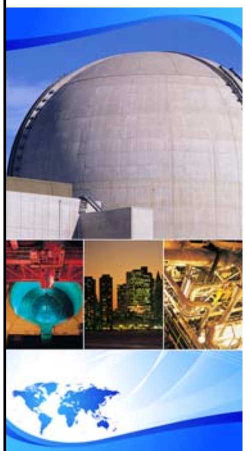


# EPRI/NRC-RES FIRE PRA METHODOLOGY

## Module 2: Fire PRA Circuit Analysis Overview

D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories

Joint RES/EPRI Fire PRA Course
June and October 2009

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

# CIRCUIT ANALYSIS OVERVIEW
## Introductions

- Instructors
  - Daniel Funk, P.E., Edan Engineering
  - Frank Wyant, Sandia National Labs
- Who's Here and Why?
  - Name, Organization, Experience
  - What do you want from this course?
- Logistics

# CIRCUIT ANALYSIS OVERVIEW
## Course Prerequesits

- Who Should Attend?
  - Nuclear plant personnel with electrical and plant operating knowledge, but limited exposure to Appendix R and PRA
  - Nuclear plant personnel with substantial Appendix R and/or PRA experience, but limited circuit analysis experience
  - Anyone who went to the Circuit Analysis Basics course



# CIRCUIT ANALYSIS OVERVIEW
## Objectives

- This module covers technical tasks for analysis of fire-induced circuit failures in support of a Fire PRA
- This module is geared toward PRA practitioners and fire safe shutdown analysts with a practical understanding of the concepts and methods of fire-induced circuit failure analysis within the context of Fire PRA or Appendix R circuit failure assessments. Specifically, familiarity with the following topics is recommended:
  - General circuit design and operational control for typical plant equipment
  - Basic circuit analysis techniques for identifying and classifying fire-induced circuit failure modes
  - Working level knowledge of typical electrical drawings, including one-line diagrams, schematic diagrams, electrical block diagrams, wiring/connection diagrams, raceway layout drawings, instrument loop diagrams, etc.
  - Cable and raceway, Appendix R safe shutdown, and Fire PRA database structures and software
  - Appendix R safe shutdown circuit analysis
  - Emerging issues and challenges associated with the analysis of multiple spurious operations
- It is expected that upon completion of the Circuit Analysis Module, attendees will have sufficient working knowledge of techniques and methods to perform at a practical level the electrical analysis tasks associated with supporting a Fire PRA

# CIRCUIT ANALYSIS OVERVIEW
## Presentation Road Map

- Course Introduction
- Circuit Analysis Process, Methods, and Criteria
- Walk Through Sample Problems
- Hands-on Sample Problems
- Database & Data Management
- Project Strategy, Key Considerations, Lessons Learned



**Module 2 - Fire PRA Circuit Analysis** **Agenda**

| Time | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|
| 8:30 | **General Session** - Introduction to all Modules | **Presentation** - Detailed Circuit Failure Analysis (Task 9) | **Presentation** - Fire PRA Database | **Exercises** - Work Task 10 Sample Problems |
| 9:45 | | | **Break** | **Break** |
| 10:00 | | | - Fire PRA Database (continued) | **Discussion** - Task 10 Sample Problems |
| 10:15 | | **Break** | | |
| 10:30 | | **Presentation** - Task 3 & Task 9 Sample Problem Definition and Examples | | |
| 11:00 | | | **Discussion** - Open, Q&A, etc. | **Discussion** - Summary and Conclusions |
| 12:00 | **LUNCH BREAK** | **LUNCH BREAK** | **LUNCH BREAK** | **LUNCH BREAK** |
| 13:00 | **Presentation** - Fire PRA Circuit Analysis Overview | **Exercises** - Work Task 3 & Task 9 Sample Problems | **Presentation** - Circuit Failure Mode Likelihood Analysis (Task 10) | **General Session** - Closing: All Modules |
| 14:00 | **Presentation** - Fire PRA Cable Selection (Task 3) | | | |
| 14:30 | **Break** | | **Break** | |
| 14:45 | - Fire PRA Cable Selection (continued) | | - Circuit Failure Mode Likelihood Analysis (continued) | |
| 15:45 | **Break** | **Break** | **Break** | |
| 16:00 | - Fire PRA Cable Selection (continued) | **Discussion** - Task 3 & Task 9 Sample Problems | - Circuit Failure Mode Likelihood Analysis (cont.) | |
| 16:30 | | | **Presentation** - Task 10 Sample Problems | |
| 17:00 | **ADJOURN** | **ADJOURN** | **ADJOURN** | **ADJOURN** |

