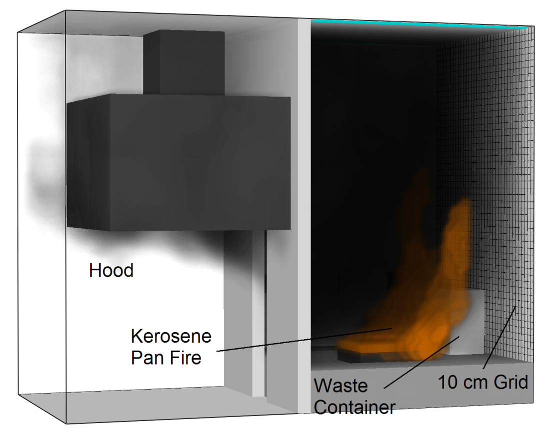
$$T_g - T_\infty = 6.85\left(\frac{\dot{Q}^2}{A_0\sqrt{H_0}\,h_k A_T}\right)^{1/3}$$

McCaffrey, Quintiere, Harkleroad (MQH)

Two-Zone Models



CFD



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Fire Model V&V

- NRC has produced a V&V Guide for 5 different fire models (NUREG 1824)
- 2 sets of hand calcs, 2 zone, 1 CFD
- Experimental Uncertainty and Model Error quantified in a novel way
- Defines current state of the art

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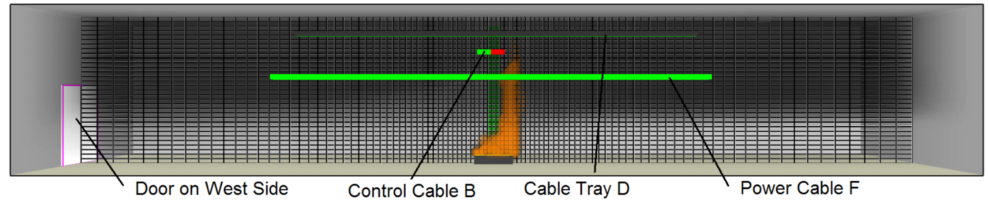
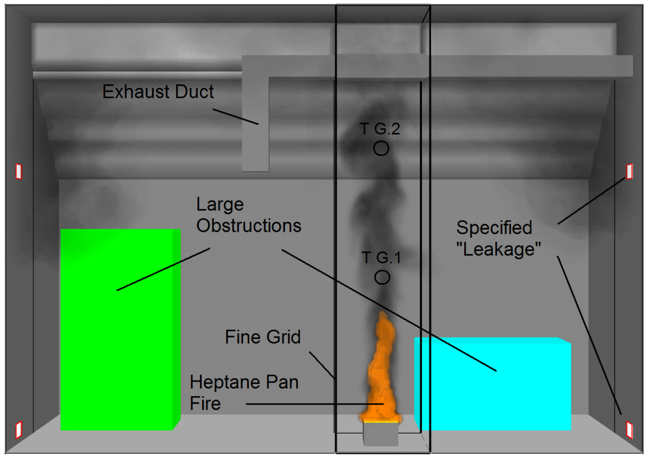
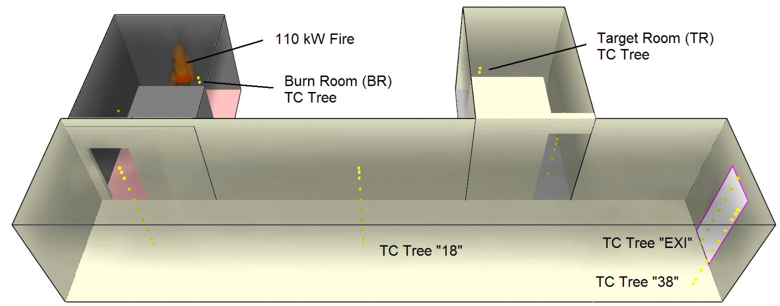


