ACRS Full Committee
549th Meeting
February 7, 2008

RES Office of Nuclear Regulatory Research

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Agenda

- Cable Response to Live Fire (CAROLFIRE) Project is complete
  - Request a letter from ACRS

CAROLFIRE

- RIS 2004-03
- Three Volumes:
  - Volume 1 Circuit Interaction
  - Volume 2 Thermal Data
  - Volume 3 Fire Modeling Improvements
- Extensive Review:
  - Peer-reviewed
  - Public Comment
  - ACRS Quality Review
  - ACRS Subcommittee Review
  - Asking for ACRS Letter

Principle Presenters

- Mr. Gabe Taylor
  - NRC/RES
- Dr. Kevin McGrattan
  - National Institute Standards and Technology

Advisory Committee on Reactor Safeguards
549th Meeting February 7, 2008

CAROLFIRE

Cable Response to Live Fire

Presented by:
Gabe Taylor
Office of Nuclear Regulatory Research
Fire Research Branch

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CAROLFIRE Objectives

- Resolution of ‘Bin 2’ circuit configuration
  - Regulatory Issue Summary (RIS) 2004-03, Rev. 1, - “Risk-informed Approach For Post-Fire Safe-Shutdown Circuit Inspection”
  - Document places cable/circuit configurations in one of three bins:
    - Bin 1 : Circuit configurations that are most likely to fail
    - **Bin 2 : Circuit configurations that need more research to determine failure characteristics**
    - Bin 3 : Circuit configurations that are unlikely or least likely to fail
- Fire Model Improvement
  - To reduce uncertainty associated with predictions of fire-induced cable damage

Summary & CAROLFIRE Results of RIS 2004-03 'Bin 2' Items

- Item A – Inter-cable shorting for Thermoset Cable
  - Plausible, but less likely than intra-cable failure mode

- Item B – Inter-cable shorting between Thermoplastic and Thermoset Cable
  - Plausible, but less likely than intra-cable failure mode

- Item C – Configurations requiring failures of three or more cables
  - Plausible
    - i.e., How many failures should be considered?
    - No a priori limit; dependent on scenario; risk significance

Summary & CAROLFIRE Results of RIS 2004-03 'Bin 2' Items

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- Item D – Multiple spurious operations in control circuits with "properly sized" CPTs
  - Inconclusive, results do not coincide with NEI/EPRI results
- Item E – Fire-Induced hot shorts lasting longer than 20 minutes
  - Unlikely
- Item F – Spurious actuations for cold shutdown circuits (Item F was not investigated by CAROLFIRE)

CAROLFIRE was a Collaborative Effort

- Office of Nuclear Reactor Regulation
- Office of Nuclear Regulatory Research
- Sandia National Laboratories
- National Institute of Standards and Technology
- University of Maryland

Peer Review

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- CAROLFIRE Test Plan was developed by SNL and went through the RES peer review process
- All Collaborative partners participated in Peer Review
  - Nathan Siu (RES)
  - Dan Frumkin and Naeem Iqbal (NRR)
  - Anthony Hamins (NIST)
  - Mohammad Modarres (UMd)
  - Vern Nicolette (SNL)
- External expert and author of the EPRI report on the NEI/EPRI circuit tests of 2001
  - Dan Funk (EDAN Engineering)

CAROLFIRE Testing Approach

- Two Scales of testing were pursued
  - Small-scale radiant heating experiments
  - Intermediate-scale open burn tests

Small Scale Tests

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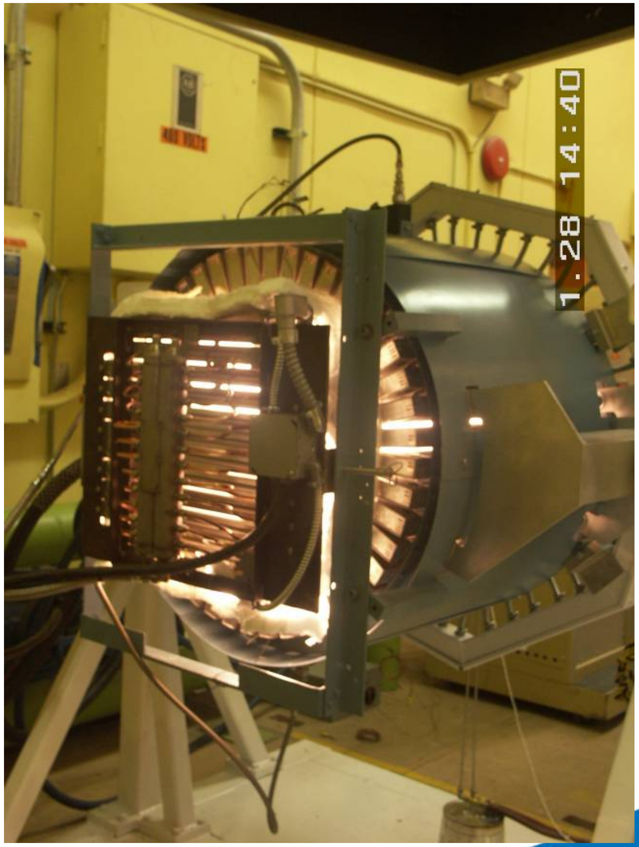
- *Penlight* heats target cables via grey-body radiation from a heated shroud
- Well controlled, well instrumented tests
- Allows for many experiments in a short time
- Single cables and small cable bundles (up to six cables)
- Cable trays, air drops, conduits



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Typical Penlight Setup for CAROLFIRE

