# CAROLFIRE Project
# Part 2: The Test Program

# International Information Exchange with IRSN Staff (France)

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Predecisional

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.

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# Reminder: CAROLFIRE* is addressing two issues/needs

- **Fire-induced cable failure modes and effects analysis**
  - **Cable failures leading to spurious operation of plant equipment**
  - **Regulatory Information Summary 2004-03 and the "Bin 2" Items: circuit/cable configurations requiring additional research**
- **Fire modeling improvement: predicting the thermal and electrical failure response**

*Cable Response to Open Live Fire

# Reminder:
# The RIS 2004-03 Bin 2 items

- ***Item A:*** **Intercable shorting for thermoset cables**
- ***Item B:*** **Intercable shorting between thermoplastic and thermoset cables**
- ***Item C:*** **Configurations requiring failures of three or more cables**
- ***Item D:*** **Multiple spurious operations in control circuits with properly sized control power transformers (CPTs) on the source conductors**
- ***Item E:*** **Fire-induced hot shorts that must last more than 20 minutes**

- **(*Item F:* Consideration of cold shutdown circuits - Outside CAROLFIRE scope)**

# General Approach: Conduct a series of cable fire tests and monitor cable thermal and electrical response

- Thermal response will be used for fire model calibration
  - Uses a separate length of cable from that monitored for electrical response
    - Side-by-side with cable monitored for electrical integrity
  - Thermocouples placed within the cable (e.g., under the outer jacket) to monitor temperature response
  - Basic measurements of the external fire conditions
    - Air temperatures, raceway temperatures, etc.
    - Heat release rate for open burn tests
- Electrical response measurements include mode of failure and mode transitions
  - Intra-cable shorts
  - Inter-cable shorts
  - Shorts to ground
  - Spurious operation on a surrogate control circuit

## Tests to be performed in two scales, and under radiant heating and open burn conditions:

- **Small-Scale: *Penlight* radiant heating**
  - **Testing of samples from a single cable length up to as many as six cables in a bundle**
  - **Open ladder-back cable trays, conduits and air-drops**
  - **A total of 68 individual tests**
- **Intermediate Scale: Radiant Heat Tests**
  - **Electrically heated radiant panel as exposure source**
  - **One or two loaded raceways (trays/conduits) per test located above radiant panel**
  - **36 individual tests**
- **Intermediate Scale: Open burn tests**
  - **Propylene gas burner as fire source**
  - **Generally 5 raceways per test**
  - **17 individual tests**

# Testing will involve several cable insulation/jacket types

- **Thermosets:**
  - **Cross-linked Polyethylene (XLPE) with Hypalon jacket**
  - **Silicone-Rubber (SR) with fiberglass braid on conductors, SR jacket and amarid braid overall**
  - **Ethylene Propylene Rubber (EPR) with Hypalon jacket**
  - **XLPE low-smoke zero halogen**
  - **Vita-Link (Rockbestos SR that ceramifies when burned)**
- **Thermoplastics:**
  - **Polyethylene (PE) with a Polyvinyl Chloride (PVC) jacket**
  - **PVC with a PVC jacket**
  - **Tefzel 280 with Tefzel 200 jacket**
- **Mixed type:**
  - **XLPE with PVC jacket**

# Cable/Conductor Configurations

Using three primary conductor configurations that yield a similar overall diameter but varies the relative content of plastic to copper:

- 7-conductor, 12 AWG control cable
  - Approximately 2.3 mm conductor diameter
  - 'Core' sample configuration
  - Very typical of U.S. control circuits
- 12-conductor, 18 AWG control/indication cable
  - Approximately 1.2 mm conductor diameter
  - Lower copper, higher plastic content
- 3-conductor, 8 AWG light power cable
  - Approximately 4.2 mm conductor diameter
  - High copper, lower plastic content

Also testing one instrument cable:

