U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Fire Research Activities at Nuclear Regulatory Commission NIST 2007 Annual Fire Conference

Office of Nuclear Regulatory Research

FIRE TEAM

Mark Henry Salley, P.E.
Fire Research Team Leader
MXS3@nrc.gov
301-415-2840

Major Program Areas

- Fire Modeling for Nuclear Power Plant Applications
- Fire PRA
- Operator Manual Actions
- Cable Response to Live Fire (CAROLFIRE)
- Collaboration with EPRI, NIST, EdF, U of MD
- Provide a overview on each major program

Fire Model V&V NUREG-1824

- "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications"
- NFPA 805: "Fire models shall be verified and validated."
- Comparing 5 models with experimental data to determine predictive capabilities
- Follows ASTM E 1355
- 13 different parameters/26 different experiments
- Graphical comparisons of the experimental measurements and the model output

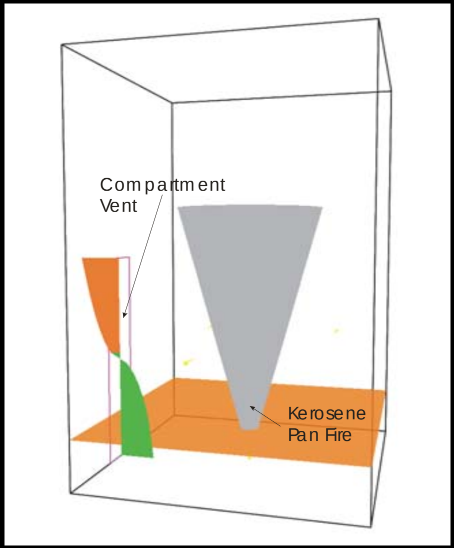
Three Classes of Fire Models

Hand Calculations

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

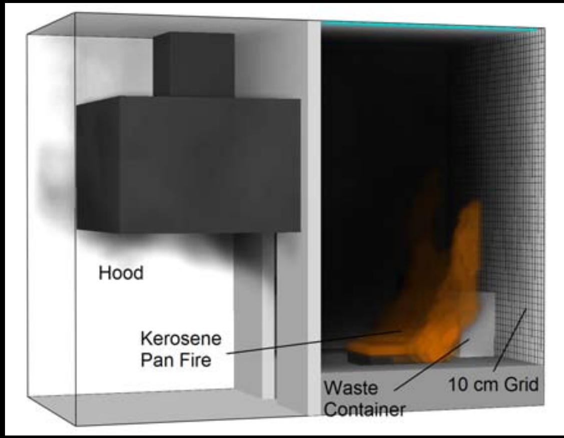
McCaffrey, Quintiere, Harkleroad (MQH)

