U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

RIC 2007

Fire Research-Integrating Research into Practical Applications

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

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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**

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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 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**

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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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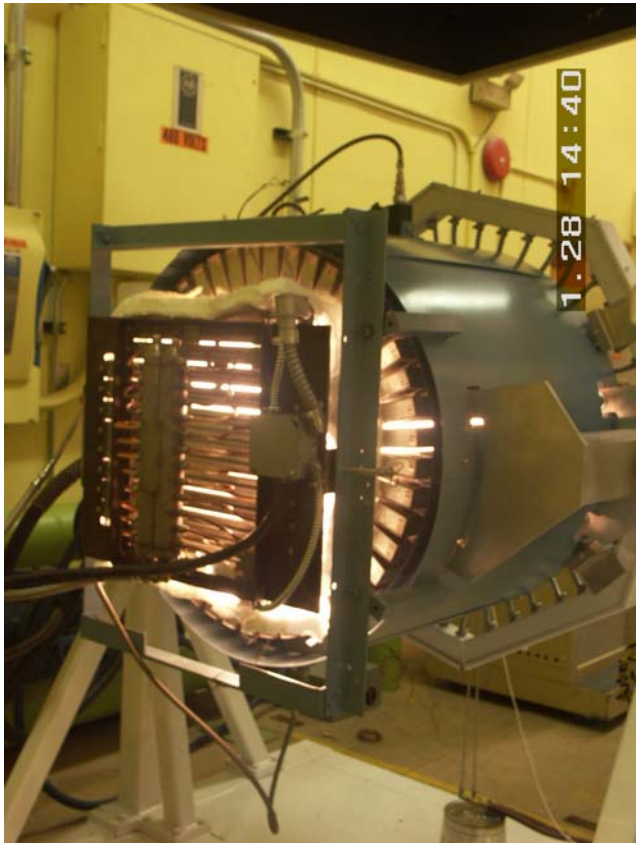
Small Scale Tests