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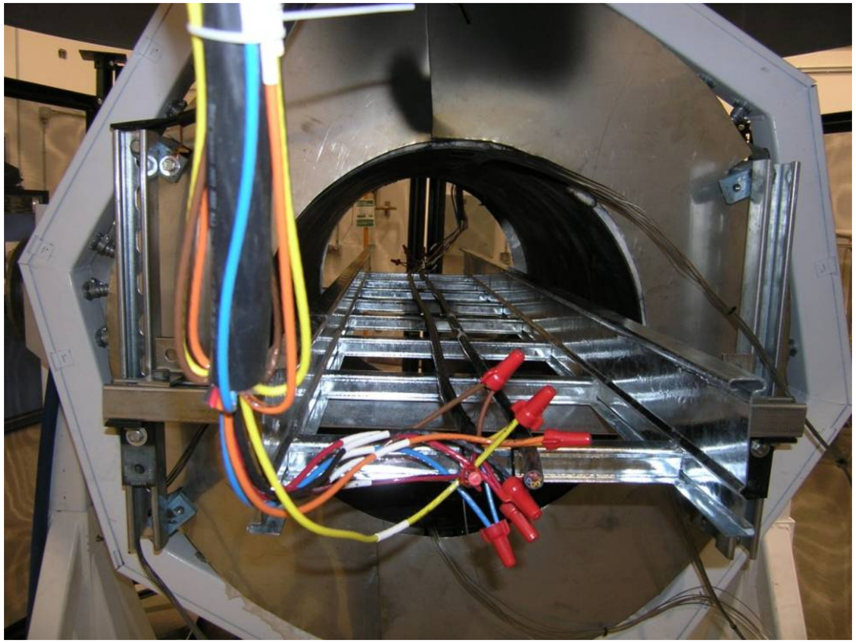
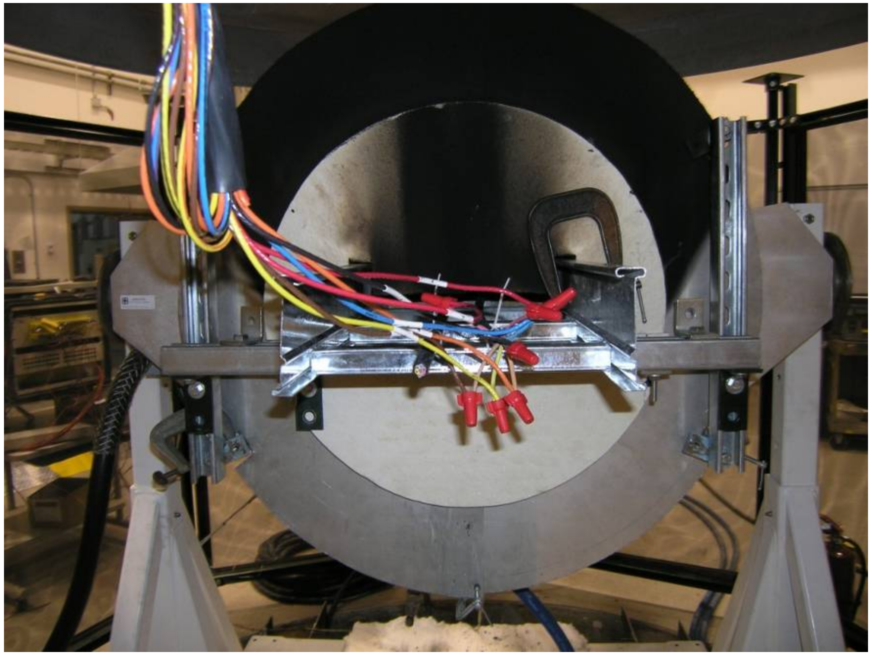
Open Tray



Closed Tray



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Typical Penlight Setup for CAROLFIRE

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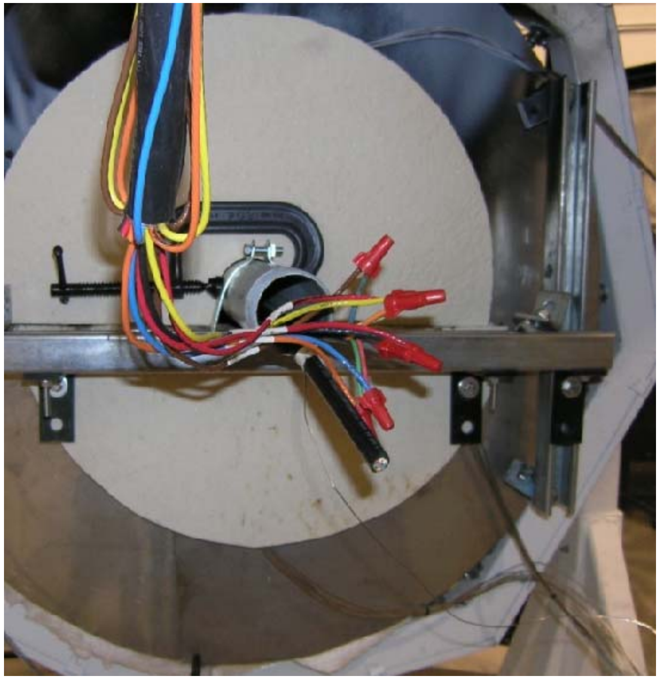
Conduit



Air Drop

TS vs. TP Physical Failure Characteristics

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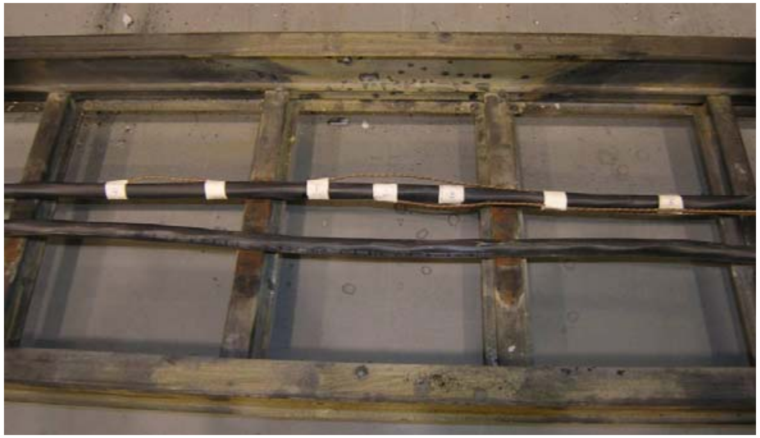
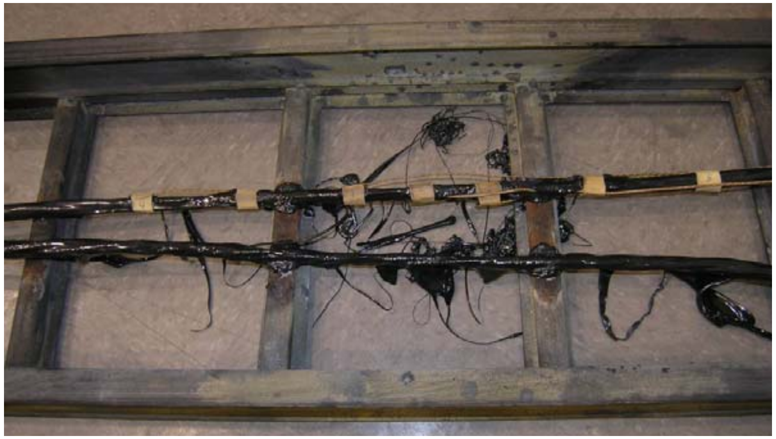
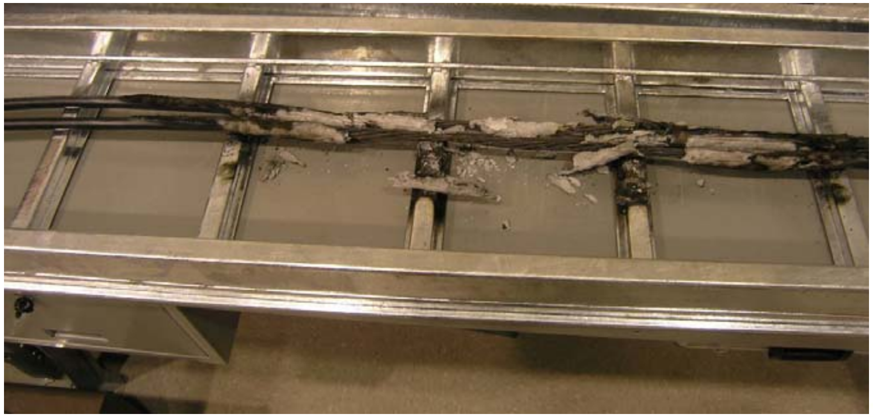




