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Circuit Response to Cable Fire Environments

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  - H.W. ‘Roy’ Woods, RES Project Manager for CAROLFIRE
  - Gabe Taylor, RES Project Manager for DESIREE-FIRE
  - Mark Salley, RES Management Lead for both projects
- Collaborative partners for CAROLFIRE:
  - NIST – Dr. Kevin McGrattan
  - UMd – Mohamed Modares, Elyahu Avidor and Genebelin Valbuena
- Collaborative partner for DESIREE-FIRE:
  - Electric Power Research Institute (EPRI)

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Project Objectives (CAROLFIRE)

- Cable Response to Live Fire
- Two major areas of investigation:
  - Resolution of ‘Bin 2’ circuit configurations 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

The ‘Bin 2’ Issues

- 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 (2)

- 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

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

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

Cable Monitoring Units

- Surrogate Circuit Diagnostic Unit (SCDU)
  - Simulates an AC MOV circuit from a NPP
  - Electrical rack depicts control room indication lights
- Insulation Resistance Measurement System (IRMS)
  - Monitors insulation resistance between conductors within a cable
  - Device allows specific details to insulation degrades within a fire environment

Cable types tested represent a 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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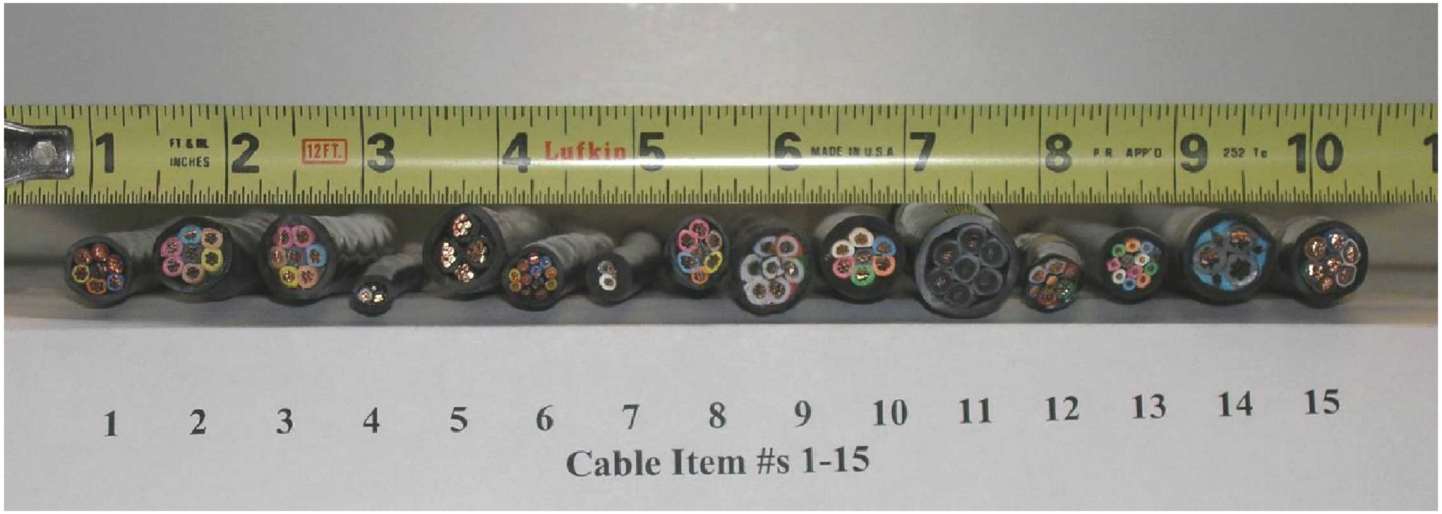
Photo that Compares the Tested Cables



The Testing Approach

- Two Scales of testing were pursued
  - Small-scale radiant heating experiments
  - Intermediate-scale open burn tests
- Testing a broad range of cable products (list follows)
  - Note that CAROLFIRE did exclude armored cables
  - Armored cables were being tested by Duke during the same time period and using similar methods

