EPRI/NRC-RES FIRE PRA METHODOLOGY

Module I-1: Fire Risk Requantification Project

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Joint RES/EPRI Fire PRA Workshop

May 24-26, 2006

Rockville, MD

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

BACKGROUND

- MOU between NRC-RES and EPRI on fire risk
- One of several elements on MOU
- Primary objective of this program: develop, field test, and document state-of-art

MOTIVATION

- Improved methods, tools, and data
  - Needed for RI/PB regulatory applications
  - Will support development of ANS fire risk standard
- More robust technical guidance will improve current environment
  - Likely to be more agreement among technical experts

SCOPE

- Full power, including estimates of LERF
- Excludes
  - Low power and shutdown modes of operation
  - Spent fuel pool accidents
  - Sabotage
  - Level 3 estimates of consequence

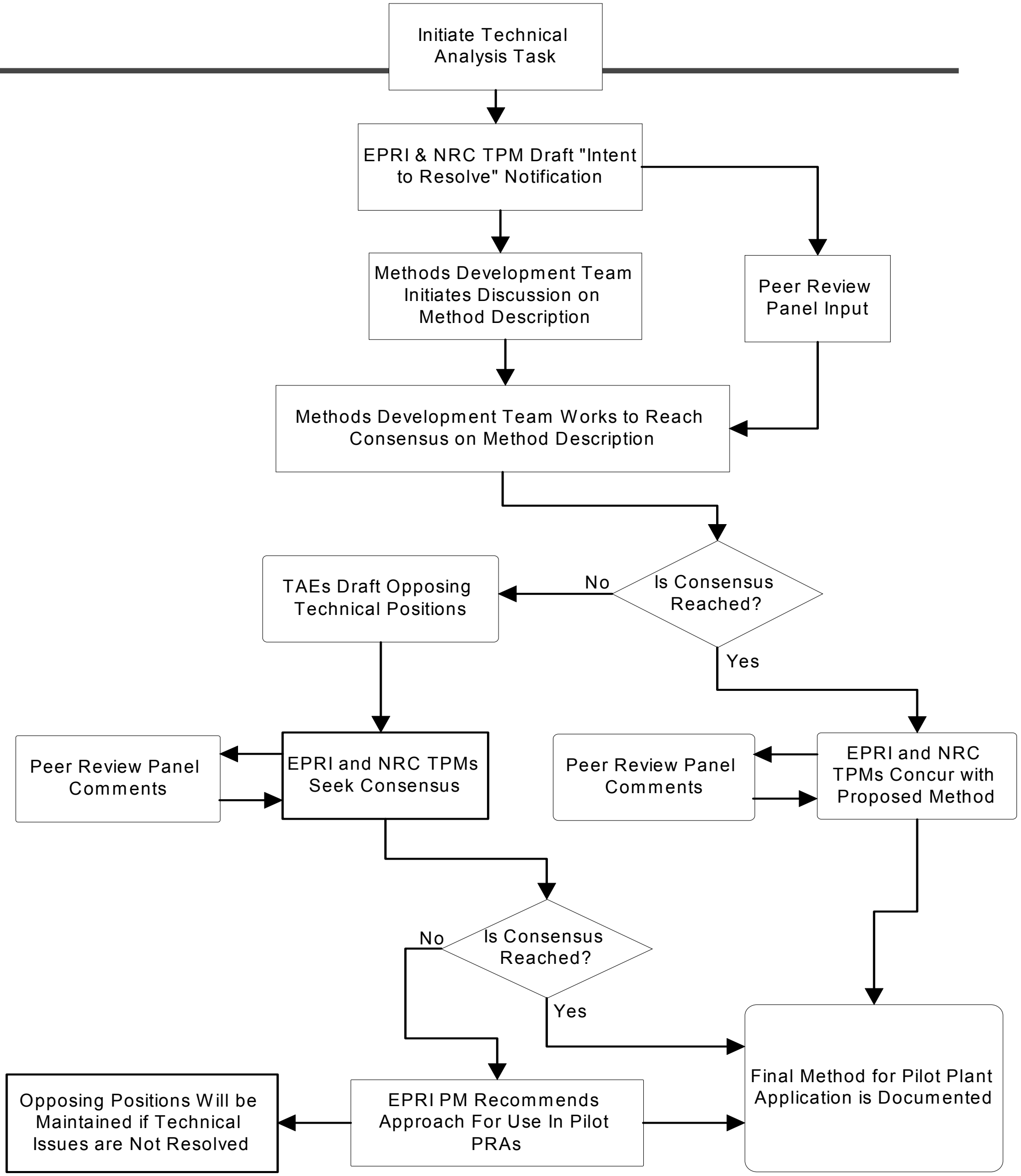
ROLES OF PARTICIPANTS

- NRC-RES and EPRI develop and test methods
- Three volunteer pilot plants support testing
- Other participating licensees provide peer-review of methods

- EPRI and NRC-RES reach consensus on documented methodology

TECHNICAL ISSUE RESOLUTION

- Clear process to allow consideration of all views
- Strive for consensus at many points in process
- Each party maintains own point of view if consensus not reached



EXPECTED USE OF METHODOLOGY

- Support for new rule 10CFR50.48c implementation
- Analyses under the current fire protection regulations (i.e. exemptions/deviations or plant changes due to risk-informed technical specifications)
- Basis for review guidance that RES developed for NFPA 805 related changes
- ANS fire risk standard
- Analysis and reviews of fire protection inspection findings (phase 3 SDP)

ADVANCEMENT TO STATE OF ART

- Improvements made in areas important to fire risk (resource constraints considered)
- Means to advance
  - Consolidate existing research
  - Analyze more extensive data
  - Modify existing methods
  - Develop new approaches

RELATIONSHIP TO FIRE MODEL V&V

- Fire modeling tools provide input to fire PRA
- Fire model verification and validation (V&V) is required for NFPA 805 applications
- In limited cases, fire models (empirical correlations) utilized
  - Address cases where computational fire models inadequate
  - Fill important gaps in fire PRA
