Module II – Circuit Analysis

Task 9: Detailed Circuit Failure Analysis

Joint EPRI/NRC-RES Fire PRA Workshop
June 25-29, 2018

Gabe Taylor – U.S. NRC

Daniel Funk – JENSEN HUGHES

Dane Lovelace – JENSEN HUGHES

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

DETAILED CIRCUIT FAILURE ANALYSIS

Purpose & Scope (per NUREG/CR-6850, EPRI 1011989)

The Detailed Circuit Failure Analysis Task is intended to:

- Identify the potential response of circuits and components to specific cable failure modes associated with fire-induced cable damage
- Screen out cables that do not impact the ability of a component to complete its credited function
- Screen out power supplies and interlocks that do not impact the ability of a component to complete its credited function

DETAILED CIRCUIT FAILURE ANALYSIS
Corresponding PRA Standard Elements

- One match is to element CS – Cable Selection
  - CS Objectives (as stated in the PRA standard):

    "[T]o ensure that

    (a) all cables needed to support proper operation of equipment selected per technical element ES (see 4-2.2) are identified and assessed for relevance to the Fire PRA plant response model

    (b) the plant location information for selected cables is sufficient to support the Fire PRA and its intended applications."

DETAILED CIRCUIT FAILURE ANALYSIS

Corresponding PRA Standard Elements (continued)

- Another match is to element CF – Circuit Failures
  - CF Objectives (as stated in the PRA standard):

    “[T]o

    (a) refine the understanding and treatment of fire-induced circuit failures on an individual fire scenario basis

    (b) ensure that the consequences of each fire scenario on the damaged cables and circuits have been addressed”

DETAILED CIRCUIT FAILURE ANALYSIS

HLRs (per the PRA Standard) – CS element

- HLR-CS-A: The Fire PRA shall identify *and* locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C). (11 SRs)
- HLR-CS-B: The Fire PRA shall

  (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit

  (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard. (1 SR)
- HLR-CS-C: The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review. (4 SRs)

DETAILED CIRCUIT FAILURE ANALYSIS

HLRs (per the PRA Standard) – CF element

- HLR-CF-A: The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA. (2 SRs)
- HLR-CF-B: The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review. (1 SR)

DETAILED CIRCUIT FAILURE ANALYSIS

NEI 00-01, Rev. 2, Section 3.5 – Circuit Analysis and Evaluation

- NEI 00-01, Rev. 2, "Guidance for Post-Fire Safe Shutdown Circuit Analysis," May 2009
- Follows closely to Task 9 methodology of NUREG/CR-6850, EPRI 1011989
- Types of circuit failures to be considered:
  - Open circuits
  - Shorts-to-ground / Short circuits
  - Hot shorts (including GFEHS and all credible variants)
- Other considerations:
  - Common power supplies (i.e., inadequate coordination)
  - Common enclosures (i.e., inadequate circuit protection)

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (per NUREG/CR-6850, EPRI 1011989)

- Fundamentally a <u>deterministic analysis</u>
- Perform <u>coincident</u> with cable selection (Task 3) to the extent feasible and cost effective ("Task 9A")
- Difficult cases generally reserved for situations in which Quantitative Screening indicates a clear need and advantage for further analysis
- Detailed Failure Modes Analysis
  - Requires knowledge about desired functionality and component failure modes
  - Conductor-by-conductor evaluation (Hot Probe method recommended)
- Objective is to screen out all cables, power supplies, and interlocks that **CANNOT** impact the ability of a component to fulfill the specific function as defined in the Fire PRA model

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (cont.)

- Failure modes considered
  - Single shorts-to-ground (reference ground)
    - Grounded system
    - Ungrounded system
    - Resistance grounded system
  - Single hot shorts
  - Multiple hot shorts
    - Credible variants are included in NUREG/CR-7150 (New updates in NUREG/CR-7150, Vol 3)
      - Compatible polarity multiple hot shorts for ungrounded AC and DC circuits
      - Ground equivalent hot shorts (GFEHS)
      - Coincident independent hot shorts on separate cables
      - Multiple intra-cable hot shorts
      - Cables associated through a common power supply

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (cont.)

