



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**



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**

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 <i>Firewall III</i> ® 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	<i>Vita-Link</i> ®	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:

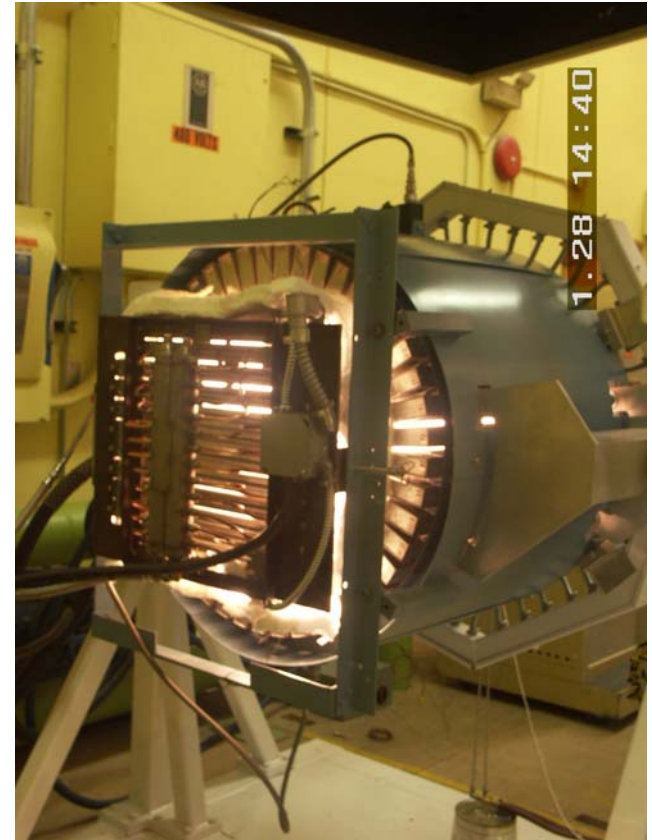
(1) - XLPE = Cross-linked polyethylene; CSPE = Chloro-sulfanated polyethylene (also known as Hypalon); XLPO = Cross-linked polyolefin; SR = Silicone rubber; EPR = Ethylene-propylene rubber; PVC = Poly-vinyl chloride; PE = Polyethylene (non cross-linked).

(2) - TS = Thermoset; TP = Thermoplastic; shown as: (insulation type)/(jacket type).

