CAROLFIRE
The Cable Response to Live Fire Project

Presented by:

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Acknowledgements

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  - H.W. ‘Roy’ Woods, RES Project Manager
  - Mark Salley, RES Management Lead
- Collaborative partners:
  - NIST – Dr. Kevin McGrattan
  - UMd – Mohamed Modares, Elyahu Avidor and Genebelin Valbuena
- SNL lead test engineer
  - Frank Wyant

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Project Objectives

- Two major areas of investigation:
  - Resolution of the ‘Bin 2’ circuit configurations as identified in Regulatory Issue Summary 2004-03, Rev 1:
    - “Risk-informed Approach For Post-Fire Safe-Shutdown Circuit Inspections”
  - Fire Modeling Improvement
    - To reduce uncertainty associated with predictions of fire-induced cable damage

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The 'Bin 2' Issues

- The 'Bin 2' issues are related to fire-induced cable failure modes and effects and the potential spurious operation of plant equipment
  - Information Notice 99-17, "Problems Associated With Post-Fire Safe-Shutdown Circuit Analysis."
  - November 29, 2000, inspections of associated circuits were temporarily suspended (ML003773142)
  - Nuclear Energy Institute (NEI) developed NEI 00-01, "Guidance for Post-Fire Safe-Shutdown Analysis," Rev. D (2001)
  - NRC perspective on past practice: "Introduction to Post-Fire Safe-Shutdown Analyses" (ML023430533, 2001)

The Bin 2 Issues (2)

- 2001 - NEI/EPRI test program with RES collaboration investigates cable failure modes and effects:
  - "Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing," EPRI TR 1003326, Dec 2002
  - "Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of an Expert Elicitation," EPRI TR 1006961, May 2002
  - "Cable Insulation Resistance Measurement Made During Cable Fire Tests," NUREG/CR-6776, June 2002

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The ‘Bin 2’ Issues (3)

- Feb 19 2004: NRC holds a facilitated public workshop to establish guidance under which the moratorium on associated circuit inspections would be lifted.

- The workshop led to the “binning” of circuit configurations:
  - 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).

The ‘Bin 2’ Issues (4)

- And the Bin 2 issues are:
  A. Inter-cable shorting for thermoset cables
  B. Inter-cable shorting between thermoplastic and thermoset cables
  C. Configurations requiring failures of 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 cold shutdown circuits

- Our goal is to move each Bin 2 issue (except for F) into either Bin 1 or Bin 3.