- Failure modes **NOT** considered
  - 3-phase proper sequence hot shorts
    - NUREG/CR-6850: Consider for high consequence equipment with thermoplastic insulated conductor or ungrounded configuration
    - NUREG/CR-7150: Excluded in all cases
  - See NUREG/CR-7150 for multiple hot shorts variants that can be excluded from consideration (New updates in NUREG/CR-7150, Vol 3)
  - Open circuit conductor failures

    Note: Based on DESIREE-FIRE test results, excluding open circuits for ally circuit types might not be technically appropriate
  - Multiple high-impedance faults

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (cont.)

Application of Task 9A versus Task 9B:

- Task 9A circuit analysis performed as part of the Task 3, Cable Selection, process
  - Intended to be a quick screening determination whether a given cable is able to adversely impact the ability of a required component to complete its credited function
- Detailed circuit analysis (Task 9B) is performed as described by the Task 9 methodology (i.e., the basis of this presentation)
  - Intended to be a more robust assessment of a cable's potential impact on the Fire PRA component of interest and is performed later in the overall Fire PRA process, after some screening has occurred

Note: The more experience an analyst has performing Task 9B level analyses, the more proficient they become in performing Task 9A level screening.

DETAILED CIRCUIT FAILURE ANALYSIS

Process

- The Task 9 procedure is subdivided into three (3) primary steps:
  - Step 1: Compile and Evaluate Prerequisite Information and Data
  - Step 2: Perform Detailed Circuit/Cable Failure Analysis
  - Step 3: Generate Equipment Failure Response Reports

DETAILED CIRCUIT FAILURE ANALYSIS

Task Interfaces - Inputs

- Fire PRA Components List (Task 2)
- Fire PRA Cable List (Task 3)
- Fire PRA Database (Support Task B)
- Results of Quantitative Screening (Task 7)
- Results of Detailed Fire Modeling (Task 11)
- Appendix R Circuit Analysis
- Plant Drawings
- CRS Database

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Outputs

- Same as Task 3
- May include updates to:
  - Component Analysis (“Work”) Packages and circuit analysis data
  - Circuit Analysis Power Supply and Interlock Dependencies
  - Fire PRA Database & Model Updates

DETAILED CIRCUIT FAILURE ANALYSIS

Step 1 - Compile Prerequisite Information

- Same prerequisites as Task 3
- Might need additional drawings or information to ascertain failure modes
- Might need additional expertise in specialty areas, e.g., instrumentation, protective relay fault protection, SSPS

DETAILED CIRCUIT FAILURE ANALYSIS

Step 2 - Perform Circuit Failure Analysis

- Step 2.1: Develop Strategy/Plan for Circuit Analysis
- Step 2.2: Develop Plant-Specific Rules for Performing the Detailed Circuit Analysis
- Step 2.3: Perform Detailed Circuit Failure Analysis
- Document Analysis Results $\Rightarrow$ Component Work Packages
- Corresponding PRA Standard SRs: CS-A2, A3, A5, A6, A7, A8, A9
- Corresponding NEI 00-01, Rev. 2, Section: 3.5.2

DETAILED CIRCUIT FAILURE ANALYSIS

Considerations in Developing Plant Specific Rules

- Translate the credible failure modes to practical working instructions
- Pay attention to ungrounded control circuits – they are the most difficult to get right
- Set conventions so analysts perform and document the analysis in a consistent manner
- What sub-component breakouts are beneficial
- Where should “pseudo” components be used
- How will cable fault codes be used