Small Scale Tests

- *Penlight* **heats target cables via grey-body radiation from a heated shroud**
- *Penlight* **was originally developed to support RES testing in the 1980's and has been used in a number of prior test programs**
- **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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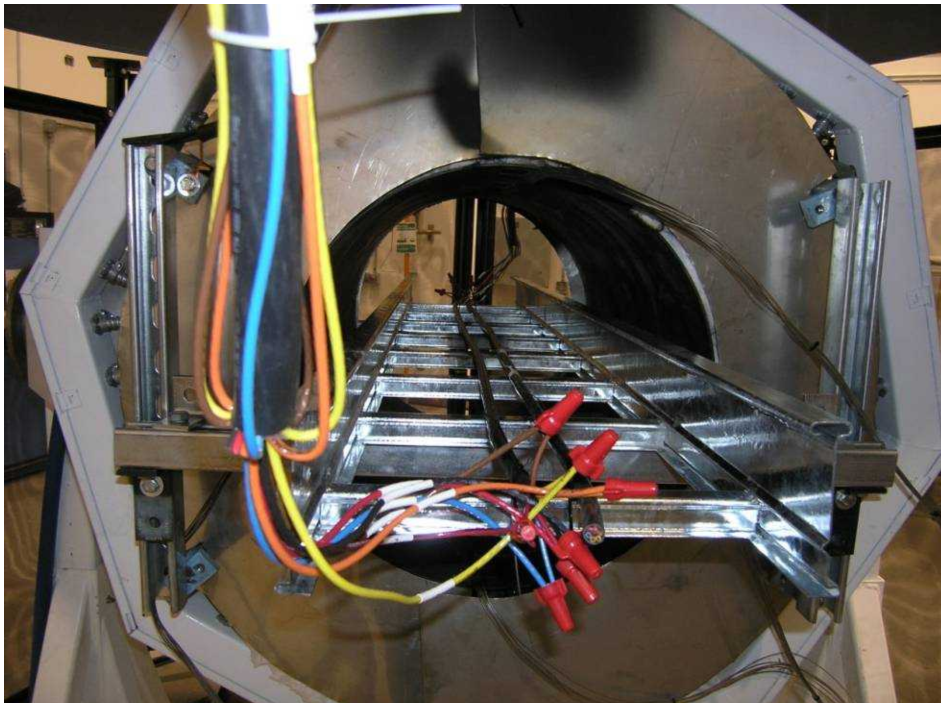
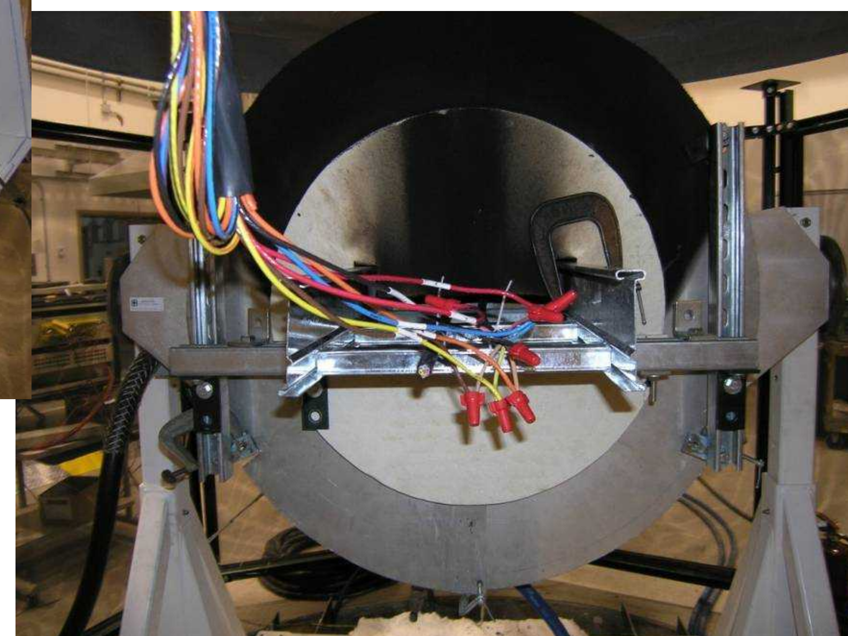
Typical Penlight Setup for CAROLFIRE

This figure illustrates the use of end covers closing off the shroud as were used during most of the tests



This is a typical cable tray setup, in this case, with one electrical performance cable and one thermal response cable. The cable dropping from the upper left connects to the electrical performance monitoring system