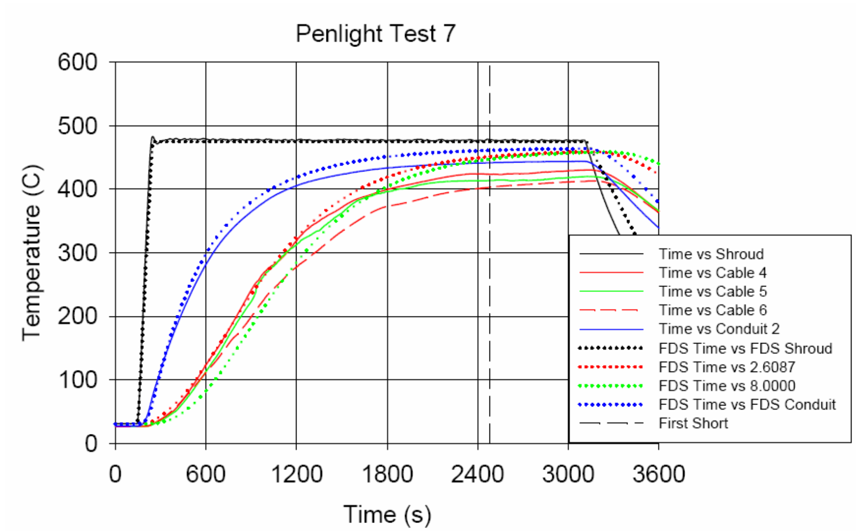
Fire Model Improvement

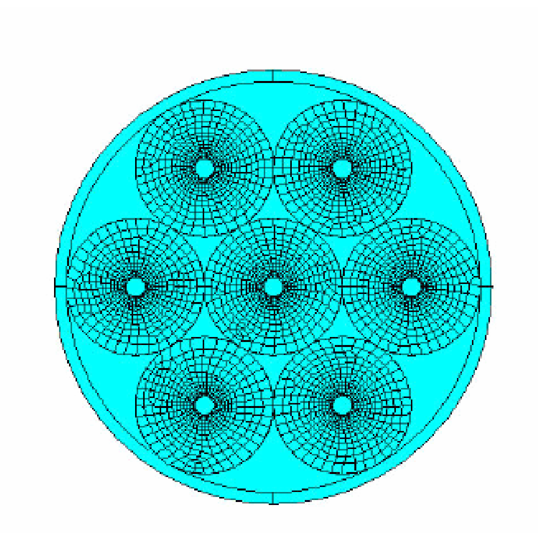
- RES has a separate effort underway dealing with Verification and Validation of fire models
  - Joint project with EPRI
  - NUREG-1824: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications (publication expected January 2007)

- Our goal is complimentary – to provide data to support the improvement of fire modeling tools
  - Reduce uncertainties associated with fire modeling and modeling applications
  - One of the most significant needs relative to NPP applications is to predict cables damage times
  - Most models lack this capability, and validation data is sparse at best
  - CAROLFIRE aims to remedy this by providing quality data upon which improved fire modeling tools can be developed

Fire Modeling Improvement (2)

- **NIST is pursuing a relatively simple approach based on one-dimensional heat transfer modeling**





UMd is pursuing two lines of research:

- **Efficacy of more detailed finite element models**
- **A coupling of a physical based degradation model with statistical models to predict cable failure**

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The testing Approach

- Two Scales of testing are being pursued
  - Small-scale radiant heating experiments
  - Intermediate-scale open burn tests
- Testing focuses on measuring:
  - Cable thermal response under varying heating/fire conditions
  - The onset and modes of cable failure

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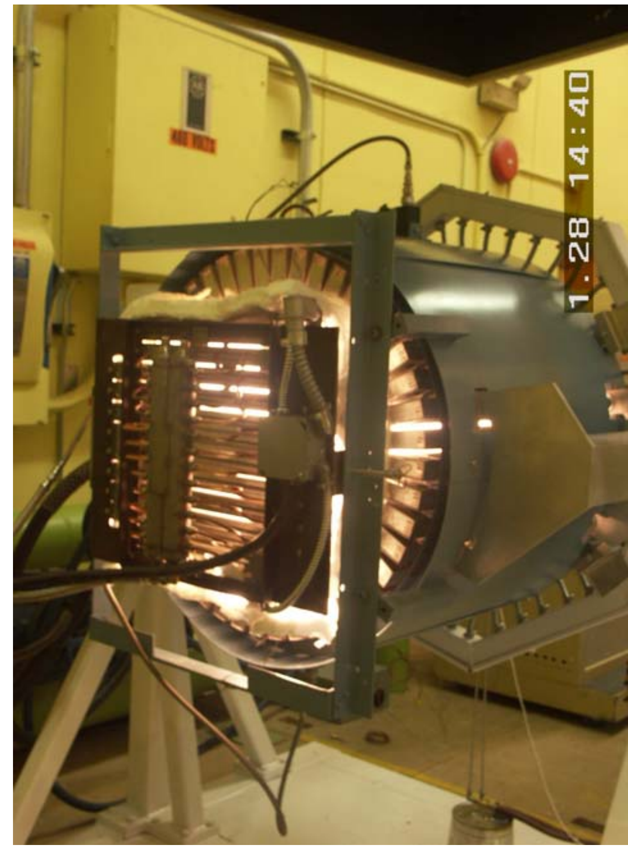
Small Scale Tests