Two-Zone Models



CFAST, NIST

CFD

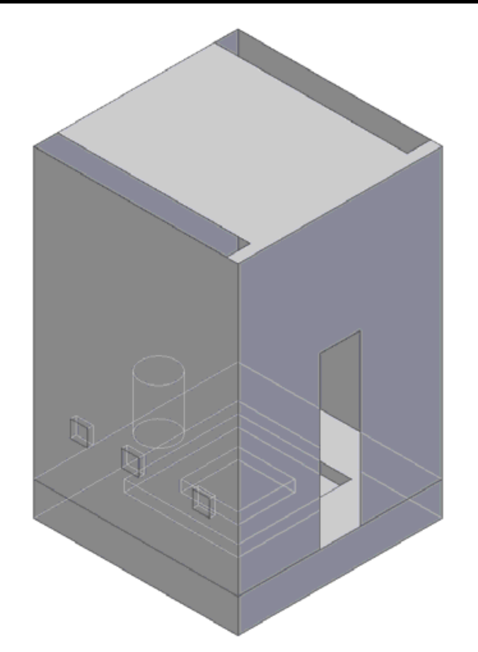


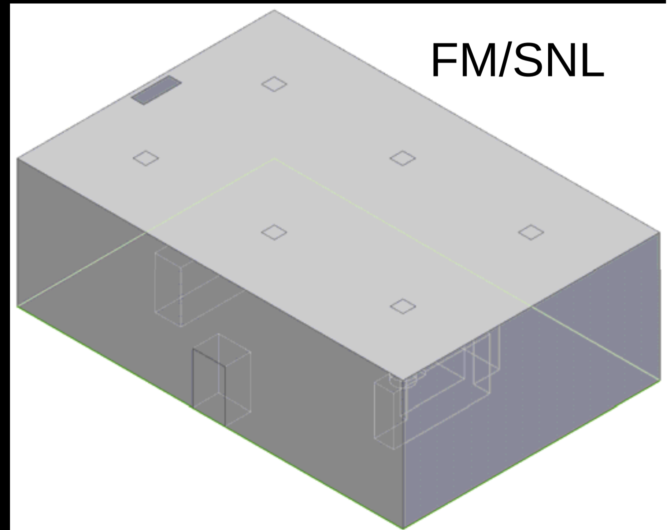
FDS, NIST

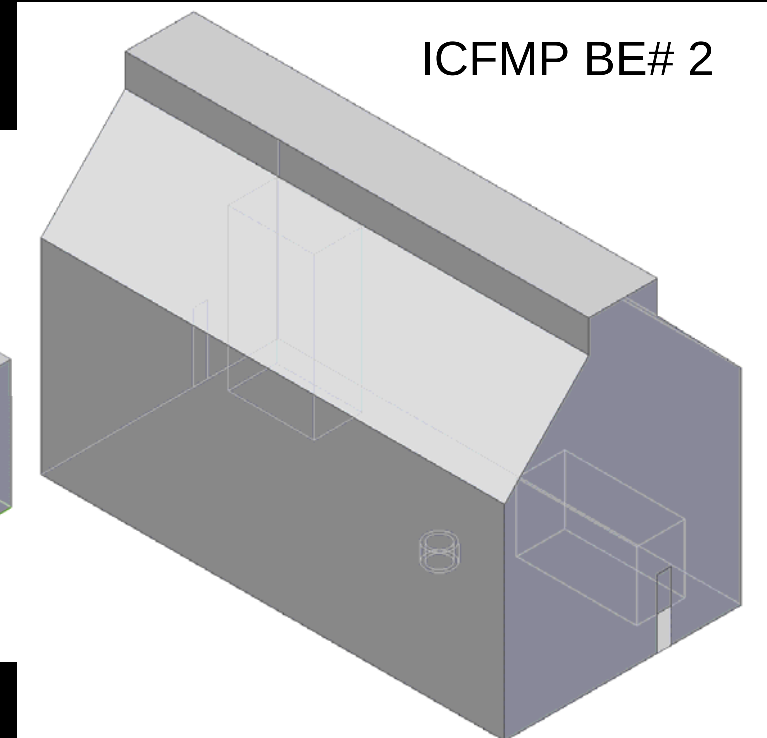
NUREG-1824

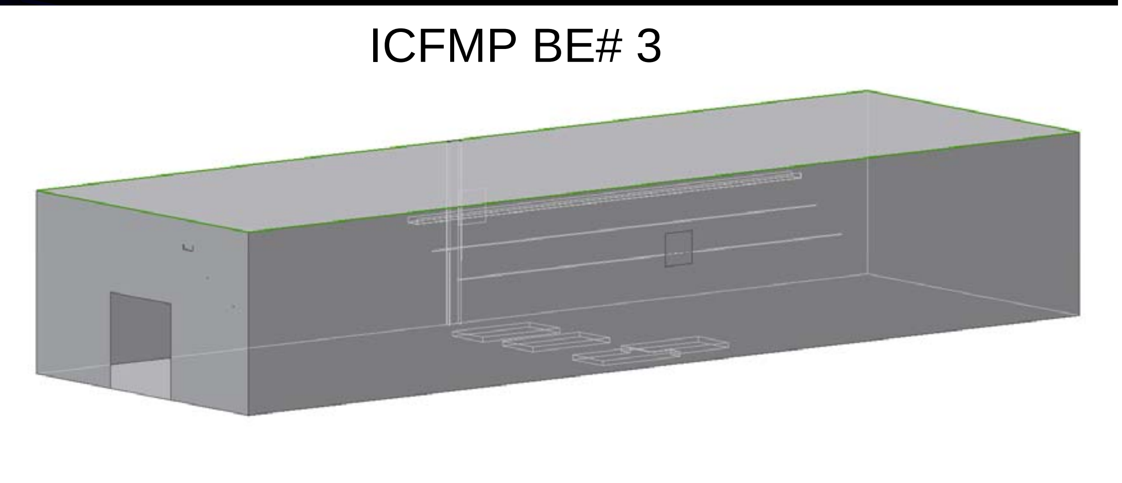
- Examined 13 different fire dynamics parameters:
  - Hot Gas Layer Temperature
  - Hot Gas Layer Height
  - Plume Temperature
  - Ceiling Jet Temperature
  - Oxygen Concentration
  - Smoke Concentration
  - Room Pressure
  - Radiant Heat Flux
  - Total Heat Flux
  - Wall Heat Flux
  - Wall Temperature
  - Target Temperature
  - Flame Height