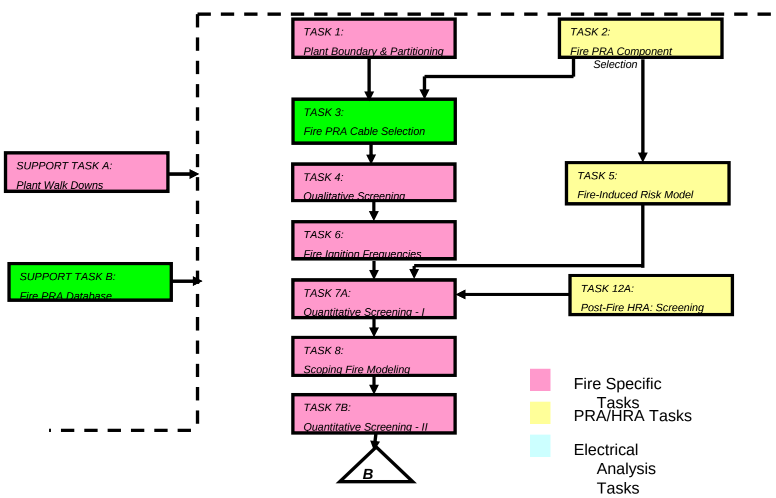
# CIRCUIT ANALYSIS OVERVIEW
## Circuit Analysis Tasks

- Task 3: Fire PRA Cable Selection
  - What cables are associated with the FPRA components?
- Task 9: Detailed Circuit Analysis
  - Which cables can affect the credited functionality?
  - What failure modes are possible given fire damage to the cable?
- Task 10: Circuit Failure Mode Likelihood Analysis
  - How likely to occur are the failure modes of concern?
- Support Task B: Fire PRA Database
  - Warehousing data and determining impacts

*Joint Fire PRA Course, June & October 2009*
**Module 2: Fire PRA Circuit Analysis Overview**
*Slide 7*
*A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)*

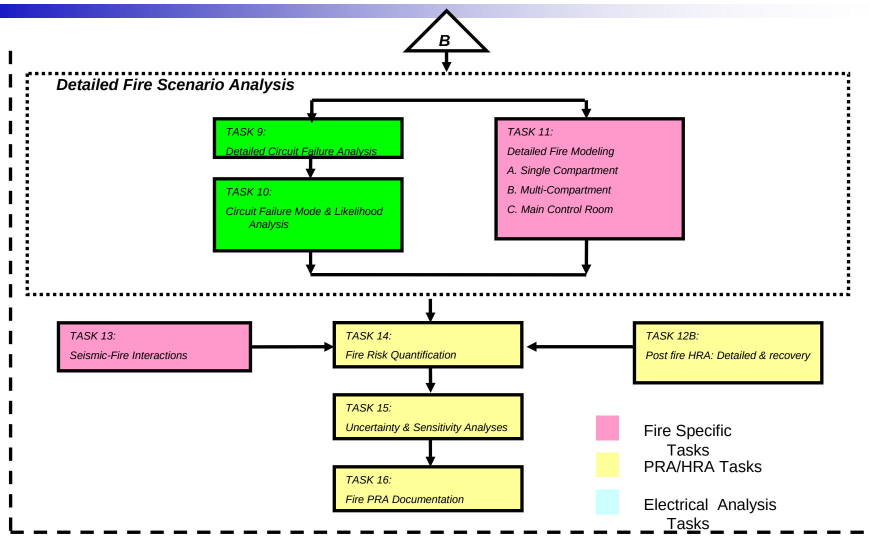
# CIRCUIT ANALYSIS OVERVIEW

## PRA Task Flow Chart




*Joint Fire PRA Course, June & October 2009*
**Module 2: Fire PRA Circuit Analysis Overview**
*Slide 8*
*A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)*

# CIRCUIT ANALYSIS OVERVIEW
## PRA Task Flow Chart, cont…




*Joint Fire PRA Course, June & October 2009*
**Module 2: Fire PRA Circuit Analysis Overview**

*Slide 9*

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

# CIRCUIT ANALYSIS OVERVIEW
## Key Considerations

- Each Electrical Analysis Task Represents a Refined Level of Detail, i.e., Graded Approach
- Existing Appendix R Circuit Analysis is NOT as Useful as Originally Envisioned
- Circuit Analysis for Fire PRA is More Complex and Difficult Compared to Appendix R
- Circuit Analysis (including cable tracing) Can Consume 40%-70% of Overall Budget
- Circuit Analysis Scope MUST be a Primary Consideration During Project Scoping