- *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**
- **Cable trays, air drops, conduits**
- **Aimed primarily at fire modeling improvement (calibration of the response models)**
- **Some benefit to the Bin 2 issues Items A and B (inter-cable interactions)**



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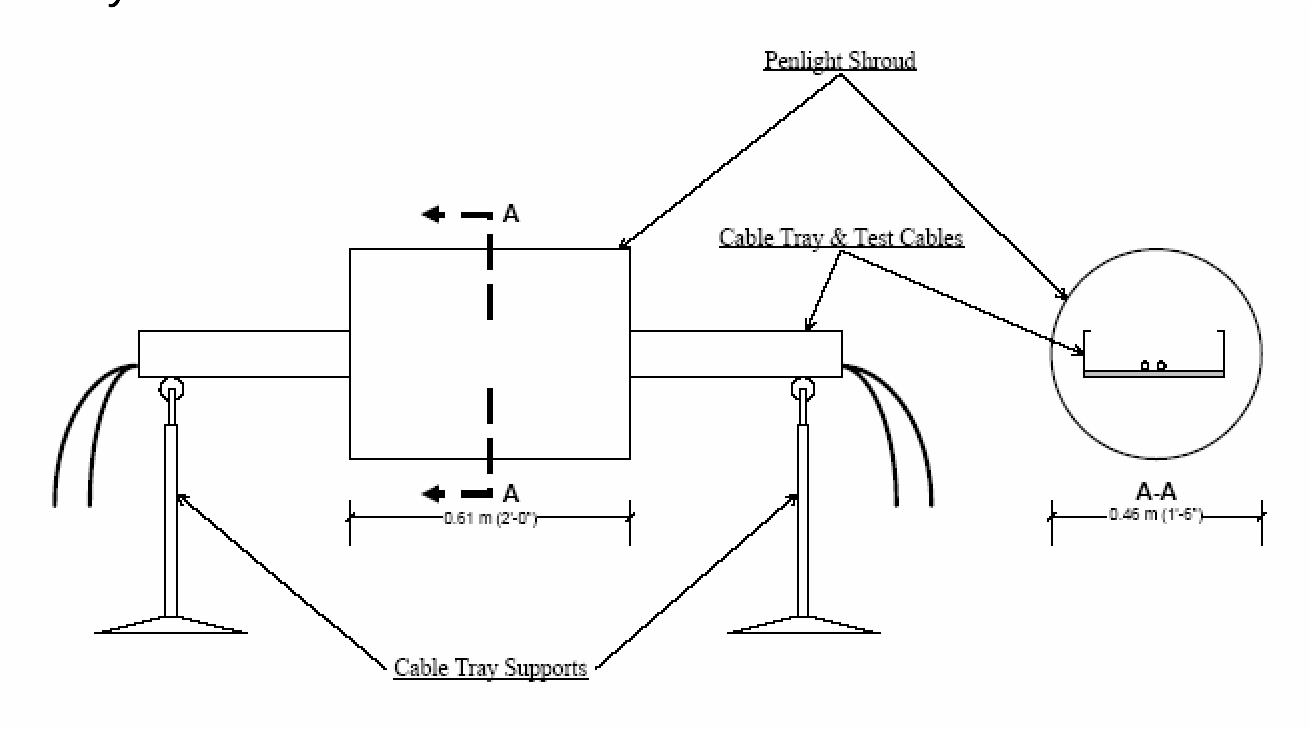
Small-Scale Tests (2)

Typical test configuration has raceway running through the center of Penlight, heated by the cylindrical shroud which is closed on each end.