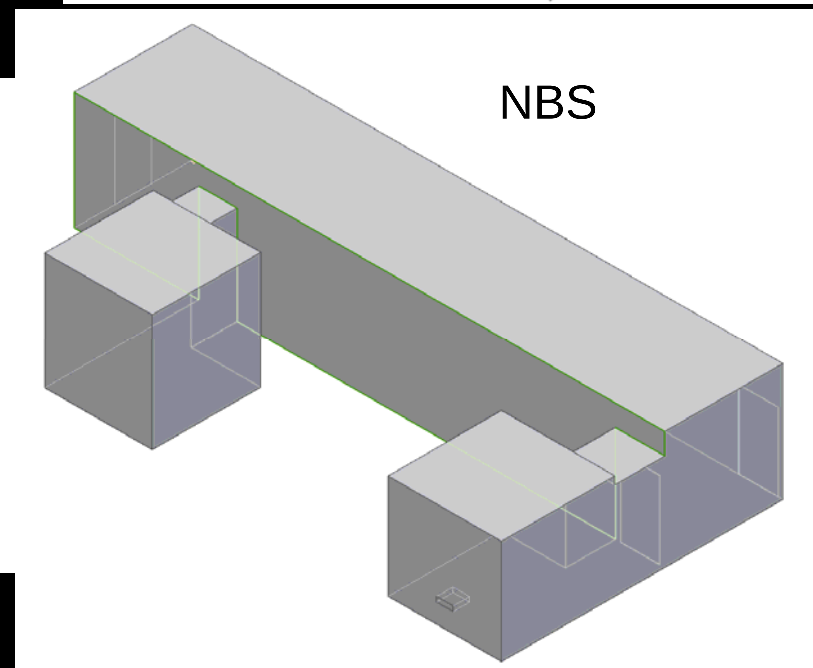
ICFMP BE #4, 5











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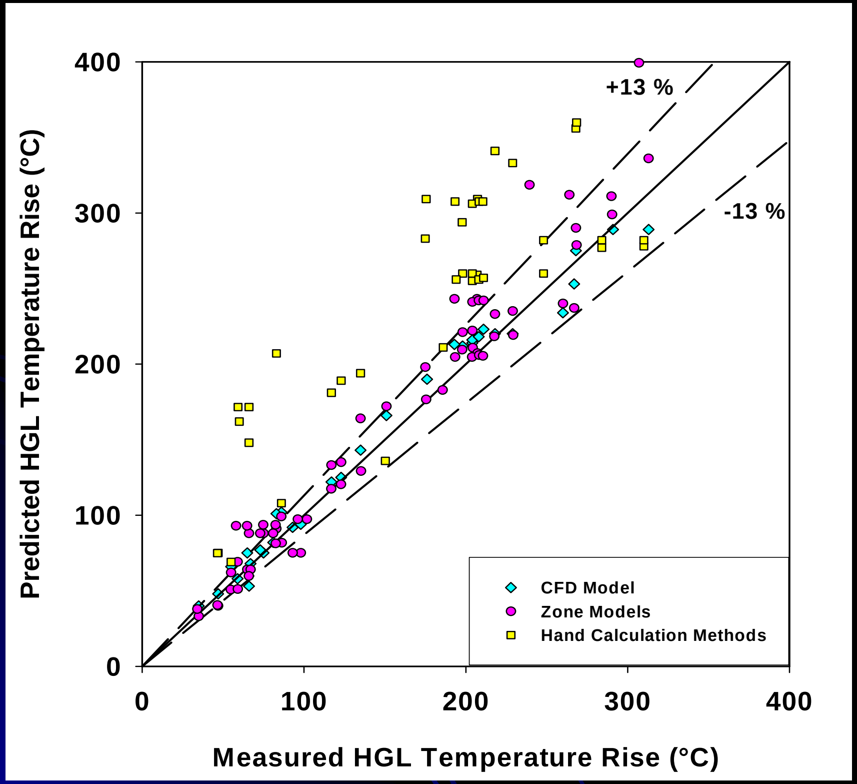
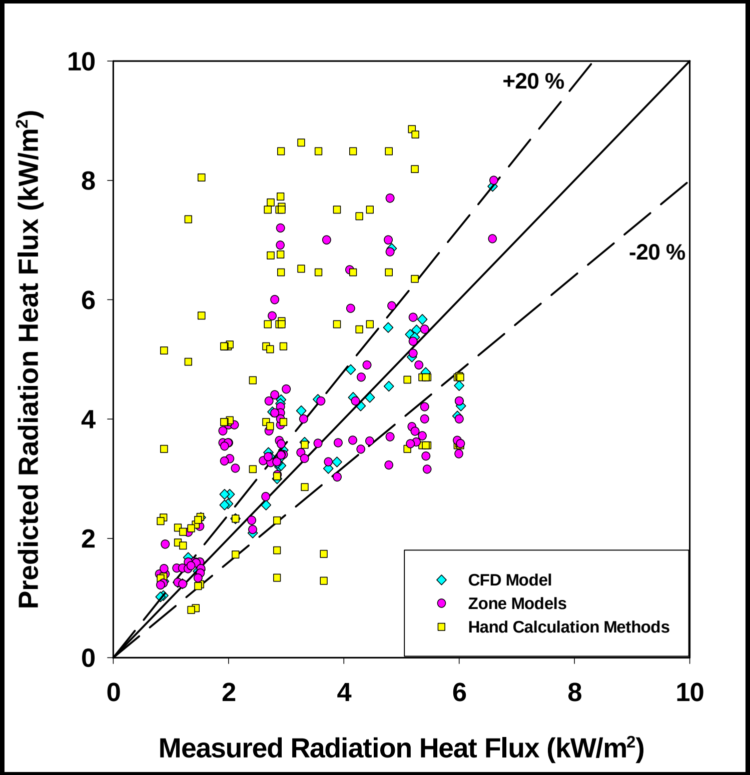
Results of NRC V&V (NUREG 1824)