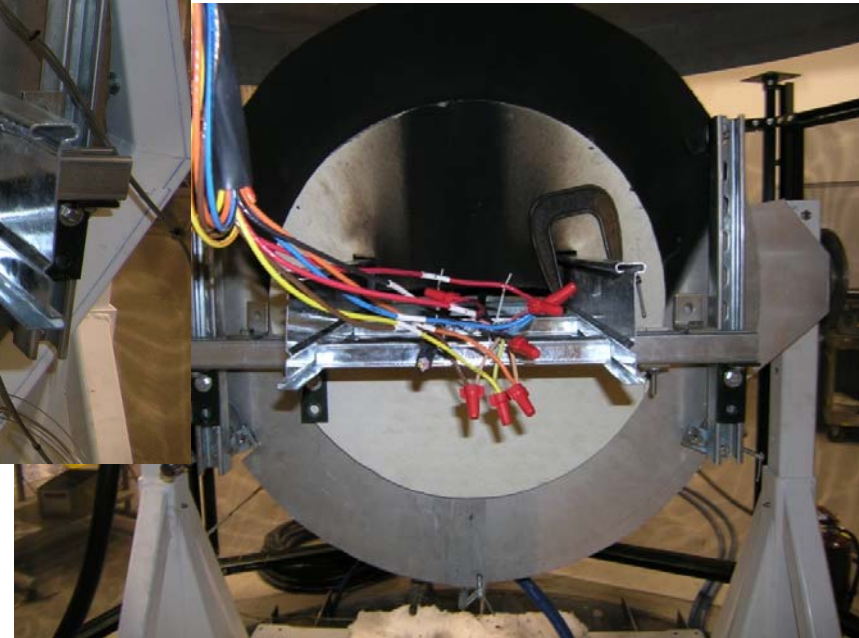
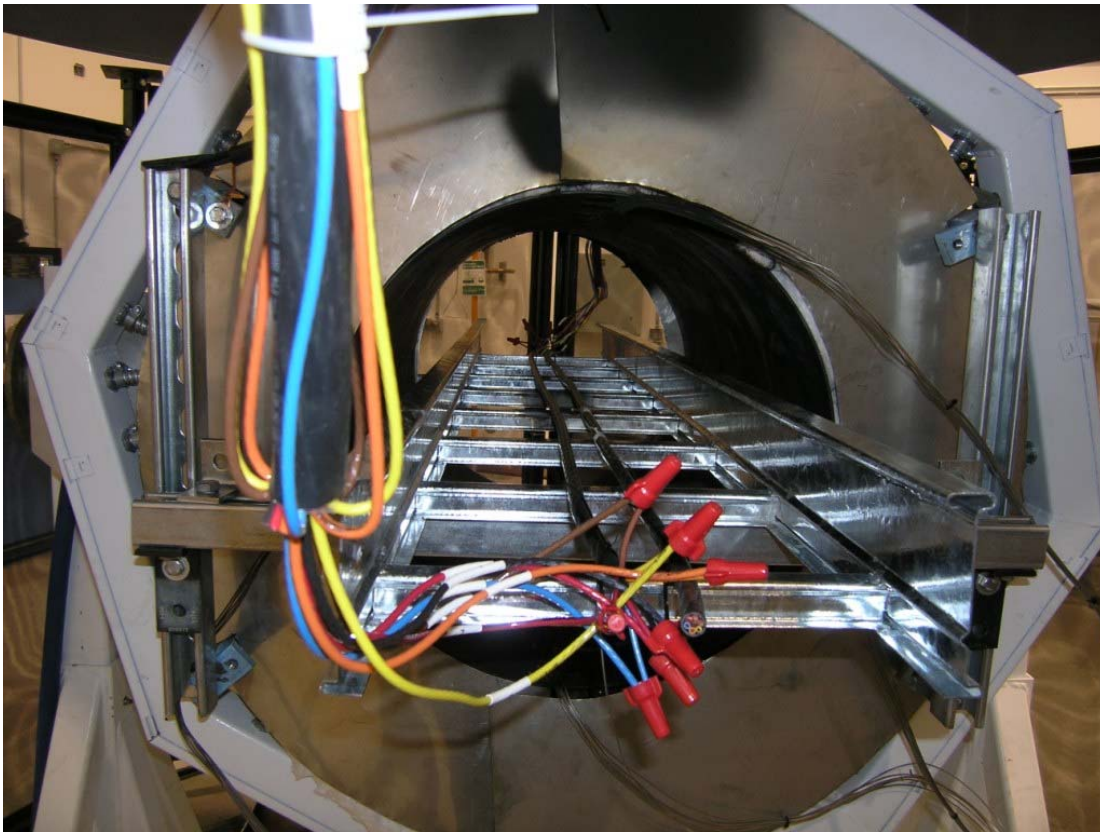
(3) - All power and control cables are un-shielded.