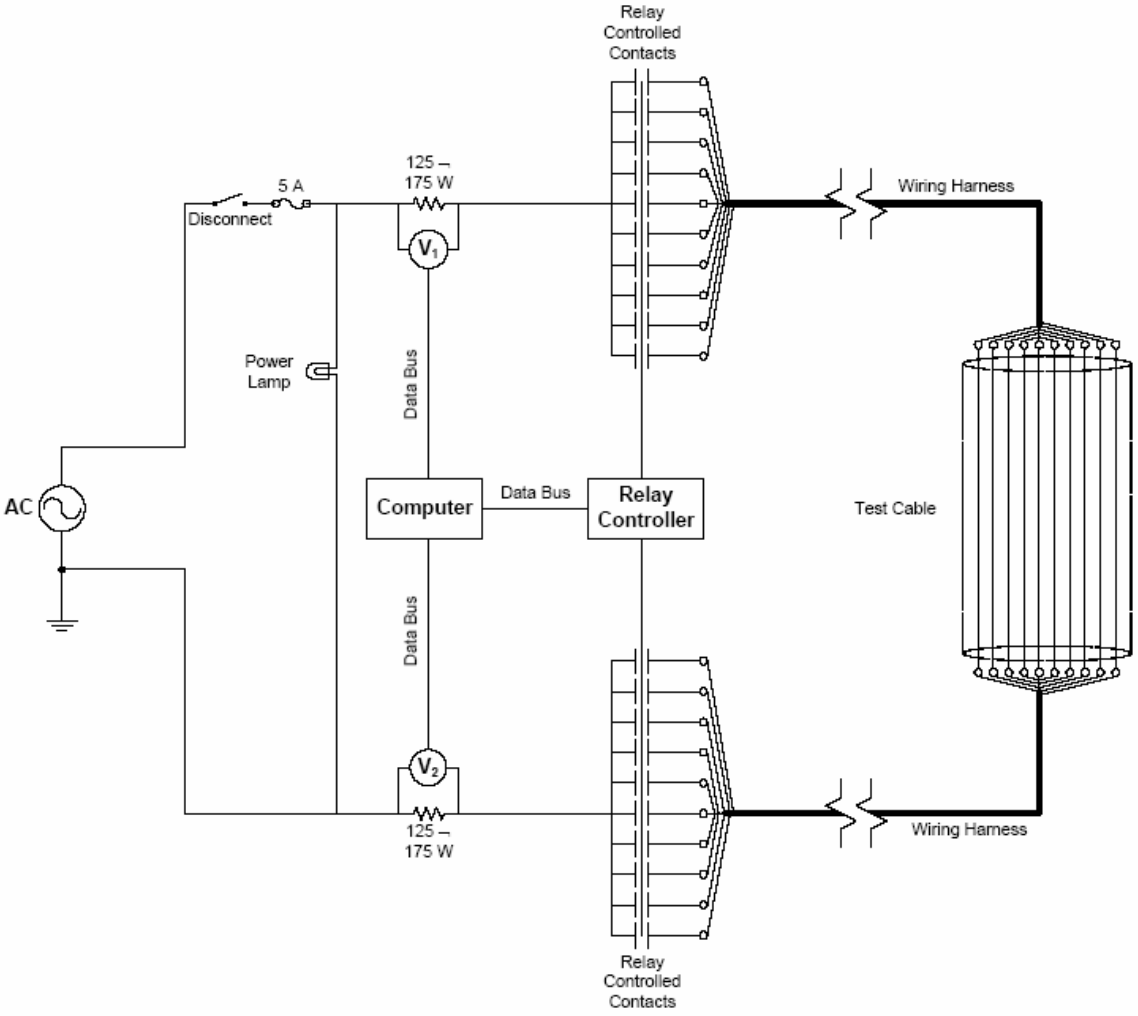
- 2-conductor, 16 AWG
  - Approximately 1.5 mm conductor diameter

# Two types of in-situ measurements for cable electrical performance

- SNL Insulation Resistance Measurement System (IRMS)
  - Measures insulation resistant between two conductors (or between two groups of conductors) and between conductors and ground
  - Allows us to determine cable failure mode, time, and the duration of conductor-to-conductor shorts
- Surrogate control circuits
  - Using “black box” approach that allows us to simulate a range of simple control circuits (e.g., a motor operated valve open/close controller)
  - Can wire a specific cable to the circuit simulator and monitor for the effects of cable faulting on circuit behavior (e.g., fuse blow versus spurious operation)
  - Will be able to monitor the timing and duration of hot shorts and spurious operations

