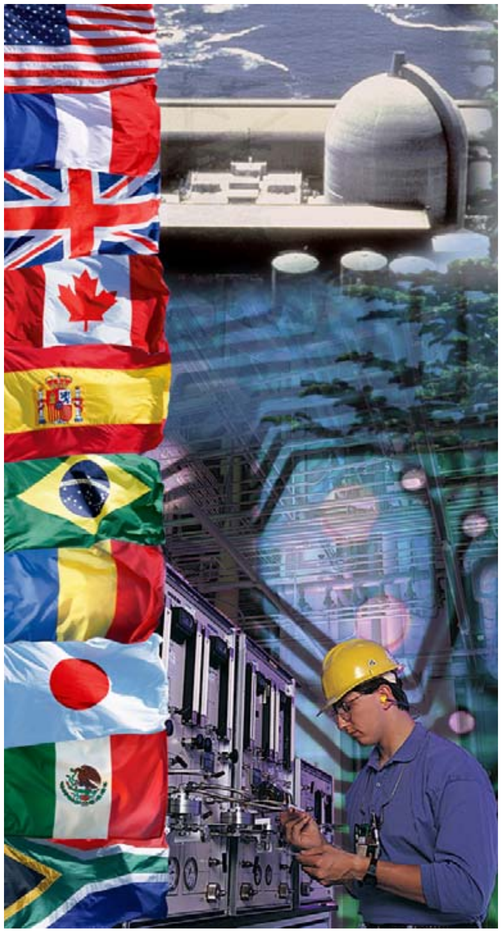


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Fire PRA Circuit Analysis Overview

D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories
Joint RES/EPRI Fire PRA Workshop
July and August 2007
Palo Alto, CA

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

CIRCUIT ANALYSIS
Presentation Road Map

- Circuit Analysis "Big Picture" Overview
- Circuit Analysis Strategy & Implementation
- Introduction to Key Considerations & Factors
- Review and Discussion of Tasks
- Relationship to Appendix R & NFPA 805
- Examples

CIRCUIT ANALYSIS
Circuit Analysis Tasks

- Task 3 – Fire PRA Cable Selection
- Task 9 – Detailed Circuit Analysis
- Task 10 – Circuit Failure Mode Likelihood Analysis
- Support Task B – Fire PRA Database

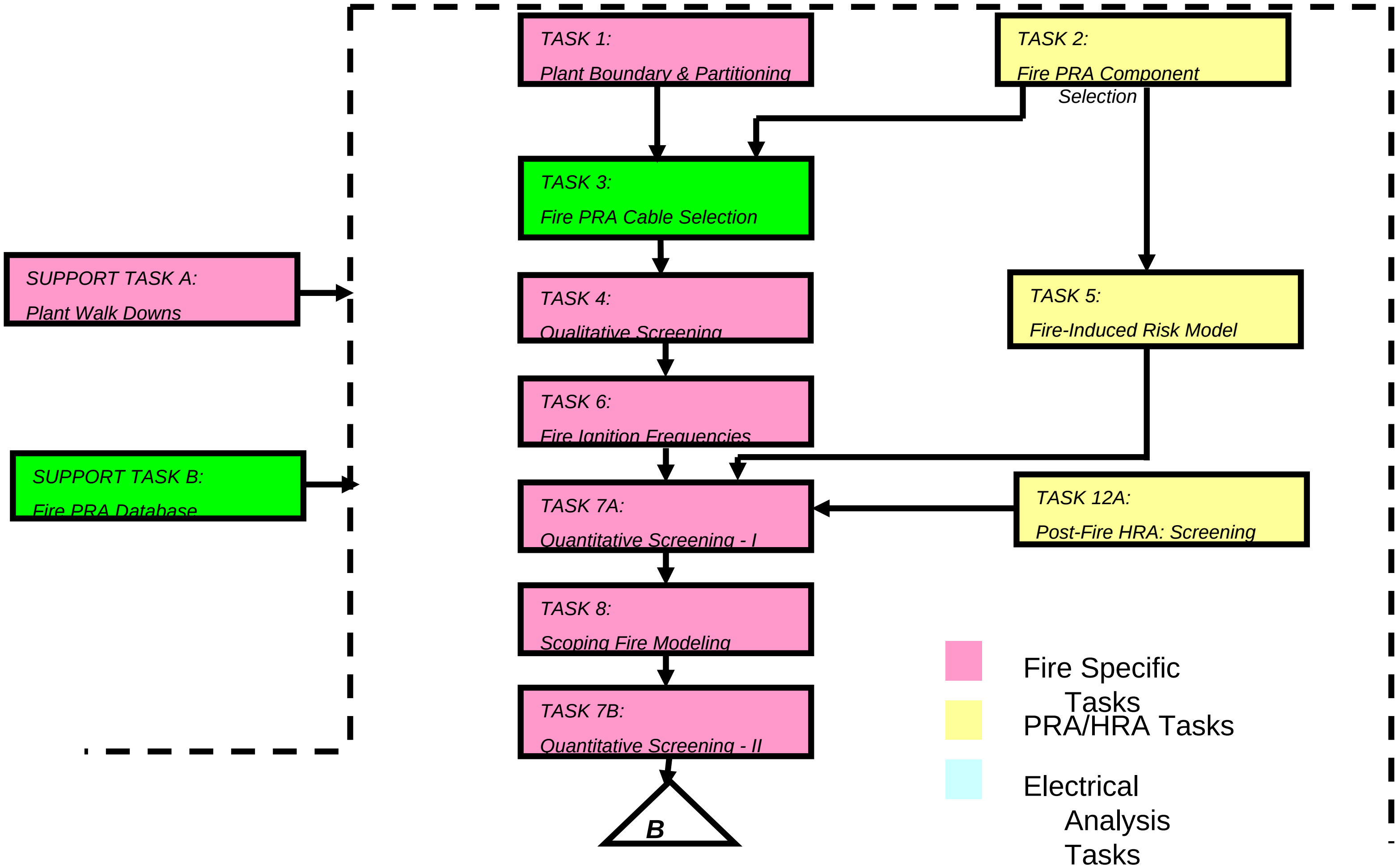
CIRCUIT ANALYSIS
Circuit Analysis Overview

- Substantial Technical and Process-Related Advances
- Collective Awareness of Circuit Failure Implications Greatly Improved
- Knowledge Base Improvements
  - Fire Tests: EPRI, CAROLFIRE, Duke: Better but not perfect understanding of fire-Induced circuit failures
  - Working knowledge in applying test results
  - Practical experience from NFPA 805 transition projects

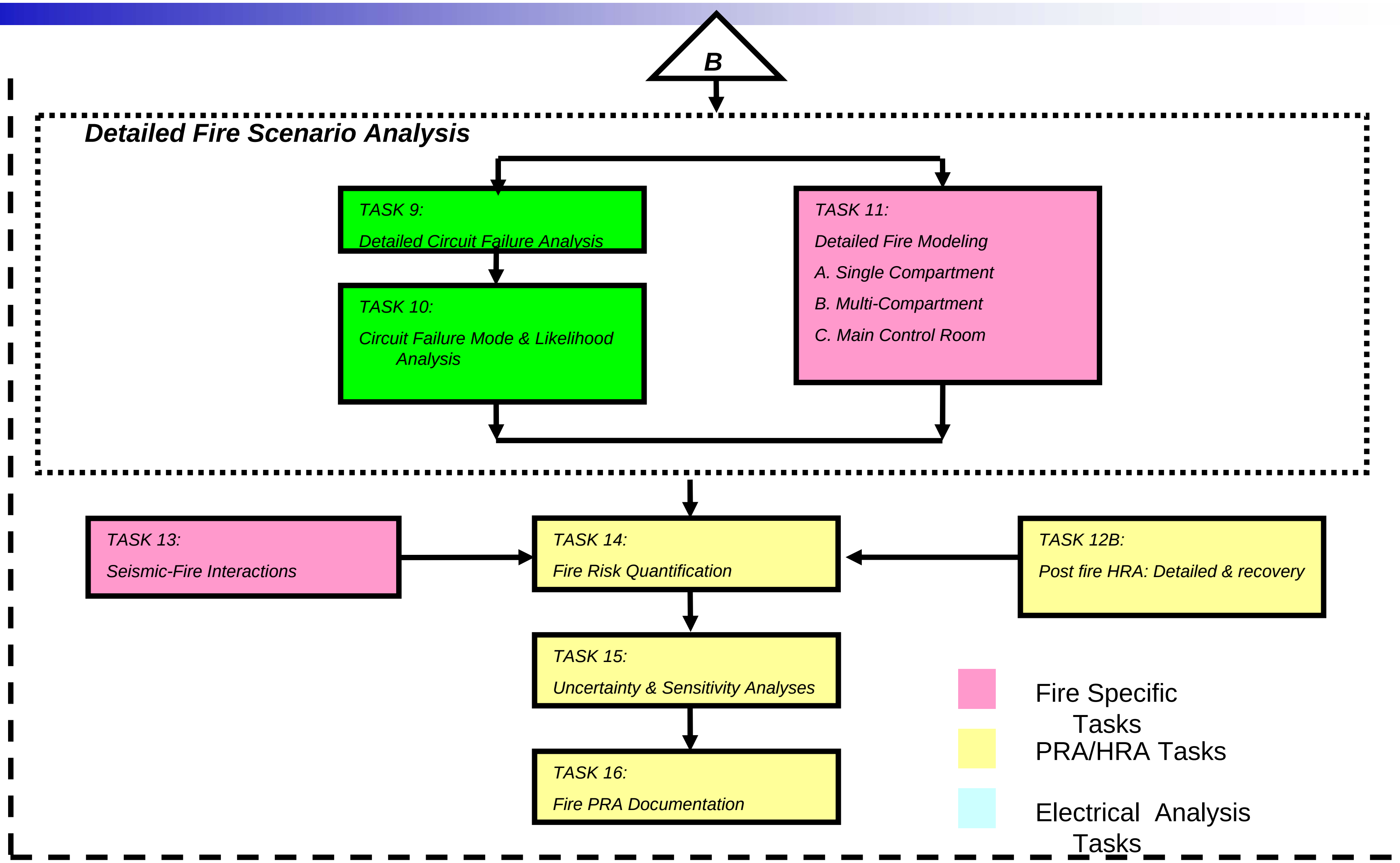
CIRCUIT ANALYSIS
Circuit Analysis Overview

- Circuit Analysis is Now an Integral and Formal Part of the Fire PRA Process
  - Rigorous and formal process for correlating cables-to-equipment-to-affected locations
  - Definitive data and criteria has replaced estimations and judgment
  - Emerging trend to Integrate with Appendix R circuit analysis
- Further Refinements to "State-of-the-Art" Techniques Realistic
  - Practical aspects of dealing with an integrated data set
  - Practical approach for dealing with MSOs

CIRCUIT ANALYSIS
PRA Task Flow Chart



CIRCUIT ANALYSIS
PRA Task Flow Chart



CIRCUIT ANALYSIS
Overall Strategy & Implementation

- Each Electrical Analysis Task Represents a Refined Level of Detail, i.e., Graded Approach
- Level-of-Effort for the Electrical Work is a Key Driver for Project Scope, Schedule, and Resources
  - High Programmatic Risk if Not Carefully Controlled
  - Analysis and Routing of all Cables can be a Large Resource Sink with Minimal Overall Benefit
  - Concerns Validated by Numerous Projects
- Detailed Analysis Driven by Quantitative Screening Results
  - Intelligence-Based Circuit Analysis
  - Iterative Process
  - Conservative First Pass with Realism Incorporated Where it Matters

CIRCUIT ANALYSIS
Overall Strategy & Implementation

- Recommended Methods are Consistent with Industry Best Practices
- Use Risk Perspectives to Streamline and Focus Analysis
- Remains a Technically and Logistically Challenging Area
- Limitations to the State-of-the-Art:
  - Number of Multiple Hot Shorts/Spurious Actuations
  - Spurious Actuation Probabilities
  - Timing Considerations

CIRCUIT ANALYSIS
Overall Strategy & Implementation

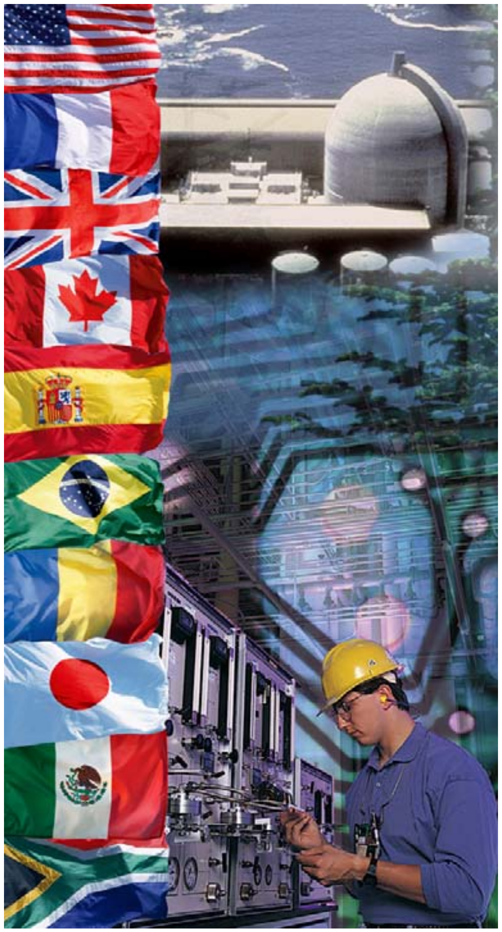
- Circuit Analysis (including cable tracing) Can Consume 40%-70% of Overall Budget
- Circuit Analysis Scope MUST be a Primary Consideration During Project Scoping
- Qualified and Experienced Electrical Analysts Must be Integral Member of PRA Team
- Coordination and Integration with Appendix R Must Occur Early and Must be Rigorous
- Coordination with Task 2 (Component Section) is Essential – MUST Understand the EXACT Functionality Credited for Each Component