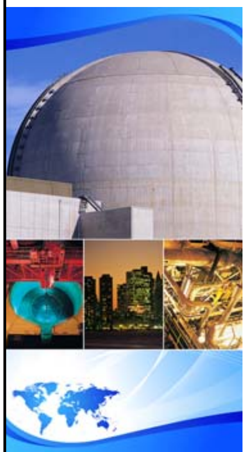
*Joint Fire PRA Course, June & October 2009*
**Module 2: Fire PRA Circuit Analysis Overview**

*Slide 10*

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

# CIRCUIT ANALYSIS OVERVIEW
## Questions

Any Questions Before we Start ???



# EPRI/NRC-RES FIRE PRA METHODOLOGY

## Module 2: Fire PRA Circuit Analysis Summary


D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories


Joint RES/EPRI Fire PRA Course
June & October 2009

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

# CIRCUIT ANALYSIS SUMMARY
## Topics

- Circuit Analysis “Big Picture” Road Map
- Interface with Fire PRA Group
- Circuit Analysis Strategy & Implementation
- Key Considerations & Factors
- Relationship to Appendix R & NFPA 805
- Lessons Learned

## CIRCUIT ANALYSIS SUMMARY
### Circuit Analysis Road Map

- Task 3 / 9A
  - Fire PRA Cable Selection
  - Circuit Analysis (Part A): Design Attributes
- Task 9B / 10
  - Circuit Analysis (Part B): Configuration Attributes
  - Circuit Failure Mode Likelihood Analysis
- Support Task B – Fire PRA Database

Remember – You cannot work in a vacuum! You must interface continuously with all team members!



## CIRCUIT ANALYSIS SUMMARY
### Interface with Fire PRA Group

- Coordination with Task 2 (Component Section) is Essential – MUST Understand the EXACT Functionality Credited for Each Component
- Essential that Fire PRA and NFPA-805 data be fully integrated

  *Note: The subtleties of aligning Fire PRA and traditional Appendix R / NFPA-805 data is more complex than originally anticipated. This primarily shows up in Component Selection (Task 2), but has major ramifications to the circuit analysis*

- Existing Appendix R Circuit Analysis is **NOT** as Useful as Originally Envisioned Essential

## CIRCUIT ANALYSIS SUMMARY
### Interface with Fire PRA Group, cont…

- Be forewarned…the PRA process is iterative and the components / function states will change, i.e., you will redo some analyses

- Do not expect the PRA analysts to fully understand the various nuances with the circuit analysis for any given any functional state – you will need to question them on inherent assumptions with Basic Events

  Example: What automatic functions are inherently credited for a given Basic Event? Is the automatic function really required for the Fire scenario?



## CIRCUIT ANALYSIS SUMMARY
### Strategy and 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 most projects
- Important to screen out obvious “Not Required” cables during the initial cable selection process (Task 9A), with refinement driven by quantitative screening (Task 9B)

## CIRCUIT ANALYSIS SUMMARY
### Strategy and Implementation, cont…

- 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 members of the PRA team
- Evaluation, coordination, and integration with Appendix R must occur early and must be rigorous
- Long-term strategy for data configuration control – especially if shared data with Appendix R / NFPA 805



## CIRCUIT ANALYSIS SUMMARY
### Key Considerations & Factors

- Circuit analysis remains a technically and logistically challenging area
  - Practical aspects of dealing with an integrated data set
  - Practical approach for dealing with MSOs
  - Circuit analysis is more complex and difficult than analyses performed under Appendix R
- Availability, quality, and format of cable data
- Availability of electrical engineering support
  - Circuit analysis is a developed expertise
  - Do not expect to be a proficient analyst based on a simple introductory course

## CIRCUIT ANALYSIS SUMMARY
### Key Considerations & Factors, cont…

- Usability of Appendix R circuit analysis data
  - Not as useful as originally envisioned
  - Automated tools are essential
  - Functional state analysis is critical – overly conservative cable selection will not work for Fire PRA
  - Many plants are finding that circuit analysis re-baseline is necessary to support upgraded Fire PRA and NFPA-805 projects
- User-friendliness of electrical drawings



## CIRCUIT ANALYSIS SUMMARY
### Relationship to Appendix R & NFPA 805

- Practical aspects of dealing with an integrated data set
- Practical approach for dealing with MSOs
- Implication of these Advances: Circuit analysis is more complex and difficult than analyses performed under Appendix R