DETAILED CIRCUIT FAILURE ANALYSIS

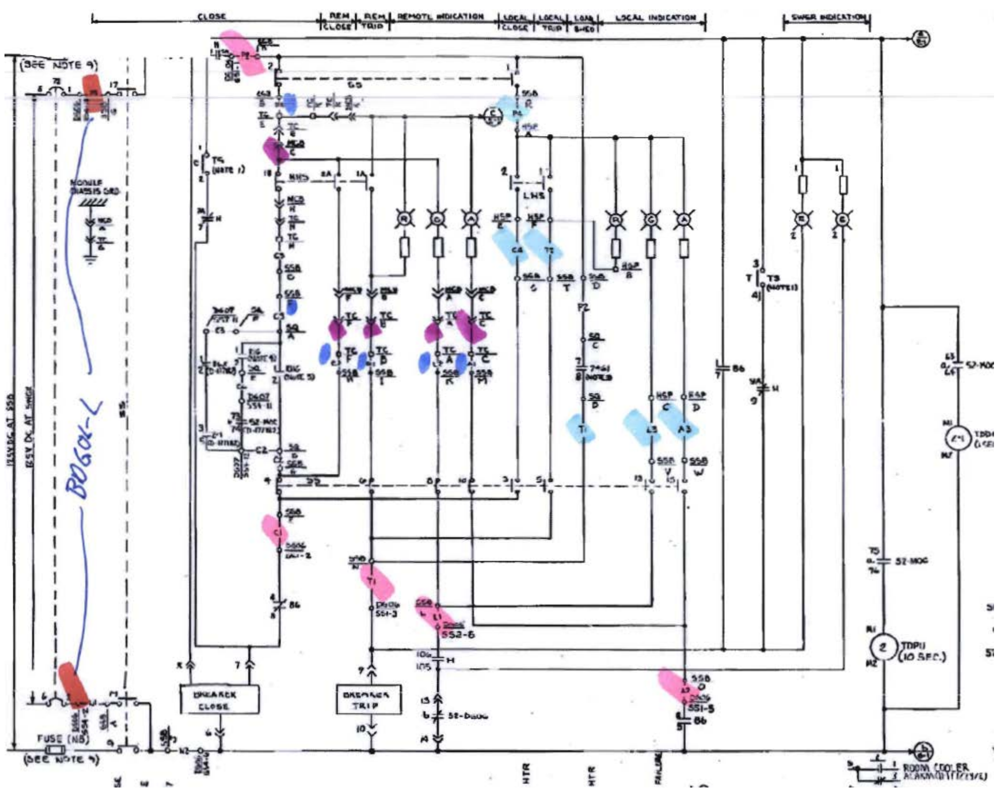
Performing Analysis

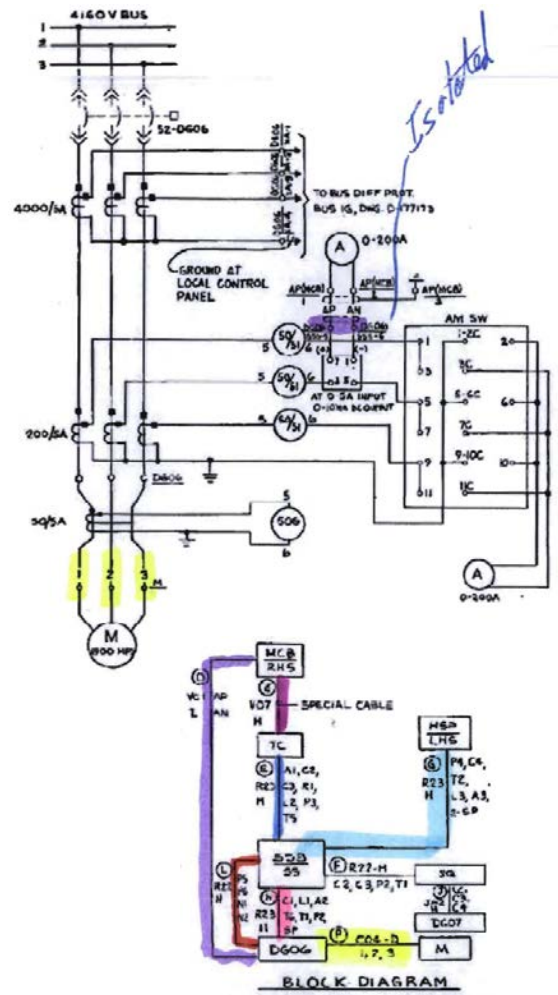
- You <u>cannot</u> perform detailed circuit analysis if you <u>do not know</u> how the circuit works
- You <u>cannot</u> perform detailed circuit analysis if you do not know the initial state and desired state of the component that corresponds to the PRA Basic Event
- You <u>cannot</u> perform detailed circuit analysis if you do not know the position of auxiliary contacts
- You <u>do need</u> to approach the analysis in a systematic manner
- Highlighting drawings is the best means of doing the analysis

DETAILED CIRCUIT FAILURE ANALYSIS

Performing Analysis (cont.)