Fire Model User's Guide

- Provide expert insight
- Specific nuclear power plant fire modeling issues
- Provide guidance for model inputs and interpretation of model outputs
- Characterize the uncertainty of model outputs
- Draft for comment in early 2008
- Final report to be issued in late 2008

Fire Modeling PIRT

- Phenomena Identification and Ranking Table (PIRT)
- Structured expert elicitation process
- Focus on the dominant fire phenomena in important NPP fire scenarios
- Rank the phenomena in terms of importance and level of knowledge
- Use to prioritize future research
- Meetings to be held Spring/Summer 2007
- Report issued early 2008

Future Work-Cable Testing

- Large stock of representative cable stored at NIST
- Data on HRR, flame spread for different cable types, configuration
- Validation data for cable failure models
- Tests to be run in 2008

Fire PRA NUREG/CR6850

- Partnership between NRC-RES and EPRI on technical issues in fire PRA (Probabilistic Risk Analysis)
- Support by consultants, Sandia National Laboratory, and University of Maryland
- Objective: Develop, field test, and document state-of-the-art in fire PRA

Product: NUREG/CR-6850, EPRI 1008239 "*EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*"

- Published in September 2005.
- Two well-attended, RES/EPRI workshops conducted in 2005 and 2006.

USE OF METHODOLOGY

- Support for 10CFR50.48c implementation with pilot plants
  - NFPA 805 Frequently-Asked-Questions (FAQ) Program
  - Fire PRA audit
- ANS fire risk standard
  - NUREG/CR-6850 established state-of-the-art
- Reactor Oversight Process (phase 3 fire protection SDP)
- Expected: Support Standard Review Plan (SRP) on fire PRA; Analyses under current fire protection regulations

Operator Manual Actions
NUREG - 1852

Demonstrating the Feasibility and Reliability Of Operator Manual Actions In Response to Fire

Operator Manual Actions (OMAs)

Those actions performed by operators to manipulate components and equipment from outside the main control room (MCR) to achieve and maintain post-fire hot shutdown, but not including “repairs.”