CIRCUIT ANALYSIS
Key Considerations

- Relationship with Appendix R/NFPA 805 Analysis
- Long-Term Strategy for Data Configuration Control – Especially if Shared Data with Appendix R
- Availability, Quality, and Format of Cable Data
- Usability of Appendix R Circuit Analysis Data
  - Recent Re-Analysis
  - Automated Tools
  - Many plants are finding that circuit analysis rebasline is necessary to support upgraded Fire PRA and Appendix R Associated Circuits (RIS 2004-003)
- User-Friendliness of Electrical Drawings
- Off-Site Power Analysis
- Availability of Electrical Engineering Support

CIRCUIT ANALYSIS
Summary

- Do Not Underestimate Scope
- Ensure Proper Resources are Committed to Project
- Very Doable But **MUST** Work Smart
- Do Not "Broad Brush" Interface with Appendix R – Have a Detailed Plan Before Starting
- Constant Interaction with Systems Analysts Critical
- Develop Project Procedures – But Don't Get Carried Away
- Compilation and Management of Large Volume of Data
  - Automated Tools Imperative for Efficient Process
  - Be Mindful of Long-Term Configuration Management



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Task 3 - Fire PRA Cable Selection

D. Funk - Edan Engineering Corp
F. Wyant - Sandia National Laboratories
Joint RES/EPRI Fire PRA Course
July and August 2007
Palo Alto, CA

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

FIRE PRA CABLE SELECTION
Purpose & Scope

- Identify Circuits/Cables Associated with Fire PRA Components
- Determine Routing/Location of the Identified Cables
- Use Component-to-Cable-to-Location Relationships to Determine What Components Could be Affected for Postulated Fire Scenarios

  Note: Scenario can be Fire Area, Room, Raceway, or Other Specific Location

- Identify Fire PRA Power Supplies

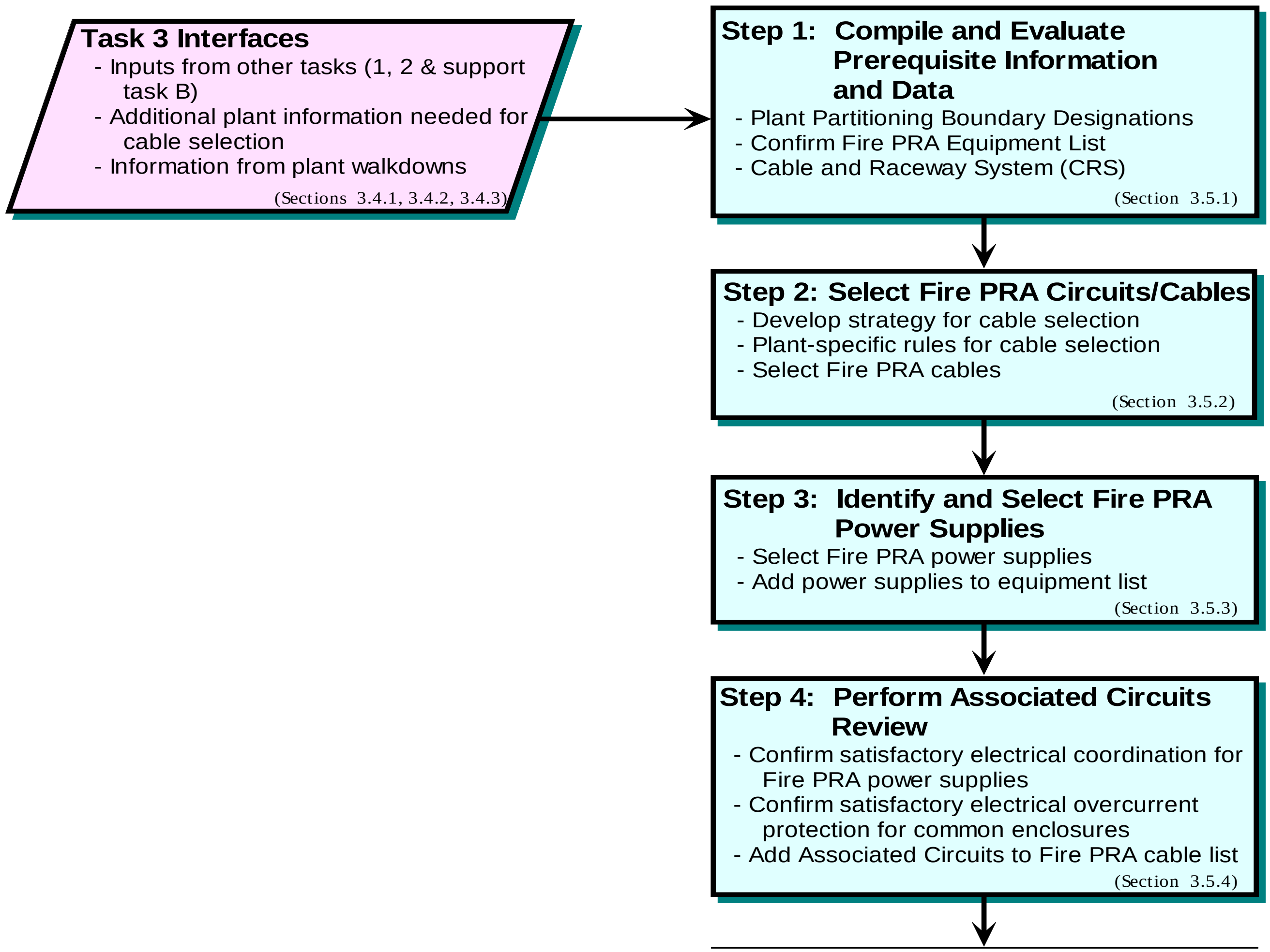
FIRE PRA CABLE SELECTION
Introduction

- Conducted for all Fire PRA Components

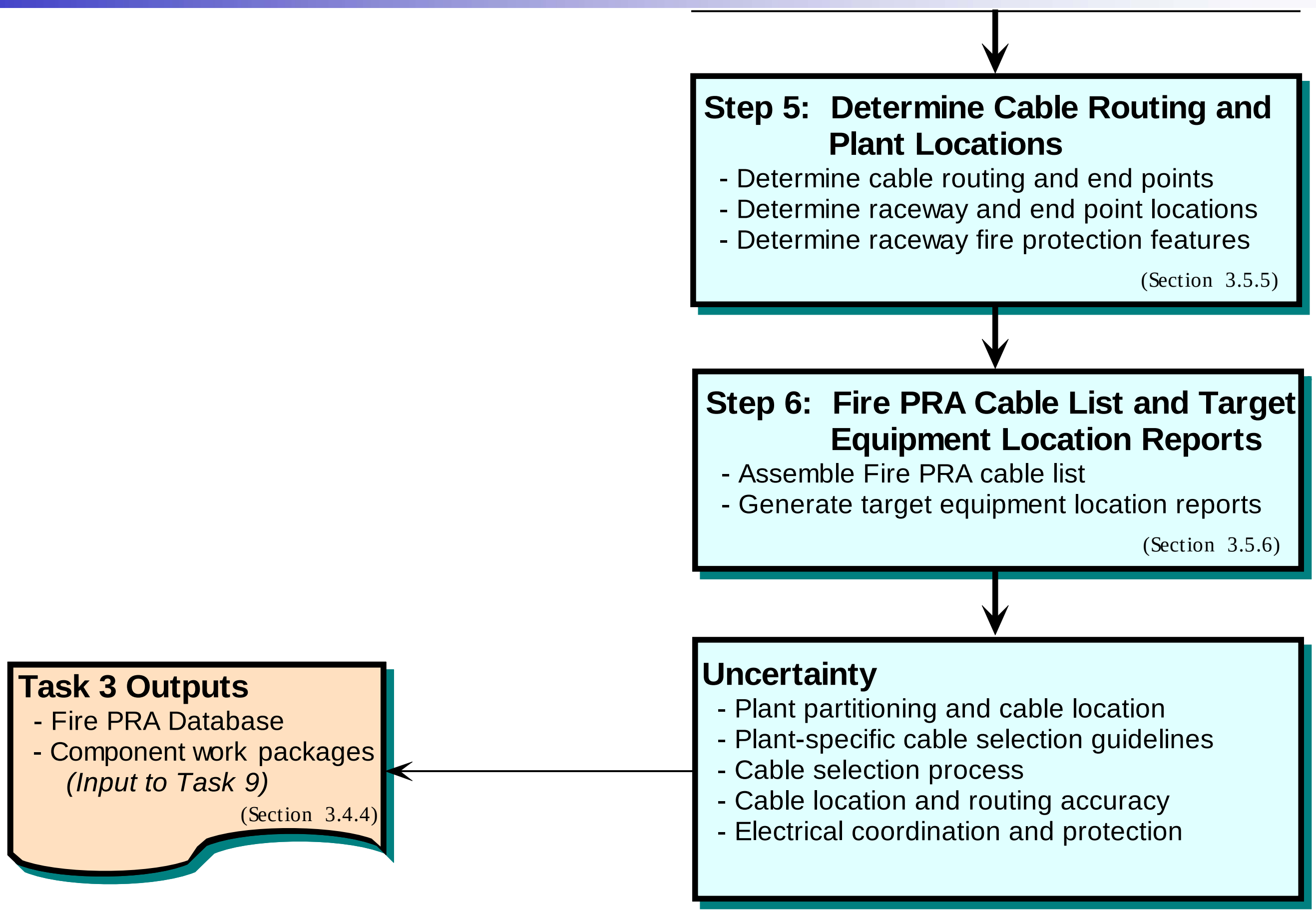
  Note: Exceptions do exist

- Deterministic Process
- Cables Associated to Components Irrespective of Failure Mode
  - Some circuit analysis incorporated to prevent overwhelming the PRA model with inconsequential cable failures
  - Final product is a listing of components that could be impacted by a fire for a given location (Fire Area, Fire Compartment, Fire Scenario)
- Procedure subdivided into six (6) distinct steps

FIRE PRA CABLE SELECTION
Flowchart



FIRE PRA CABLE SELECTION
Flowchart



FIRE PRA CABLE SELECTION
Task Interfaces - Input

- Plant Boundary Partitions (Task 1)
- Fire PRA Component List (Task 2)
- Fire PRA Database (Support Task B)
- Appendix R Circuit Analysis
- Plant Cable & Raceway Database
- Plant Drawings

FIRE PRA CABLE SELECTION
Task Interfaces - Output

- Fire PRA Cable List
- Fire PRA Power Supply List
- Associated Circuits review
- Component Analysis Packages
- Target Equipment Location Reports (Potential Equipment Losses Broken Down by Location or Scenario)

FIRE PRA CABLE SELECTION
Step 1 – Prerequisite Information

- Confirm Plant Partitioning is Compatible
  - Do partitions align with cable location data?
- Confirm PRA Equipment List is Final
  - Input into a formal and controlled database
- Evaluate Database Requirements
  - What currently exists?
  - What is needed to support work?
  - How is data to be managed and controlled?
  - This is a “Biggy”

FIRE PRA CABLE SELECTION
Step 2 – Select Fire PRA Cables

- Analysis Cases
  - Appendix R Component with Same Functional Requirements
  - Appendix R Component with Different Functional Requirements
  - Non-Appendix R Component with Cable Location Data
  - Non-Appendix R Component without Cable Location Data

- Analysis Sub-Steps
  - Step 2.1 - Analysis Strategy
  - Step 2.2 - Plant Specific Rules
  - Step 2.3 - Select Cables

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy

- Coordinate with Systems Analysts to Establish Functional Requirements and General Rules
  - Equipment functional states, basic events, initiators
  - Initial conditions and equipment lines (i.e., normal state)
  - Consistent conventions for equipment functions/state/position
  - Multiple function components
- Evaluate Appendix R Component & Circuit Data
  - Ensure equipment list comparison conducted during Task 2
  - Review in detail the comparison list – ask questions
  - Essential that comparison includes detailed review/comparison of "desired functional state(s)"

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy

- Goal – Efficient and Accurate Process to Obtain Required Information
- Revisit Past Assumptions, Conventions, Approach
- Potential Trouble Areas
  - How is off-site power going to be handled?
  - Instrument circuits – understand exactly what is credited
  - ESAFA, Load-Shed, EDG Sequencer
  - Medium-voltage switchgear control power
- Extent of Detailed Analysis to be Conducted Concurrently
- Determine How Analysis Will be Documented

FIRE PRA CABLE SELECTION
Step 2.2 – Plant Specific Cable Selection Rules

- Objective is Consistency
- Approach for Groups of Components
- Approach for Spurious Actuation Equipment
- Auxiliary Contacts
- System-Wide Actuation Signals
- Bus or Breaker?
- Subcomponents
- Identification of Permanent Damage Scenarios
- Procedure - Develop Circuit Analysis Procedure/Guidelines

FIRE PRA CABLE SELECTION
Step 2.2 – Ready to Start?