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

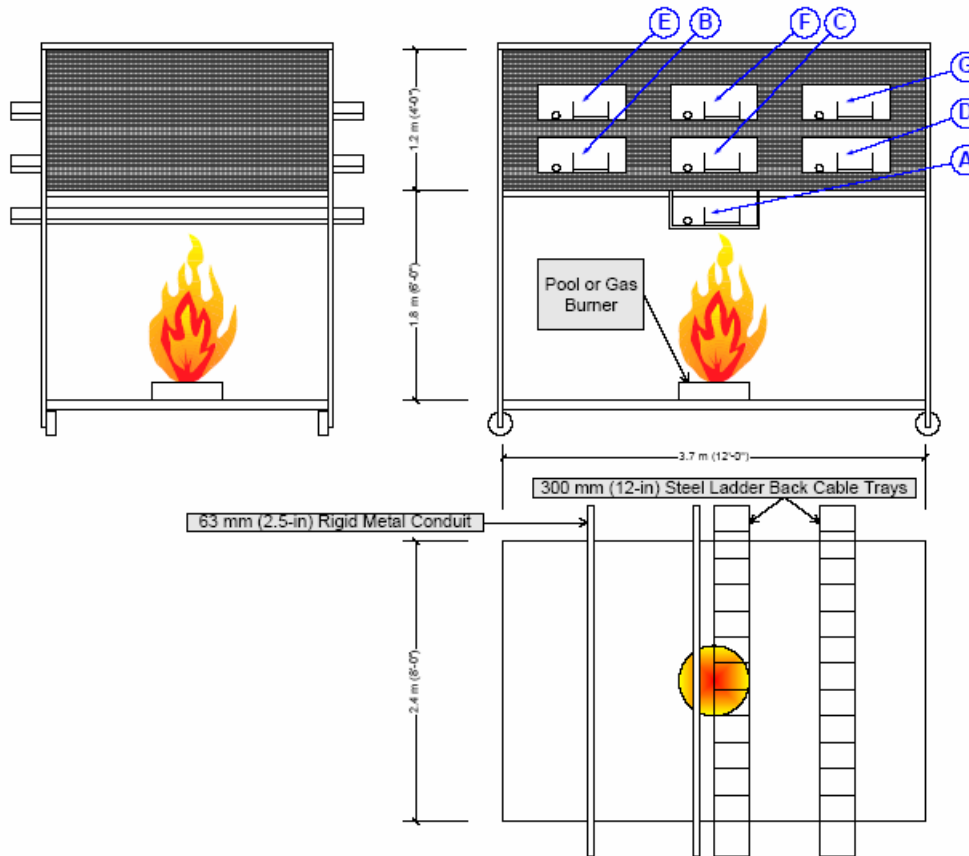


Typical Penlight setup



Intermediate-Scale Tests

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**