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

- 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
- CAROLFIRE's goal:
  - Assess Bin 2 items A-E through experiments
  - Provide data to NRR for resolution

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 UMd are leading the modeling efforts
- SNL 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

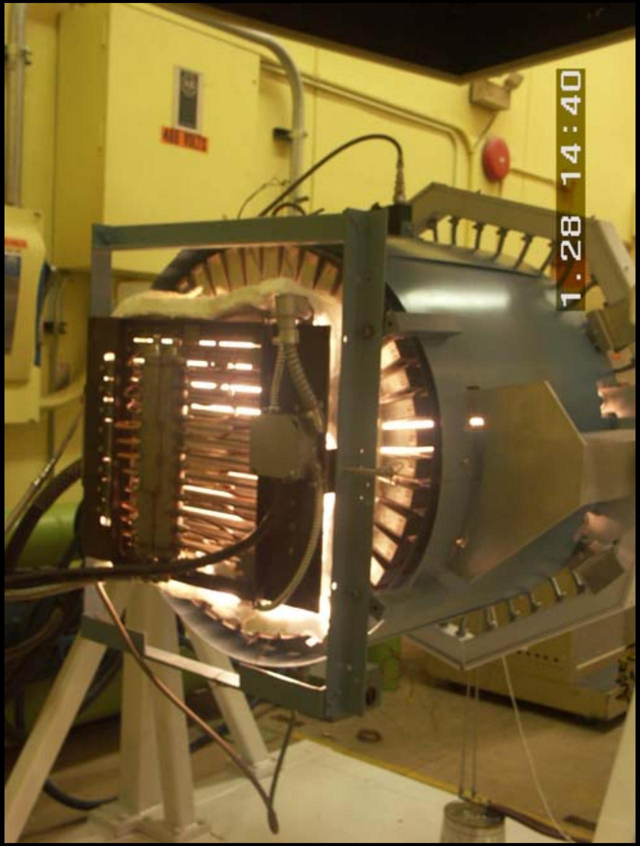
Cable types being tested represent wide range of NPP products

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.

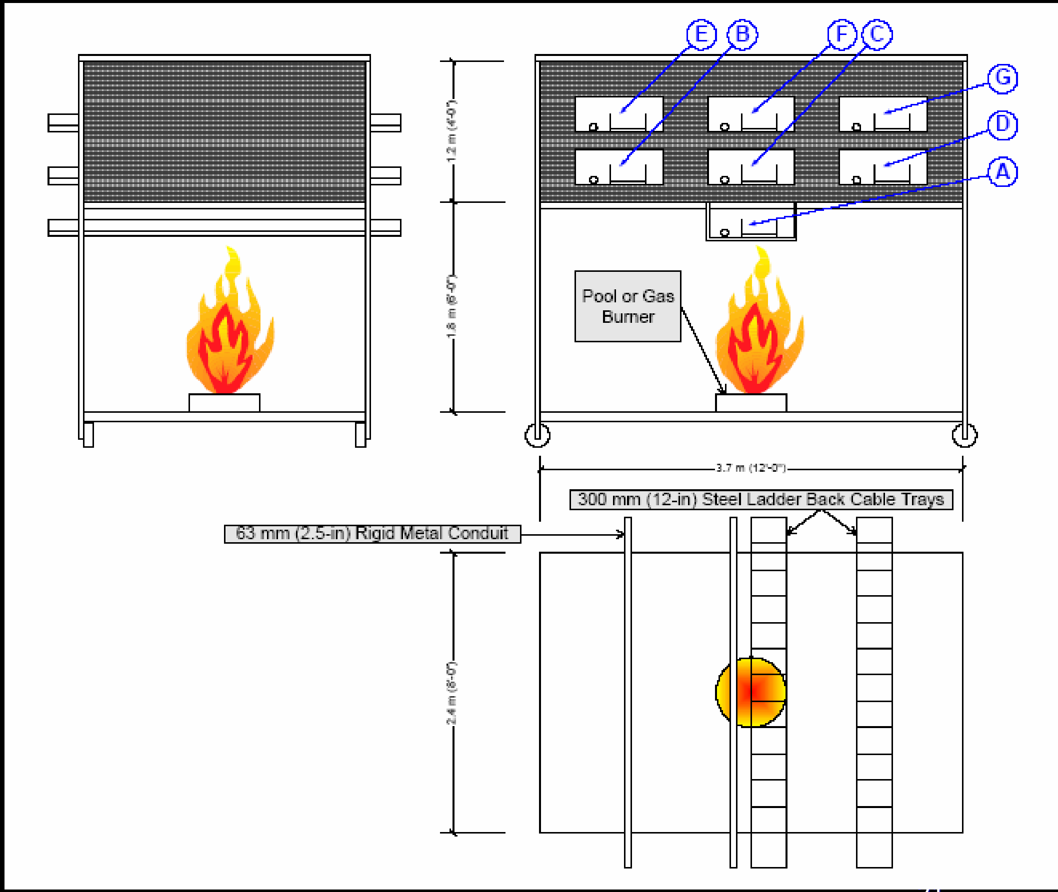
Small Scale Tests

- ***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



Layout of the intermediate-scale test structure.