- Develop Written Project Procedure/Guidelines
  - Consistency, Consistency, Consistency
  - Checking Process?
  - Problem Resolution

- Training for Analysts

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- Case 1: Incorporate Existing Appendix R Analysis
  - Confirm adequacy of existing analyses IAW plan
- Cases 2 & 3: New Functional State/Component: w/ Cable Routing Data
  - Collect drawings and/or past analysis information
  - Identify/select cables IAW plant specific procedure/guidelines
  - Conduct detailed analysis to the extent decided upon
  - Formally document cable selection IAW established procedures/guidelines

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- Case 3: New Component: w/o Cable Routing Data Available
  - Same as Case 2 & 3, plus…
  - Determine cable routing and associate with plant locations

- Analysis Work Packages
  - Retrieve from Past Appendix R Analysis
  - Highly Recommended for New Components
  - Major time saver for future work

FIRE PRA CABLE SELECTION
Step 3 – Select Fire PRA Power Supplies

- Identify Power Supplies as Integral Part of Cable Selection
  – Make sure to differentiate between “Required” and “Not Required” power supplies
  – Switchgear and Instrument power supplies can be tricky
- Add Power Supplies to Fire PRA Component List
- Make sure Fire PRA model, equipment list, and electrical analysis are consistent
- Does Fire PRA model consider spurious circuit breaker operations?

FIRE PRA CABLE SELECTION
Step 4 – Associated Circuits Review

- Objective is to Confirm Existing Studies Adequate
- View the Process as a “Gap Analysis”
- Common Power Supply Circuits - Assess Plant Coordination Studies
- Common Enclosure Circuits - Assess Plant Electrical Protection
- Roll Up Results to Circuit Analysis or Model as Appropriate

  Note: Ensure Switchgear Internal Fusing Supports Analysis Assumptions

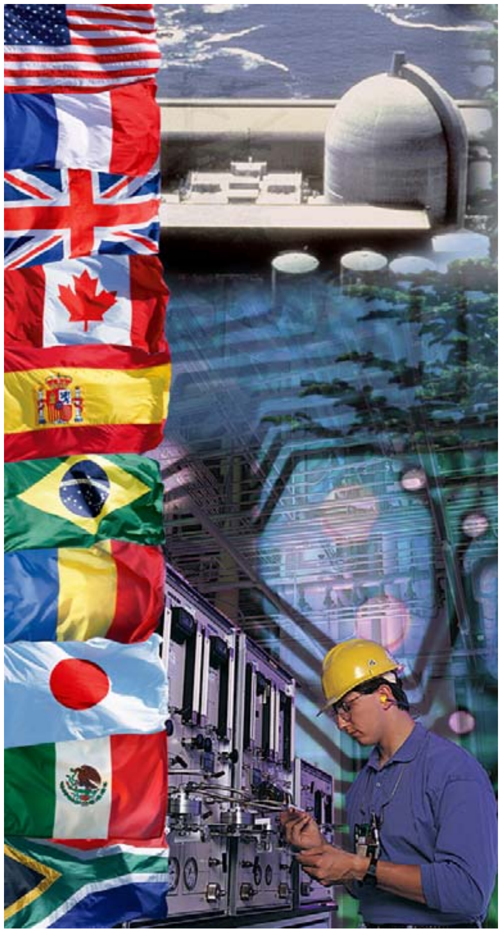
FIRE PRA CABLE SELECTION
Step 5 – Determine Cable Routing and Locations

- Correlate Cables-to-Raceways-to-Locations
- Conceptually Straightforward
- Logistically Challenging
  - Labor intensive
  - Manual review of layout drawings
  - Plant walkdowns often required
- Determine Cable Protective Features
  - Fire wraps
  - Embedded conduit

FIRE PRA CABLE SELECTION
Step 6 – Target Equipment Loss Reports

- Data Entered into Fire PRA Database
- Sorts and Queries to Generate Target Equipment Location Reports

Perspective….Cable selection process should be viewed as providing "Design Input" to the Fire PRA. It does not, however, provide any risk-based results. In its simplest form it provides a list of equipment that could be affected by a fire at a specified location or for a specific scenario.



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Task 9 - Detailed Circuit Failure Analysis

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D. Funk - Edan Engineering Corp.
Joint RES/EPRI Fire PRA Course
July and August 2007
Palo Alto, CA

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

DETAILED CIRCUIT FAILURE ANALYSIS
Purpose & Scope

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

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (1)

- Fundamentally a deterministic analysis
- Conduct coincident with cable selection (Task 3) to the extent feasible and cost effective
- 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 that CANNOT impact the ability of a component to fulfill the specific function of interest

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (2)

- Failure Modes Considered
  - Single Shorts-to-Ground (Reference Ground)
    - Grounded System
    - Ungrounded System
    - Resistance Grounded System
  - Single Hot Shorts
  - Compatible Polarity Multiple Hot Shorts for Ungrounded AC and DC Circuits
  - Coincident Independent Hot Shorts On Separate Cables
  - Multiple Intra-cable Hot Shorts
  - Cables Associated Through Common Power Supply

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (3)

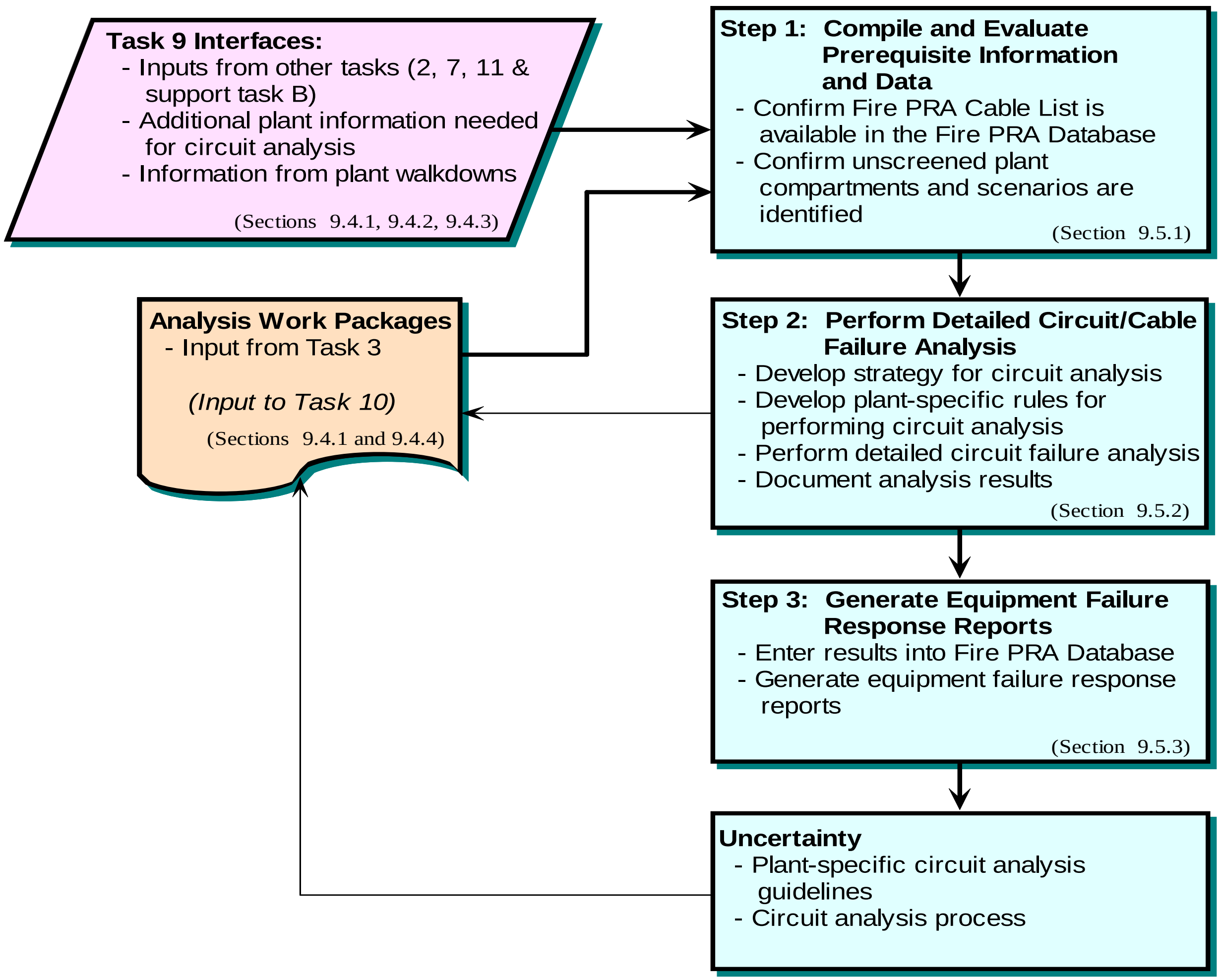
- Failure Modes NOT Considered
  - 3-phase proper sequence hot shorts (except high consequence equipment and thermoplastic insulated conductor)
  - Inter-cable hot shorts for armored cable and cable in dedicated conduit
  - Open circuit conductor failures
  - Multiple high-impedance faults

DETAILED CIRCUIT FAILURE ANALYSIS
Assumptions

The Following Assumptions Form the Basis for Task 9:

- An Appendix R analysis for the plant has been completed and is available for identifying equipment failure responses to specific cable failure modes
- Component **Work Packages** have been assembled as part of the Task 3 activities or previous Appendix R analyses
- Equipment is assumed to be in its normal position or operating condition at the onset of the fire – the equipment state might be variable
- Users of this procedure are knowledgeable on and have experience with circuit design and analysis methods

DETAILED CIRCUIT FAILURE ANALYSIS
Flowchart



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 Screenings (Task 7)
- Results of Detailed Fire Modeling (Task 11)
- Appendix R Circuit Analysis
- Plant Drawings
- CRS Database

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Outputs

- Equipment Failure Response Reports
- Component Analysis Packages (Updated)
- Revised Cable List
- Fire PRA Database & Model Updates

DETAILED CIRCUIT FAILURE ANALYSIS
Step 1 - Compile Prerequisite Information

- Ensure that prerequisite information and data is available and usable before beginning the analyses (ideally the necessary drawings are already in the Work Packages).
- Step 1.1: Confirm Fire PRA Cable List is Available in the Fire PRA Database
  - Component $\Rightarrow$ Cable $\Rightarrow$ Raceway $\Rightarrow$ Compartment
- Step 1.2: Confirm Unscreened Plant Compartments and Scenarios are Identified
  - Target Equipment Location Reports
  - Equipment ID, Normal Status, Functional Requirements, etc.

DETAILED CIRCUIT FAILURE ANALYSIS
Step 2 - Perform Circuit Failure Analysis

- Perform a *Deterministic-Based* detailed circuit analysis for the Fire PRA cables of interest that are located in the unscreened plant locations.
- 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

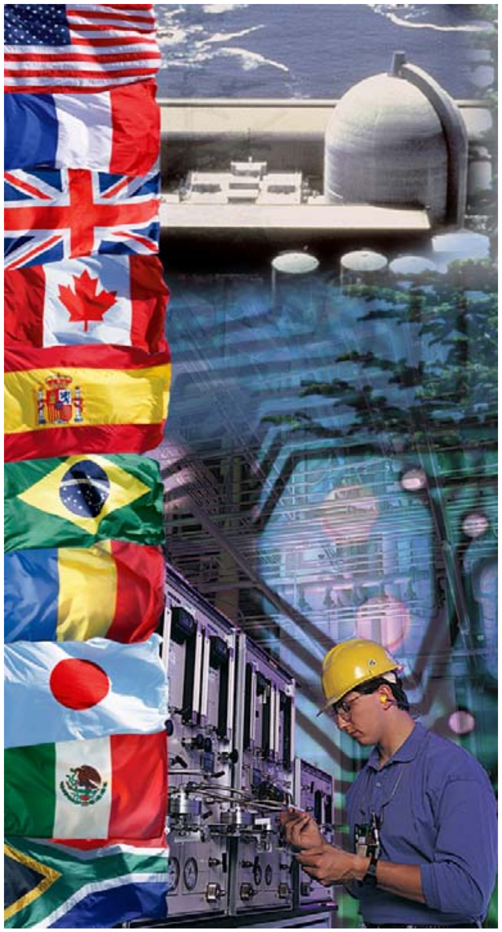
DETAILED CIRCUIT FAILURE ANALYSIS
Step 3 - Generate Equipment Failure Response Reports

- Enter Results into Fire PRA Database

- Generate Equipment Failure Response Reports
  - A Listing by location (room, zone, area) of equipment and associated cables affected by fire
  - Provides specific equipment responses that are possible as a result of fire damage to the cables
  - May only need to track equipment responses of concern to the PRA Model

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



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Task 10 - Circuit Failure Mode Likelihood Analysis

F. Wyant - Sandia National Laboratories
D. Funk - Edan Engineering Corp.
Joint RES/EPRI Fire PRA Workshop
July 23-25, 2007 and August 27-30, 2007
Palo Alto, CA

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

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Purpose & Scope

The Circuit Failure Mode Likelihood Analysis Task is Intended to:

- Establish First-Order Probability Estimates for the Circuit Failure Modes of Interest

AND

- Correlate Those Failure Mode Probabilities to Specific Components

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (1)

- Probabilistic Based Analysis
- Two Methods Presented
  - Expert Panel Results (Look-Up Tables)
  - Computation-Based Analysis (Formulas)
- Requires Knowledge About Circuit Design, Cable Type and Construction, Installed Configuration, and Component Attributes
- Generally Reserved for Only Those Cases that Cannot be Resolved Through Other Means