## CIRCUIT ANALYSIS SUMMARY
### Lessons Learned

- Do not underestimate scope
- Ensure proper resources are committed to project
- Doable but **MUST** work smart
- Do not “broad brush” interface with Appendix R – have a detailed plan before starting
- Interface between PRA and Electrical groups is typically poor
- Develop project procedures – but don’t get carried away
- Compilation and management of large volume of data
  - Automated tools imperative for efficient process
  - Long-term configuration management often overlooked until very end of the project



## CIRCUIT ANALYSIS SUMMARY
### Lessons Learned, cont…

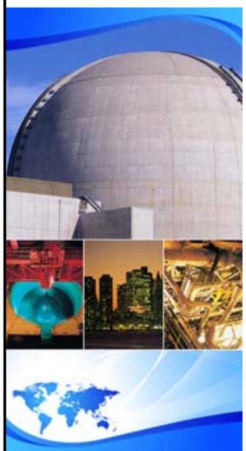
- NFPA 805 projects assume too much about the ability of the Fire PRA model to answer specific Appendix R questions

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation



# 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
June and October 2009

*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 Based on Specified Functionality
    - Basic circuit analysis (Task 9) incorporated into Task 3 work to prevent overwhelming the PRA model with inconsequential cable failures
    - Final product is a listing of defined Basic Events (component and credited function) that could be impacted by a fire for a given location (Fire Area, Fire Compartment, Fire Scenario)



## FIRE PRA CABLE SELECTION
### Introduction (continued)

- Procedure subdivided into six (6) distinct steps

    Step 1: Compile and Evaluate Prerequisite Information and Data

    Step 2: Select Fire PRA Circuits/Cables

    Step 3: Identify and Select Fire PRA Power Supplies

    Step 4: Perform Associated Circuits Review

    Step 5: Determine Cable Routing and Plant Locations

    Step 6: Generate Fire PRA Cable List and Target Equipment Location Reports

## 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 Loss Reports (Potential Equipment Functional 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?
  - What data is available and what is missing?
- Confirm PRA Equipment List is Final
  - Input into a formal and controlled database
  - For NFPA-805 transition projects a joint "consistency" review of NSP task and PRA component selection task is highly recommended
  - *Critical that electrical analysts understand what the Basic Events really mean*
- 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
    - Must consider which (if any) automatic features are included in the existing analysis
    - Aligning existing analyses to Fire PRA Basic Events is not straightforward
  - 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
  - Equipment-level dependencies and primary components
  - Multiple function components
  - Super 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 (continued)

- 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, other automatic functions
  - Medium-voltage switchgear control power
- Extent that Circuit Analysis is 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 – Critical Area for Completeness
- System-Wide Actuation Signals
- Bus or Breaker?
- Subcomponents & Primary Components
- 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?
  - Data Entry
  - Problem Resolution
- Training for Analysts
  - Prior circuit analysis experience is a prerequisite for key team members
  - Familiarity with plant drawings and circuits is highly beneficial
  - A junior engineer with no prior circuit analysis experience will not be able to work independently

## FIRE PRA CABLE SELECTION
### Step 2.3 – Select Cables

- Case 1: Incorporate Existing Appendix R Analysis
  - Confirm adequacy of existing analyses IAW plan
  - Careful consideration of automatic functions
  - Exact alignment for credited functionality
- 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 circuit analysis to the extent decided upon
  - Formally document cable selection IAW established procedures/guidelines



## FIRE PRA CABLE SELECTION
### Step 2.3 – Select Cables (continued)

- Case 3: New Component: w/o Cable Routing Data Available
  - Same as Case 2 & 3, plus…
  - Determine cable routing and associate with plant locations, including cable end points
- Analysis Work Packages
  - Retrieve from Past Appendix R Analysis
  - Highly Recommended for New Components
  - Major time saver for future work

More on Work Packages later in this presentation…

## 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
  - Useful to identify the applicable breaker/fuse
- 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?
  - Must understand how this is modeled to correctly select cables



## 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



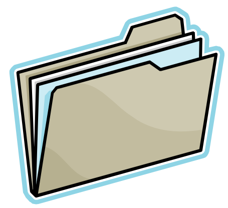
## FIRE PRA CABLE SELECTION
### Step 6 – Target Equipment Loss Reports