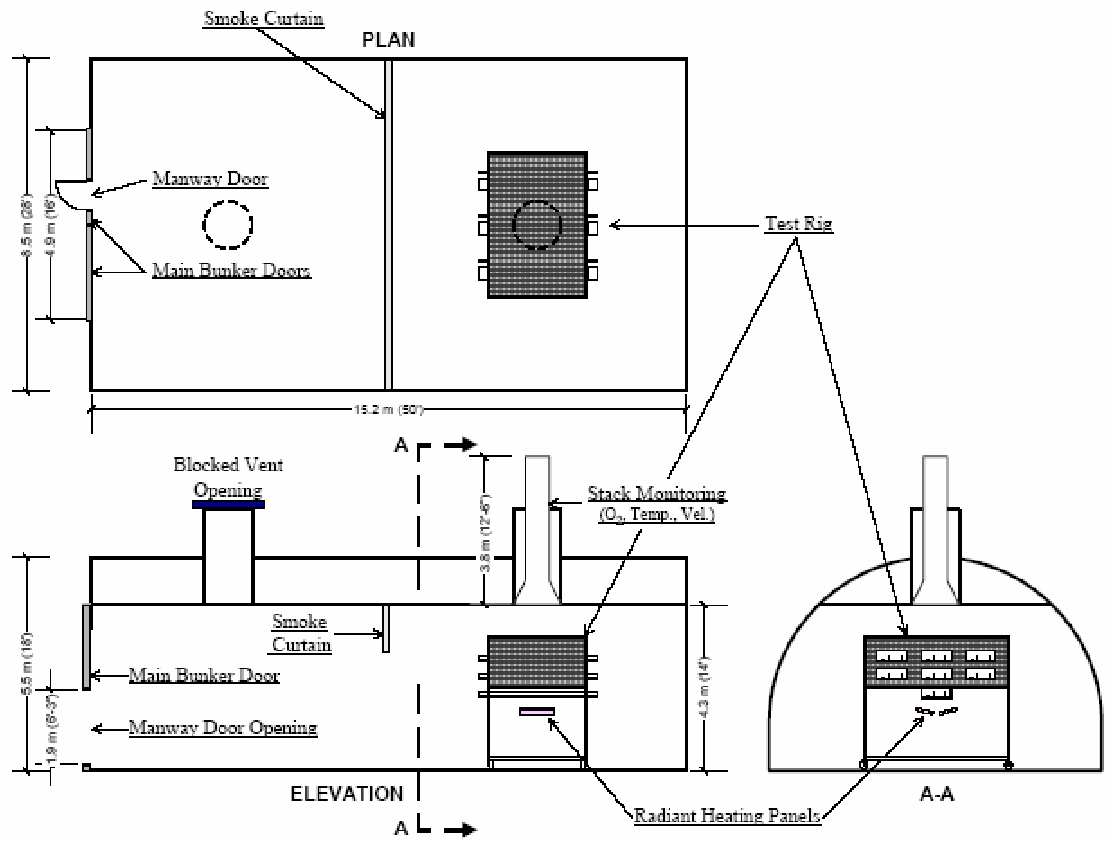


Intermediate Scale Tests

- Less controlled, but a more realistic testing scale
- Propene (Propylene) burner fire source (200 kW typical)
- Cables in trays, conduits and air drop
- Ranging from single cables to loaded raceways
- Aimed at both Fire Model Improvement and Bin 2