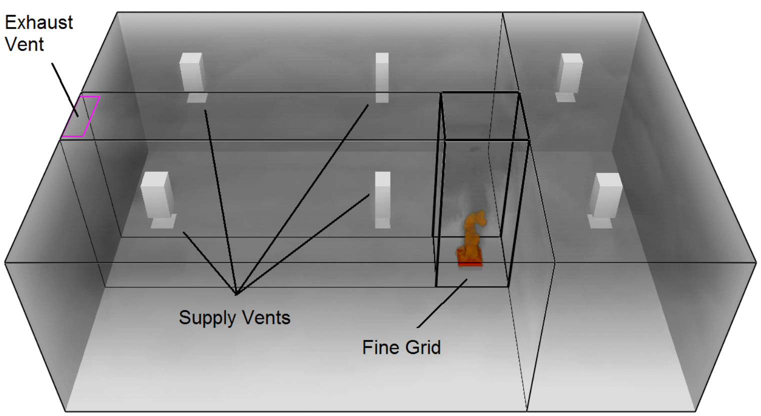
NIST, USA



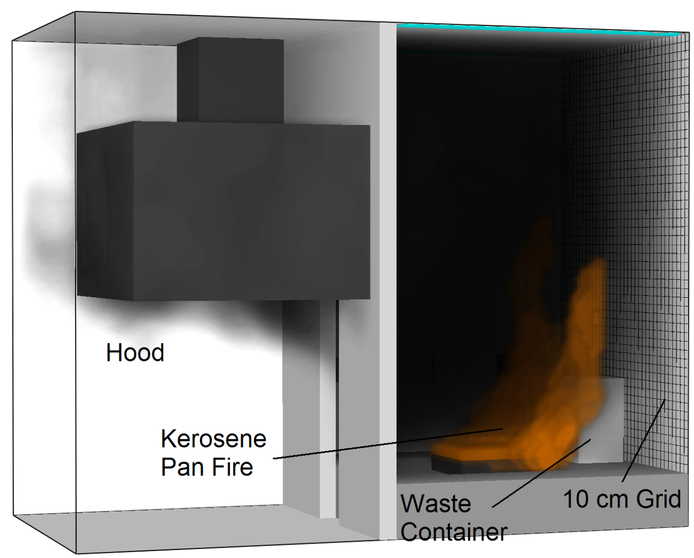
VTT, Finland



NBS, USA



Sandia/FM (USA)



iBMB, Germany

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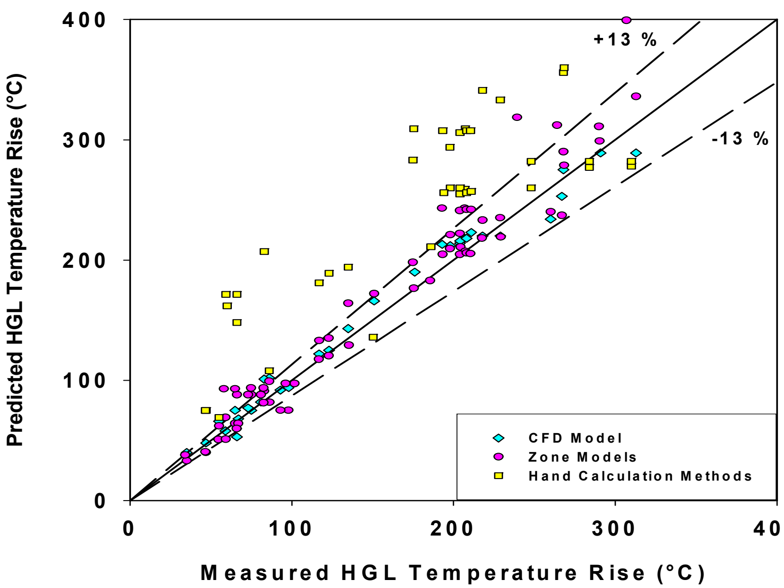
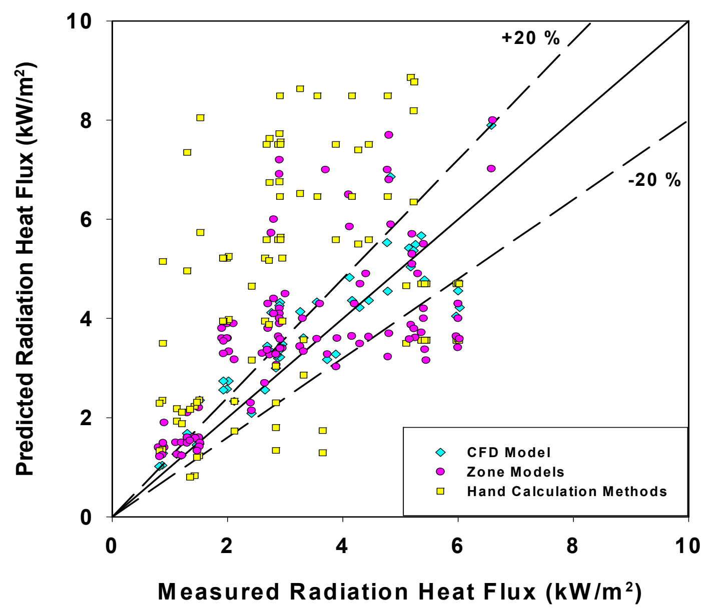
Results of NRC V&V (NUREG 1824)