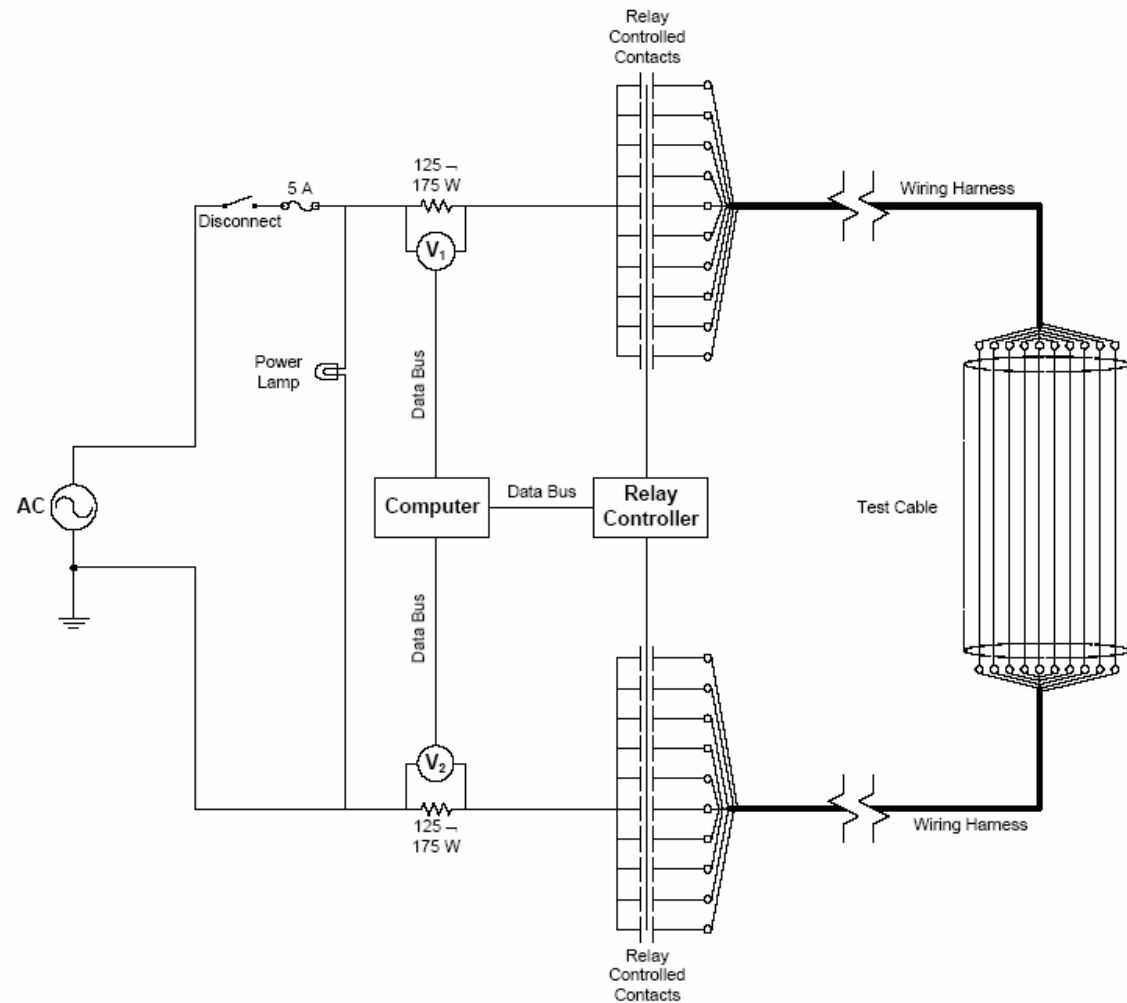


Instrumentation

- **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)**

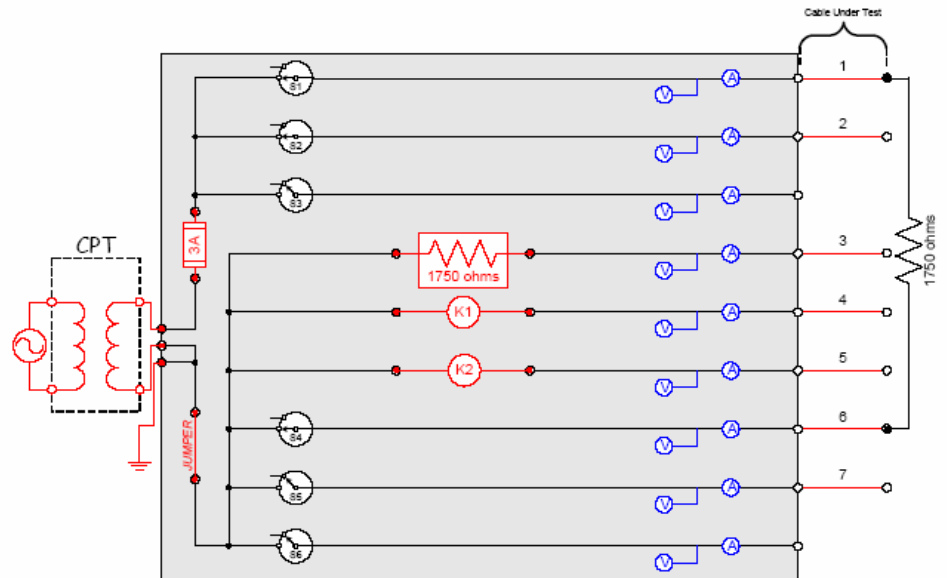
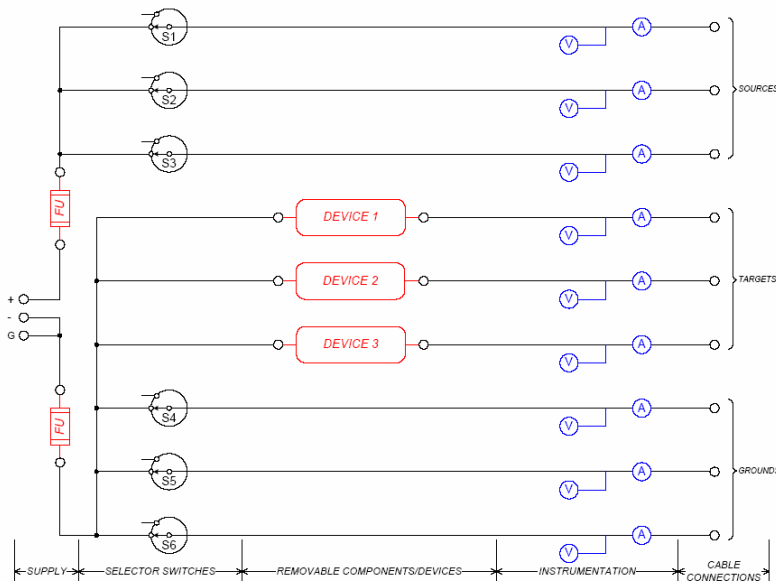
Instrumentation (2)