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (2)

- Caveats:
  - Our Knowledge is Greatly Improved but Uncertainties are Still High
    - Very limited data for many issues
  - For This Reason, Implementing Guidance is Conservative
  - Practical Implementation is Challenging
  - Further Analysis of Existing Test Data and Follow-On Tests Would be Beneficial:
    - Reduce Uncertainties, including conservatisms as appropriate
    - Solidify Key Influence Factors
    - Incorporate Time as a Factor
    - Incorporate "End-Device" Functional Attributes and States (e.g., latching circuits vs. drop-out design)
  - Computation-based method (formula) is an extrapolation of existing data; validation remains to be done. Conservatism has not been established.
- Probabilities of sufficient quality to move ahead

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (3)

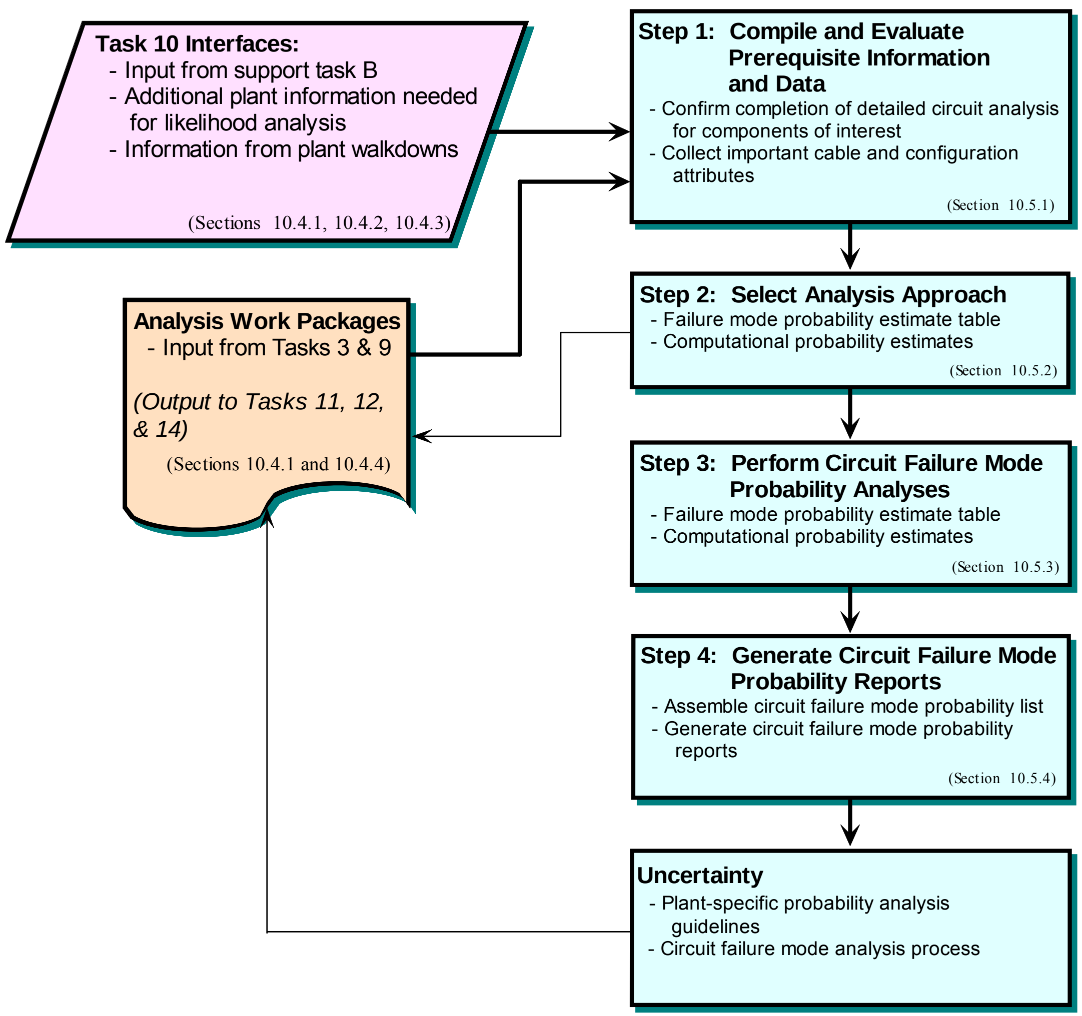
- Public and Peer Review Comments
  - Several Questions Involving Interpretation of the EPRI Test Data Lead to Extensive Discussions Regarding the Most Appropriate Way to Tally Spurious Actuation Probabilities (Many Subtleties for Implementation)
  - Team's Consensus is that Expert Panel Values are, in General, somewhat Conservative
  - Additional Independent Review of the Computational Method was Solicited as a Result of Peer and Public Comments
    - Review was Favorable, However the Team Acknowledges the Inevitable Limitations With a "Version 1.0" Release

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Assumptions

The Following Assumptions Form the Basis for Task 10:

- Specific Cable/Circuit Configuration Attributes are Available or Can Be Determined
- The Equipment is in Its Normal Position or Operating Condition at the Onset of the Fire
- Users of This Procedure are Knowledgeable and Have Experience with Circuit Design and Analysis Methods and Probability Estimating Techniques
- This Analysis Method is Applied to Cables with No More than 15 Conductors

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Flowchart



CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Task Interfaces - Inputs

- Fire PRA Cable List (Task 3)
- Fire PRA Database (Support Task B)
- Results of Detailed Circuit Failure Analysis (Task 9)
- Specific Scenarios Identifying Affected Cables (Tasks 11 & 14)
- Cable & Circuit Configuration Attributes
- Plant Drawings

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Task Interfaces - Outputs

- Quantification of Fire Risk (Task 14)
- Post-Fire HRA (Task 12)
- Detailed Fire Scenario Quantification (Task 11)
- Circuit Failure Mode Probability Reports
- Component Work Packages (Finalized)
- Fire PRA Database & Model

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 1 - Compile Prerequisite Information

Ensure that Prerequisite Information and Data is Available and Usable before Beginning the Analyses.

- Confirm Completion of Detailed Circuit Analysis for Components of Interest
- Collect Important Cable and Configuration Attributes
  - Insulation
  - Number of Conductors
  - Raceway Types
  - Power Source(s)
  - Number of Source & Target Conductors (for Option #2 Only)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 2 - Select Analysis Approach

Decide Which Analysis Option is Best Suited for Conducting the Evaluation.

1. Failure Mode Probability Estimate Tables
   - Grounded Circuit Design
   - Non-Complex Control Circuit
   - Single Component Service
   - Cable Configuration Matches Table Categories
   - Principal Failure Mode of Concern is Spurious Actuation
2. Computational Probability Estimate Formulas
   - Ungrounded or Resistance-Grounded Circuit Design
   - Complex Circuit or Component
   - Failure Potentially Affects Multiple Components
   - Cable Configuration Not Easily Categorized in Tables

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 3 - Estimate Circuit Failure Mode Probabilities

Estimate Circuit Failure Mode Probabilities Employing the Selected Method

Option #1: Failure Mode Probability Estimate Tables

- Table 10-1, Thermoset Cables with CPTs
- Table 10-2, Thermoset Cables without CPTs
- Table 10-3, Thermoplastic Cables with CPTs
- Table 10-4, Thermoplastic Cables without CPTs
- Table 10-5, Armored or Shielded Cables

Option #2: Computational Probability Estimate Formulas

$$P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 \times C_G) + n]$$

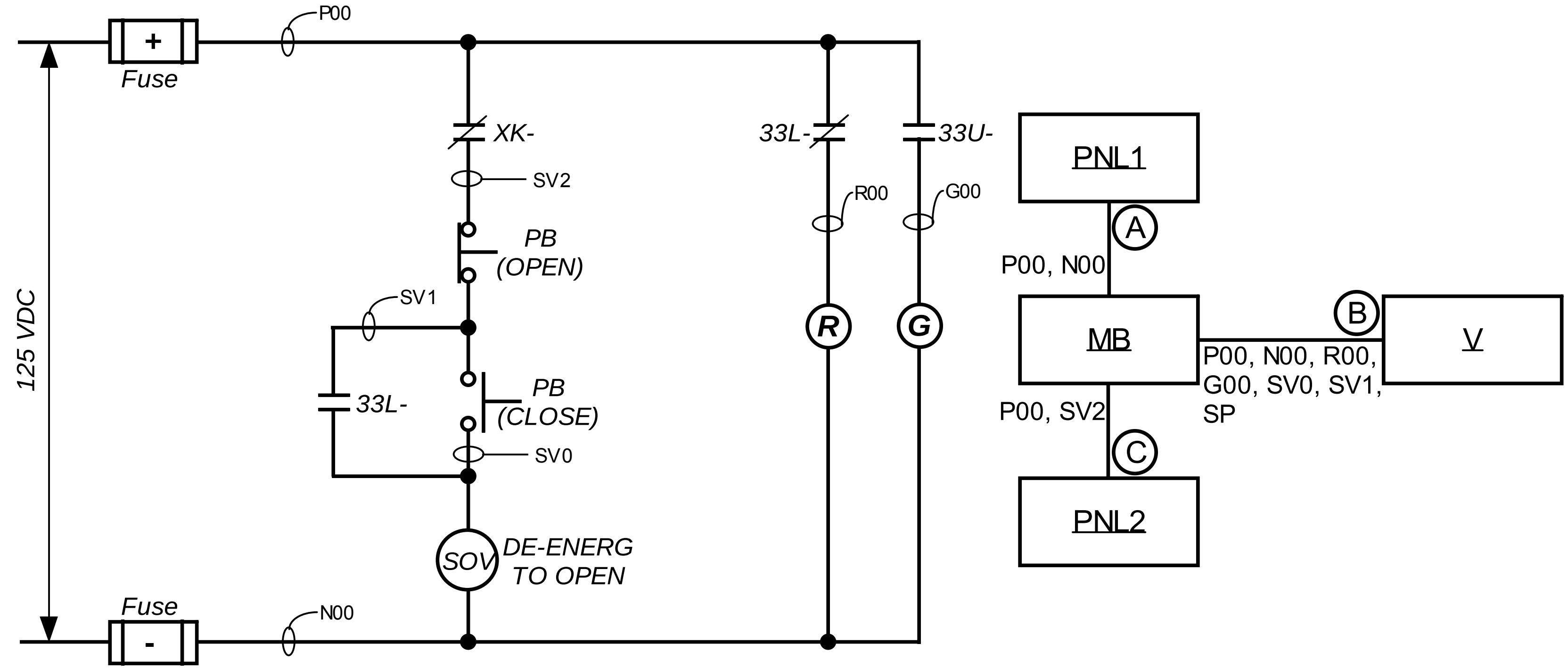
$$CF = \{C_T \times [C_S + (0.5 / C_{Tot})]\} / C_{Tot}$$

$$P_{FM} = CF \times P_{CC}$$

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 4 - Generate Failure Mode Probability Reports

- Enter Results into Fire PRA Database
- Generate Circuit Failure Mode Probability Reports
  - Listing the Probability Estimates for the Circuit Failure Modes of Concern for Each Component of Interest by Plant Area (Compartment, Fire Area, Fire Zone, etc.)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example - SOV Control Circuit



Valve Shown in Open Position

QUESTION: What is the *probability* that damage to Cable B will result in spurious closure of the SOV?

See next slide →

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 1: Prerequisite Information

- Detailed circuit analysis completed & documented? ***Yes***

Cable	+125 VDC Hot Probe	-125 VDC Hot Probe
A	LOC	LOC
B	LOC, EI, SO - Close	LOC
C	NC	LOC

- Collect important cable and configuration data:
  - Cable insulation? ***Thermoset***
  - Number of conductors? ***Seven***
  - Raceway type? ***Tray***
  - Power source? ***Ungrounded DC bus (no CPT)***
  - Number of source & target conductors? ***3 sources, 1 target***

See next slide →

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 2: Select Analysis Approach

- Option #1: Failure Mode Probability Tables
  - Grounded circuit design? ***No***
  - Control circuit cable? ***Yes***
  - Single component circuit? ***Yes***
  - Known cable configuration? ***Yes***
  - Spurious operation concern? ***Yes***
- Option #2: Computational Probability Estimate
  - Ungrounded circuit? ***Yes***
  - Complex circuit/component? ***No***
  - Multiple component circuit? ***No***
  - Cable configuration not categorized? ***No***

For this example, we'll show both methods

See next slide →

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 3: Perform Analysis (1)

- Option #1:
  - Which Table to Use? ***Table 10-2, Thermoset Cable without CPT***

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.60 0.40 0.20 0.02 – 0.1	0.20 – 1.0 0.1 – 0.60 0.1 – 0.40
Conduit	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.15 0.1 0.05 0.01 – 0.02	0.05 – 0.25 0.025 – 0.15 0.025 – 0.1

  - Probability Estimate, **P** = <u>0.62</u> (0.60 + 0.06 – 0.60*0.06)

See next slide →

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 3: Perform Analysis (2)

- Option #2:
  - Calculate probability of a conductor-to-conductor short:

$$P_{CC} = (C_{Tot} – C_G) / [(C_{Tot} – C_G) + (2 * C_G)]$$

$$P_{CC} = (7 – 1) / [(7 – 1) + (2 * 1)]$$

$$P_{CC} = 6 / [6 + 2]$$

$$P_{CC} = 0.75$$

  - Determine cable configuration factor:

$$CF_{SO} = \{C_T * [C_S + (0.5 / C_{Tot})]\} / C_{Tot}$$

$$CF_{SO} = \{1 * [3 + (0.5 / 7)]\} / 7$$

$$CF_{SO} = 3.071 / 7$$

$$CF_{SO} = 0.44$$

  - Probability of spurious operation, $\mathbf{P}_{SO}$ = 0.75 * 0.44 = <u>0.33</u>

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 4: Failure Mode Probability Report

Failure Code	Estimated Probability (Calculated)	Estimated Probability (From Table 10-2)
SO (Closed)	0.33	0.62

Task 10: Circuit Failure Mode Likelihood Analysis Methodology

This document summarizes the process for determining the probability, or likelihood, of a particular circuit failure mode occurrence. It includes the five Failure Mode Probability Estimate Tables employed under the Option #1 analysis approach, and the Option #2 Computational Probability Estimate formulas. **Important!** Please refer to the complete discussion of this methodology provided in NUREG/CR-6850, EPRI 1011989, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities; Volume 2: Detailed Methodology," Final Report, September 2005.