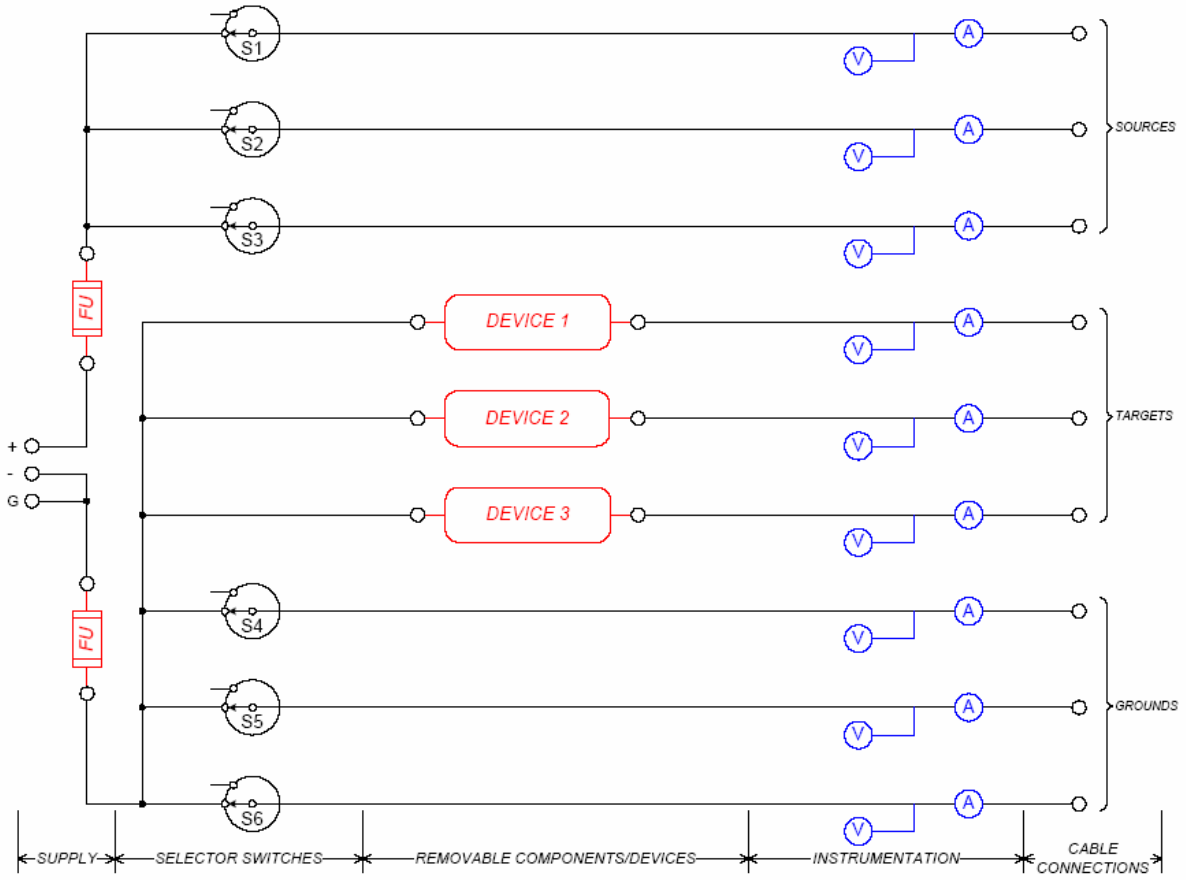
# IRMS

- System applies AC or DC power to the test conductors one at a time, then monitors for leakage current to any other conductor or to ground.
- Analysis of data yields conductor-to-conductor and conductor-to-ground insulation resistance values as a function of time.