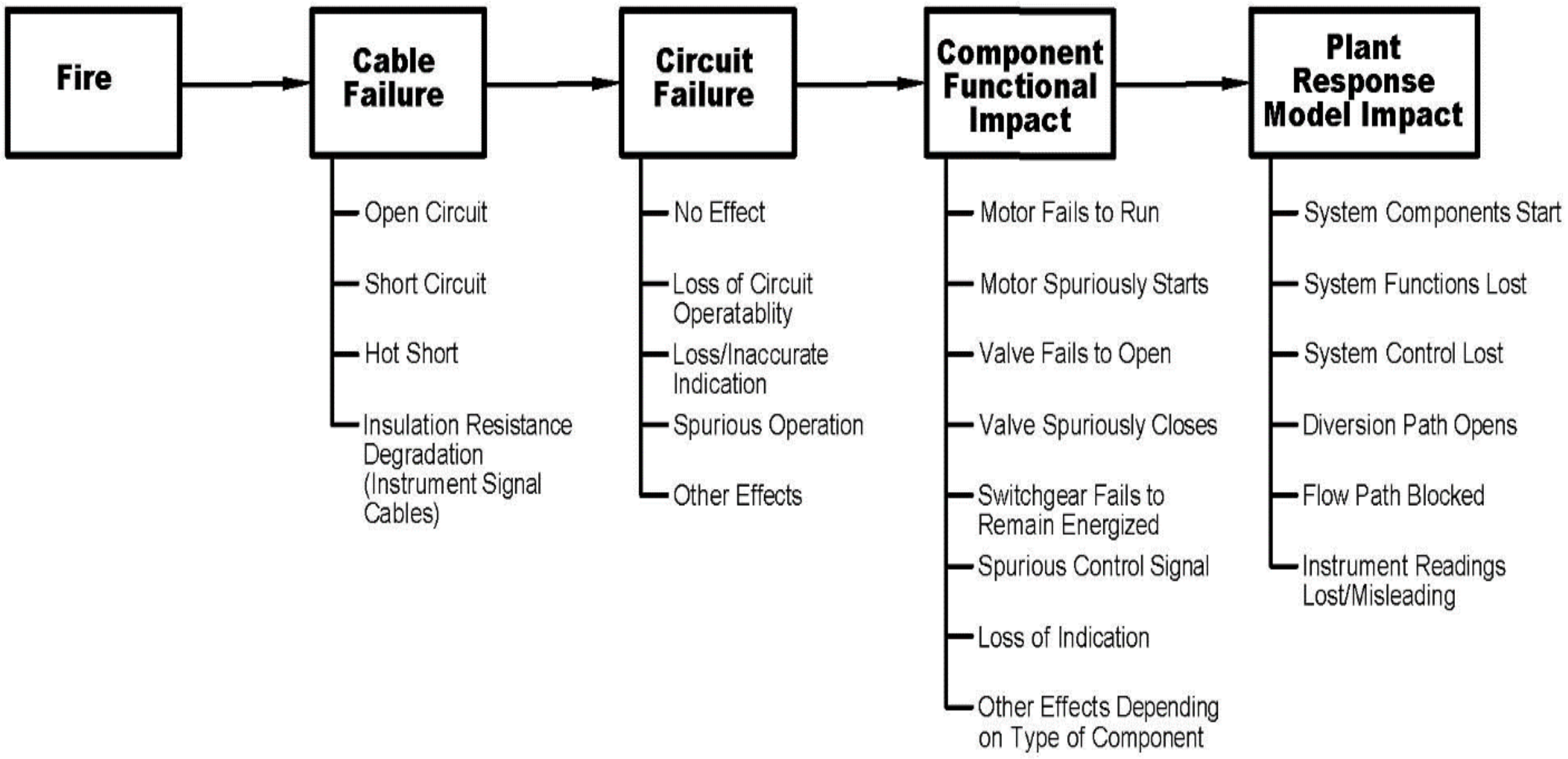
- Analyze conductors
- Document cables





DETAILED CIRCUIT FAILURE ANALYSIS

Logical Thinking



DETAILED CIRCUIT FAILURE ANALYSIS

Step 3 – Target Equipment Failure Response

- Same process as described for Task 3
  - Data Entered into Fire PRA Database
  - Mapping of Circuit Analysis to Model Basic Events is CRITICAL to accurate results
  - Sorts and Queries to Generate Target Equipment Loss Reports
- Corresponding PRA Standard SRs: CF-B1