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Cable Failure Model

$$\rho_s c_s \frac{\partial T_s}{\partial t} = \frac{k_s}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T_s}{\partial r} \right)$$

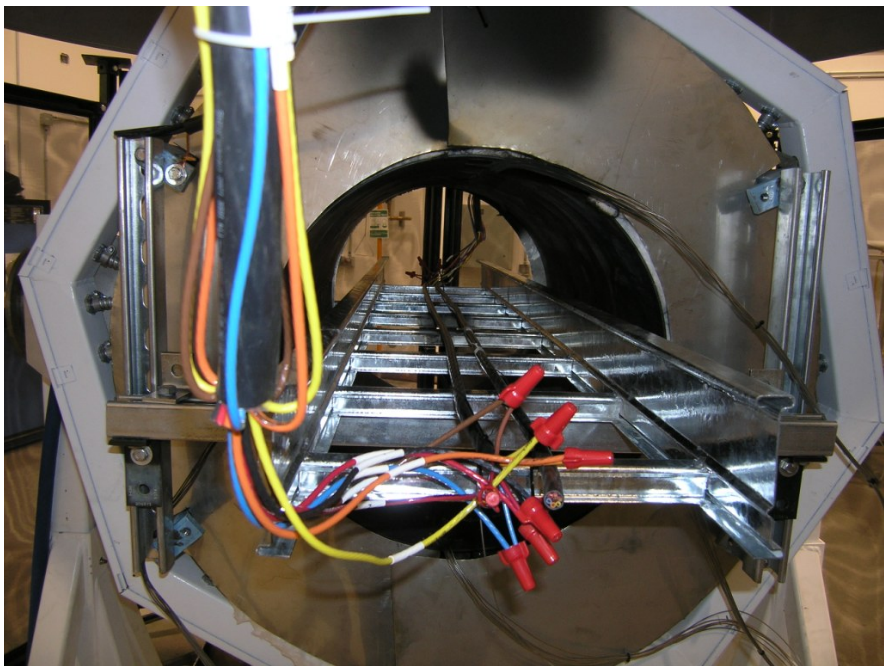
$$-k_s \frac{\partial T_s}{\partial r} = \dot{q}_c'' + \dot{q}_r''$$

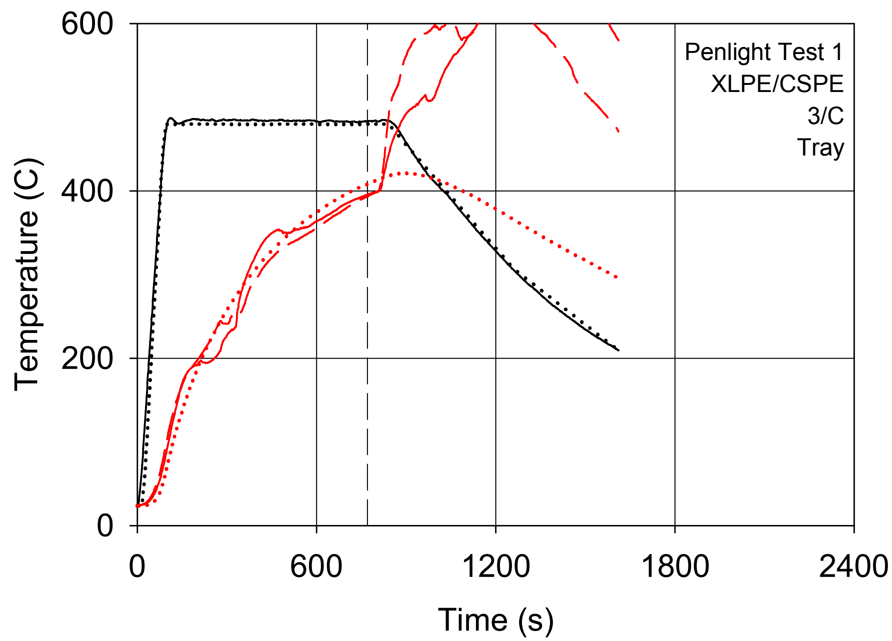
1-D heat conduction into homogenous cylinder. Thermal conductivity (k) and specific heat (c) assumed constant for all cables. Density (ρ) obtained from cable diameter and mass per unit length. Failure temperature obtained experimentally.