Selecting the Analysis Approach

1. Option #1: Failure Mode Probability Estimate Tables

   Tables of probability estimates would appropriately be used for cables that meet the following criteria:

   - The circuit is of a grounded design (including impedance grounded systems with ground fault trip capability),
   - The cable is part of the control circuit for a typical component (e.g., non-complex MOVs, SOVs, pumps),
   - The cable is associated with a single component,
   - The cable configuration is known and can be readily associated with one of the defined configurations in Tables 1 through 5, and
   - The principal hot short failure mode of concern is a spurious operation of the component.

2. Option #2: Computational Probability Estimates

   Use of the probability estimate formulas are recommended for cases where:

   - The circuit is ungrounded or is impedance grounded without ground fault trip capability,
   - The cable is part of a relatively complex circuit or component,
   - The cable is associated with or can influence the behavior of multiple components (e.g., safeguards actuation signal, bus shed scheme, etc.),
   - The cable configuration is not easily categorized into one of the defined configurations contained in Tables 1 through 5.

Performing the Circuit Failure Mode Probability Analyses

Option #1: Failure Mode Probability Estimate Tables

1. Categorize the circuit of interest based on its configuration attributes.

2. From the appropriate table (Tables 1 to 5), select the probability estimates for the failure modes of concern.
3. If the cable failure mode can occur due to different cable interactions, the probability estimate is taken as the simple sum of both estimates. For example, if a particular thermoset cable failure mode can be induced either by an intra-cable shorting event (P = 0.30) or by an inter-cable shorting event (P = 0.03; mid-range of 0.01–0.05), the overall probability of that failure mode is estimated to be 0.33.

Table-1
Failure Mode Probability Estimates Given Cable Damage
Thermoset Cable with Control Power Transformer (CPT)

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable	0.30	0.10 – 0.50
	1/C Inter-cable	0.20	0.05 – 0.30
	M/C → 1/C Inter-cable	0.10	0.05 – 0.20
	M/C → M/C Inter-cable	0.01 – 0.05	
Conduit	M/C Intra-cable	0.075	0.025 – 0.125
	1/C Inter-cable	0.05	0.0125 – 0.075
	M/C → 1/C Inter-cable	0.025	0.0125 – 0.05
	M/C → M/C Inter-cable	0.005 – 0.01	

M/C: Multi-conductor cable
1/C: Single conductor cable
Intra-cable: An internally generated hot short. The source conductor is part of the cable of interest
Inter-cable: An externally generated hot short. The source conductor is from a separate cable

Table-2
Failure Mode Probability Estimates Given Cable Damage
Thermoset Cable without CPT

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable	0.60	0.20 – 1.0
	1/C Inter-cable	0.40	0.1 – 0.60
	M/C → 1/C Inter-cable	0.20	0.1 – 0.40
	M/C → M/C Inter-cable	0.02 – 0.1	
Conduit	M/C Intra-cable	0.15	0.05 – 0.25
	1/C Inter-cable	0.1	0.025 – 0.15
	M/C → 1/C Inter-cable	0.05	0.025 – 0.1
	M/C → M/C Inter-cable	0.01 – 0.02	

Table-3
Failure Mode Probability Estimates Given Cable Damage
Thermoplastic Cable with CPT

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.30 0.20 0.10 0.01 – 0.05	0.10 – 0.50 0.05 – 0.30 0.05 – 0.20
Conduit	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.075 0.05 0.025 0.005 – 0.01	0.025 – 0.125 0.0125 – 0.075 0.0125 – 0.05

Table-4
Failure Mode Probability Estimates Given Cable Damage
Thermoplastic Cable without CPT

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.60 0.40 0.20 0.02 – 0.1	0.20 – 1.0 0.1 – 0.60 0.1 – 0.40
Conduit	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.15 0.1 0.05 0.01 – 0.02	0.05 – 0.25 0.025 – 0.15 0.025 – 0.1

Table-5
Failure Mode Probability Estimates Given Cable Damage
Armored or Shielded Cable

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
With CPT	M/C Intra-cable	0.075	0.02 – 0.15
Without CPT	M/C Intra-cable	0.15	0.04 – 0.30

3. When more than one cable can cause the component failure mode of concern, and those cables are within the boundary of influence for the scenario under investigation, the

probability estimates associated with all affected cables should be considered when deriving a failure estimate for the component. In general, the probabilities should be combined as follows:

$$P_{\text{Component failure}} = (P_{\text{Failure Cable A}}) + (P_{\text{Failure Cable B}}) - (P_{\text{Failure Cable A}})(P_{\text{Failure Cable B}})$$

Option #2: Computational Probability Estimates

Application of this calculational method is more complex and is only recommended for cases where Option #1 cannot reasonably be applied. The intent is to give the analyst a means of refining the estimated circuit failure mode probabilities based on the most important characteristics of the cable/circuit under study.

This computational method involves applying circuit failure mode probability estimation formulas. The following discussions provide only the minimum definition of the failure mode likelihood estimation formulas and their terms. For a complete discussion of the technical basis, detailed explanations, and examples of usage, please refer to Appendices J and K in Volume 2 of EPRI 1011989, NUREG/CR-6850.

The probability of occurrence for a specific hot short failure mode (P_{FM}) is estimated by the formula:

$$P_{FM} = CF \times P_{CC},$$

Where:

P_{FM} = The probability that a specific hot short failure mode of interest will occur in a specific circuit given a fire of sufficient intensity to cause cable damage,

P_{CC} = The probability that a conductor-to-conductor short will occur prior to a short-to-ground or short to a grounded conductor, and

CF = A configuration factor applied to P_{CC} to account for the relative number of source conductors and target conductors. Target conductors are those conductors of a circuit that, if contacted by an electrical source of proper magnitude and voltage, will result in abnormal energization of the circuit, component or device of concern. Source conductors represent energized conductors that are a potential source of electrical energy.

1. Calculate P_{CC} as follows:

   Cables in trays: $P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 \times C_G) + 1]$

   Cables in conduit[1]: $P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 \times C_G) + 3]$

   Ungrounded systems: $P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 \times C_G)]$

[1] Armored and shielded cable should use the equation for conduit.

Where:

C_{Tot} = The total number of conductors in the cable of interest (including spares), and

C_G = The number of grounded (or common) conductors in the cable of interest. The analyst should determine the number of grounded/common conductors based on the circuit configuration (contact positions, etc.) that represent the normal operating state of the component. If this information is unavailable or indeterminate, the worst-case conditions should be assumed.

Note: For ungrounded AC and DC systems, C_G represents the number of return conductors to the power source associated with the circuit of interest (e.g., the negative polarity conductors for an ungrounded 125 VDC circuit)

2. Calculate CF as follows.

Non-armored cables: $CF = \{C_T \times [C_S + (0.5 / C_{Tot})]\} / C_{Tot}$

Armored cables: $CF = (C_T \times C_S) / C_{Tot}$

Where:

C_S = The total number of source conductors in the cable under evaluation,

C_T = The total number of target conductors in the cable[2], and

C_{Tot} = The total number of conductors in the cable, as before.

Note: CF should be ≤ 1.0. If the calculated value of CF is greater than 1, then set CF = 1. In practical applications it is highly unlikely that the calculated value of CF will ever exceed 1. For this to occur, virtually all conductors in the cable would need to be either a source conductor or target conductor.

Note: The analyst should determine the number of target and source conductors based on the circuit configuration (contact positions, etc.) that represents the normal operating state of the component. If this information is unavailable or indeterminate, the worst-case conditions should be assumed.

3. Calculate P_{FM} as follows:

$P_{FM} = CF \times P_{CC}$,

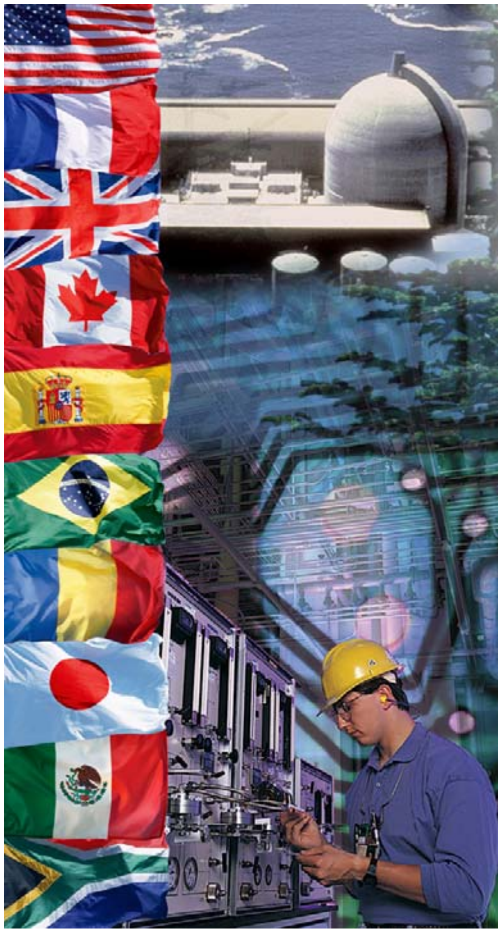
where CF and P_{CC} are determined using the formulas discussed above.

4. When more than one cable can cause the component failure mode of concern, and those cables are within the boundary of influence for the scenario under investigation, the

[2] Target conductors are only those cable conductors capable of forcing the component or circuit into the undesired state or condition of interest. For example, the target conductors associated with causing a spurious operation of the component will likely differ from target conductors associated with causing a loss of control condition.

probability estimates associated with all affected cables should be considered in deriving a failure estimate for the component. In general, the probabilities should be combined as follows:

$$P_{\text{Component failure}} = (P_{\text{Failure Cable A}}) + (P_{\text{Failure Cable B}}) - (P_{\text{Failure Cable A}})(P_{\text{Failure Cable B}})$$



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Support Task B - Fire PRA Database

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Joint RES/EPRI Fire PRA Course
July and August 2007
Palo Alto, CA

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

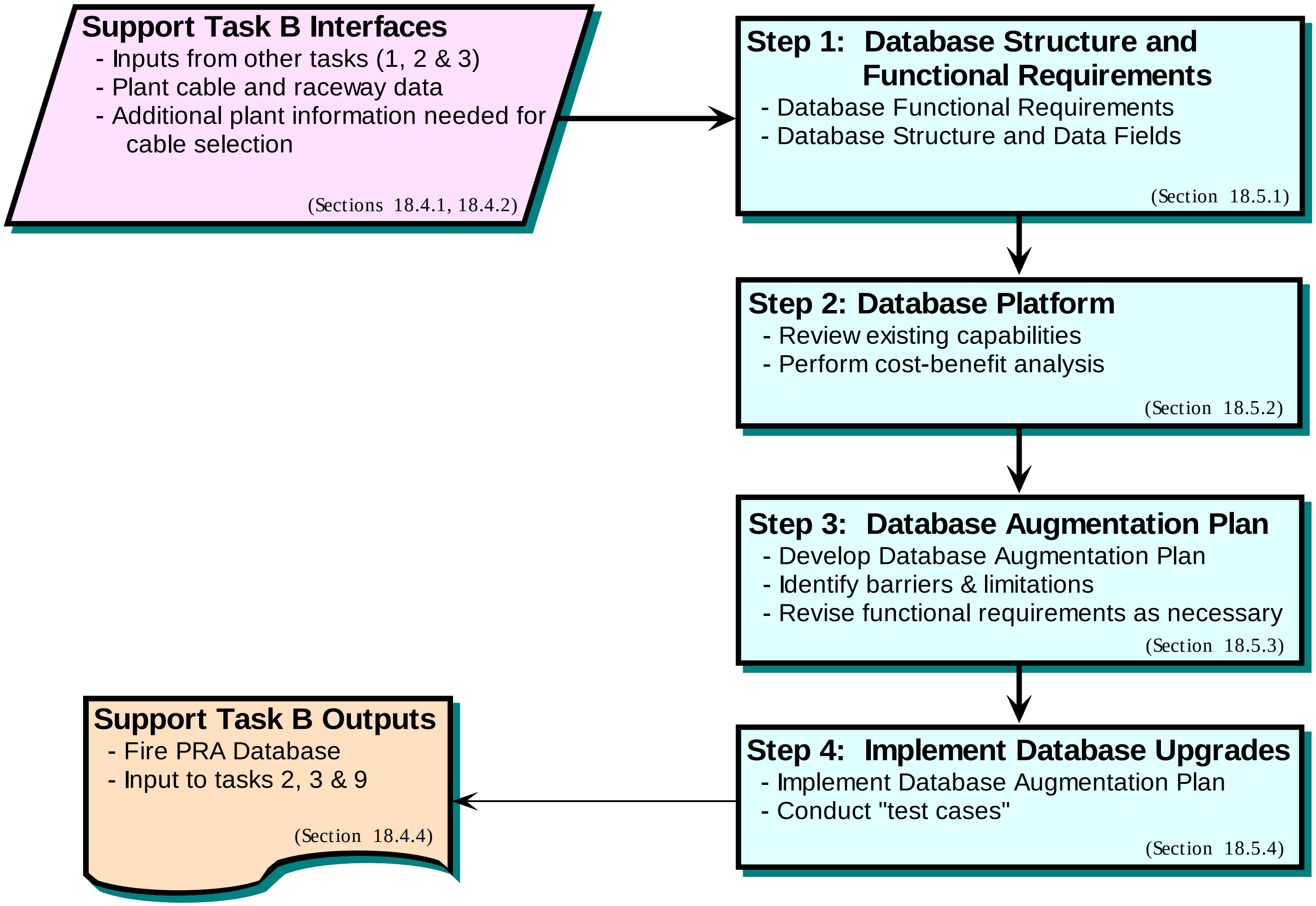
FIRE PRA DATABASE
Purpose & Scope

- Identify Required Database Functionality
- Assess Capability of Existing Systems
- Implement Structured Process to Obtain the Required Database Capability
- New Software and Data Management Tools are Finding Their Way Into the Market