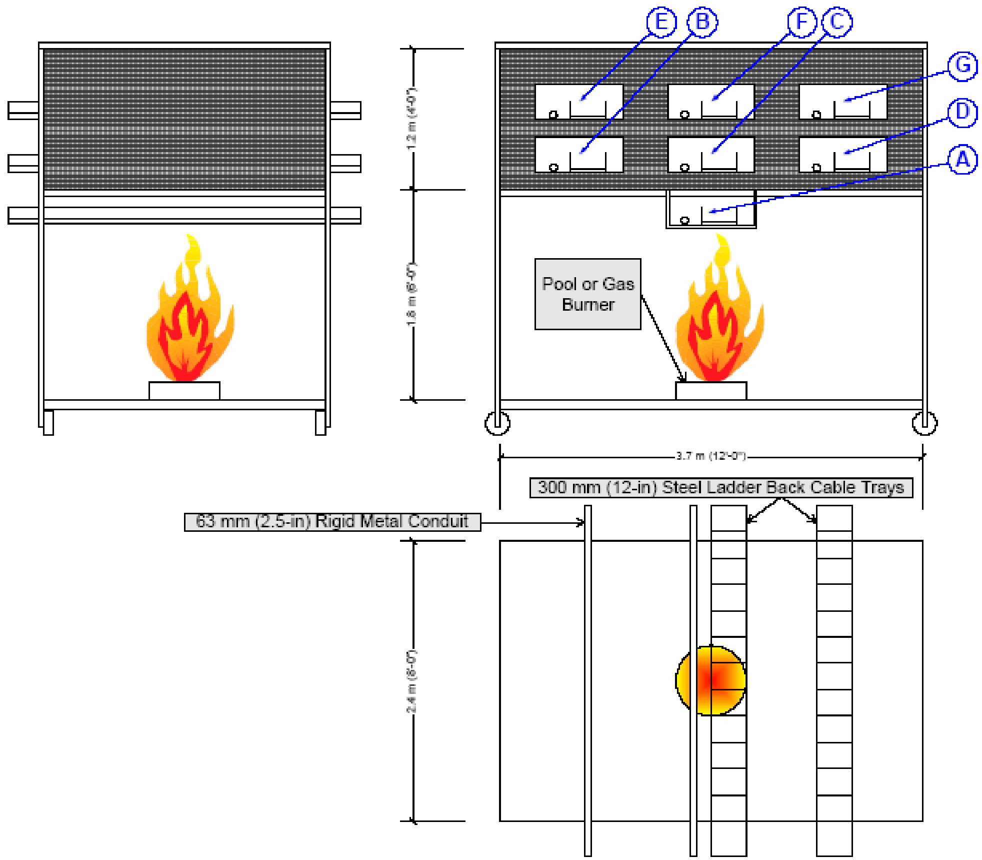
Intermediate-Scale Tests (2)

- We have built a smaller ‘capture hood’ within the larger test facility
- Hood is roughly the size of a typical ASTM E603 type room fire test facility (more open to allow for ready access)



Intermediate-Scale Tests (3)

Rough layout of the capture hood illustrating the various locations that cable raceways can be placed