Structure was located within a larger test facility.



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)

Cable Failure Model

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

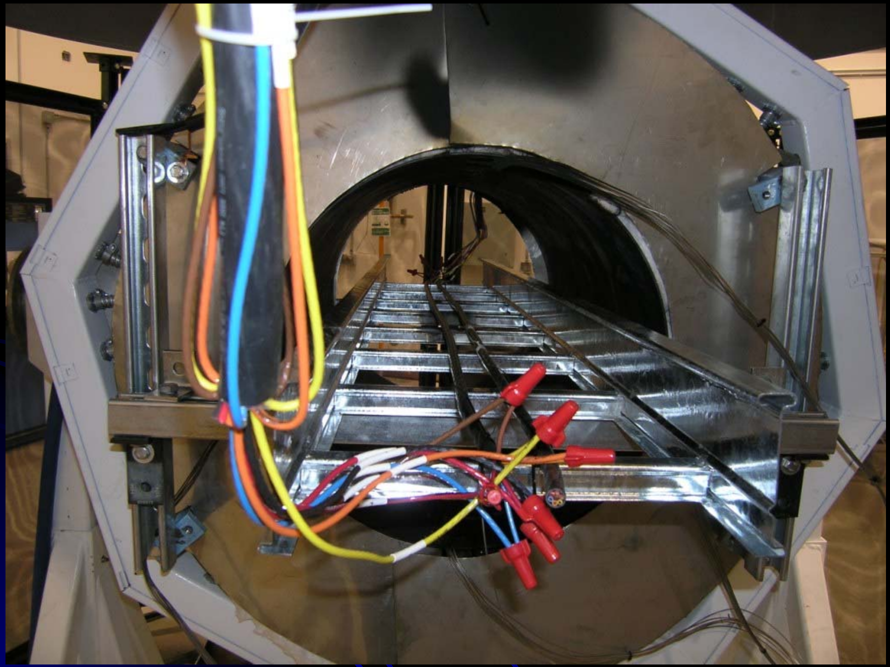
$$-k_s \frac{\partial T_s}{\partial r} = \dot{q}''_c + \dot{q}''_r$$

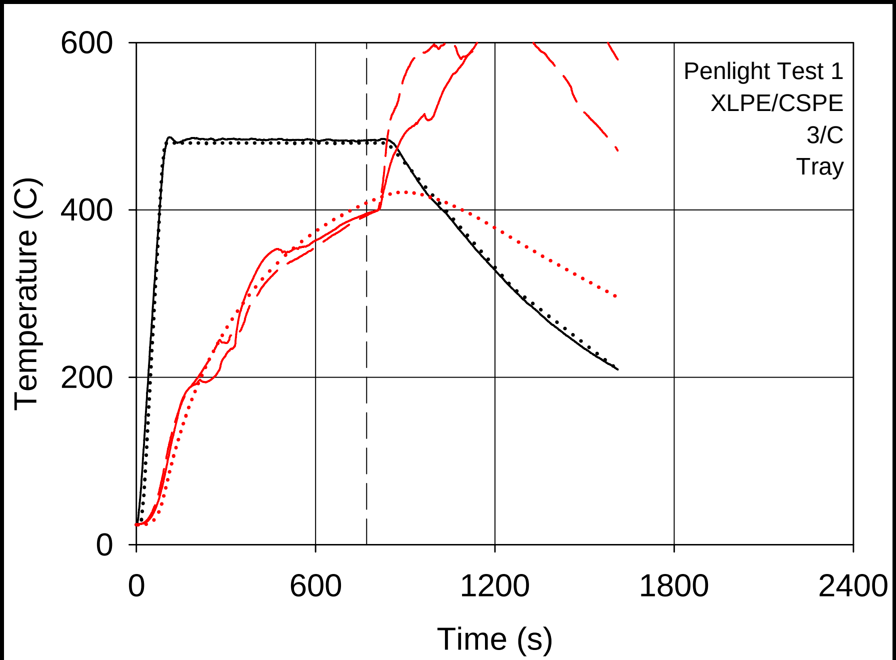
1-D heat conduction into homogenous cylinder. Thermal conductivity (k) and specific heat (c) assumed constant for all cables. Density (ρ) obtained from cable diameter and mass per unit length. Failure temperature obtained experimentally.