- *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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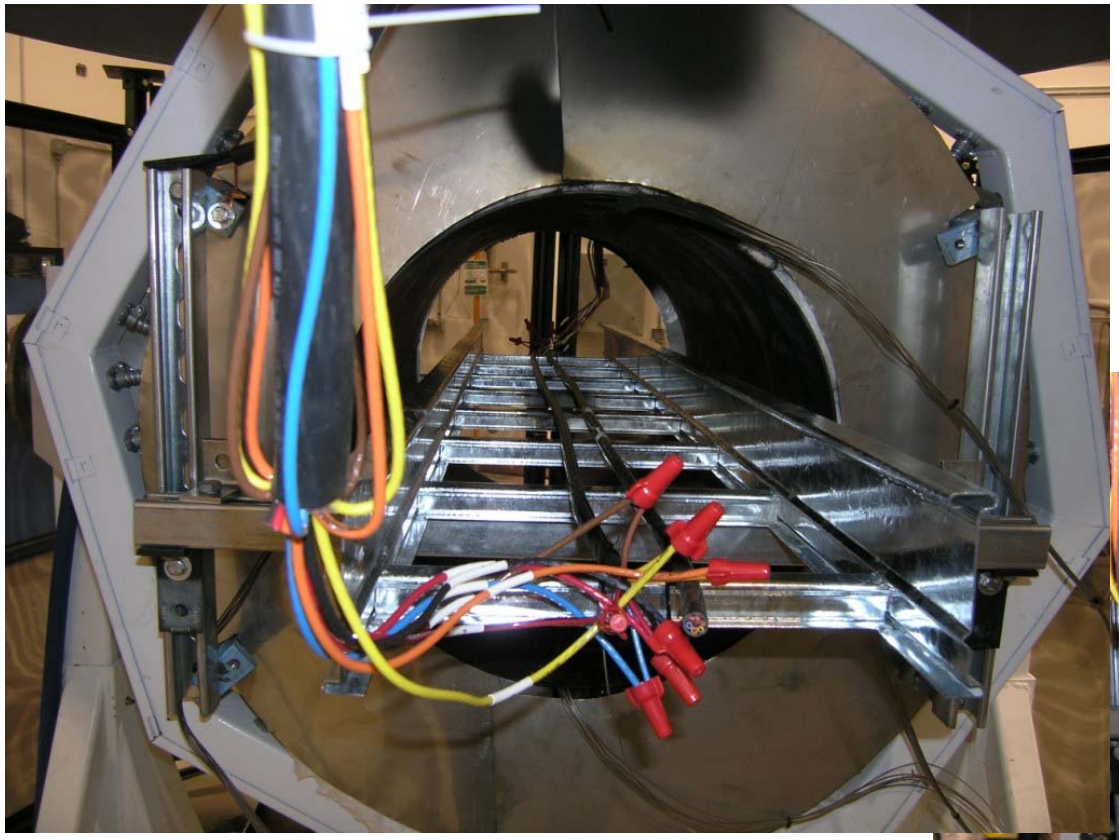
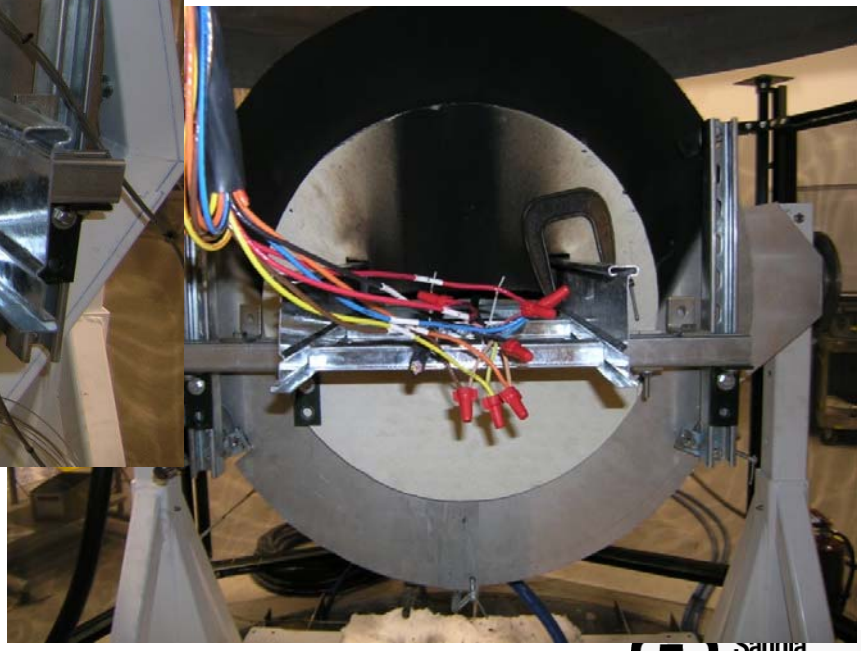
Typical Penlight setup