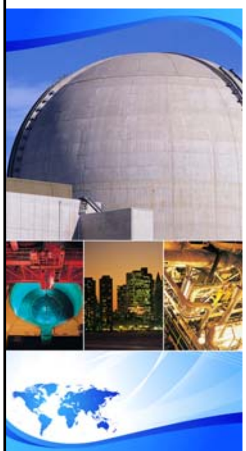
- Data Entered into Fire PRA Database
- Sorts and Queries to Generate Target Equipment Loss Reports

*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.*

# FIRE PRA CABLE SELECTION
## Work Packages

- A work package for each Fire PRA component consists of a compilation of drawings and documents that provide the basis of the circuit analysis results for that component
- Contents typically include
  - One-line diagram (highlighted to show the component's power supply)
  - Elementary diagram (marked up to show cable associations)
  - Block diagram (highlighted)
  - Loop diagram (if applicable)
  - Component circuit analysis worksheets
  - Other descriptive/supporting information





# EPRI/NRC-RES FIRE PRA METHODOLOGY

## Module 2: Task 9 - Detailed Circuit Failure Analysis


F. Wyant - Sandia National Laboratories
D. Funk - Edan Engineering Corp.


Joint RES/EPRI Fire PRA Course
June and October 2009

*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
- Perform 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 with thermoplastic insulated conductor or ungrounded configuration)
  - Inter-cable hot shorts for armored cable and cable in dedicated conduit
  - Open circuit conductor failures
  - Multiple high-impedance faults

*Note: if conducting a combined NFPA-805 and Fire PRA circuit analysis, NEI 00-01 suggests that open circuits be considered*



## 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
## *Process*

- The Task 9 procedure 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 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 ⇒ Cable ⇒ Raceway ⇒ Compartment
- Step 1.2: Confirm Unscreened Plant Compartments and Scenarios are Identified
  - Target Equipment Loss 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 ⇒ Component Work Packages



## DETAILED CIRCUIT FAILURE ANALYSIS
### *Considerations in Developing Plant-Specific Rules*

- Consider the following while developing the plant-specific circuit analysis rules:
  - The types of cable failure modes (hot shorts, shorts to ground) and the effects of concern (spurious operation, loss of power, loss of control, etc.) on the Fire PRA component.
  - Three-phase proper polarity hot shorts on AC power cables
    - Grounded AC systems using thermoset-insulated cable
    - Ungrounded AC systems **or** thermoplastic-insulated cable
    - Armored cable or cable in dedicated conduit
  - Intra-cable versus Inter-cable hot shorts
  - DC circuit cable failures
  - Coincident independent hot shorts involving separate cables
  - Compatible polarity multiple hot shorts on ungrounded circuits

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

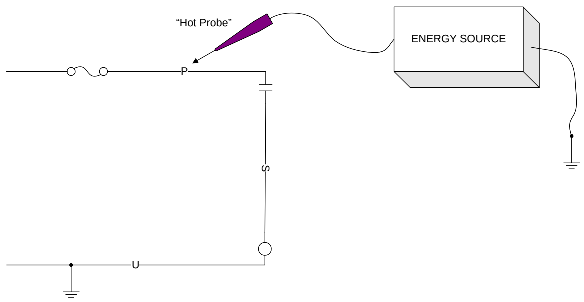
- Enter Results into Fire PRA Database
- Generate Equipment Failure Response Reports
  - A Listing by location (room, zone, area) of equipment and associated cables affected by fire
  - Provides specific equipment responses (cable failure consequences) that affect the credited function being analyzed
  - Equipment losses should be correlated to each Basic Event



## 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
## *Hot Probe Method*




What happens when the Hot Probe contacts:

**P**?

**S**?

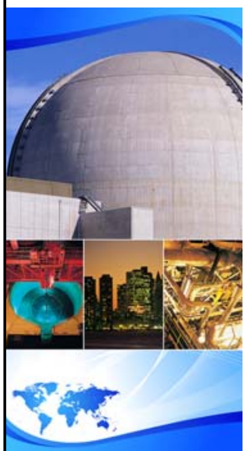
**U**?