FIRE PRA DATABASE
Introduction

- Task is Distinctly Different from Other Tasks
- Essential Element of PRA
  - Proposed Methods Require Manipulation and Correlation of Large Amounts of Data
  - Must be Efficient and User Friendly for Effective Implementation
  - Manual Analysis Not Practical

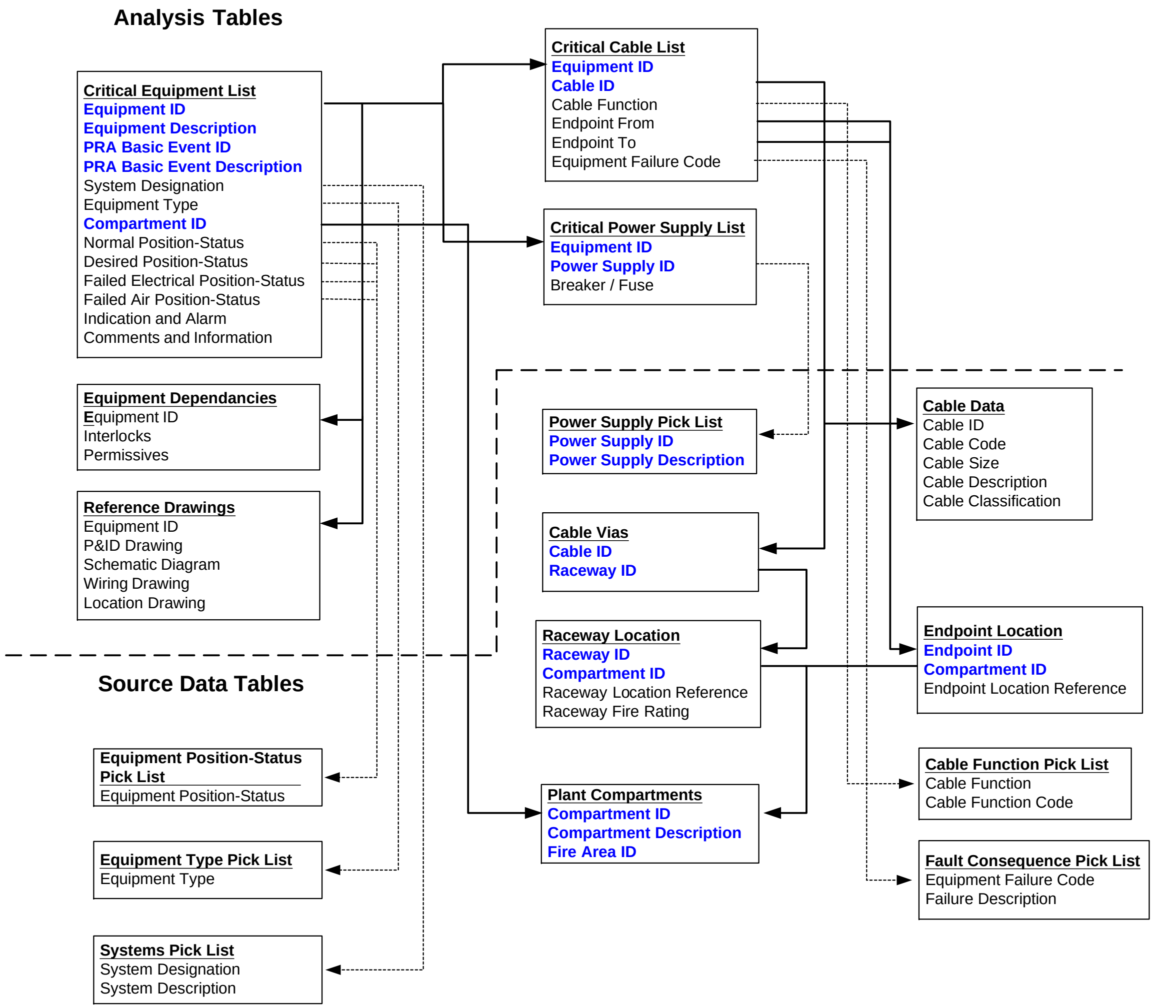
FIRE PRA DATABASE
Flowchart



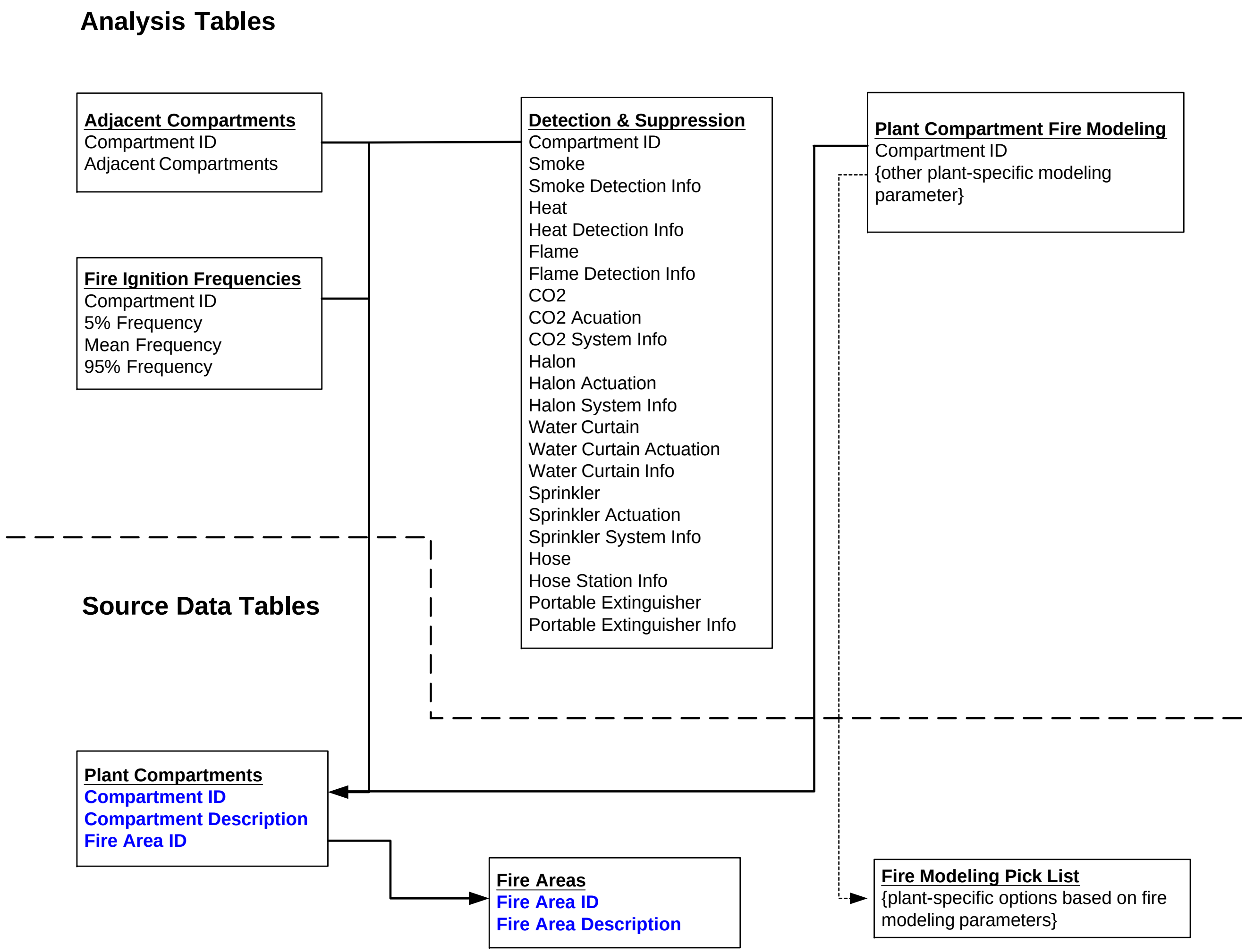
FIRE PRA DATABASE
Step 1.1 - Database Functional Criteria

- Data Input Criteria
  - In what shape and format is existing data?
  - How and who will entered and control data?
  - Will data be shared by separate groups? If so, who can change data?
- Data Output Criteria
  - Define Required Output Reports
  - Define Sort and Query Options

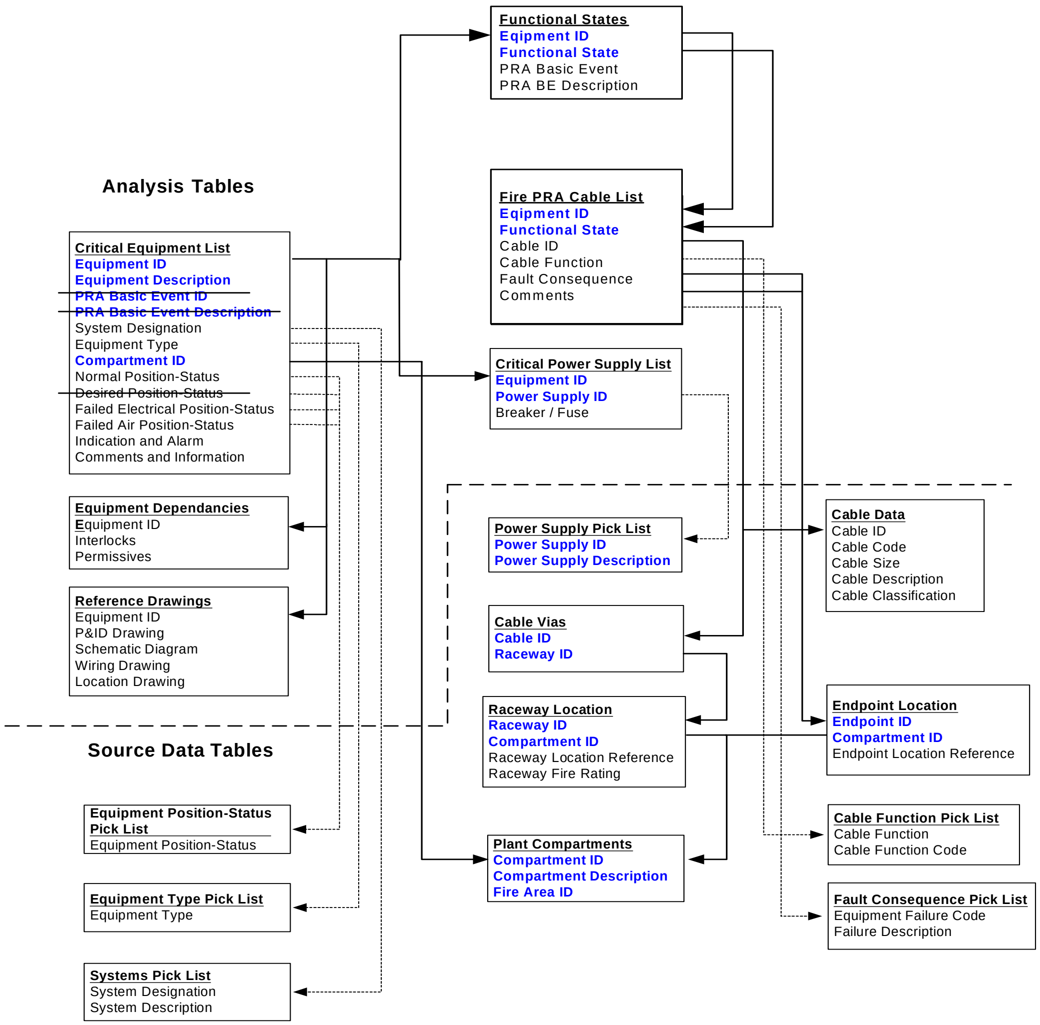
FIRE PRA DATABASE
Step 1.2 - Database Structure (Example A)



FIRE PRA DATABASE
Step 1.2 - Database Structure (Example A)



FIRE PRA DATABASE
Step 1.2 - Database Structure (Example B)