Thermoplastic

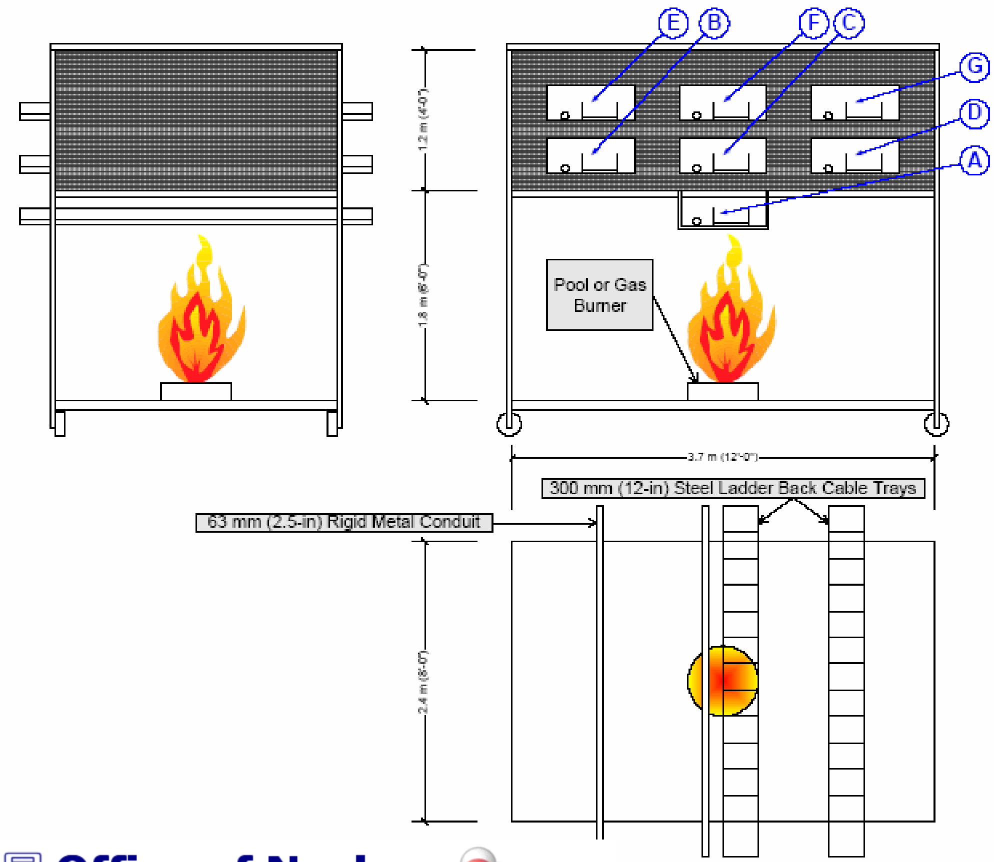
Thermoset

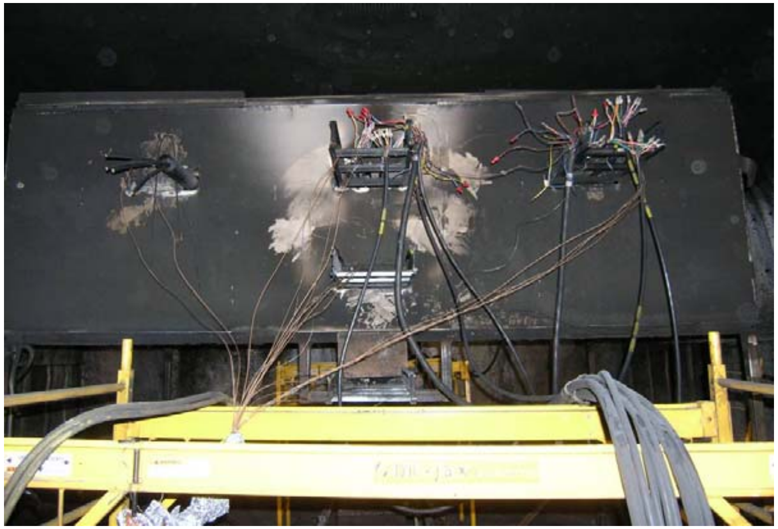


Penlight did allow cables to burn and burning was common

Intermediate-Scale Tests

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





Intermediate-Scale Tests

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- Less controlled, but a more realistic testing scale
- Located in larger test facility
- Propene (Propylene) gas diffusion burner fire source (200 kW typical)
- Cables in trays, conduits and air drop

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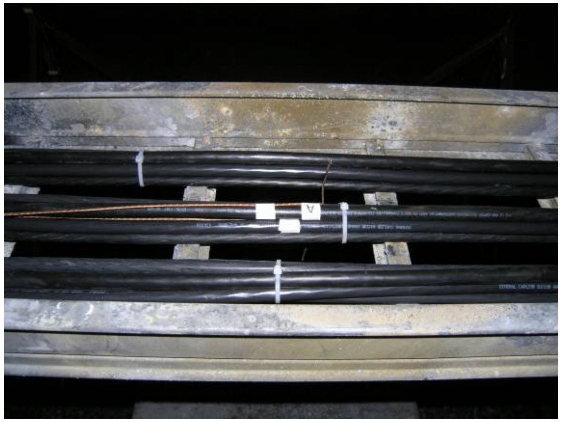
Typical Setups

Single cables

Bundles



Airdrops

Random fill trays

Cable Selection

- Testing a broad range of cable products
  - 15 cable products tested
    - 9 Control (8 were 12 AWG – 7/C)
    - 4 Instrument (16 or 18 AWG, 2/C or 12/C)
    - 2 Power (8 AWG, 3/C)
  - CAROLFIRE excluded armored cables
    - Duke armored cable tests