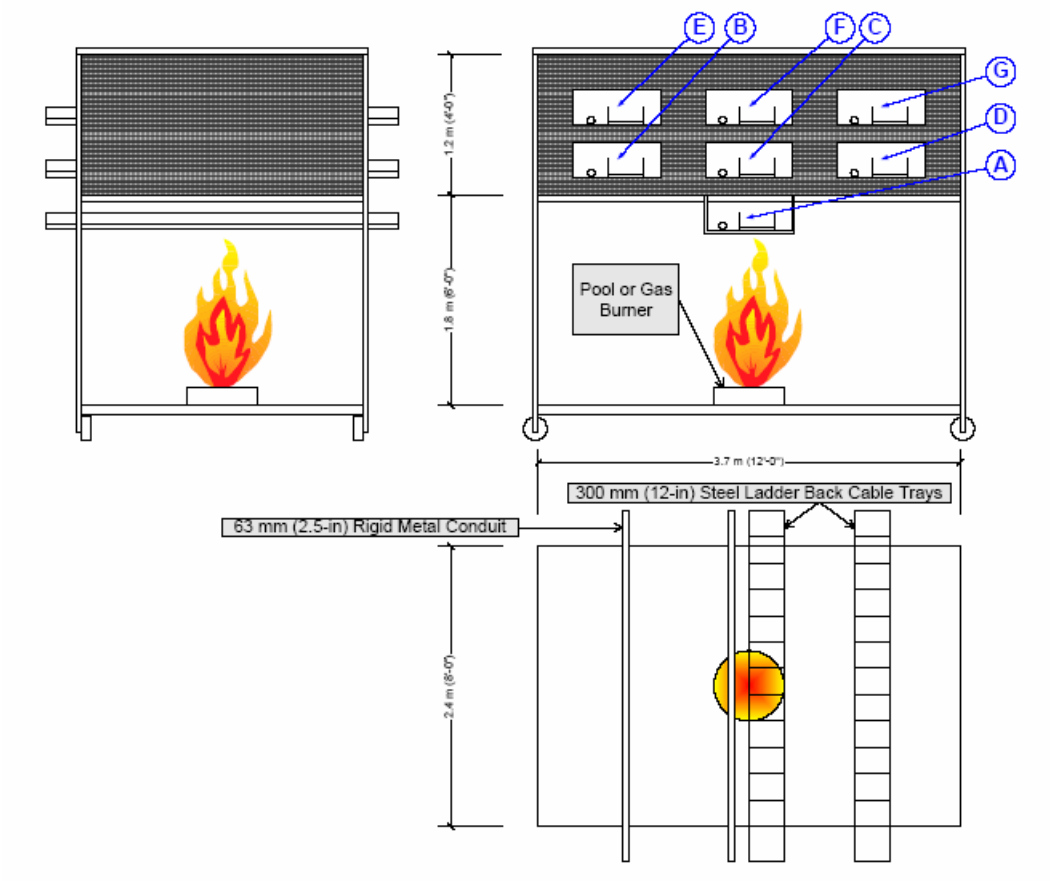




Intermediate-Scale Tests

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

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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)

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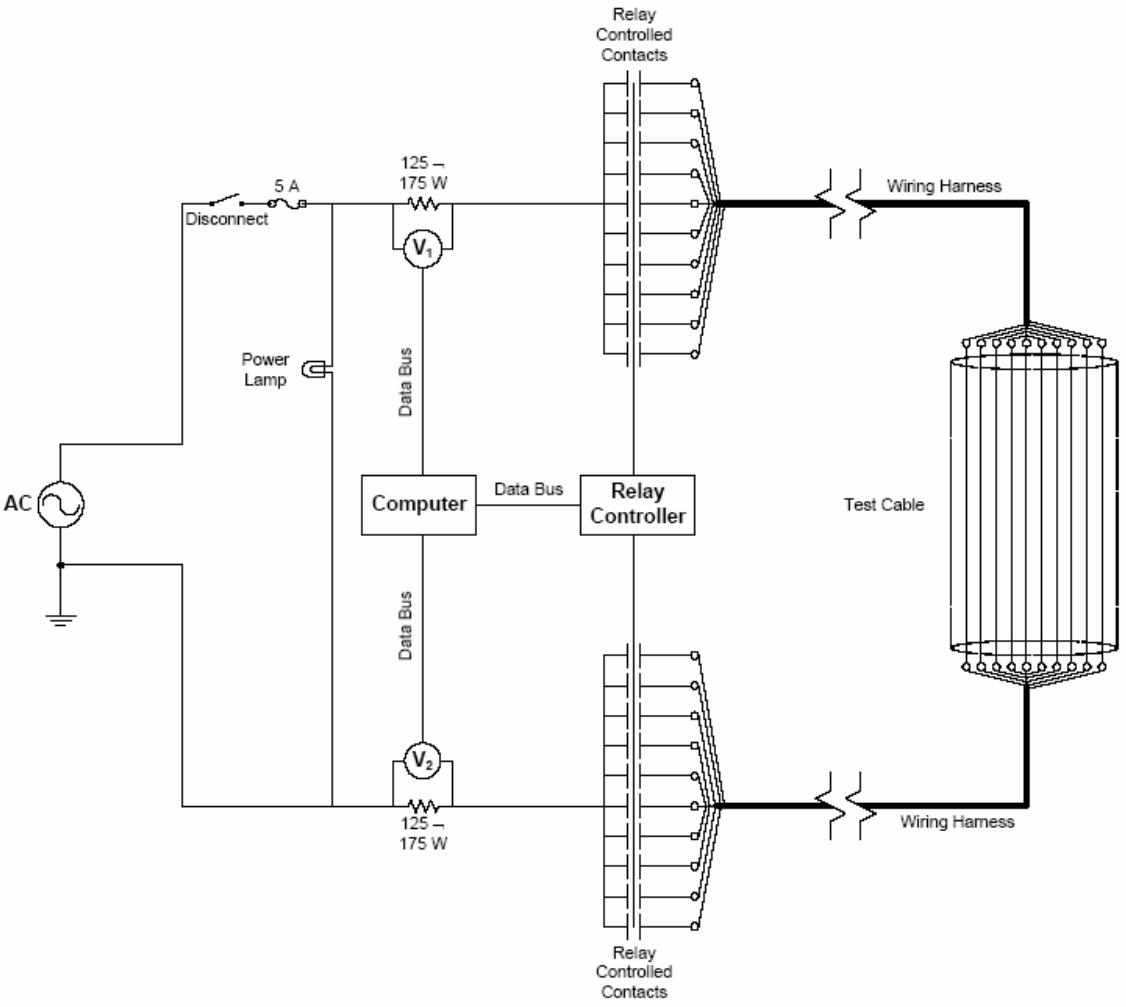
Instrumentation (2)