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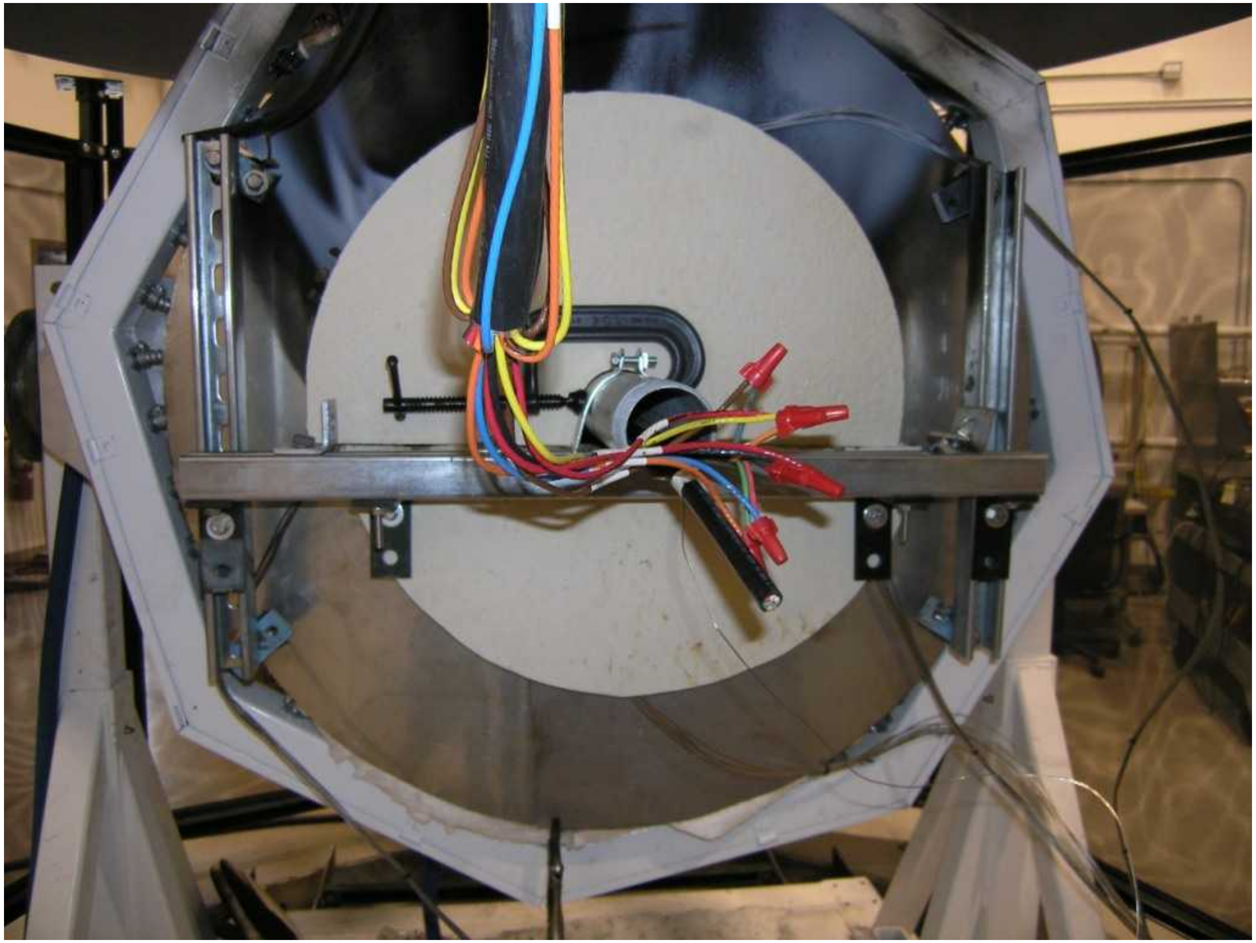
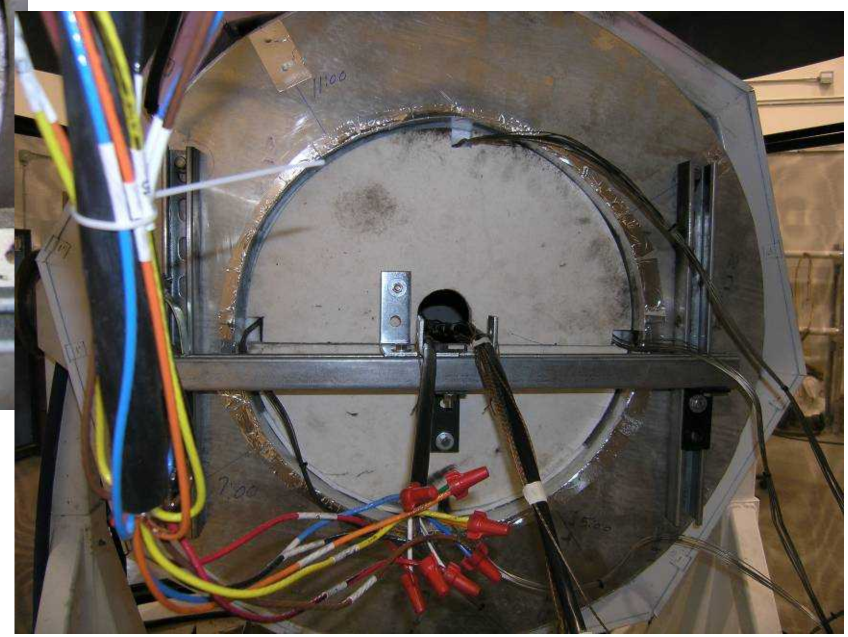
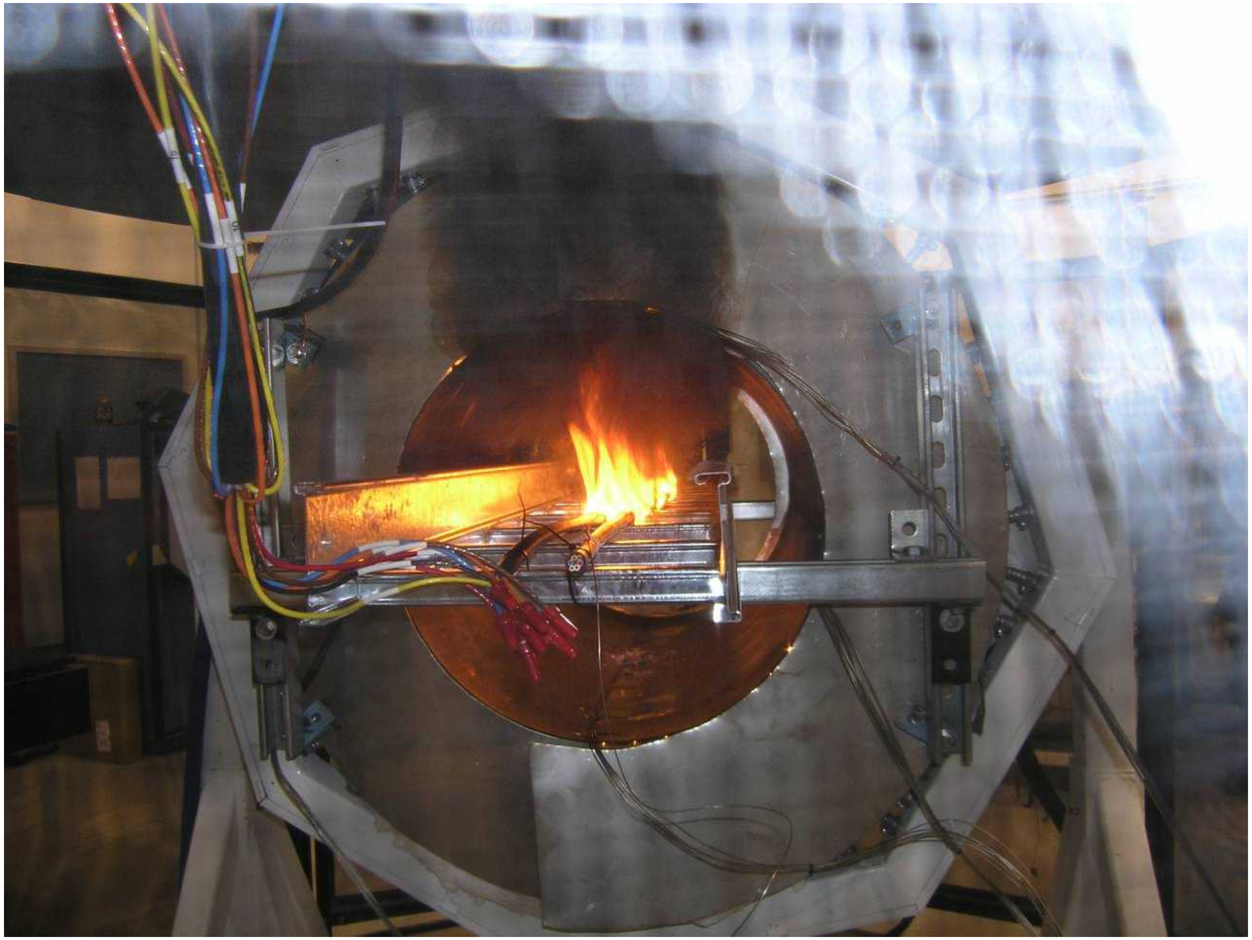
Typical Penlight Conduit Setup