Photo of Tested Cables

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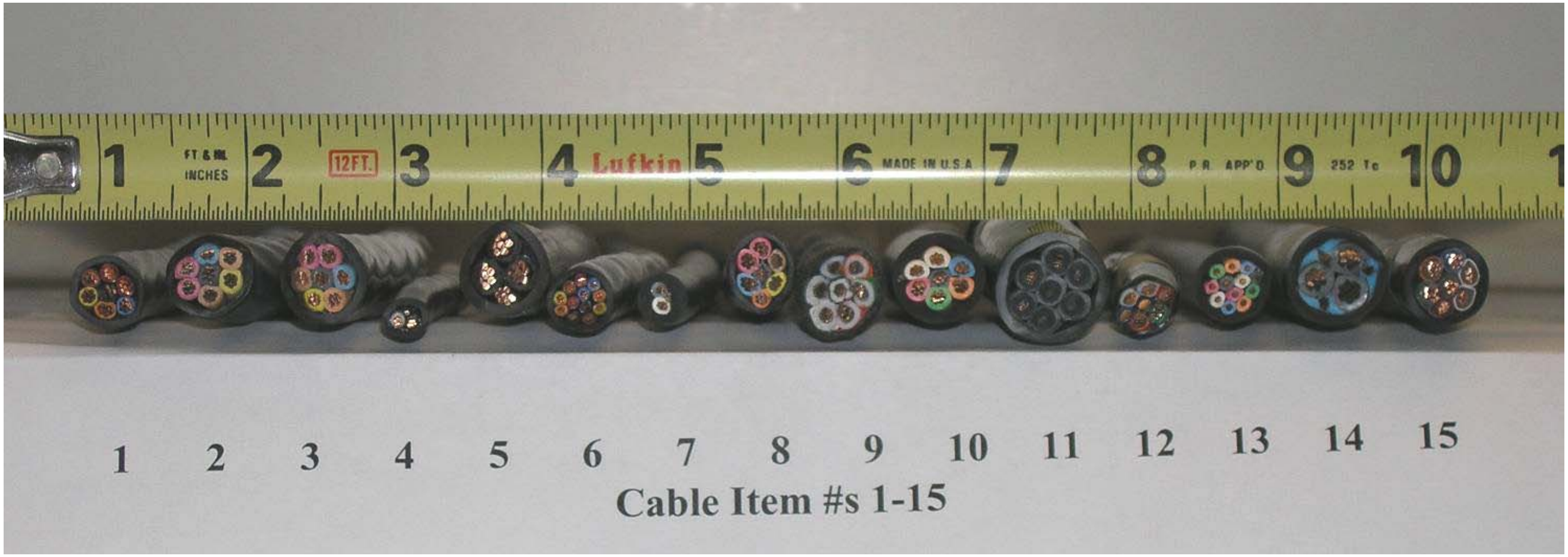

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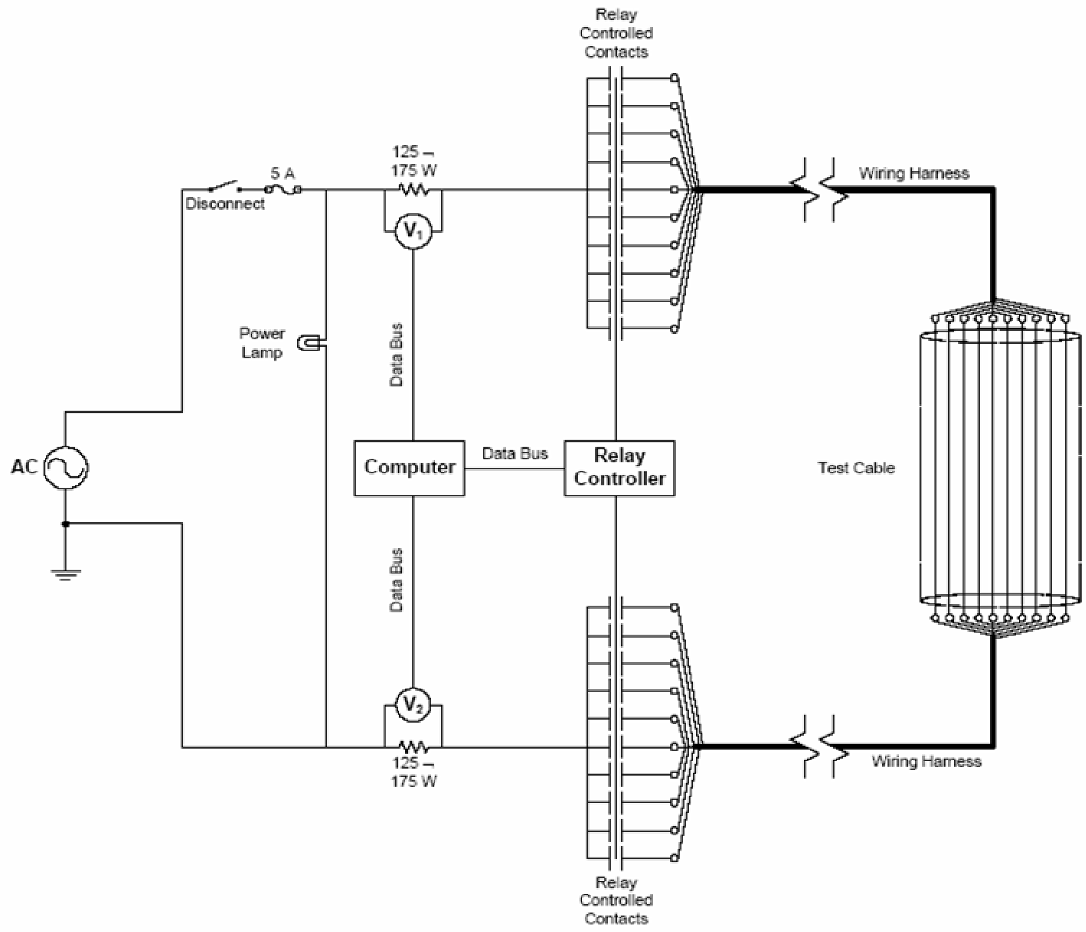
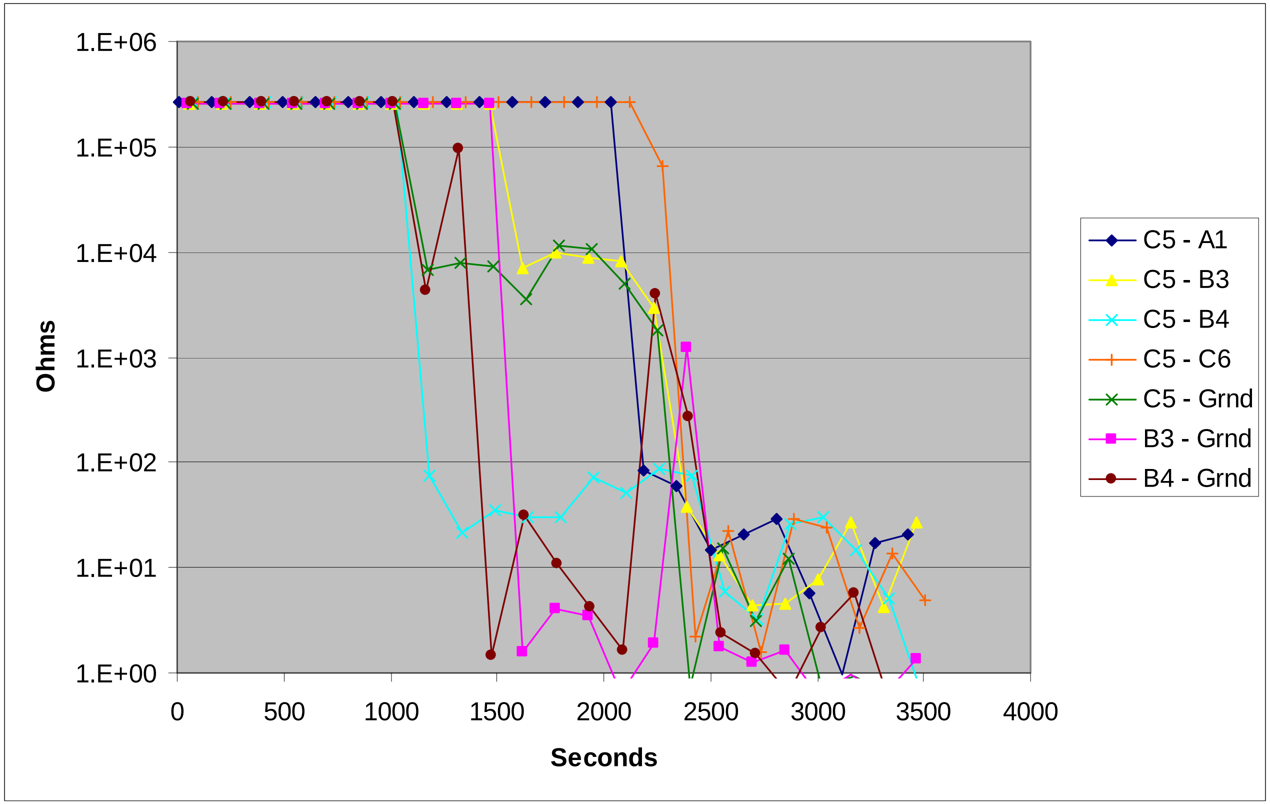
Electrical Instrumentation