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

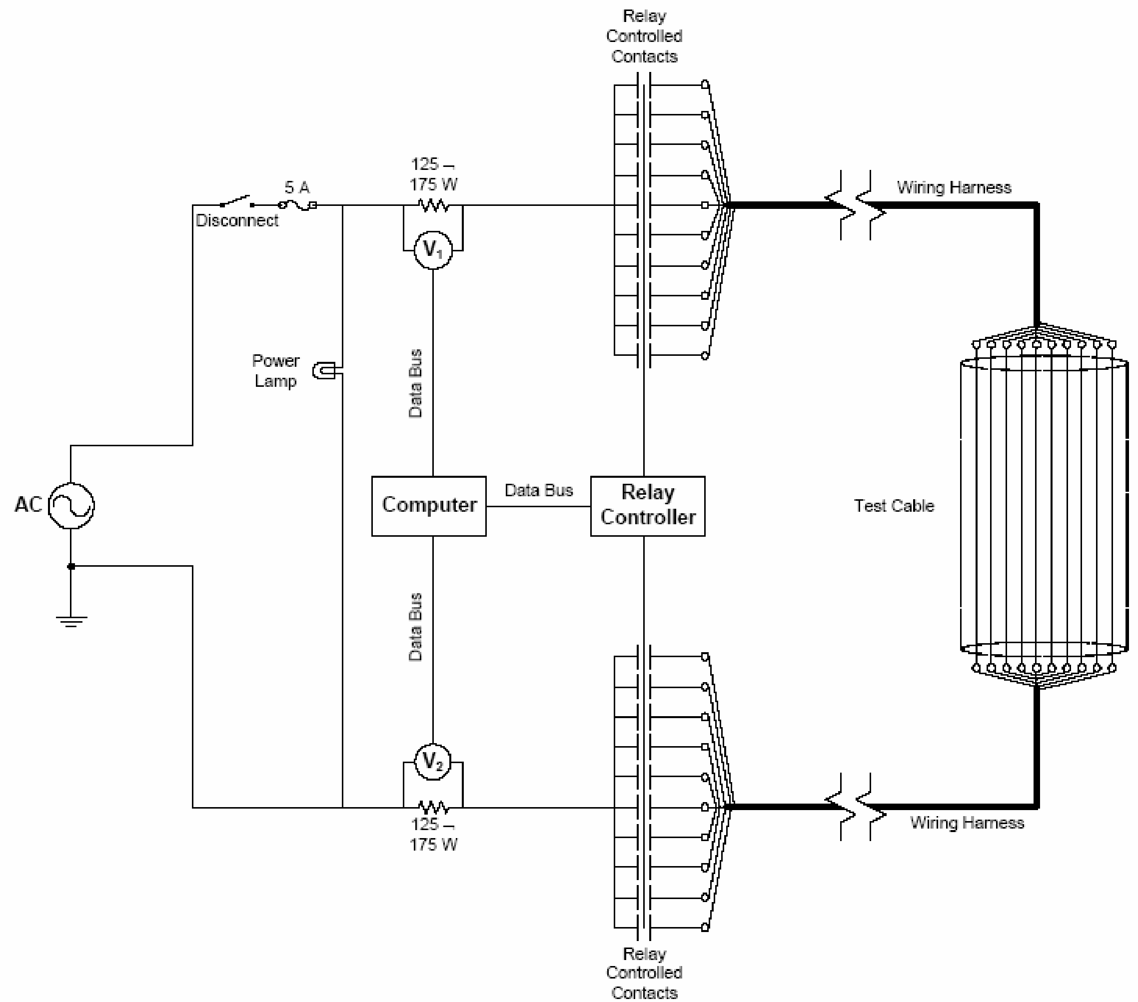
Additional Notes:
(1) - XLPE = Cross-linked polyethylene; CSPE = Chloro-sulfanated polyethylene (also known as Hypalon); XLPO = Cross-linked polyolefin; SR = Silicone rubber; EPR = Ethylene-propylene rubber; PVC = Poly-vinyl chloride; PE = Polyethylene (non cross-linked).
(2) - TS = Thermoset; TP = Thermoplastic;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

Instrumentation

- Cable thermal response
  - Thermocouples at various locations along cable length
  - Thermocouples attached to cable surface, below jacket, embedded deep into the cable
  - Raceway surface temperature
  - Individual cables, small bundles, loaded raceways
- Exposure environment – Penlight: shroud temperature
- Exposure environment – intermediate-scale:
  - Air temperatures
  - Slug calorimeters
  - Fire heat release rate by Oxygen consumption