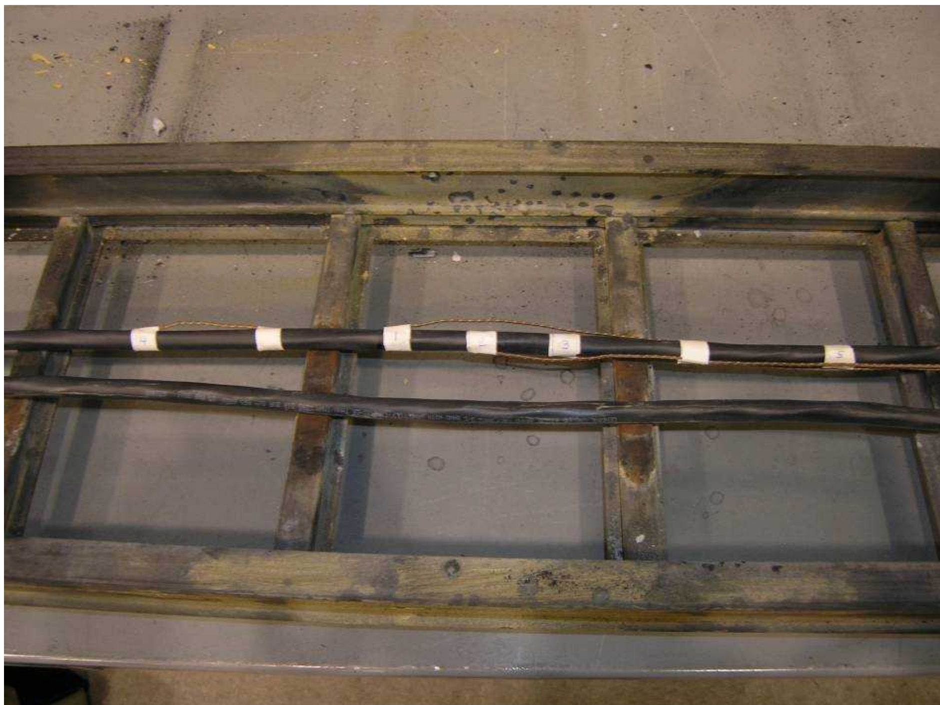
Typical Penlight Airdrop Setup



Note that Penlight did allow for cable burning, and this was common



Typical Before/After for Thermoplastic Cables



Note the obvious melting behavior typical of thermoplastics

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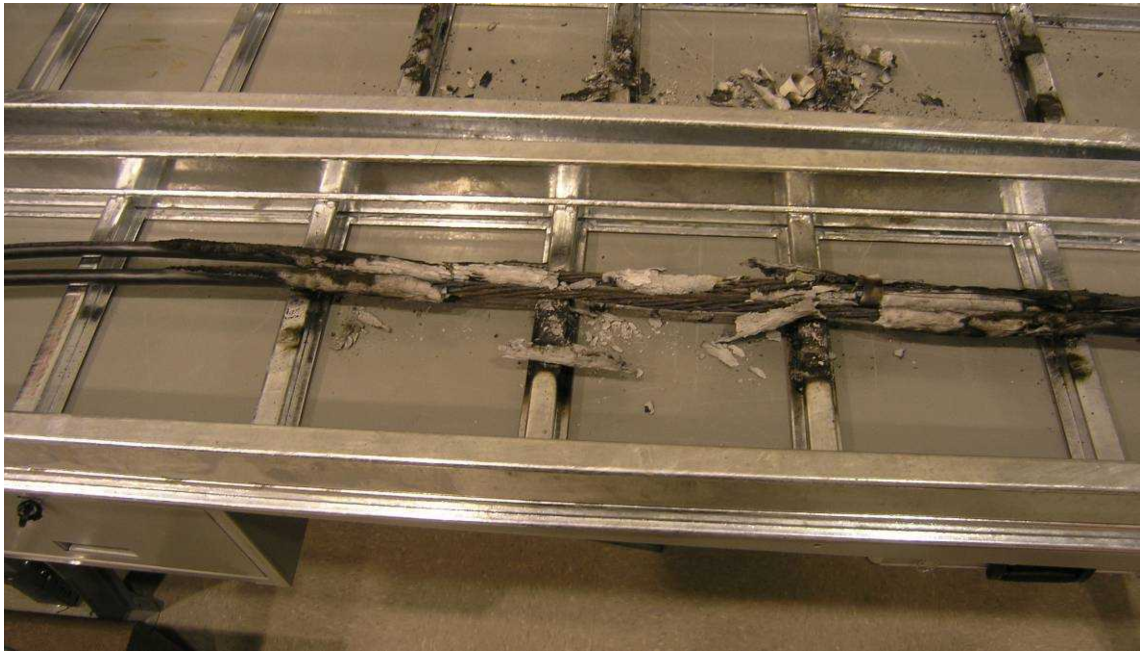
Typical Post-Test Conditions for Thermoset Cables



Note the remnants of charred insulation and jacket, but no melted materials. These cables did burn during the test.