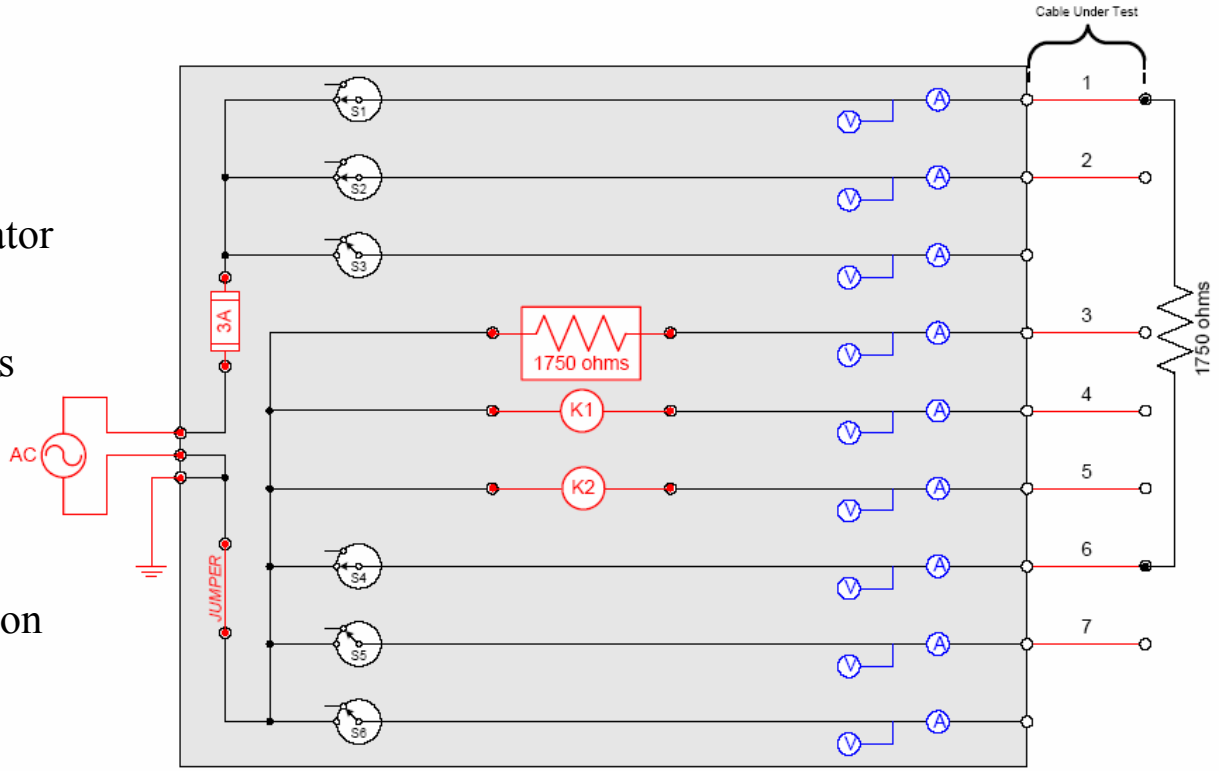
# ‘Black Box’ Circuit Simulator

- System provides any combination of up to 3 power supply lines (sources), 3 control devices (targets), and 3 ground connections.
- Connections are flexible to suit a range of circuits
- All conductor paths are monitored for voltage and current so we can detect hot shorts and spurious actuation signals.