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



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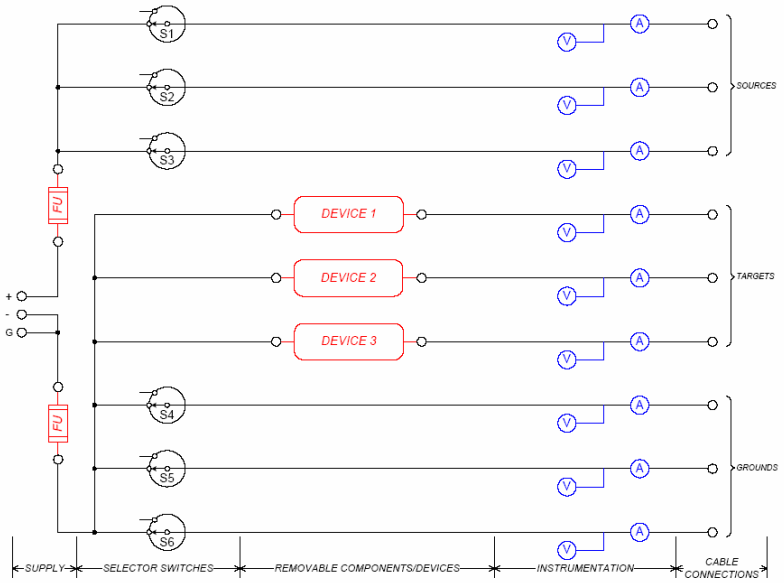
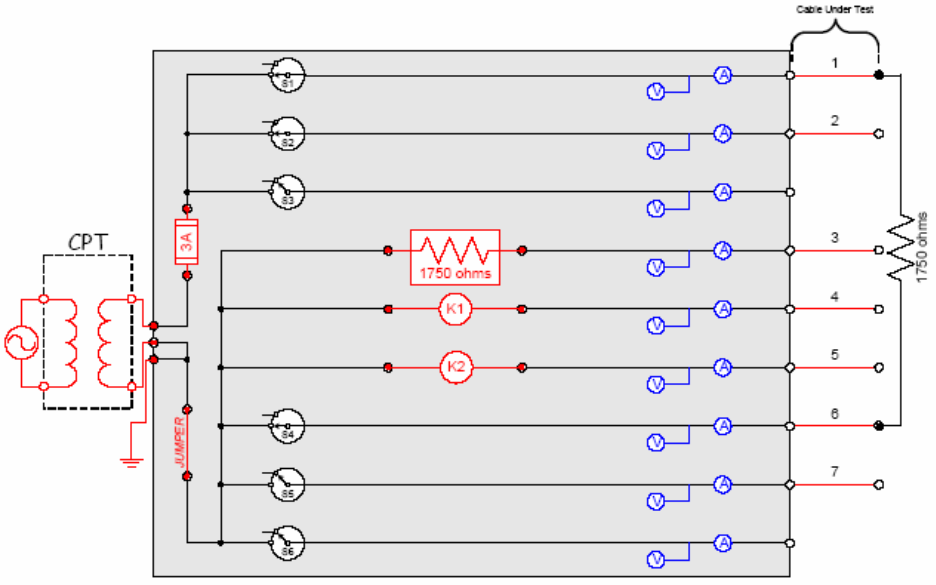
Instrumentation (3)