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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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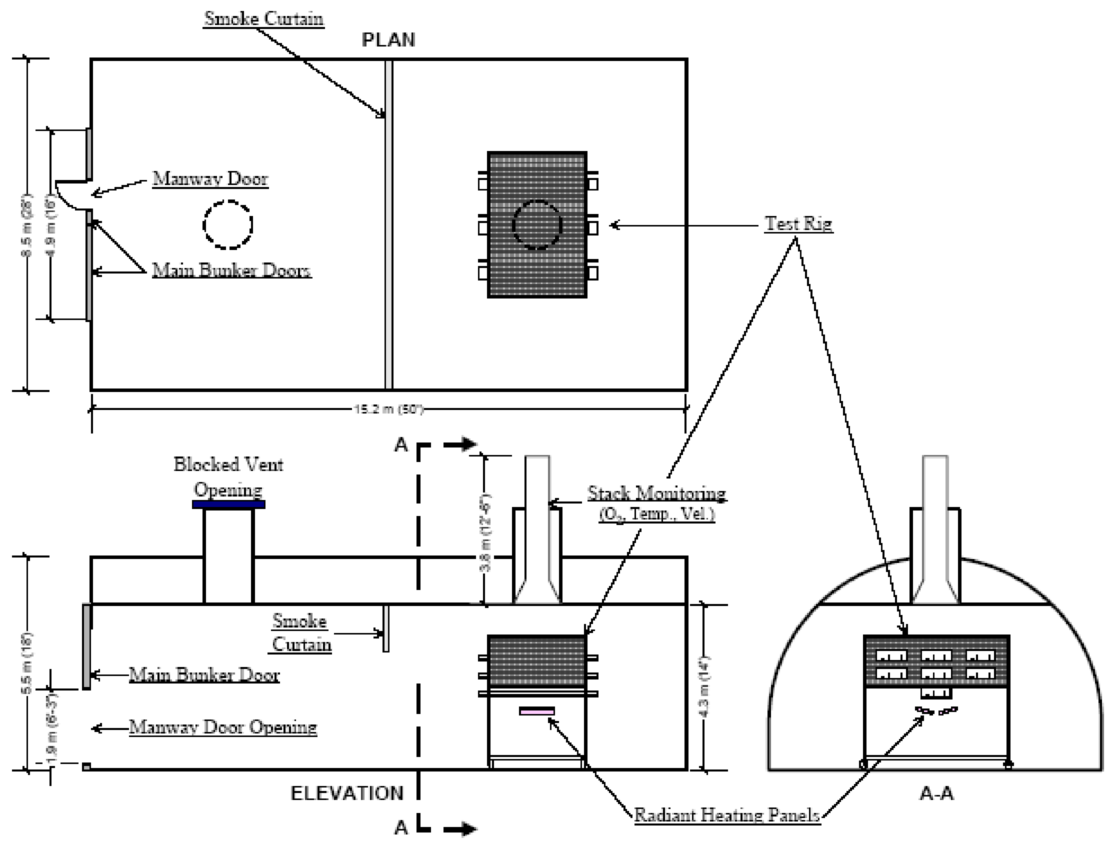
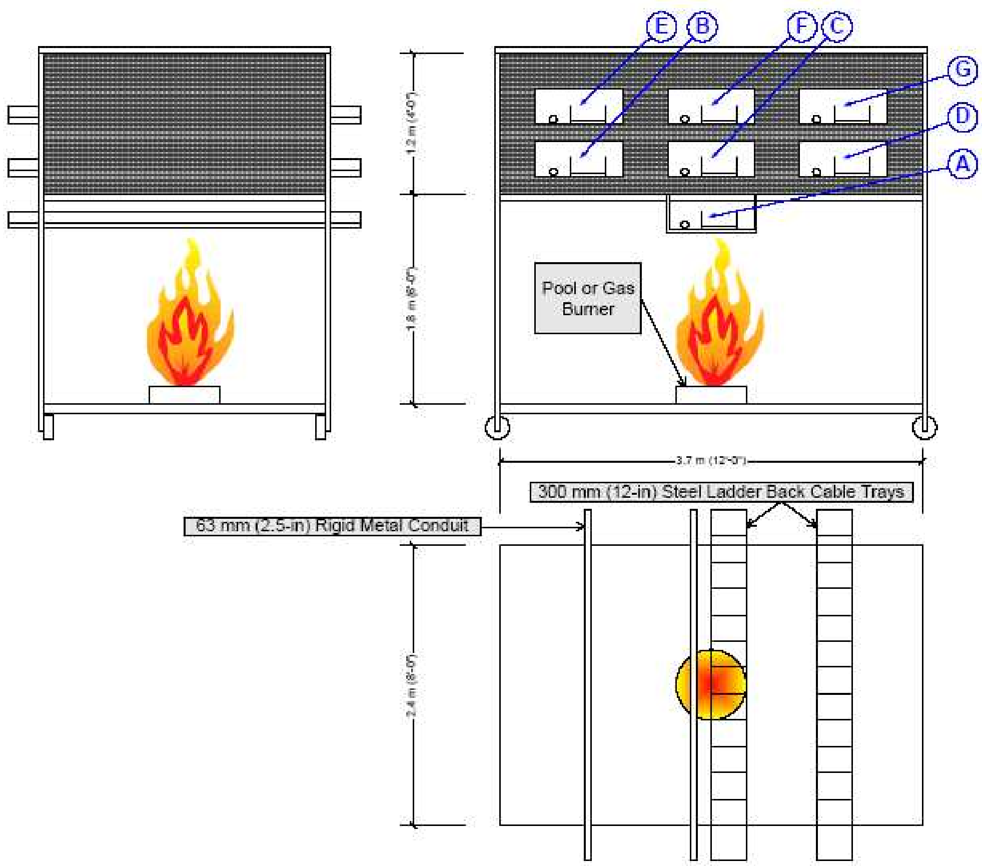
Intermediate-Scale Tests (2)

- 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

- Layout of the intermediate-scale test structure.
- Structure was located within a larger test facility.