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



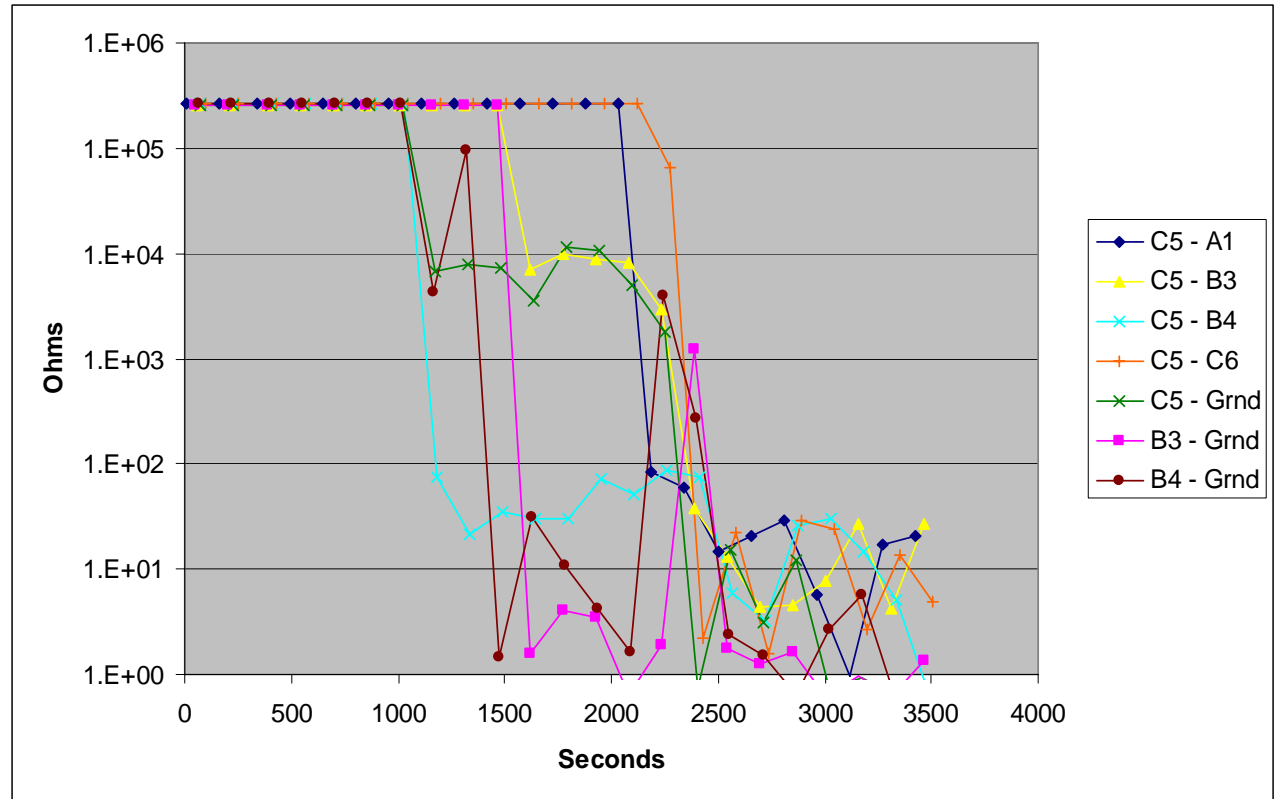
Instrumentation (3)