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
*Protecting People and the Environment*

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation



# 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 Course
June and October 2009

*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 (FAQ 007-051; Status: Open)
    - Incorporate “End-Device” Functional Attributes and States (e.g., latching circuits vs. drop-out design)
    - Expert elicitation to produce refined spurious operation probabilities (planned for 2010)
  - 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 of the Methodology



## 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
### *Process*

- The Task 10 procedure is subdivided into four (4) primary steps:
  - Step 1: Compile and Evaluate Prerequisite Information and Data
  - Step 2: Select Analysis Approach
  - Step 3: Perform Circuit Failure Mode Probability Analyses
  - Step 4: Generate Circuit Failure Mode Probability Reports



## 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 3 – Related FAQ*

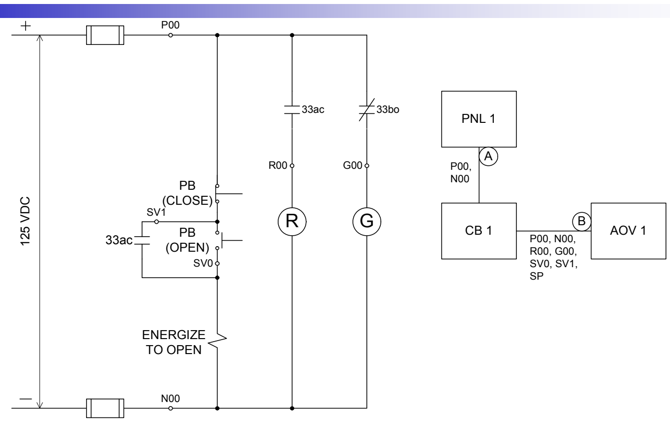
- FAQ 08-0047 Cable Dependency
  - Issue:
    - Guidance (Vol. 2, Page 10-7, Bullet 3) states that when more than one cable can cause the same spurious actuation you combine probabilities using “exclusive or”
    - This assumes faults/effects are independent
  - General approach to resolution:
    - Consensus reached that “exclusive or” is not appropriate if faults are dependent (e.g., a common power supply for both cables)
    - Clarify treatment to determine and address dependency
  - Status:
    - Closed



## 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 – Simple AOV/SOV Control Circuit*




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

*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 | LOP | LOP |
| B | LOP, EI, SO - Open | LOP |

- 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<br>1/C Inter-cable<br>M/C → 1/C Inter-cable<br>M/C → M/C Inter-cable | 0.60<br>0.40<br>0.20<br>0.02 – 0.1 | 0.20 – 1.0<br>0.1 – 0.60<br>0.1 – 0.40 |
| Conduit | M/C Intra-cable<br>1/C Inter-cable<br>M/C → 1/C Inter-cable<br>M/C → M/C Inter-cable | 0.15<br>0.1<br>0.05<br>0.01 – 0.02 | 0.05 – 0.25<br>0.025 – 0.15<br>0.025 – 0.1 |

  - $SO_{Open}$ 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, $\mathbf{P}_{SO(Open)}$ = 0.75 * 0.44 = <u>0.33</u>



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

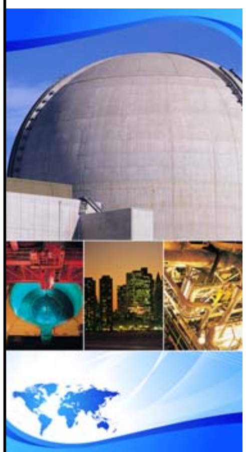
| Failure Code | Estimated Probability (Calculated) | Estimated Probability (From Table 10-2) |
|---|---|---|
| SO (Open) | 0.33 | 0.62 |

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation



# EPRI/NRC-RES FIRE PRA METHODOLOGY

## Module 2: Support Task B - Fire PRA Database

D. Funk - Edan Engineering Corp
F. Wyant - Sandia National Laboratories

Joint RES/EPRI Fire PRA Course
June and October 2009

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

# FIRE PRA DATABASE
## Purpose & Scope

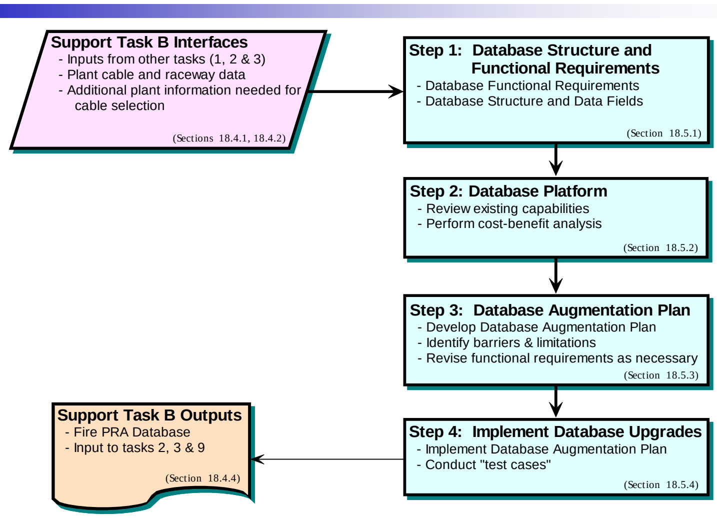
- Identify Required Database Functionality
- Assess Capability of Existing Systems
- Implement Structured Process to Obtain the Required Database Capability
- New Software and Data Management Tools are Finding Their Way Into the Market