Photos to Illustrate Intermediate-Scale Test Structure

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The Gas Diffusion Burner

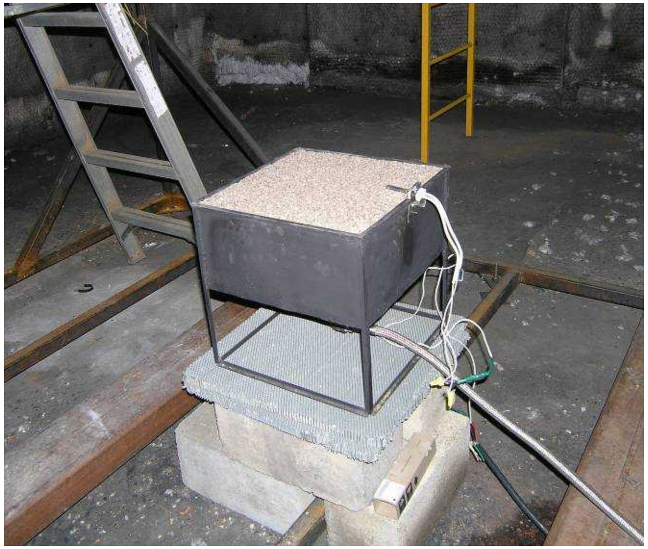
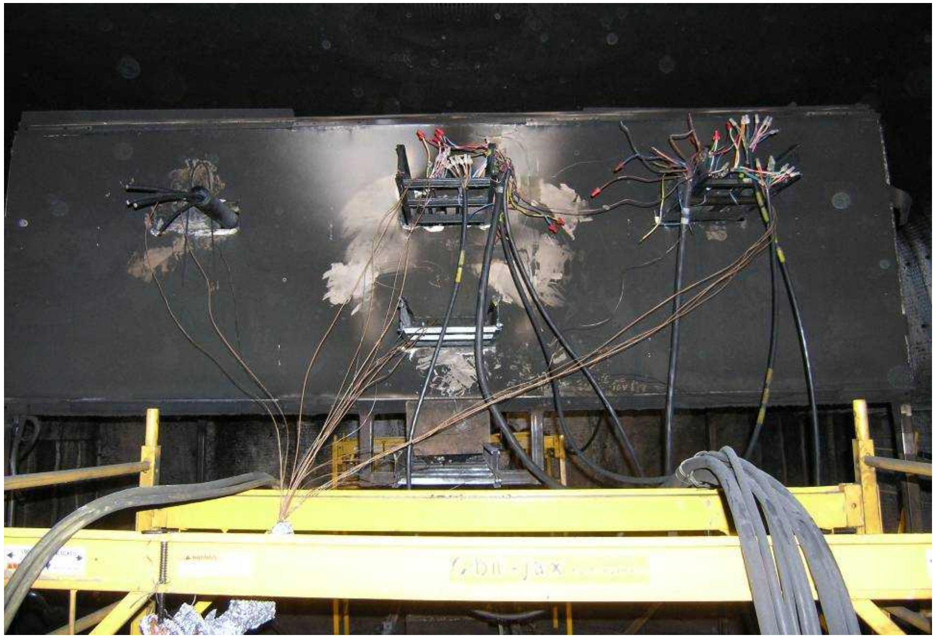


Photo of the Intermediate Scale Test Structure Just Prior to a Test



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Typical Setups

Single cables

Bundles

Airdrops

Random fill trays

Typical Post-Test Conditions

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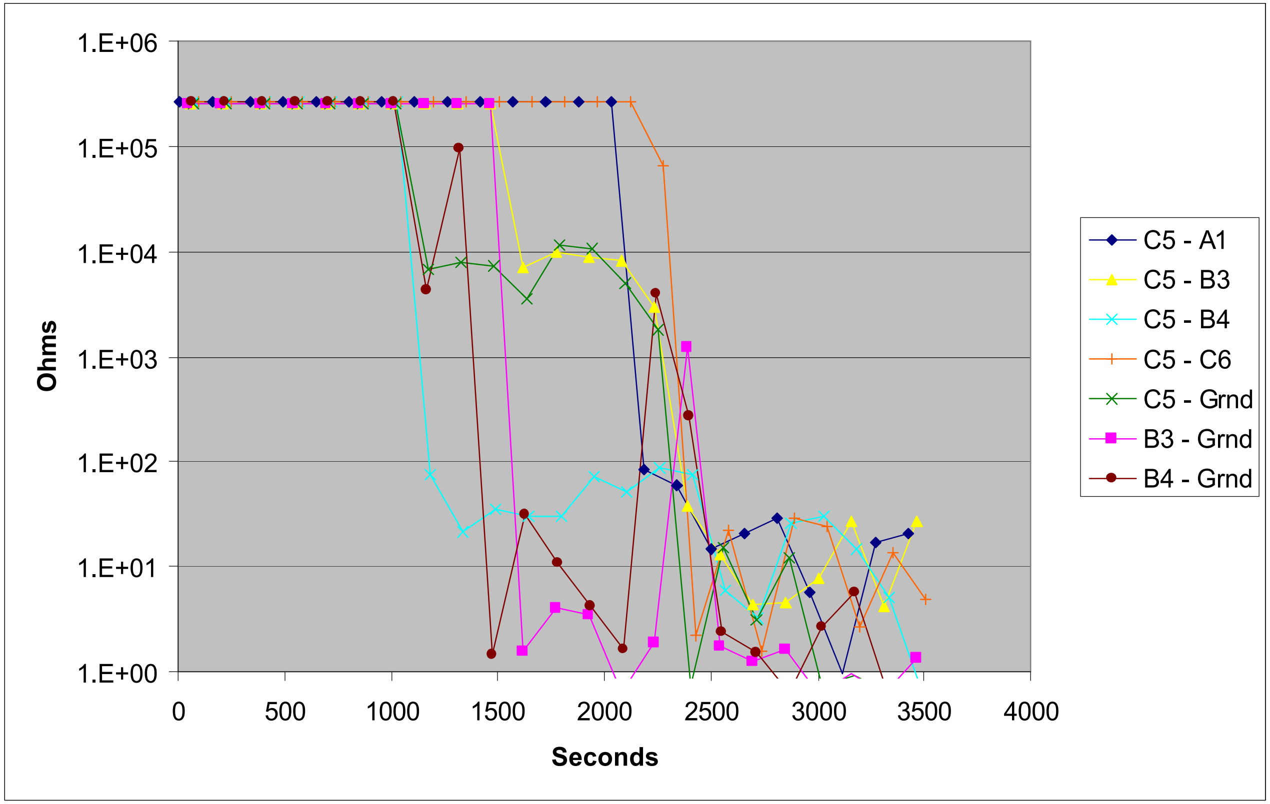
Sub-jacket Thermocouples

Measurements made of sub-jacket cable temperatures are one of the key measurements of interest to the fire model improvement efforts. Every test included one or more such measurements.