- **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**





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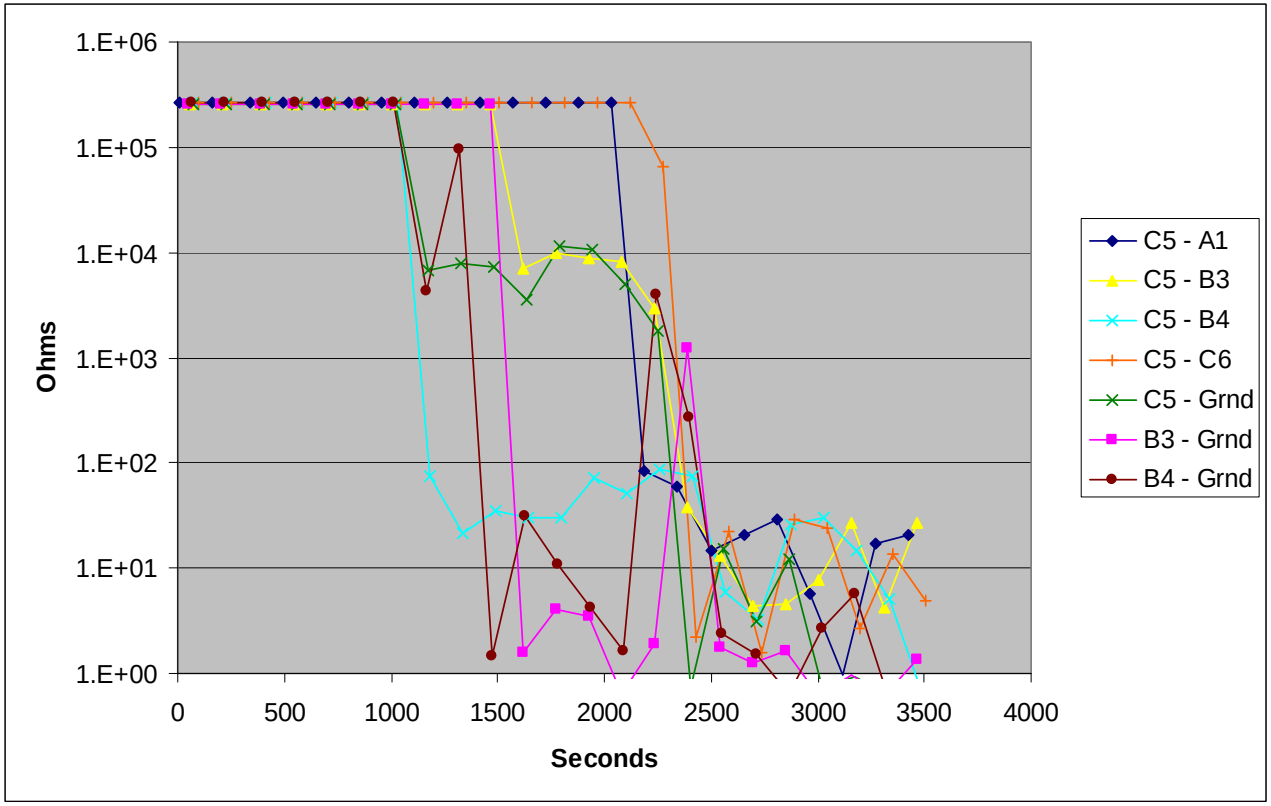
Item A – Thermoset-to-Thermoset

- 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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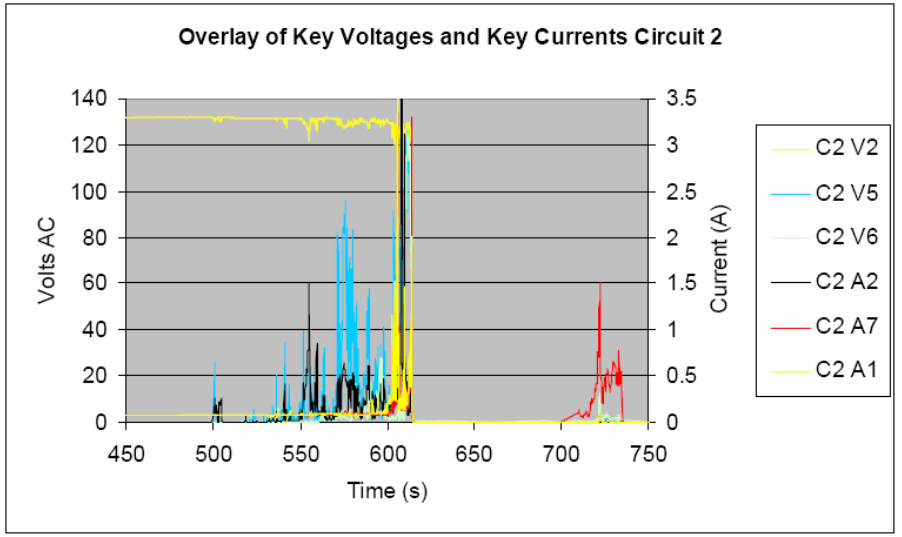
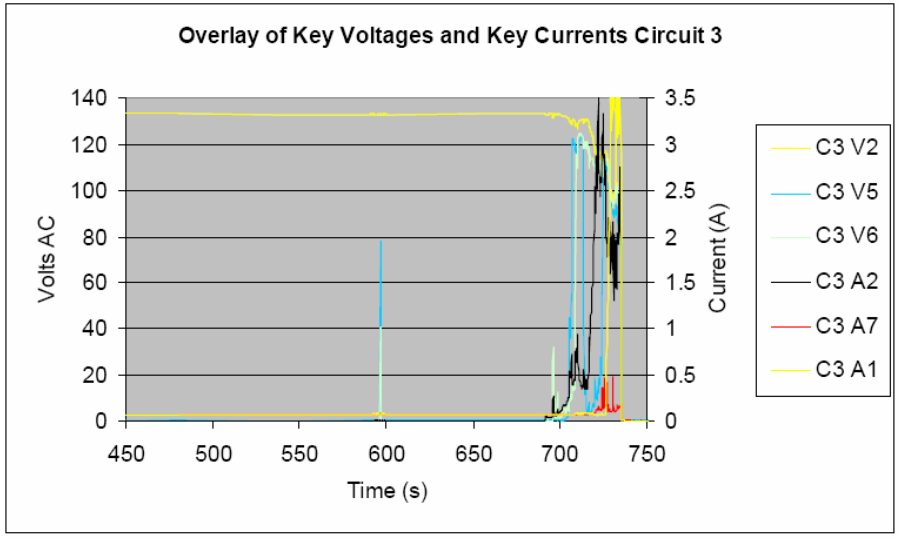
Item B – Thermoset-to-Thermoplastic

- 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, has been submitted to NRC publication office for printing
    - Volume 2, on fire modeling improvement, draft currently under review