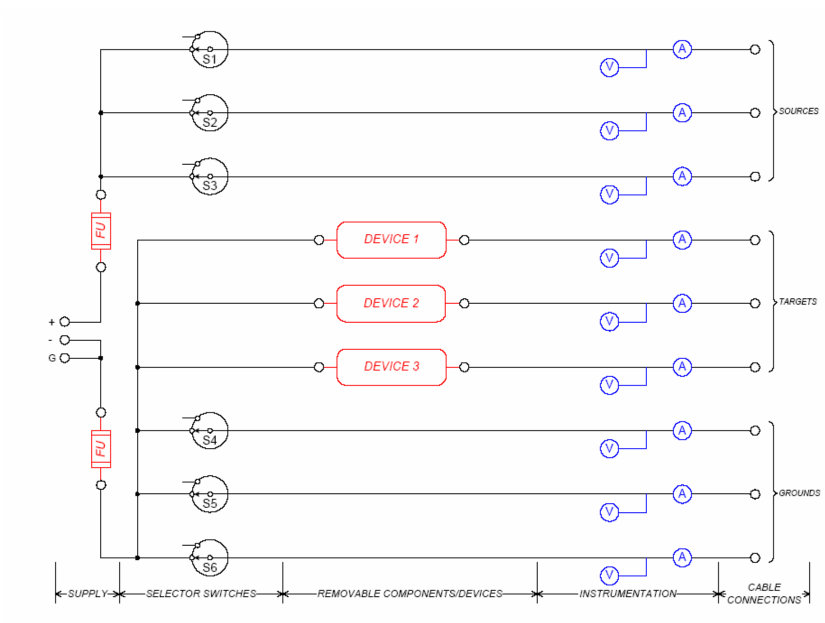
Instrumentation (2)

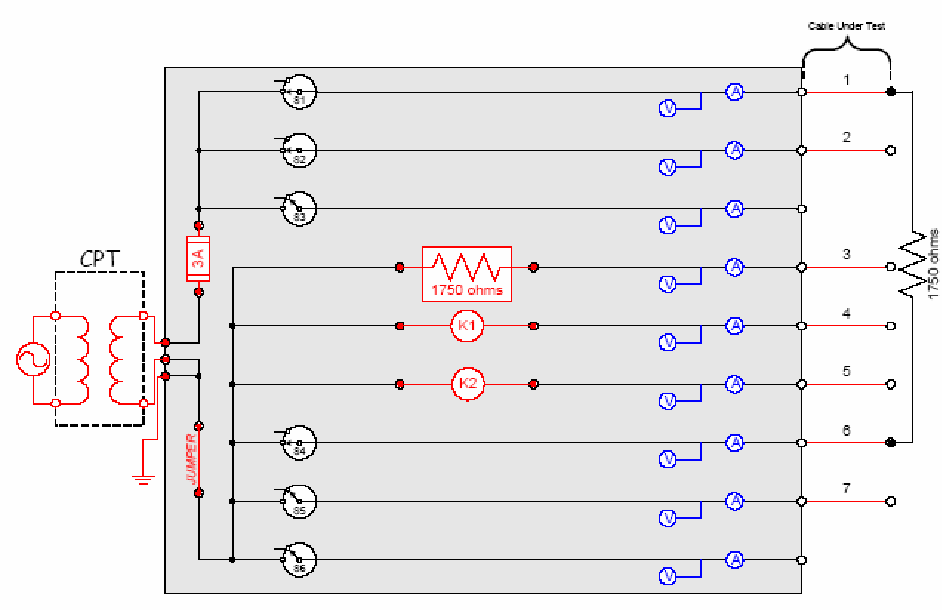
- **All tests – SNL Insulation Resistance Measurement System**
- **Continuous measurement of cable degradation and functionality**