- 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 industry



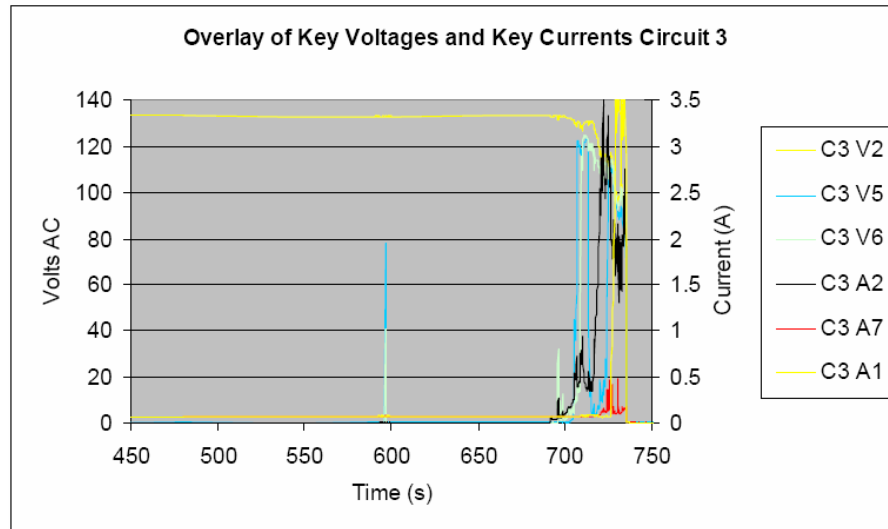
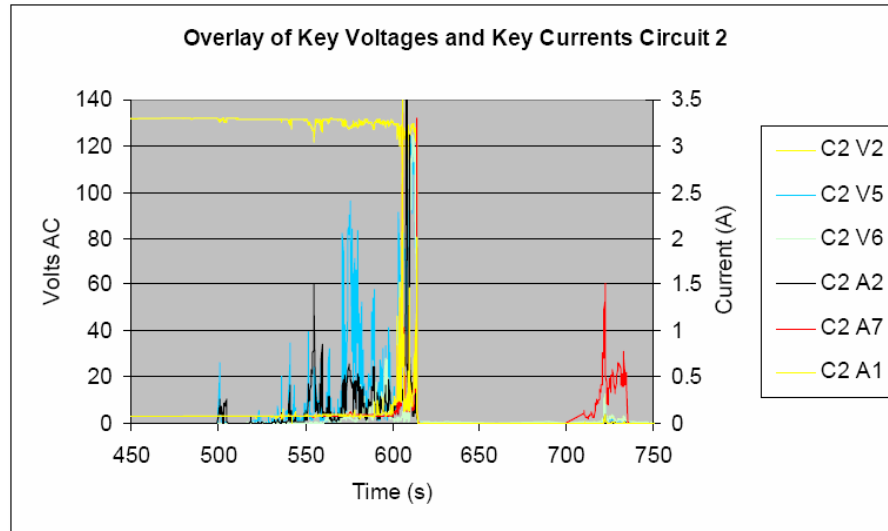
Item A – Thermoset-to-Thermoset

- 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



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





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