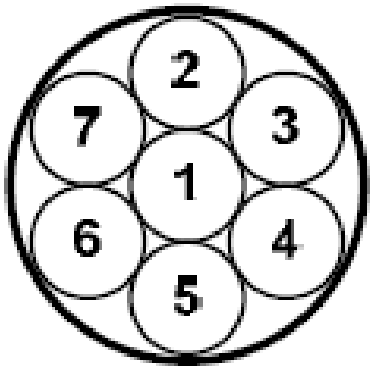
Insulation Resistance Monitoring System

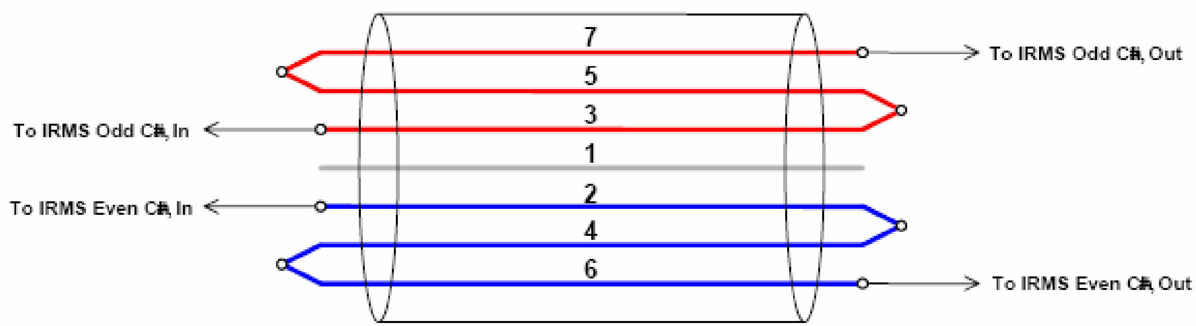
- All tests – SNL Insulation Resistance Measurement System (IRMS)
- Continuous measurement of cable degradation and functionality
- Very detailed look at conductor interactions
- Patented system developed and deployed originally during the NEI/EPRI tests (NUREG/CR-6776)



IRMS Results

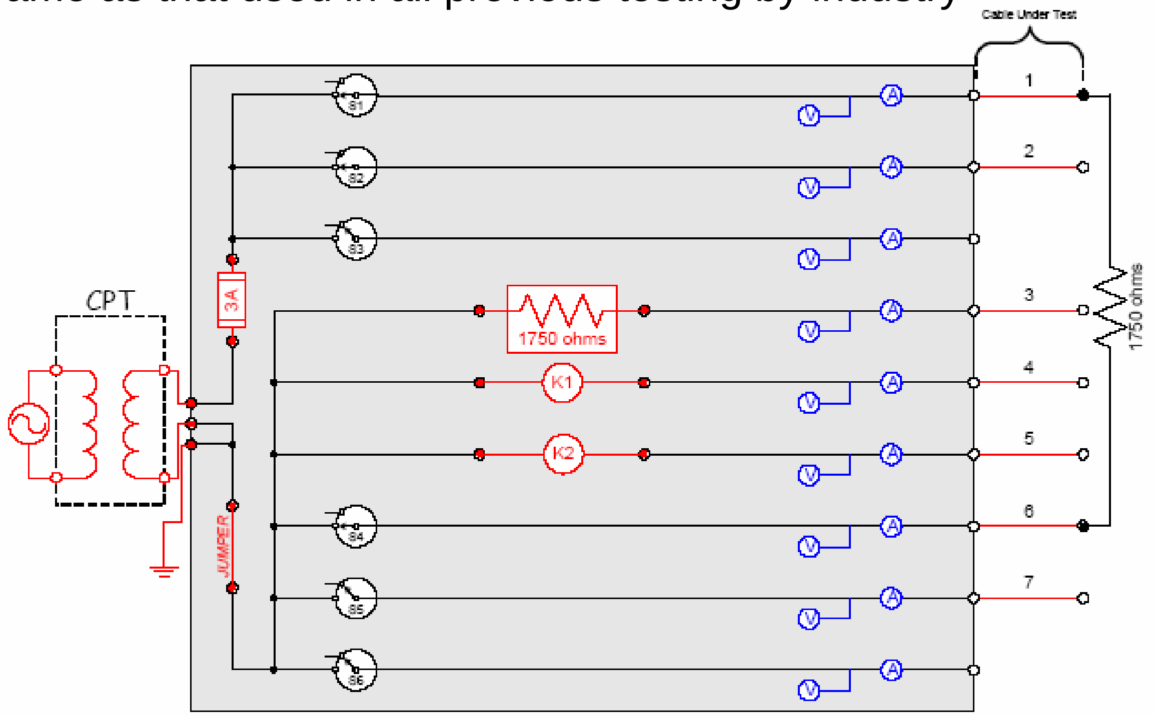






Electrical Instrumentation

- Intermediate-scale only: 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



Thermal Instrumentation

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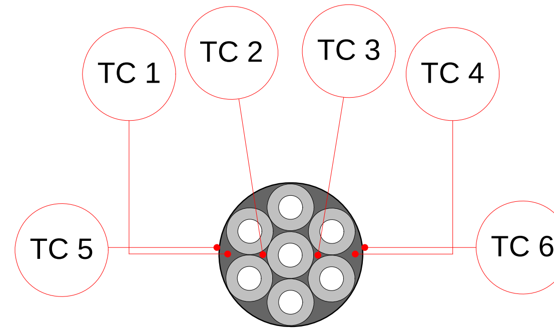
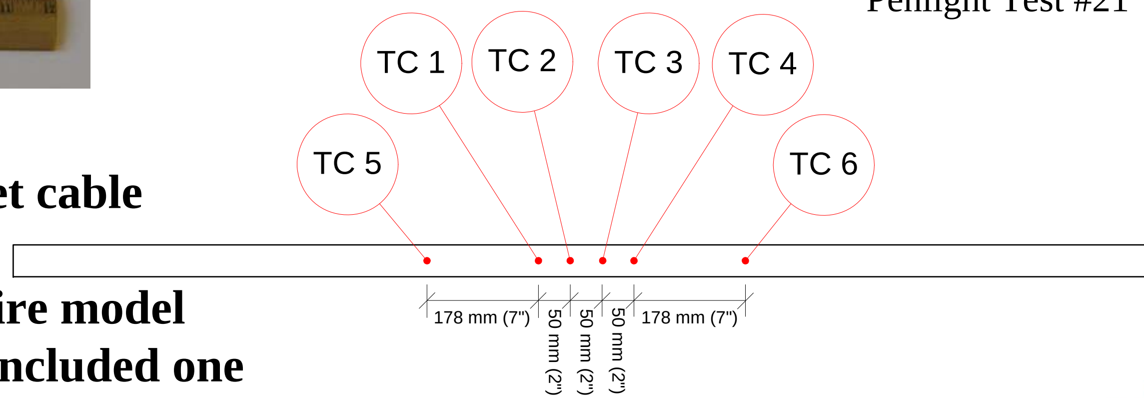
Sub-jacket placement

Sub-jacket TC bead location



Penlight Test #21



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.

Raceway Temperatures

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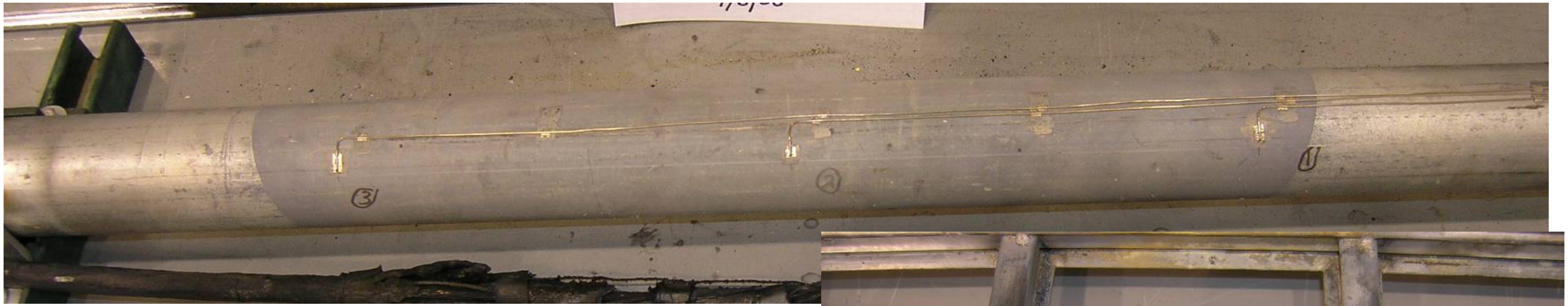

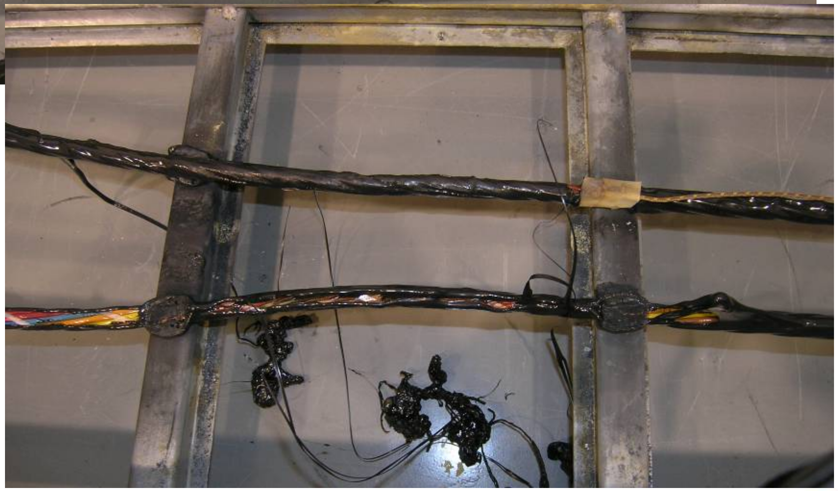

Conduit and cable tray surface temperatures are also important to fire modeling efforts.

Electrical & Thermal Data

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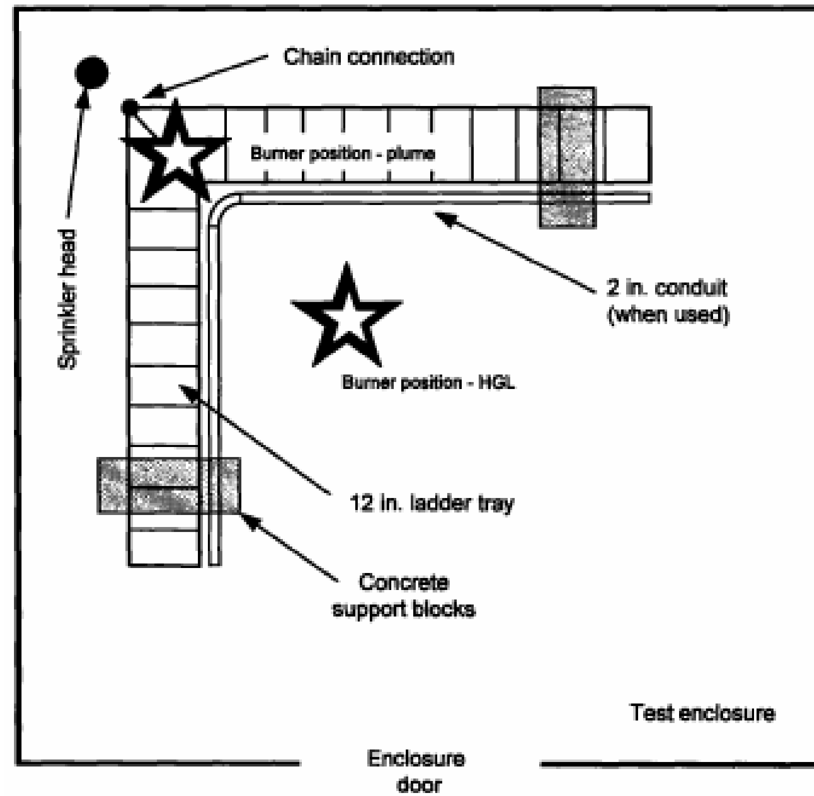
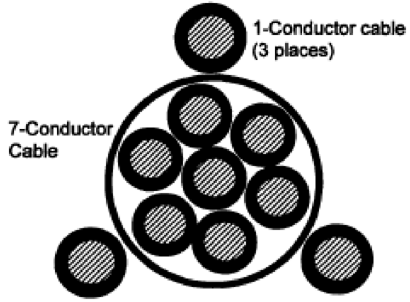
- All tests were extensively documented in excel spreadsheets that includes:
  - Shorting Summary
  - Thermocouple Map
  - Plots of various electrical failure characteristics and temperatures
  - Processed and Raw Data
- All test data will be placed onto a CD and issued with the NUREG/CR
- Pictures and other related documents will also be included on a CD