DETAILED CIRCUIT FAILURE ANALYSIS
Caveats & Recommendations

- This detailed circuit failure analysis methodology is a Static Analysis (no timing issues are considered)
- Be aware of possible Cable Logic Relationships
- Work Packages (Highly Recommended!)
- “Hot Probe” (Conductor-to-Conductor) analysis must be rolled-up to cable/component level
- Outputs need to be Compatible with Fire PRA Database format and field structure
- Coordinate with the Fire PRA Modelers/Analysts early-on to Define the Fire PRA Component Failure Modes of Concern

DETAILED CIRCUIT FAILURE ANALYSIS

Caveats & Recommendations (Cont.)

- In most cases the “Hot Probe” method is all inclusive of intra- and inter-cable hot shorts
- When doing detailed circuit analysis think in terms of the “Target” conductors and not the “Source” conductors
- Task 9A analysis is fundamentally “design based” and not “configuration based”
  - Is the fault mode possible by the inherent design and required functionality?
  - Configuration-based screening often boils down to determining if credible source conductors exist
- Be cautious of screening cables based on old fault codes assigned to cables

DETAILED CIRCUIT FAILURE ANALYSIS
Recommended Notation for Analysis

- It is highly recommended that the analysts employ a consistent notation for documenting results
- In this training course, we will use the following notations

Primary Circuit Failure Mode Descriptions

EI	Erroneous Indication
EIS	Erroneous Indicating Signal
LIS	Loss of Indicating Signal
LOC	Loss of Control
LOCP	Loss of Control Power (usually applies only to metalclad switchgear that depend on a separate control power source to actuate)
LOI	Loss of Indication
LOP	Loss of Power (to the circuit)
SA	Spuriously Actuates or Spurious Actuation
SC	Spuriously Closes
SO	Spuriously Opens
SS	Spuriously Starts/Runs