# 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

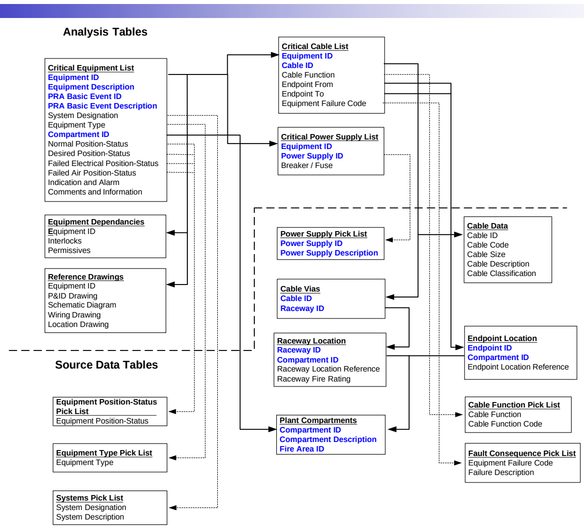


# FIRE PRA DATABASE
## Step 1.1 - Database Functional Criteria

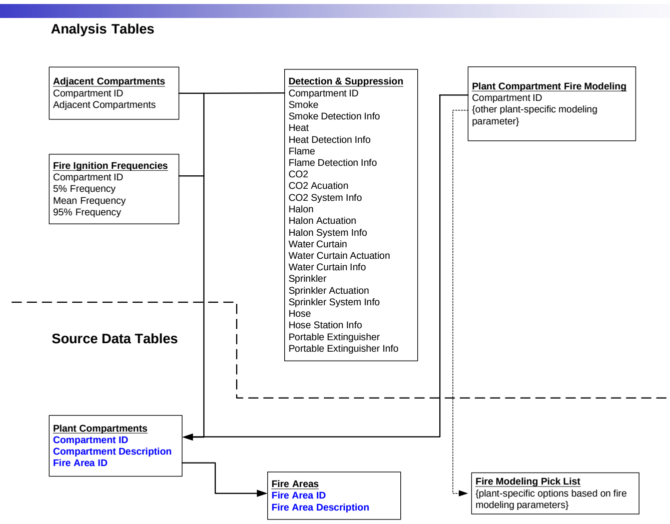
- Data Input Criteria
  - In what shape and format is existing data?
  - How and who will entered and control data?
  - Will data be shared by separate groups? If so, who can change data?
- Data Output Criteria
  - Define required output reports
  - Define sort and query options
  - Establish electronic data transfer requirements



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

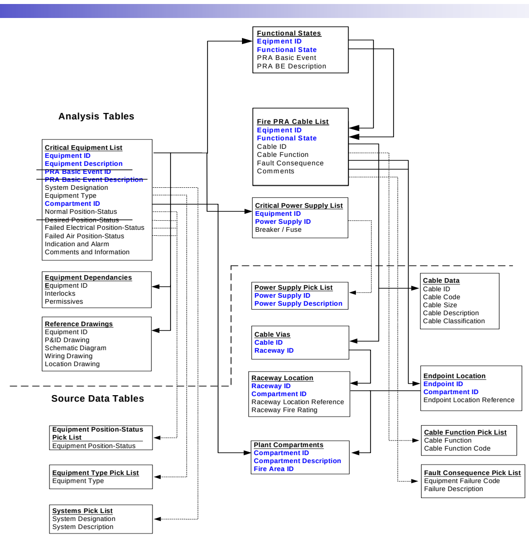


# FIRE PRA DATABASE
## Step 1.2 - Database Structure (Example A)






# 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 just now emerging as a viable production tool



## 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

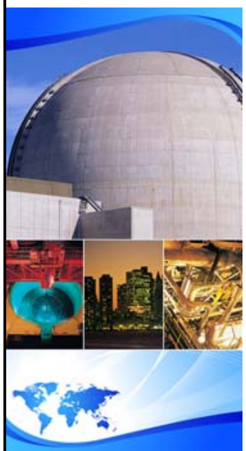
- Have a Clear Plan BEFORE Beginning any Significant Work
- Consider Long-Term Maintainability
- Plan for De-bugging and Test Runs
- Do Not Overlook Data Integrity and Configuration Control Features
- Determine All Affected Users and Involve Then Early
- The Days of “Rouge” PRA Databases are Gone!