NEI Test Compartment



CAROLFIRE to NEI/EPRI Comparison

- **18 tests**
- **EPRI Report 1003326**
- **10’x10’x8’**
- **Varied several parameters**
- **Long times to failure for HGL**
- **MOV test Circuit**
- **SNL IRMS was used and results are reported in NUREG/CR-6776**



Parameter

Raceway loading
Raceway configuration
Exposure Conditions
Cables
Bundling Arrangements
Cable Combinations
Cable Thermal Response
CPT Size

Review of CAROLFIRE Research As It Relates to Bin 2 Items

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- Item A – Thermoset-to-Thermoset
  - Plausible
    - one solid case of TS-to-TS shorting as primary failure
    - Several cases of secondary or tertiary failure mode
- Item B – Themoset-to-Themoplastic
  - Plausible
    - One case of hot short from a TS-to-TP cable

Conclusions on Bin 2 Items

- Item C – Concurrent for three or more cable failures
    - i.e., How many failures should be considered?
  - Plausible
    - No a priori limit; dependent on scenario; risk significance
    - Every test program conducted to date has seen as many as four out of four simulated control circuits spuriously actuate, including CAROLFIRE
- Item D – Concurrent spurious actuations given properly sized CPT
  - Inconclusive
    - Larger than intended CPT versus actuation device ratings were tested (What is meant by "properly sized")
    - No apparent affect on spurious actuations

Conclusions on Bin 2 Items

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- Item E – Hot shorts lasting more than 20 minutes
  - Unlikely

  Longest Hot Short
    - CAROLFIRE ~ 7.6 minutes
    - NEI/EPRI ~ 11.3 minutes
    - Duke armored cable tests showed similar results
  - 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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Public Comment Process

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- Two sources of public comments:
  - Industry comments collected and submitted through NEI
  - ACRS comments

- Additional NRC staff comments

Key Public Comments

- The “cable physical characteristics” table was expanded to include quantitative copper/plastic ratios
- Thermal (heat transfer) properties - Unfortunately, are not available for the materials and could not be provided
- Added a summary table for Penlight results
- New plots overlaying cable thermal and electrical response
- New plots illustrating the temperature at failure

Examples of New Plots

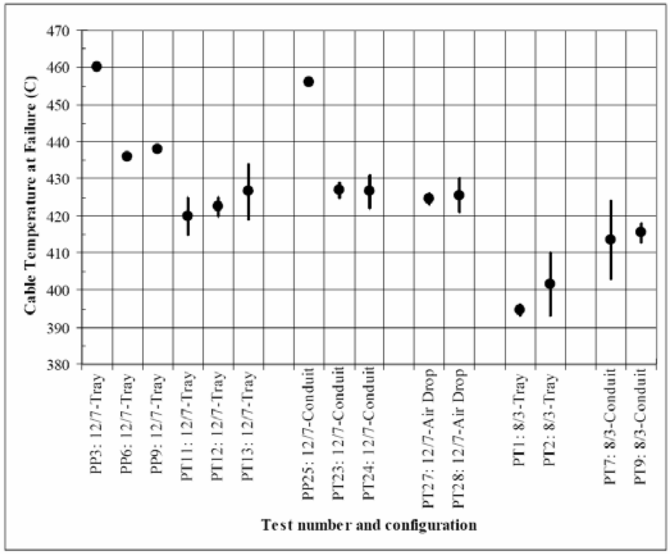


Figure 5.31: Compilation of test results for the XLPE-insulated cables.

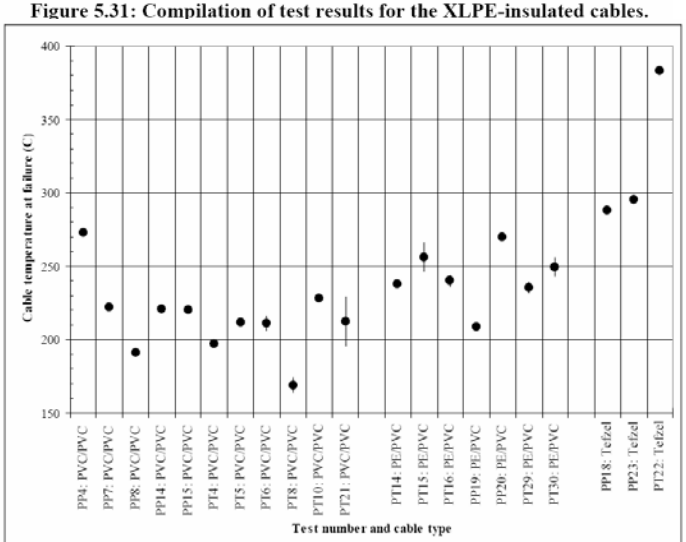
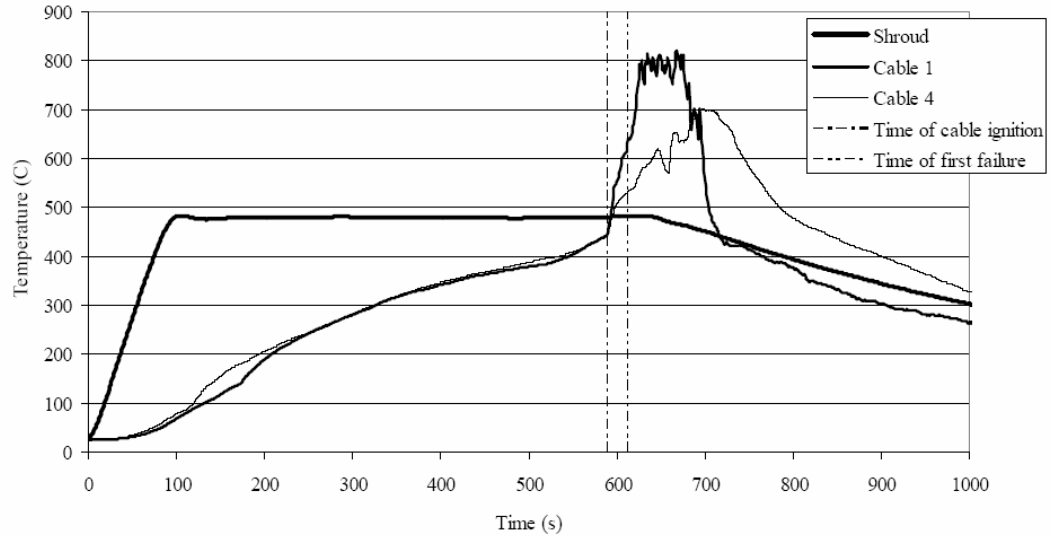


Figure 5.32: Compilation of the test results for the TP cable types.