The Fire Model provides the convective and radiative heat flux at the cable surface.

Source: Andersson and Van Hees, SP Fire, Sweden.

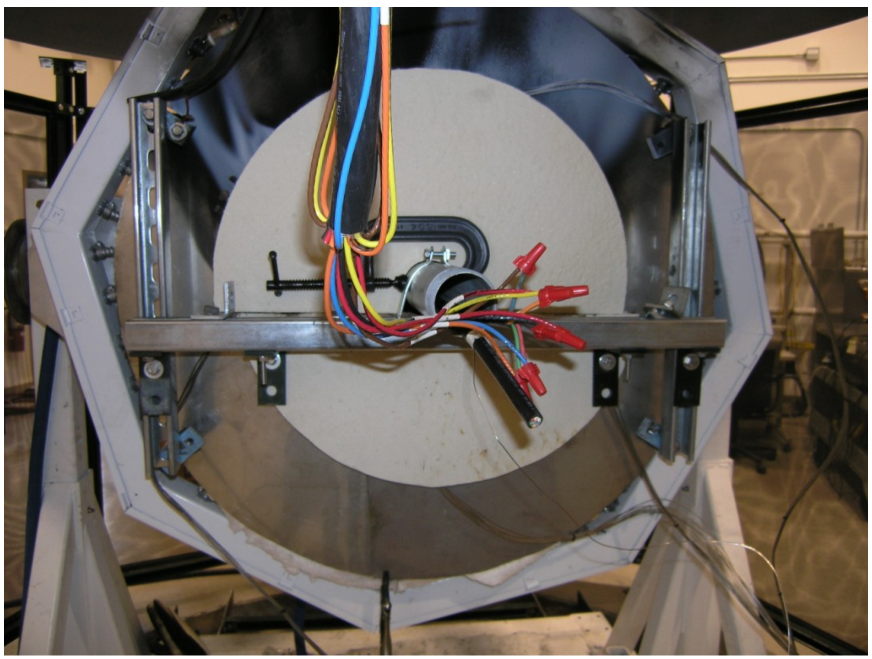
Results



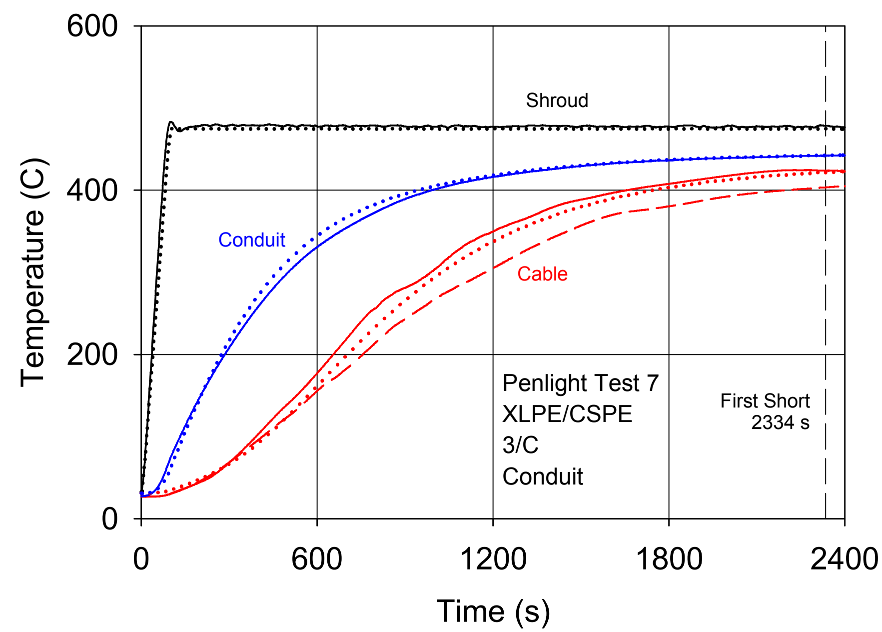


Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory

More Results



Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory



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Summary

- Cable model developed in conjunction with CAROLFIRE test program
- Simplicity and accuracy of the model consistent with current generation large-scale fire models

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