FIRE PRA DATABASE
Step 2 - Database Platform

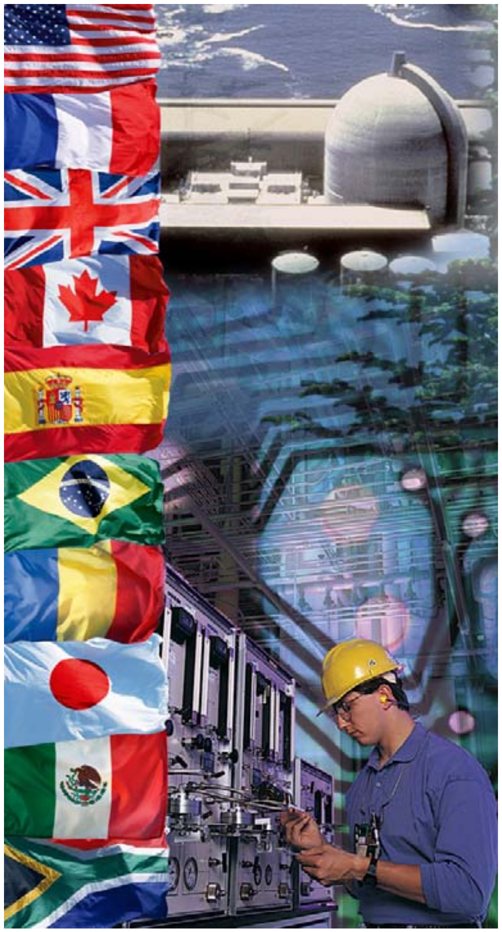
- Decide on Platform for Database
  - Existing System
  - New Stand Alone System
  - Upgrade Existing System
  - Combination of Existing and New
- Vendors are Responding to the Call for New and Improved Software Functionality
  - Highly Integrated Solutions are Emerging as the Standard for NFPA 805 Plants
  - Seamless Link to Fire PRA Software is in the Works But Not Yet Available as Production Software

FIRE PRA DATABASE
Step 3 - Database Augmentation Plan

- Augmentation Plan is Based on the Results of Step 2
- Formalize Process for Upgrades/Changes
- Determine Necessary Resources
  - This Effort Can Innocently Affect Many Plant Organizations
  - The Cost, Resources, Schedule, Training, Procedural Changes and Overall Impact of Major Software Changes **ALWAYS** Seems to be Underestimated
- Involve IS/IT Department from the Beginning

FIRE PRA DATABASE
Step 4 – Implement Database Upgrades

- Have a Clear Plan BEFORE Beginning any Significant Work
- Consider Long-Term Maintainability
- Plan for De-bugging and Test Runs
- Do Not Overlook Data Integrity and Configuration Control Features
- Determine All Affected Users and Involve Then Early
- The Days of "Rouge" PRA Databases are Gone!



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Electrical Examples

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July and August 2007
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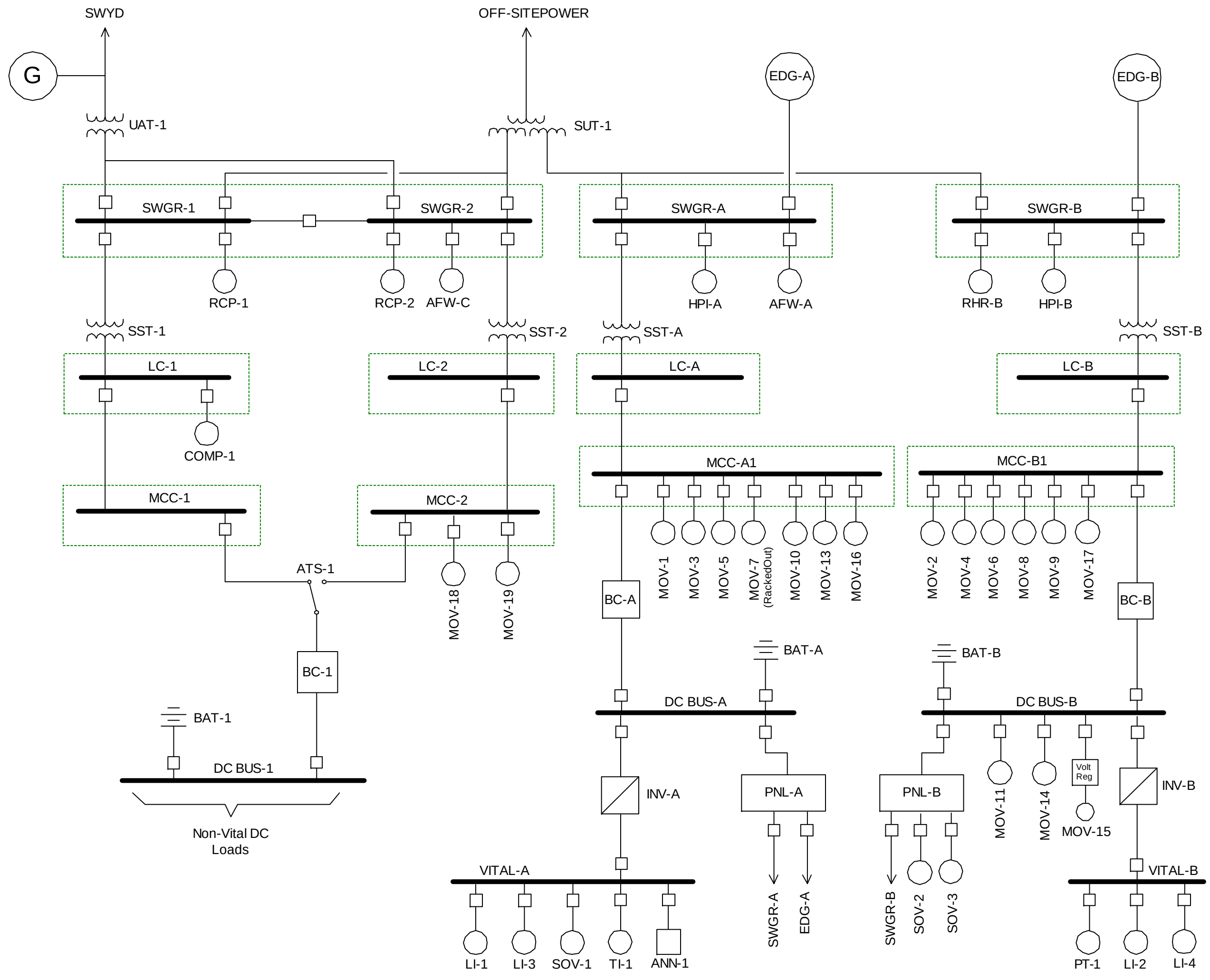
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

OVERVIEW OF EXAMPLES

- Provide Hands-On Practical Experience
- Cover Many (But Not All) Typical Cases
- Exposure to Typical Problems and Decisions
- Appreciation for Challenges and Trade-Offs
- A Worn Out Expression, Yes…But for Circuit Analysis the "Devil is in the Detail"

SNPP ONE-LINE DIAGRAM



EXAMPLE PROBLEMS

Example No.	Component	Description of Analysis	NUREG/CR-6850	Comments
1	AOV-1 (SOV-1)	Std AC Solenoid Control Circuit	No	Multi-function component - analyzed for open and close
2	AOV-3 (SOV-3)	Std **DC** Solenoid Control Circuit	Yes - Figure I-2	Spurious only analysis
3	MOV-9	Typ MOV Control Circuit	Yes - Figure I-4	Functional anlysis - change of position required
4	MOV-15	Double Pole **DC** Motor Control Circuit	Yes - Figure I-6	Functional anlysis - change of position required
5	MOV-13	Ungnd AC, Inverted MOV Control Circuit	Yes - Figure I-8	Functional analysis - change of position required
6	MOV-10	Ungnd AC MOV Control Circuit	Yes - Figure I-10	Functional anlysis - change of position required
7	MOV-8	MOV Control Circuit w/ Dual Controls	Yes - Figure I-12	Spurious only, classified as high consequence component
8	MOV-11	Typ **DC** MOV Control Circuit	No	Functional analysis - change of position required
9	MOV-16	Typ MOV Control Circuit	Yes - Figure I-4	Spurious Only
10	PI-1	Instrument Circuit	No	Indication only
11	ANN-1	Annunciator Circuit	No	No false indication
12	HPI-B	4.16 kV Motor	No	Functional analysis
13	COMP-1	480 V Motor	No	Functional analysis
14	SWGR-B	4.16 kV Bus	No	Multiple source options
15	LC-B	480V LC	No	Functional analysis
16	MCC-1B	480V MCC	No	Functional analysis

HANDS ON WORK

CIRCUIT ANALYSIS WORKSHEET

Component ID:________________ Component Type:_________________________

Component Description:_______________________________

BE Code: ______________________

Required Position:
Functional State ______________________

Normal Position: ______________________

Failed Electrical Position: ______________________

Failed Air Position: ______________________

High Consequence Component Yes ☐ No ☐

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

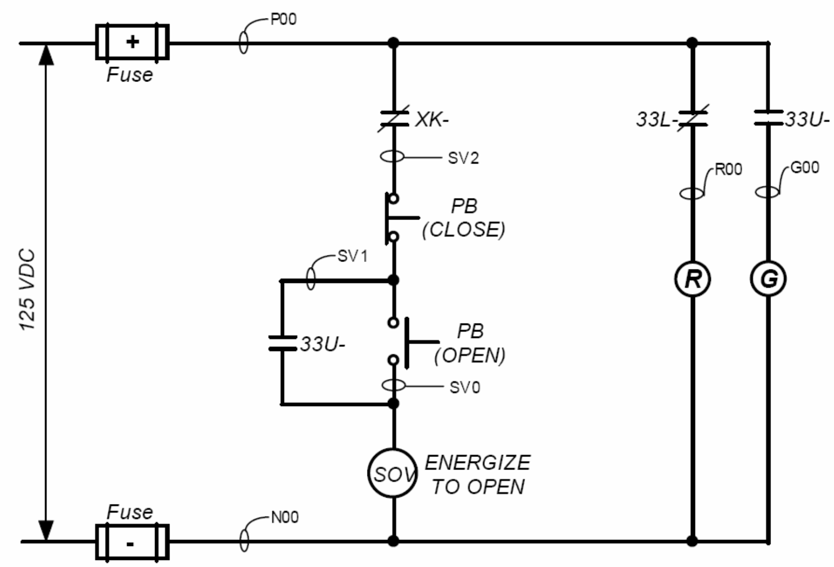
Cable ID	Required?	Function	Fault Consequence	Commments

Comments:

____

____

____



VALVE SHOWN CLOSED

Circuit Analysis Example Summary

Example No.	Component	Description of Analysis	NUREG/CR-6850	Comments
1	AOV-1 (SOV-1)	Std AC Solenoid Control Circuit	No	Multi-function component - analyzed for open and close
2	AOV-3 (SOV-3)	Std **DC** Solenoid Control Circuit	Yes - Figure I-2	Spurious only analysis
3	MOV-9	Typ MOV Control Circuit	Yes - Figure I-4	Functional anlysis - change of position required
4	MOV-15	Double Pole **DC** Motor Control Circuit	Yes - Figure I-6	Functional anlysis - change of position required
5	MOV-13	Ungnd AC, Inverted MOV Control Circuit	Yes - Figure I-8	Functional analysis - change of position required
6	MOV-10	Ungnd AC MOV Control Circuit	Yes - Figure I-10	Functional anlysis - change of position required
7	MOV-8	MOV Control Circuit w/ Dual Controls	Yes - Figure I-12	Spurious only, classified as high consequence component
8	MOV-11	Typ **DC** MOV Control Circuit	No	Functional analysis - change of position required
9	MOV-16	Typ MOV Control Circuit	Yes - Figure I-4	Spurious Only
10	PI-1	Instrument Circuit	No	Indication only
11	ANN-1	Annunciator Circuit	No	No false indication
12	HPI-B	4.16 kV Motor	No	Functional analysis
13	COMP-1	480 V Motor	No	Functional analysis
14	SWGR-B	4.16 kV Bus	No	Multiple source options
15	LC-B	480V LC	No	Functional analysis
16	MCC-1B	480V MCC	No	Functional analysis

CIRCUIT ANALYSIS WORKSHEET

Component ID:__________________ Component Type:____________________________

Component Description:___________________________________

BE Code: ______________________________

Required Position: ______________________________
Functional State

Normal Position: ______________________________

Failed Electrical Position: ______________________________

Failed Air Position: ______________________________

High Consequence Component Yes ☐ No ☐

Power Supplies: ________________________ Breaker: ________________________

________________________ Breaker: ________________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Commments

Comments:

____

____

____

CIRCUIT ANALYSIS WORKSHEET

Component ID:__________________ Continuation Sheet (___ of ___)