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





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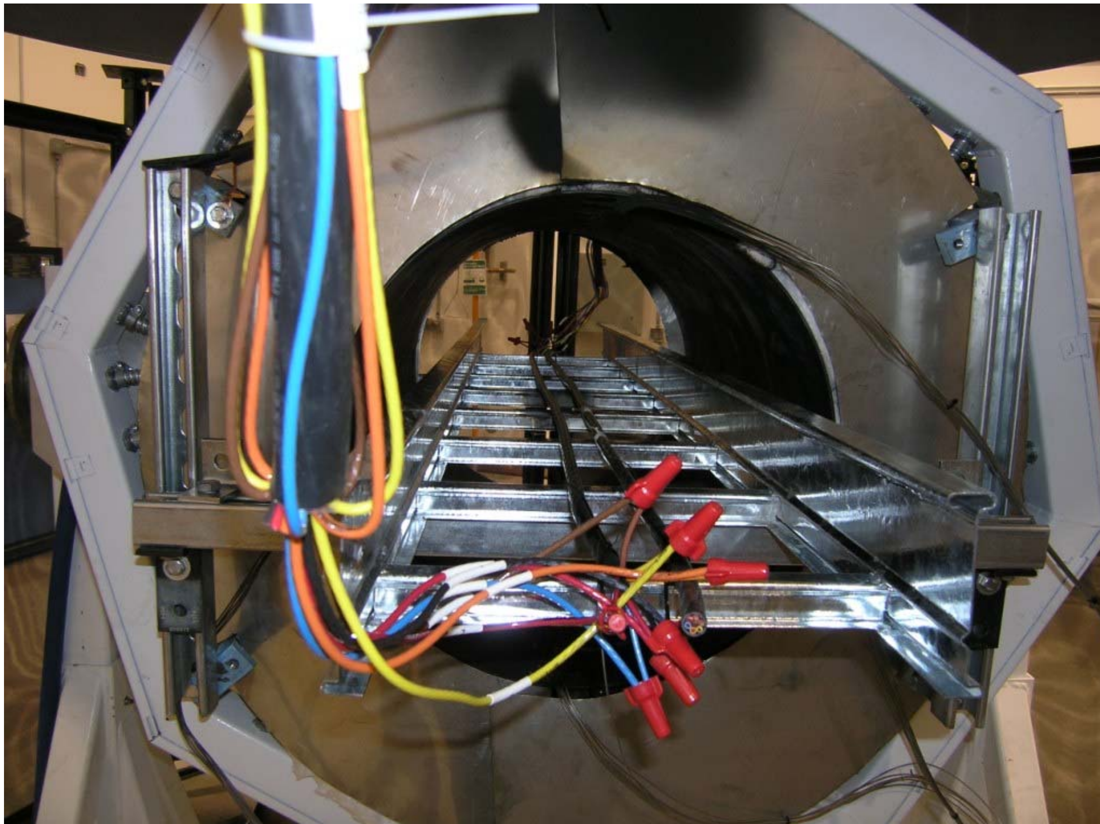
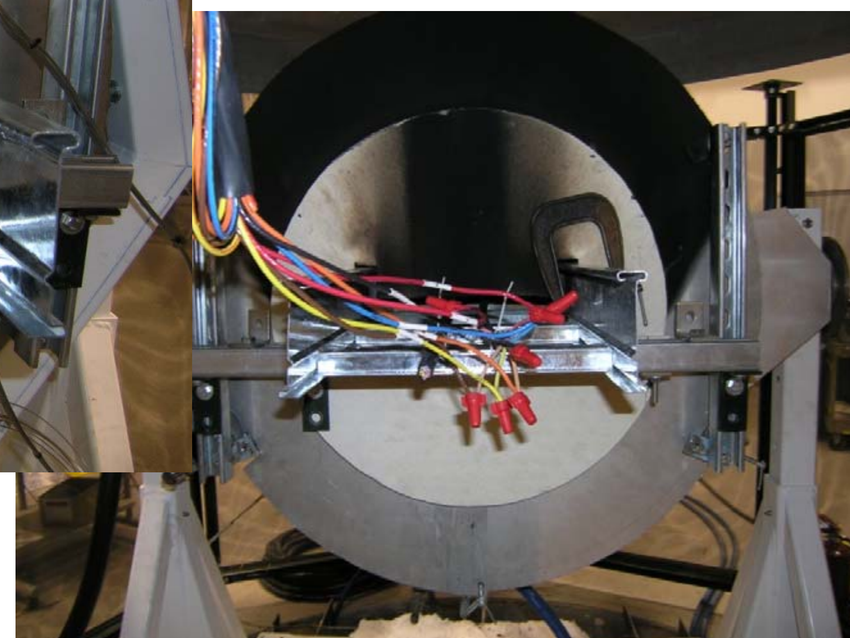
Typical Penlight setup





Cables burning during a Penlight test