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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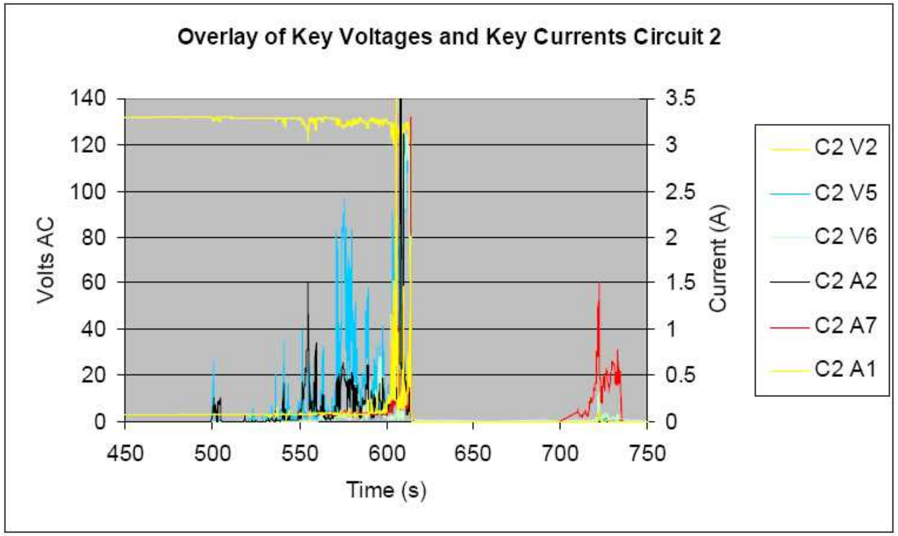
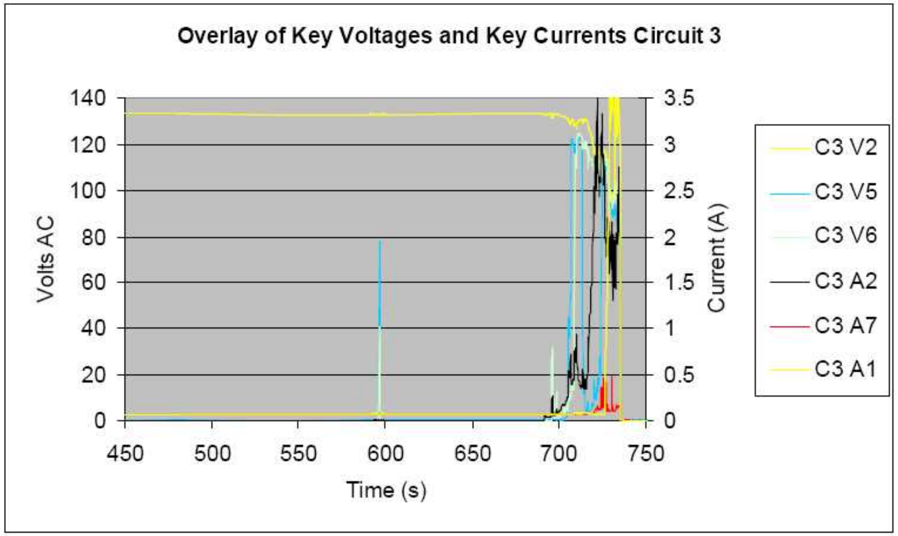
Item B – Thermoset-to-Thermoplastic

- 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.

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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 appear to indicate that once cable degradation begins, it will cascade through all modes within a relatively short time

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Project Objectives (DESIREE-FIRE)

- Direct Current Electrical Shorting in Response to Exposure Fire
- Understand DC circuit performance during cable fire exposure
- Compare results with limited Duke Energy experiments
- Analyze differences between AC and DC circuits
- Less emphasis on fire modeling
- Begin to explore smoke impact on sensitive equipment

Comparison to CAROLFIRE

- Similarities
  - Majority of test cables will be identical, some new additions (e.g. Kerite, Armored)
  - Small and intermediate scale tests
- Differences
  - Multiple DC circuits
  - Battery bank rather than wall power

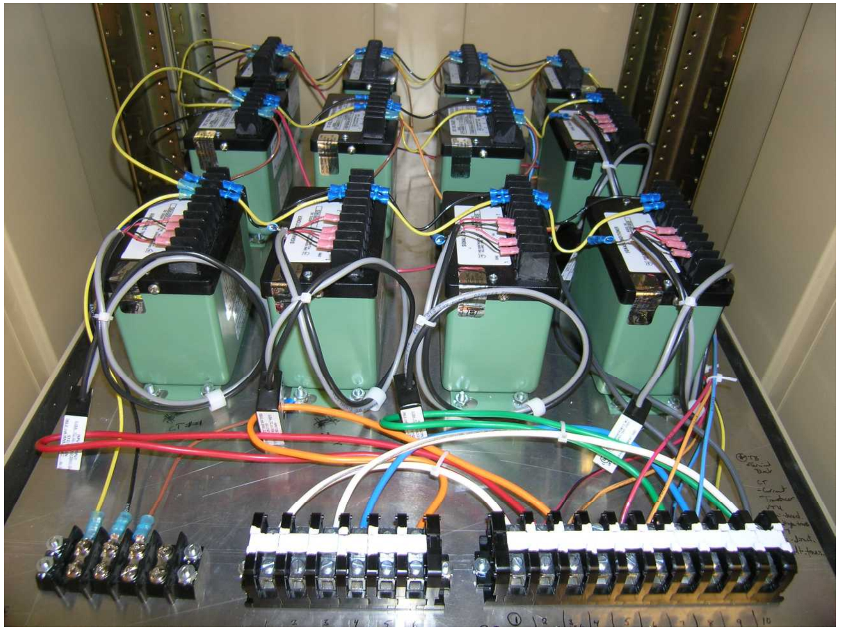
Insights from Duke Energy Tests (2006)