Summary

- CAROLFIRE has contributed to two critical need areas
  - Data for resolution of RIS 2004-03
  - Improving the fire modeling of cable response and failure
- CAROLFIRE represents a valuable source of information that the fire protection community world-wide will likely be using for many years to come

BACKUP SLIDES

Cable Response to Live Fire

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Cable types tested represent a wide range of NPP products

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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

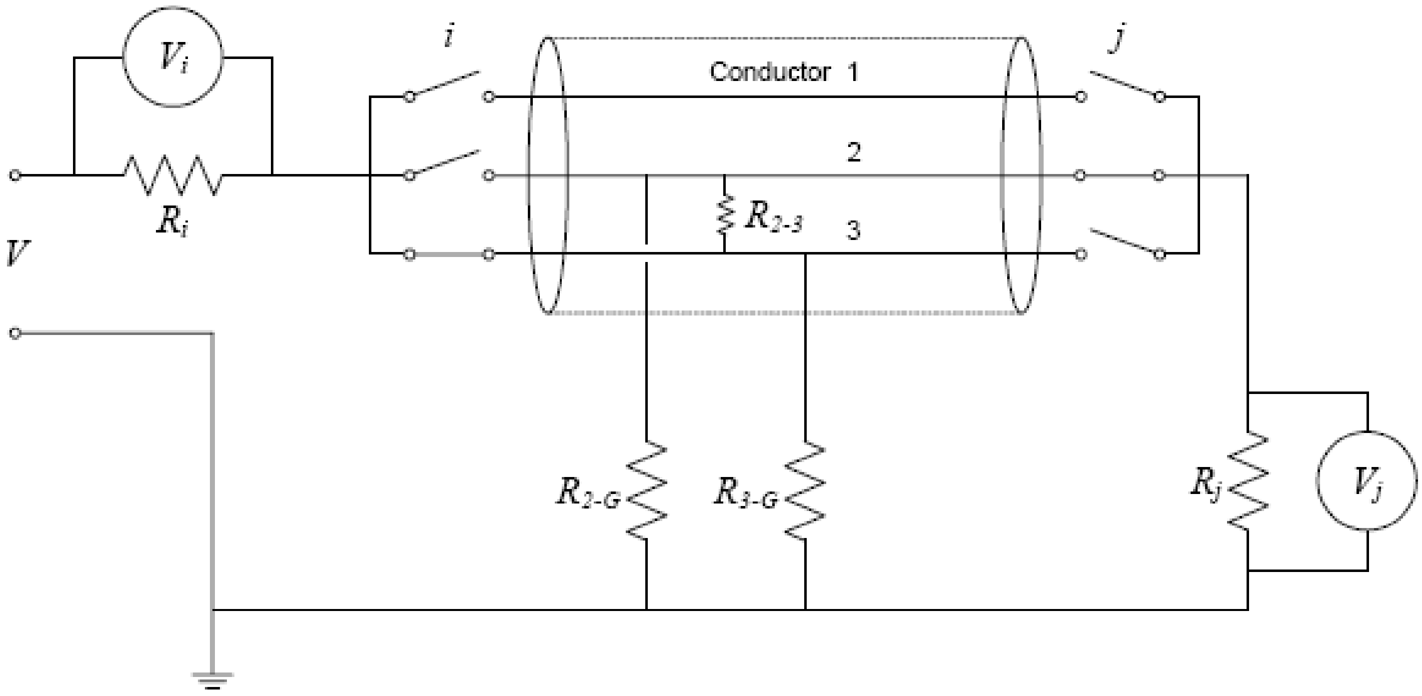
Additional Notes:
(1) - XLPE = Cross-linked polyethylene; CSPE = Chloro-sulfanated polyethylene (also known as Hypalon); XLPO = Cross-linked polyolefin; SR = Silicone rubber; EPR = Ethylene-propylene rubber; PVC = Poly-vinyl chloride; PE = Polyethylene (non cross-linked).
(2) - TS = Thermoset; TP = Thermoplastic;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

Instrumentation – Thermal & Electrical

- Cable thermal response (surface and interior)
  - Direct measurement of the cable temperatures during the tests
  - Can be used to calculate fire-to-cable net heat transfer (i.e., every cable is in effect a target specific slug calorimeter)
- Raceway surface temperatures
  - Conduits and cable trays
- Exposure environment temperatures
  - Air and surface, additional slug calorimeters
- Cable electrical response via two monitoring systems
  - The SNL Insulation Resistance Measurement System (IRMS)
  - Surrogate Circuit Diagnostic Units (circuit simulators - SCDU)

Electrical Instrumentation

Simplified View of Insulation Resistance Monitoring System



Public Comment Process

- Expansion of data analysis and reporting
  - Addressed within the limits of the project scope and funding
- Data plots have been revised to start (t=0) at fire/exposure time
  - Rather than starting when the monitoring systems were started.

Public Comment Resolution

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- Interpretation of results for regulatory applications and positions
  - This NUREG/CR objective is to report the results of the testing and NRR has the lead role in determining the results regulatory applications

Public Comment Process

- Foreword was modified regarding the potential risk significance of spurious actuations
  - "under certain conditions" were added to clarify the risk hot short pose
- Clarification of "risk-relevant" and its intent as used in the report
  - Report clarifies that the intent was not to say "risk-significant" but rather, to identify factors or configurations that could have a bearing on a fire PRA circuit failure modes and effects

Public Comment Process

- Added a summary table for Penlight results
  - Electrical failure results
  - Correlates temperature response and sub-jacket temperature at time of failure (where possible)
- New plots overlaying cable thermal and electrical response
- New plots illustrating the temperature at failure

Public Comment Process

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- Additional discussions have been added relative to the use of cables as thermal targets and the potential for analyzing these data to estimate net fire-to-cable heat transfer
  - Unfortunately, available scope did not allow SNL to actually perform the required calculations
- Additional discussions added relative to the “pulsing” behavior of the gas burner to clarify that this is an anticipated and expected behavior for a gas diffusion burner operating in the turbulent regime
- Some additional discussion of burner efficiency as an uncertainty factor have been added