Causal Modifiers

BF	Blown Fuse
HS	Hot Short
PR	Protective Relay
SG	Short to Ground

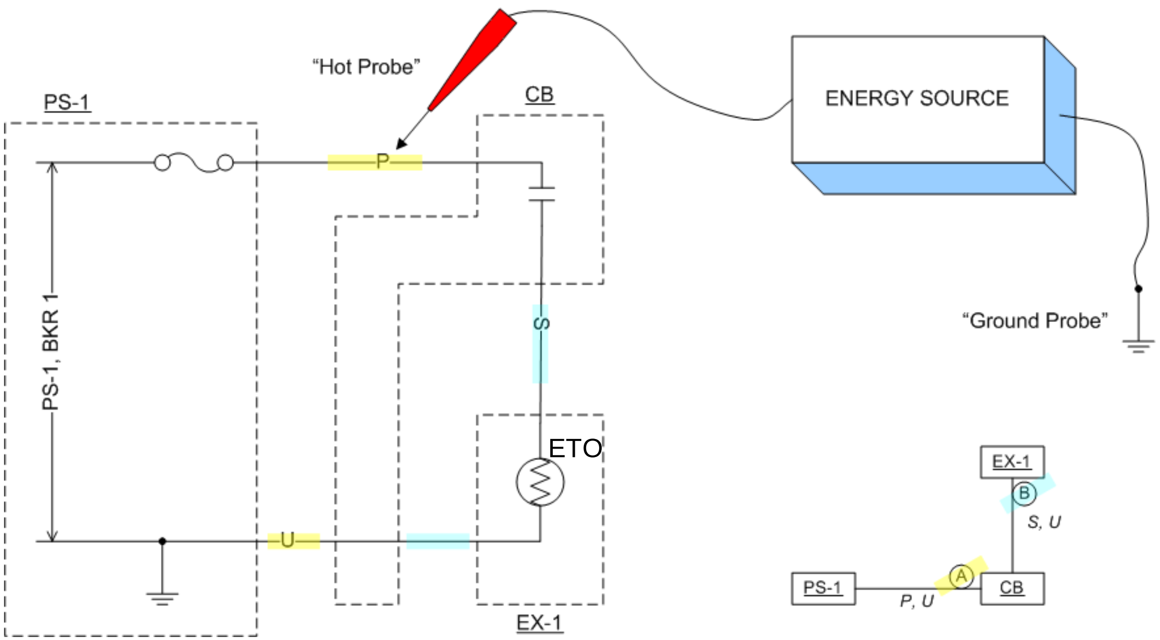
+

Example Usage:

LOP-BF:	Loss of power due to a blown fuse
SO-HS:	Spuriously opens due to a hot short
LOC-PR:	Loss of control due to a protective relay

DETAILED CIRCUIT FAILURE ANALYSIS

Hot Probe Method – A very simple example



What happens when the **Hot** & **Ground** probes contact:

Conductor	Hot (+) Probe	Ground Probe
P?	None	LOC-BF
S?	SO-HS	LOC-BF
U?	None	None

DETAILED CIRCUIT FAILURE ANALYSIS

Hot Probe Method Results & Documentation

CIRCUIT ANALYSIS WORKSHEET

Component ID MOV-8112-A Component Type MOV

Component Description RCP #1 Seal Water Return Isolation

Normal Position Open
Failed Electrical Position As-Is
Failed Air Position N/A
Function State 8112A-OPEN-OPEN
Initial Position Open
Desired Position Closed
BE Code 8112A-FTC

High Consequence Component Yes ☐ No ☒

Power Supplies MCC-1B Breaker 11BD Req'd ☒
Breaker Req'd ☐

Cable Analysis

Cable ID	Req'd?	MHS?	Fault Consequence	Comments
1VAFU-T4A				
1VAFU-T4B				
1VAFU-T4C				
1VAFU-T4D				
1VAFU-T4F				
1VAFU-T4P				
1VAFU-T4Q				
1VAFU-T4Z				

This information should be available from component selection.

If not complete, then get the missing information before beginning.

This part and 2nd page ***you*** will complete.

Basically, this documents your analysis.

DETAILED CIRCUIT FAILURE ANALYSIS

Task 3 / 9A Process

Cable Selection /Circuit Analysis
Recommended Process for Task 3 & Task 9A

Preparation

1. Collect Drawings
2. Understand functional state requirements of the circuit
3. Decide on:

   Active functional state - Power is required to meet function state requirements

   or

   Passive functional state – Power is not required to meet function state requirements

Power Supply

4. Identify power supply and breaker/fuse for the circuit
5. Is power required to achieve/maintain functional state?
6. Determine requirement for "Alternate" power (if applicable)

Contact Positions / Cable-Conductor Markup

7. Mark up contact positions on drawings for "**Initial**" condition or state (*Don't guess, use limit switch legends and switch developments*)
8. Highlight schematic (elementary) & block diagrams to show cable - conductor relationship

Hot-Probe Assessment

9. Using Hot-Probe and Ground-Probe technique, identify failure mode(s) for each conductor

   NOTE: Remember that this technique for Task 3/9A assumes a "source" conductor is present and does not distinguish between intra-cable and inter-cable hot short
10. Roll up conductor failure modes to cable(s)

Cable Selection /Circuit Analysis
Recommended Process for Task 3 & Task 9A

Off-Scheme Circuits / Dependencies

11. Assess each control contact from off-scheme circuits (auxiliary contacts) to decide if it can impact the function state:
    - Is contact needed for proper operation of a credited automatic function
    - Could contact prevent automatic or manual operation
    - Could contact by itself (or in conjunction with another circuit failure) cause a spurious operation
12. If contact could affect function state, then an "Equipment Dependency" exists with the contact's circuit.

Document Analysis

13. Document analysis per established process
14. File all markup drawings and notes in component work package (Current "Best Practice" is create electronic work package)
15. Generate failure reports as required to support PRA quantification

DETAILED CIRCUIT FAILURE ANALYSIS

Any Questions?