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

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

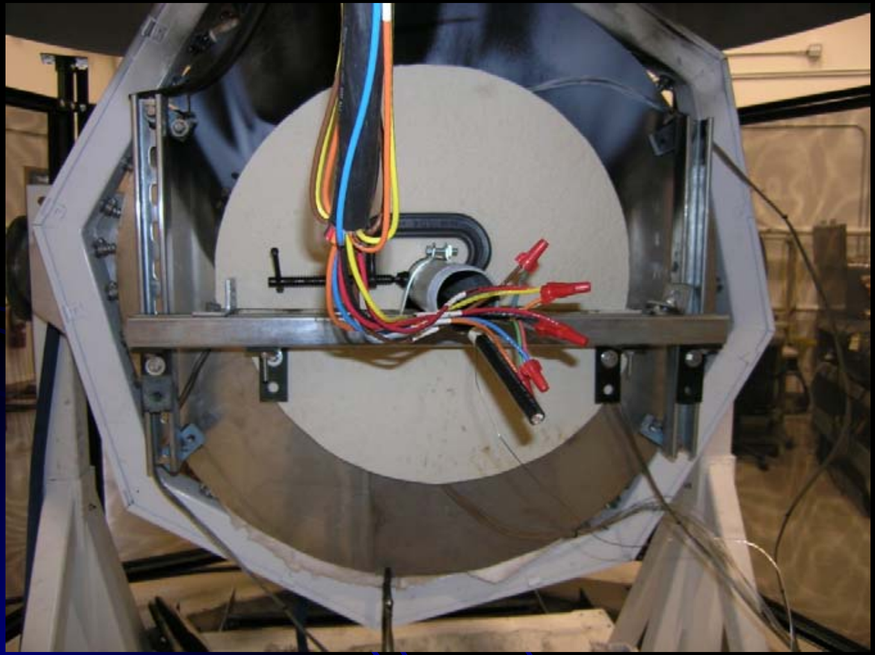
Results

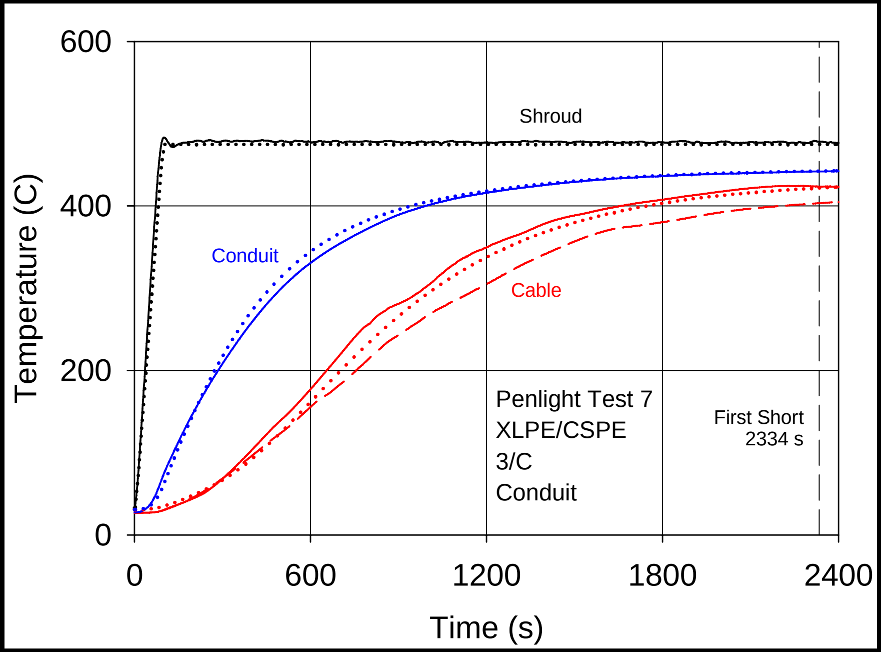




Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory

More Results





Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory

Conclusion

- CAROLFIRE addressed 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, Volume 2, on fire modeling improvement will be issued for 45 day Public Comment in May 2007,
    - Final Reports expected in 2008