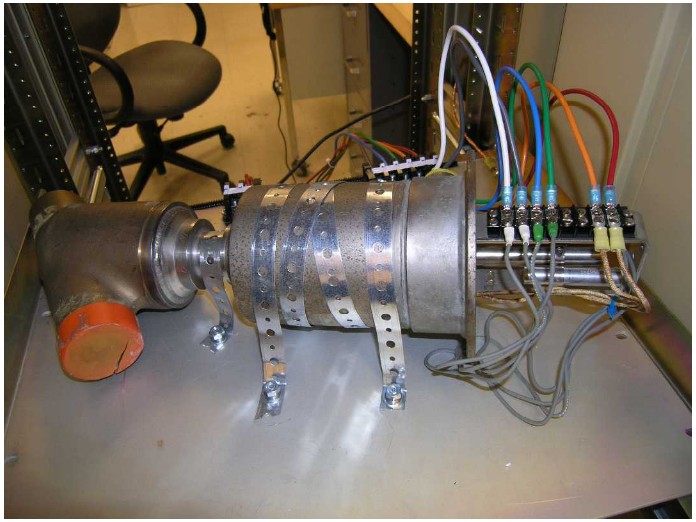
Duke performed two DC tests

- One indicated 6 out of 8 possible spurious actuations occurred
- The other indicated that 5 of 5 that experienced damage had spurious actuations
  - 3 additional could have actuated but were terminated before damage occurred
- During the second test, several circuits experienced hot shorts of both close and open coils at the same time

Multiple DC Circuits

- Two Motor Operated Valves (MOV)
- Two Solenoid Operated Valves (SOV)
- 15kV Switchgear
- One-Inch Valve and Coil
- Large Coil





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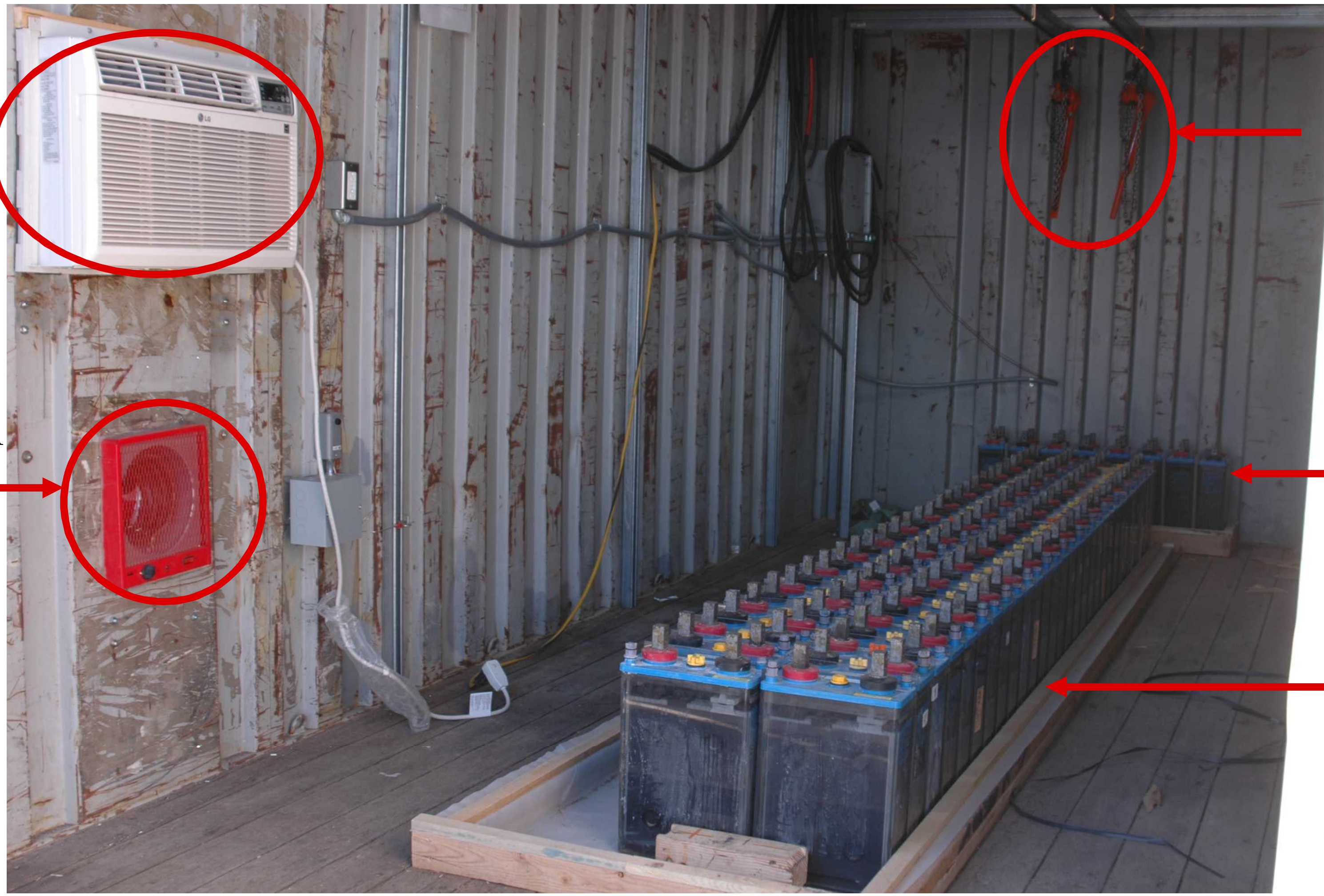
DC Sim Panels

Battery Bank

- End-of-life batteries donated through NRC and EPRI collaboration
- 60 Exide ES-13 cells provide a nominal 125VDC
  - Just over 2VDC each cell
  - 13,000 fault current
  - Wet-acid batteries
  - Lead-calcium alloy
- Custom transportainer with climate control

Transportainer



Transportainer (2)

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Test Plan and Experiments

- Public comment period commenced from September 16 to October 28, 2008
- Peer review period lasted until December 19, 2008
- Comments from both were typically accepted into the test plan
- Experiments are set to begin in July 2009
- Subsequent reports will follow

Questions?