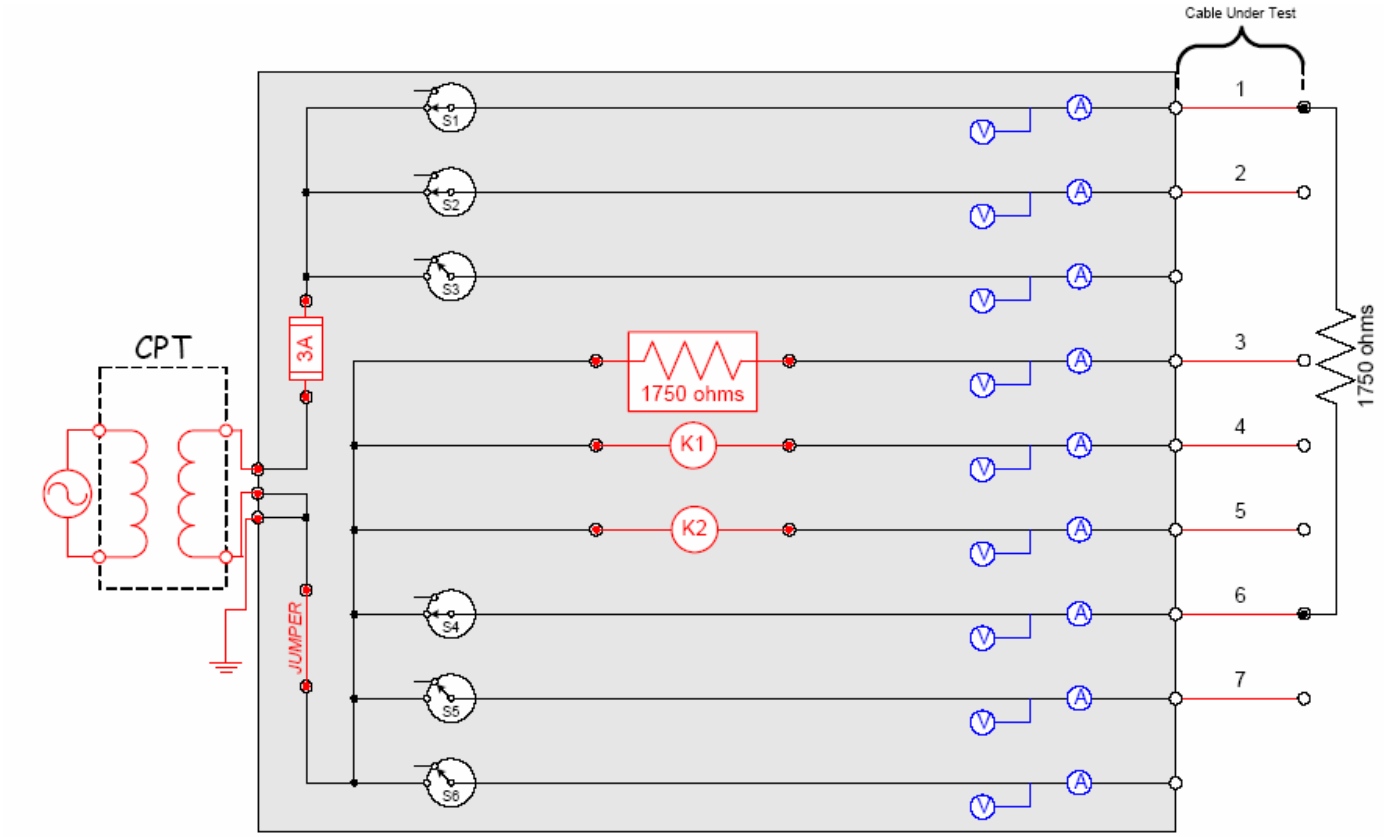


# Black Box Example: MOV circuit

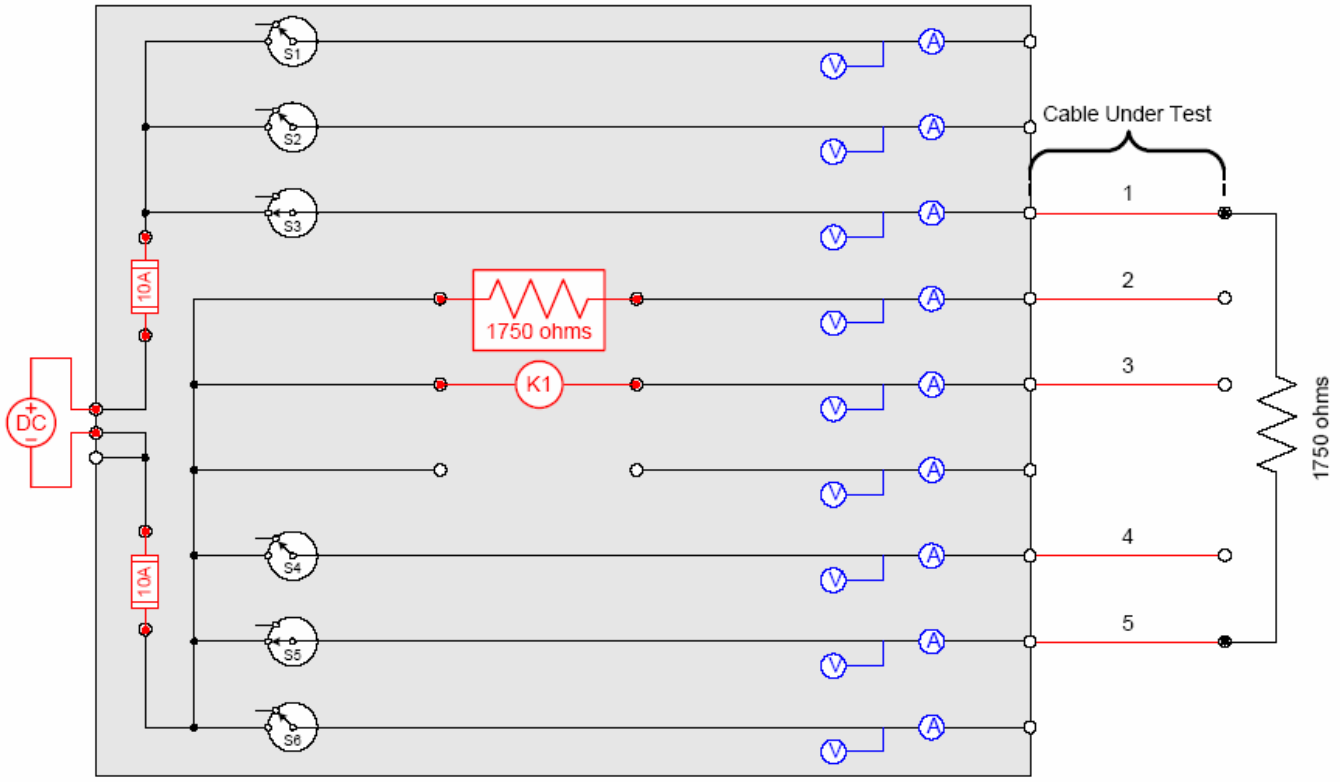
- S1 and S2 closed to create two source conductors (energized)
- S4 represents one ground conductor
- K1 & K2 represent motor operator actuation coils
- 1750Ω center resistor represents indicator light (not normally lit)
- Resistor to right represents normally lit indicator light
- 3A fuse in supply side, no fuse on ground side
- S5 is open but connected as a spare
- S2 and S6 are open and not used in circuit