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
*Protecting People and the Environment*

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation



# EPRI/NRC-RES FIRE PRA METHODOLOGY

## Module 2: Electrical Examples


D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories

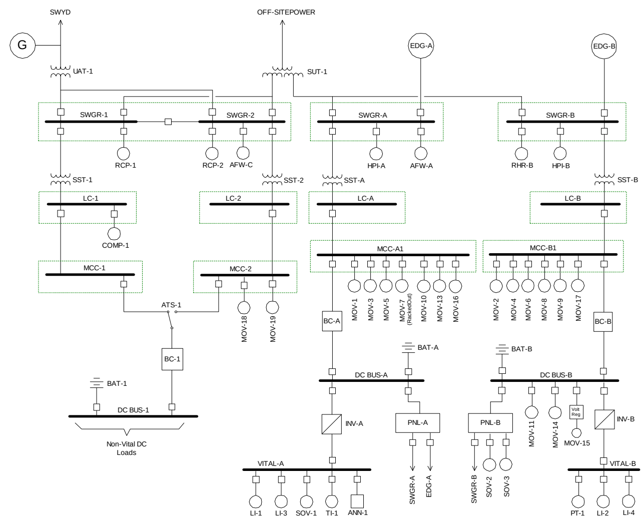

Joint RES/EPRI Fire PRA Course
June and October 2009

***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 <u>is</u> in the Details"

## SNPP ONE-LINE DIAGRAM






## EXAMPLE PROBLEMS

| Example No. | Component | Description of Example | Function State |
|---|---|---|---|
| 1 | AOV-8879B | Easy AOV circuit with desired change of state to failsafe position | Open - Closed |
| 2 | AOV-8879B | Easy AOV circuit with desired position to maintain energized state | Open - Open |
| 3 | MOV-8888 | Easy MOV circuit with desired position to maintain initial state | Open - Open |
| 4 | MOV-8888 | Easy MOV circuit with desired change of state | Open - Closed |
| 5 | MOV-11 | DC MOV control circuit with desired change of state | Close - Open |
| 6 | MOV-15 | Double pole DC motor control circuit with desired change of state – remote and local operation | 6a: Close - Throttled<br>6b: Close – Throttled Local |
| 7 | AOV-2869A | Hard AOV circuit with desired position to maintain initial state | Closed - Closed |
| 8 | AOV-2869A | Hard AOV circuit with desired change of state | Closed - Open |
| 9 | MOV-8706A | Hard MOV with desired position to maintain initial state | Closed - Closed |
| 10 | MOV-8706A | Hard MOV circuit with desired change of state | Closed - Open |
| 11 | ANN-1 | Annunciator Circuit | Unavailable – Nonspurious |
| 12 | HPI-B | 4.16 kV Motor | Standby – On |
| 13 | COMP-1 | 480 V Motor | Cycle - Cycle |
| 14 | MCC-1B | 480V MCC | Energized - Energized |
| 15 | LC-B | 480V Load Center | Energized - Energized |
| 16 | 52-DF01 | 4.16 kV OSP Breaker | Closed - Closed |
| 17 | FCV 605A | Instrument control signal to flow control valve | Closed - Modulate |
| 18 | TTR2 | Instrument loop – temperature indicator | Available - Available |

# HANDS ON WORK

**CIRCUIT ANALYSIS WORKSHEET**

Component ID: AOV-8879B    Component Type: AOV

Component Description: Example 1

Normal Position: OPEN

Failed Electrical Position: CLOSED

Failed Air Position: CLOSED

Function State:

Initial Position: OPEN

Desired Position: CLOSED

BE Code: 8879B-FTC

High Consequence Component: Yes ☐ No ☒

Power Supplies: ______ Breaker: ______ Req'd ☐

______ Breaker: ______ Req'd ☐

Cable Analysis:

| Cable ID | Req'd ? | MHS ? | Fault Consequence | Comments |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| Cable ID | Req'd ? | MHS ? | Fault Consequence | Comments |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Equipment Dependencies:

Comments:

Fault Mode Likelihood Analysis:

| Cable ID | Insulation | Raceway | 6850 Table | No. Cond | Gnd Cond | Sources | Targets | P (x) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |