CAROLFIRE Project
Part 1: Historical Background

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.

Sandia National Laboratories

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

Circuit analysis background: 1975

- **Browns Ferry cable fire, March 1975**
  - **Over 1800 cables damaged by the fire**
  - **Several unanticipated circuit faults resulted from cable damage:**
    - **Spurious operation of plant systems**
    - **Spurious/false signals**
  - **Subsequent analyses have demonstrated that simple conductor-to-conductor hot shorts can easily explain many of the observed circuit faults and spurious operations in particular**
    - **NUREG/CR-6834**

Circuits background: 1979

- **NRC issues Appendix R regulations which codify requirements to consider circuit faults:**
  - **III.G.2: *Fire protection of safe shutdown capability*: "… where cables or equipment including associated non-safety circuits that could prevent operation or cause maloperation due to hot shorts, open circuits, or shorts to ground…**
  - **III.L.7: *Alternate and dedicated shutdown capability:* "The safe shutdown equipment and systems for each fire area shall be known to be isolated from associated non-safety circuits in the fire area so that hot shorts, open circuits, or shorts to ground in the associated circuits will not prevent operation of the safe shutdown equipment. …"**

Circuits Background: 1980's and 90's NRC issues guidance and clarification

- **Guidance consolidated in Regulatory Guide 1.189 - Section 5.5.1 :**
  - **For consideration of spurious actuations, all possible functional failure states should be evaluated … (i.e., hot shorts, open circuits, and shorts to ground) …**
  - **For three-phase ac circuits, the probability of getting a hot short on all three phases in the proper sequence to cause spurious operation of a motor is considered sufficiently low as to not require evaluation except for any cases involving Hi/Lo pressure interfaces. …**
  - **For ungrounded dc circuits, if it can be shown that only two hot shorts of the proper polarity without grounding could cause spurious operation, no further evaluation is necessary except for any cases involving Hi/Lo pressure interfaces. However, two proper polarity faults in ungrounded multi-conductor dc circuits should be considered. …**
  - **Hot short conditions are assumed to exist until action has been taken to isolate the circuit from the fire area, or other actions as appropriate have been taken to negate the effects of the spurious actuation.**

***The guidance in Regulatory Position 5.5.1 is based on GL 81-12, GL 86-10, and Holahan Memo (1990).**

Circuits Background: 1997-2003
RES takes on issue in context of Fire PRA

- RES has had an ongoing fire protection research program since before the Browns Ferry fire
  - Charter has been wide ranging from experimental investigations to risk analysis methods and applications
- 1997: RES initiates a program to improve fire PRA/PSA methods, including IPEEE weaknesses (SNL lead)
  - Circuit analysis was identified as one weakness of the IPEEEs (NUREG-1742)
- A series of letter reports are written by SNL from 1999-2003
  - Ultimately these are published as NUREG/CR-6834

Circuits Background: 1997-2000 Clarifying the Regulatory Requirements

- Ongoing discussion with industry relative to regulatory requirements
- Staff sees increasing number of LERs which "identified plant-specific problems related to potential fire-induced electrical circuit failures that could prevent operation or cause maloperation of equipment necessary to achieve and maintain hot shutdown in the event of a fire." (from RIS 2004-03)
  - Information Notice 99-17, "Problems Associated With Post-Fire Safe-Shutdown Circuit Analysis."
- November 29, 2000, inspections of associated circuits were temporarily suspended (ML003773142)
- Both industry and NRC work to develop analysis guidance:
  - Nuclear Energy Institute (NEI) developed NEI 00-01, "Guidance for Post-Fire Safe-Shutdown Analysis," Rev. D (ML023010376).
  - Staff with Brookhaven National Laboratory (BNL) support develops a post-fire safe-shutdown analysis guidance letter report, "Introduction to Post-Fire Safe-Shutdown Analyses" (ML023430533).

Circuits Background: 2000-2001 Industry testing with RES collaboration

- Industry (NEI/EPRI) plans a series of cable fire tests to assess importance of hot shorts and spurious operations
  - Their expectation was to demonstrate that spurious operations are of very low likelihood
  - Things Didn't work out quite that way…
- RES collaborated on the testing
  - Test planning and design
  - SNL contracted to provide instrumentation for tests
- Results showed significant likelihood of spurious actuation given cable failure
  - In the range of 0.1 to 0.8 conditional probability for tested configurations
  - SNL/RES data showed 80%+ probability of intra-cable conductor-to-conductor shorts as first failure mode

Circuits Background: 2001-2002

- **EPRI convenes an expert panel to interpret results from the industry tests**
- **Output is table of spurious actuation conditional probability values (example from SDP)**

Table 2.8.3 - P_{SP} Factors Dependent on Cable Type and Failure Mode			
State of Cable Knowledge	Thermoset	Thermoplastic	Armored
No available information about cable type or current limiting devices (worst-case value from NEI 00-01 Table 4-4)	.6		
Cable type known, no other information known (NOI)	.6	.6	.15
Inter-cable interactions only	.02	.20	
In conduit, cable type known, NOI	.30	.6	
In conduit, inter-cable only	.01	.20	
In conduit, intra-cable	.075	.3	

Circuits Background: 2003 NRC conducts facilitated public workshop

- Panel of invited experts plus public participation (about 80 participants total)
- Objective: establish guidance that will allow NRC to lift its moratorium on associated circuit inspections
- Output is three lists:
  - Bin 1: Cable/circuit configurations that *will* be included in future inspections (four items)
  - Bin 2: Cable/circuit configurations for which inspection will be *deferred* pending additional research
    - CAROLFIRE is the "additional research"
  - Also a list of some Cable/circuit configurations considered of very low likelihood to induce spurious operation
- Bin 1 and Bin 2 items are formalized in Regulatory Information Summary 2004-03

Circuits Background: The RIS 2004-03 Bin 1 items

- **Item A: For any individual multiconductor cable (thermoset or thermoplastic), failure that may result from intracable shorting, of any possible combination of conductors within the cable may be postulated to occur concurrently regardless of number. For cases involving the potential damage of more than one multiconductor cable, assume a maximum of two cables to be damaged. Inspectors should consider only a few (three or four) of the postulated combinations whose failure is likely to significantly impact the ability to achieve and maintain hot shutdown.**

Circuits Background: The RIS 2004-03 Bin 1 items

- **Item B: For any two thermoplastic cables, failures of any combination of conductors that may result from intercable shorting (i.e., between two cables) may be postulated to occur concurrently. Inspectors should consider only a few (three or four) of the postulated combinations whose failure is likely to significantly impact the ability to achieve and maintain hot shutdown.**

Circuits Background: The RIS 2004-03 Bin 1 items

- **Item C: For cases involving direct current (DC) control circuits, consider the potential spurious operation due to failures of the control cables (even if the spurious operation requires two concurrent hot shorts of the proper polarity, e.g., plus-to-plus and minus-to-minus). Consider potential spurious actuations when the source and target conductors are each located in the same multiconductor cable.**

Circuits Background: The RIS 2004-03 Bin 1 items

- **Item D: The decay heat removal (DHR) system isolation valves at high-pressure/low-pressure interfaces may be subject to three-phase, proper-polarity hot short cable failures. Although this failure is unlikely, it could cause the opening of these valves which would pressurize the low-pressure portion of the DHR system piping outside of containment with the reactor coolant at or near normal reactor operating pressure. These three phase power cables (either thermoset or thermoplastic jacketed) will be inspected to ensure that they are not subject to three-phase hot shorts that could cause the DHR valves to spuriously open.**

Circuits Background: The RIS 2004-03 Bin 2 items

- **Item A: Intercable shorting for thermoset cables, since the failure mode is considered to be substantially less likely than intracable shorting.**

- **Item B: Intercable shorting between thermoplastic and thermoset cables, since this failure mode is considered less likely than intracable shorting of either cable type or intercable shorting of thermoplastic cables.**

Circuits Background: The RIS 2004-03 Bin 2 items

- **Item C: Configurations requiring failures of three or more cables, since the failure time and duration of three or more cables require more research to determine the number of failures that should be assumed to be "likely."**

- **Item D: Multiple spurious operations in control circuits with properly sized control power transformers (CPTs) on the source conductors, since CPTs in a circuit can substantially reduce the likelihood of spurious operation. Specifically, where multiple (i.e., two or more) concurrent spurious operations due to control cable damage are postulated, and it can be verified that the power to each impacted control circuit is supplied via a CPT with a power capacity of no more than 150 percent of the power required to supply the control circuit in its normal mode of operation (e.g., required to power one actuating device and any circuit monitoring or indication features).**

Circuits Background: The RIS 2004-03 Bin 2 items

- **Item E: Fire-induced hot shorts that must last more than 20 minutes to impair the ability of the plant to achieve hot shutdown, since recent testing strongly suggests that fire-induced hot shorts will likely self-mitigate (e.g., short to ground) in less than 20 minutes. This is of particular importance for devices such as air-operated valves (AOVs) or power-operated relief valves (PORVs) which return to their deenergized position upon abatement of the fire-induced hot short.**

- **Item F: Consideration of cold shutdown circuits, since hot shutdown can be maintained and the loss of cold shutdown circuits is not generally a significant contributor to risk.**
  - **Item F is not within CAROLFIRE scope**

CAROLFIRE Fire Modeling Background

- RES is engaged in verification and validation efforts for fire modeling tools
  - e.g., NFPA 805 requires that modeling tools have a V&V basis
  - International collaboration
  - NRC focused collaboration with EPRI and NIST
- Fire PRA has a particular need to predict the onset of thermal damage to electrical cables
  - Some models provide general target thermal response estimates
  - Tailoring models to cables is and issue
  - Validating the models is an issue

CAROLFIRE Fire modeling background

- CAROLFIRE will be testing many types of cables under various conditions and monitoring the time and mode of failure
- Obvious connection to validation needs for cable response models
- Collaborative effort to improve fire modeling tools added to the CAROLFIRE project
- Partners:
  - National Institute of Standards and Technology (NIST)
  - University of Maryland

CAROLFIRE Fire Modeling Background

- For CAROLFIRE the circuit issues are the top priority
  - That means we are *not* focused on measuring the fire environment as first priority,
  - We are focused on cable failure modes and effects as top priority
- That said, the project has been expanded to include basic measurements of the fire environment and cable thermal response:
  - Exposure conditions
  - Cable temperature response
  - Correlate thermal response to failure times