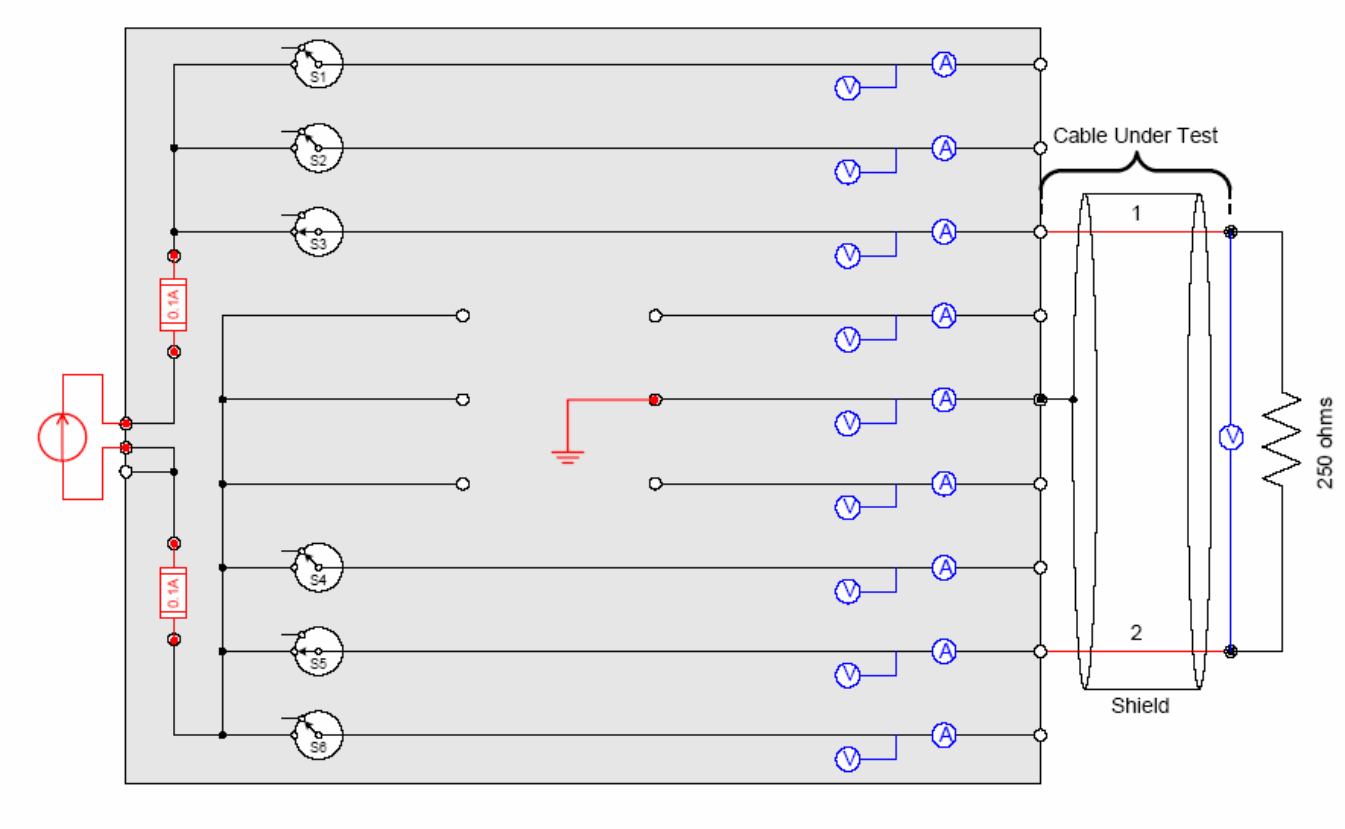
# Black Box Example: MOV with CPT



# Black Box Example: SOV



# Black Box Example: Instrument Loop



# Resolution of Bin 2 Item A:

- Inter-cable short circuits between two (or more) thermoset insulated/jacketed cables:
  - Primary measurement tool is the SNL IRMS
  - Many tests include bundles of thermoset cables
    - Some where all cables are the same type
    - Some where cable types are mixed
  - We will monitor for any evidence of cable-to-cable short circuits
  - Ultimate resolution will consider:
    - Did any interactions occur?
    - If so, what was the timing relative to shorts to ground?
    - In general, if there is evidence of interactions, we will recommend that this item remain ‘on the table’ for inspections, and we will attempt to estimate likelihoods

# Resolution of Bin 2 Item B:

- **Inter-cable shorting between thermoset and thermoplastic cables**
  - **Very similar in approach to Item A, except that we will be looking at mixed bundles of thermoset and thermoplastic cables**
  - **We anticipate that timing will be the key**
    - **Thermoplastic cables will generally fail more easily and quickly than a thermoset**
    - **Once the insulation melts, the thermoplastic cable conductors are largely exposed and will short to whatever is nearby**
    - **Question will likely come down to an issue of timing – inter-cable shorts versus shorts to ground**

# Resolution of Bin 2 Item C:

- Configurations requiring failures of three or more cables
  - This item is largely about two issues:
    - The conditional probability of spurious operation and
    - Timing/Duration of hot shorts
  - Resolution will involve direct observation and data interpretation and extrapolation:
    - Direct:
      - We have MANY opportunities for hot shorts and spurious operations to occur (many more that in the previous testing)
      - We will look for overlapping hot shorts / spurious operations
    - Extrapolation:
      - We expect to develop improved estimates of the likelihood of spurious operation
      - We will also have extensive data on failure timing and hot short durations

# Resolution of Bin 2 Item D:

- **Multiple spurious operations in control circuits with properly sized control power transformers (CPTs) on the source conductors**
  - **CPTs limit power available to circuit**
  - **We will address this item primarily using bench scale tests**
    - **We will observe the shorting behavior in burn tests**
    - **We can simulate cable failure behaviors using the "black box" circuit simulators on the bench**
    - **Repeat the bench experiments with different CPTs in the supply circuit and observe circuit response**
    - **Assess how important the CPTs are to circuit response and what influence the size of the CPT has on the outcome**
  - **We anticipate providing improved guidance for the treatment of circuits with CPTs versus circuits without CPTs**

# Resolution of Bin 2 Item E:

- Fire-induced hot shorts that must last more than 20 minutes
  - This item will be addressed based on the test data from essentially all tests performed
  - Key question is how long can a spurious operation persist?
  - Ultimately, we will provide improved guidance for how long hot shorts are likely to persist, possibly based on statistical treatment
    - Given the entire mass of test data, we can develop hot short duration distributions
    - Grouping of test results will be key
      - Cable type is likely to be an important parameter
      - Raceway type
      - Raceway loading
      - Fire conditions….

# Test Matrices

- Switch to PDF files