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Equipment Loss Report

Equipment ID	Equipment Description	Equipment Type	Location	Desired Position/ Status	Potential Loss Areas
HPI-A	High pressure safety injection pump A	Pump	Aux Bldg. El. 0 Ft	On	1, 2, 3, 10
				On	1, 2, 3, 10
HPI-B	High pressure safety injection pump B	Pump	Aux Bldg. El. 0 Ft	On	1, 2, 3, 11
				On	1, 2, 3, 11
RHR-B	Residual heat removal pump B	Pump	Aux Bldg. El. -20 Ft	Off	1, 2, 3, 4A, 9, 11
AFW-A	Motor driven AFW pump A	Pump	Aux Bldg. EL. 0 Ft	On	1, 3, 4B, 9, 10
AFW-B	Steam driven AFW pump B	Pump	Aux Bldg. EL. 0 Ft	On	1, 3, 4B, 9, 11
AFW-C	Motor driven AFW pump C	Pump	Turbine Bldg. El. 0 Ft	On	1, 3, 12
RCP-1	Reactor coolant pump 1	Pump	Containment	Off	1, 2, 3, 7, 12
RCP-2	Reactor coolant pump 2	Pump	Containment	Off	1, 2, 3, 7, 12
COMP-1	Instrument air compressor	Compressor	Turbine Bldg. El. 0 Ft	Cycle	12
AOV-1 (SOV-1)	Power operated relief valve	AOV	Containment	Closed	1, 3, 7, 9
				Open	1, 3, 7, 9, 10
AOV-2 (SOV-2)	Letdown isolation valve	AOV	Aux Bldg. El. 0 Ft	Closed	1, 2, 3, 9
AOV-3 (SOV-3)	Charging pump injection valve	AOV	Aux Bldg. El. 0 Ft	Closed	1, 2, 3, 9
MOV-1	HPI discharge valve	MOV	Aux Bldg. El. 0 Ft	Open	1, 2, 3, 9, 10
MOV-2	VCT isolation valve	MOV	Aux Bldg. El. 0 Ft	Closed	1, 2, 3, 9, 11
MOV-3	Cont. sump recirc valve	MOV	Aux Bldg. El. -20 Ft	Open/ Closed[2]	1, 2, 3, 4A, 9, 10
MOV-4	Cont. sump recirc valve	MOV	Aux Bldg. El. -20 Ft	Open/ Closed	1, 2, 3, 4A, 9, 11
MOV-5	RWST isolation valve	MOV	Aux Bldg. El. 0 Ft	Open	1, 2, 3, 12
MOV-6	RWST isolation valve	MOV	Aux Bldg. El. 0 Ft	Open	1, 2, 3, 12
MOV-7	RHR inboard suction valve	MOV	Containment	Closed	4A,7,9,12
MOV-8	RHR outboard suction valve	MOV	Aux Bldg. El. -20 Ft	Closed	4A,9,12
MOV-9	HPI discharge valve	MOV	Aux Bldg. El. 0 Ft	Open	1,2,3,,9
MOV-10	AFW pump A discharge valve	MOV	Aux Bldg. EL. 0 Ft	Open	1,3,4B,9,12
MOV-11	AFW pump B discharge valve	MOV	Aux Bldg. EL. 0 Ft	Open	1,3,4B,9,11,12
MOV-13	PORV block valve	MOV	Containment	Open/ Closed[1]	1, 3, 7, 9
MOV-14	AFW pump B turbine steam line isolation valve	MOV	Turbine Bldg. El. 0 Ft	Open	1, 3, 4B, 12

Equipment ID	Equipment Description	Equipment Type	Location	Desired Position/ Status	Potential Loss Areas
MOV-15	AFW pump B steam inlet throttle valve	MOV	Turbine Bldg. El. 0 Ft	Throttled	1, 3, 4B, 12
MOV-18	AFW pump C discharge valve	MOV	Turbine Bldg. El. 0 Ft	Open	1, 3, 12
V-12	CST isolation valve	MOV	Turbine Bldg. El. 0 Ft	Open	12
LI-1	RWST level	Instrument	Yard	Available	1, 3, 12, 13
LI-2	RWST level	Instrument	Yard	Available	1, 3, 12, 13
LI-3	Cont. sump level	Instrument	Containment	Available	1, 3, 7, 12
LI-4	Cont. sump level	Instrument	Containment	Available	1, 3, 7, 12
TI-1	Letdown heat exchanger outlet temperature	Instrument	Aux Bldg El. 0 Ft	Available	1, 2, 3, 9
PI-1	RCS pressure	Instrument	Containment	Available	1, 3, 7
ANN-1	AFW motor high temperature	Annunciator	SWG Access Room	Non spurious	1, 2, 3, 9, 4B
SWGR-A	Train A 4160 V switchgear	Switchgear	Switchgear Room A	Energized from SUT-1	1, 3, 10, 12, 13
				Energized from EDG-A	1, 3, 8A, 10, 12
SWGR-B	Train B 4160 V switchgear	Switchgear	Switchgear Room B	Energized from SUT-1	1, 3, 9, 11, 12, 13
				Energized from EDG-A	1, 3, 8B, 9, 11, 12
SWGR-1	Non-safety 4160 V switchgear	Switchgear	Turbine Bldg. El. 0ft	Energized	1, 3, 12, 13
SWGR-2	Non-safety 4160 V switchgear	Switchgear	Turbine Bldg. El. 0ft	Energized	1, 3, 12, 13
SUT-1	Startup transformer	Transformer	Yard	Energized	1, 3, 12, 13
EDG-A	Train A emergency diesel generator	Diesel Generator	DG Bldg.	On	1, 3, 8A, 10, 12
EDG-B	Train B emergency diesel generator	Diesel Generator	DG Bldg.	On	1, 3, 8B, 10, 12
LC-1	Non-safety 480 V load center	Load Center	Turbine Bldg. El. 0 ft	Energized	1, 3, 12
LC-2	Non-safety 480 V load center	Load Center	Turbine Bldg. El. 0 ft	Energized	1, 3, 12
LC-A	Train A 480 V load center	Load Center	Switchgear Room A	Energized	1, 3,10
LC-B	Train B 480 V load center	Load Center	Switchgear Room B	Energized	1, 3, 11
SST-1	Non-safety station service transformer	Transformer	Turbine Bldg. El. 0 F	Energized	12
SST-2	Non-safety station service transformer	Transformer	Turbine Bldg. El. 0 F	Energized	12
SST-A	Train A station service transformer	Transformer	Switchgear Room A	Energized	10
SST-B	Train B station service transformer	Transformer	Switchgear Room B	Energized	11
MCC-1	Non-safety 480 V motor control center	Motor Control Center	Turbine Bldg El. 0 Ft	Energized	12
MCC-2	Non-safety 480 V motor control center	Motor Control Center	Turbine Bldg El. 0 Ft	Energized	12

Equipment ID	Equipment Description	Equipment Type	Location	Desired Position/ Status	Potential Loss Areas
MCC-A1	Train A 480 V motor control center	Motor Control Center	SWG Access Room	Energized	9, 10
MCC-B1	Train B 480 V motor control center	Motor Control Center	SWG Access Room	Energized	9, 11
ATS-1	Automatic transfer switch	ATS	SWG Access Room	Energized from MCC-1	12
BC-1	Non-safety swing battery charger	Battery Charger	Turbine Bldg El. 0 Ft	Energized	12
BC-A	Train A battery charger	Battery Charger	Switchgear Room A	Energized	9, 10
BC-B	Train B battery charger	Battery Charger	Switchgear Room B	Energized	9, 11
BAT-1	Non-safety battery	Battery	Turbine Bldg El. 0 Ft	Available	12, 15
BAT-A	Train A battery	Battery	Battery Room A	Available	5, 10
BAT-B	Train B battery	Battery	Battery Room B	Available	6, 11
DC BUS-1	Non-safety 250 VDC bus	DC Bus	Turbine Bldg El. 0 Ft	Energized	12
DC BUS-A	Train A 125 VDC bus	DC Bus	Switchgear Room A	Energized	10
DC BUS-B	Train B 125 VDC bus	DC Bus	Switchgear Room B	Energized	11
PNL-A	Train A 125 VDC panel	Panelboard	Switchgear Room A	Energized	10
PNL-B	Train B 125 VDC panel	Panelboard	Switchgear Room B	Energized	11
INV-A	Train A inverter	Inverter	Switchgear Room A	Energized	3, 9, 10
INV-B	Train B inverter	Inverter	Switchgear Room B	Energized	3, 9, 11
VITAL-A	Train A 120 VAC vital bus	120VAC Bus	SWG Access Room	Energized	9, 10
VITAL-B	Train B 120 VAC vital bus	120VAC Bus	SWG Access Room	Energized	9, 11

CIRCUIT ANALYSIS WORKSHEET

Component ID: **AOV-1 (SOV-1)** Component Type: **AOV**

Component Description: **Power Operated Relief Valve**

BE Code: **AOV-1_TO (PORV AOV-1 TRANSFERS OPEN)**

Required Position: Functional State **CLOSED**

Normal Position: **CLOSED**

Failed Electrical Position: **CLOSED**

Failed Air Position: **CLOSED**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **AOV-1 (SOV-1)** Component Type: **AOV**

Component Description: **Power Operated Relief Valve**

BE Code: **AOV-1_FTO (PORV AOV-1 FAILS TO OPEN)**

Required Position: Functional State **OPEN**

Normal Position: **CLOSED**

Failed Electrical Position: **CLOSED**

Failed Air Position: **CLOSED**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **AOV-3 (SOV-3)** Component Type: **AOV**

Component Description: **Charging Pump Injection Valve**

BE Code: **AOV-3_FTC (AOV-3 FAILS TO CLOSE)**

Required Position:
Functional State **CLOSED**

Normal Position: **OPEN**

Failed Electrical Position: **CLOSED**

Failed Air Position: **CLOSED**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-9** Component Type: **MOV**

Component Description: **High Pressure Injection Valve**

BE Code: **MOV-9_FTO** **(MOV-9 FAILS TO OPEN)**

Required Position: Functional State **OPEN**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-15** Component Type: **MOV**

Component Description: **AFW Steam Inlet Throttle Valve**

BE Code: **MOV-10_FTO (MOV-10 FAILS TO OPEN)**

Required Position: Functional State **THROTTLED**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-13** Component Type: **MOV**

Component Description: **PORV Block Valve**

BE Code: **MOV-13_FTC (MOV-13 FAILS TO CLOSE)**

Required Position: Functional State **OPEN / CLOSED**

Normal Position: **OPEN**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-10** Component Type: **MOV**

Component Description: **AFW Discharge Isolation Valve**

BE Code: **MOV-10_FTO** **(MOV-10 FAILS TO OPEN)**

Required Position: Functional State **OPEN**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-8** Component Type: **MOV**

Component Description: **RHR Outboard Suction Valve**

BE Code: **MOV-8_TO** **(MOV-8 TRANSFERS OPEN)**

Required Position: Functional State **CLOSED**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☒ No ☐

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-11** Component Type: **MOV**

Component Description: **AFW Discharge Isolation Valve**

BE Code: **MOV-11_FTO** **(MOV-11 FAILS TO OPEN)**

Required Position: Functional State **OPEN**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MOV-16** Component Type: **MOV**

Component Description: **AFW Test Line Isolation Valve**

BE Code: **MOV-16_TO** **(MOV-16 TRANSFERS OPEN)**

Required Position: Functional State **CLOSED**

Normal Position: **CLOSED**

Failed Electrical Position: **AS-IS**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **PI-1** Component Type: **Instrument**

Component Description: RCS Pressure

BE Code: **PI-1_FL** **(RCS Pressure Indication Fails High)**

Required Position: Functional State **AVAILABLE**

Normal Position: **AVAILABLE**

Failed Electrical Position: **LOW**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **ANN-1** Component Type: **Annunciator**

Component Description: **AFW Motor High Temperature**

BE Code: **ANN-1_FH (AFW Pump Motor Spurious High Ann)**

Required Position: Functional State **NON-SPURIOUS**

Normal Position: **AVAILABLE**

Failed Electrical Position: **UNAVAILABLE**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________ Breaker: ____________

____________ Breaker: ____________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

CIRCUIT ANALYSIS WORKSHEET

Component ID: **HPI-B** Component Type: **Pump**

Component Description: **High Pressure Injection Pump B**

BE Code: **HPIA_FTS (HPI-A Fails to Start)**
HPIA_FTR (HPI-A Fails to Run)

Required Position: Functional State **ON**

Normal Position: **STANDBY / ON**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **COMP-1** Component Type: **Compressor**

Component Description: **Instrument Air Compressor**

BE Code: **COMP-1_FTR** **(COMP-1 Fails to Run)**

Required Position: Functional State **CYCLE**

Normal Position: **CYCLE**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **SWGR-B** Component Type: **Switchgear**

Component Description: **Train B 4160V Switchgear**

BE Code: **PNL-B EPS-4VBUSBF-1 (4KV BUS B FAULT)**

Required Position: Functional State **ENERGIZED FROM SUT-1**

Normal Position: **ENERGIZED FROM SUT-1**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **SWGR-B** Component Type: **Switchgear**

Component Description: **Train B 4160V Switchgear**

BE Code: **PNL-B EPS-4VBUSBF-2 (4KV BUS B FAULT)**

Required Position: Functional State **ENERGIZED FROM EDG-B**

Normal Position: **ENERGIZED FROM SUT-1**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **LC-B** Component Type: **Load Center**

Component Description: **Train B 480 V Load Center**

BE Code: **EPS-480VLCBF** **(480V LOAD CENTER B FAULT)**

Required Position: Functional State **ENERGIZED**

Normal Position: **ENERGIZED**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ____________________ Breaker: ____________________

____________________ Breaker: ____________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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CIRCUIT ANALYSIS WORKSHEET

Component ID: **MCC-1B** Component Type: **MCC**

Component Description: **Train B 480 V Motor Control Center**

BE Code: **EPS-480MCCB1F** **(480V MCC B1 FAULT)**

Required Position: Functional State **ENERGIZED**

Normal Position: **ENERGIZED**

Failed Electrical Position: **Off**

Failed Air Position: **N/A**

High Consequence Component Yes ☐ No ☒

Power Supplies: ______________________ Breaker: ______________________

______________________ Breaker: ______________________

Cable Analysis:

Cable ID	Required?	Function	Fault Consequence	Comments

Comments:

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