- PRA Methodology document not a reference for fire models
  - Any necessary V&V left to analyst

PUBLIC COMMENTS

- Comments provided during public comment period by industry and consultants
  - Duke Power, Florida Power and Light, EPM, RDS
- Comments provided by NRR
- No public comment required NRC-RES and EPRI to significantly adjust our approach
  - Few comments on state-of-the-art limitation
  - Remaining comments were minor and clarifications

MILESTONES

• First Public Fire PRA Workshop	Jun 2005
• Publication	Sept 2005
• BWR pilot	2006/2007
• Revision of methodology (as needed)	2008

PROJECT TEAM

- Covers all technical disciplines critical to Fire PRA
    - Technical Lead: B. Najafi, S. Nowlen
    - General PRA & plant systems analysis: A. Kolaczkowski, R. Anoba
    - Circuit Analysis and Appendix R: D. Funk, F. Wyant
    - Human Reliability Analysis: J. Forrester, W. Hannaman, A. Kolaczkowski
    - Fire analysis: F. Joglar, M. Kazarians
    - Consultants: A. Mosleh, D. Bley
- Collectively, over 250 years of relevant experience
- Principal authors of documented Fire PRA methods in the US for the past 2 decades
- Experience with use of pervious methods; their strengths and weaknesses
- The Methodology reflects the consensus of this team, EPRI and RES

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module I-2: Overview of the Fire PRA Methodology

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BACKGROUND

- Prior to IPEEE; Mostly simple approximate method for order-of-magnitude assessment of fire risk, e.g. NUREG/CR-2258, Fire Risk Analysis for Nuclear Power Plants.
- EPRI FIVE (1992)
  - A "vulnerability evaluation" methodology developed in response to IPEEE program
- EPRI Fire PRA Implementation Guide (1995)
  - Developed as a complement to FIVE for detailed evaluation of unscreened fire areas/compartments
  - More robust methods (compared to FIVE) for:
    - Development and evaluation of fire risk model, including human actions
    - Assessment of fire growth and damage, detection and suppression
    - Control room and multi-compartment fire risk

EPRI/NRC-RES FIRE PRA METHODOLOGY

- The methodology is presented in the form technical task procedures within an overall process
- The process is intended as a guide and should fit most cases
- User may adjust process based on plant-specific information, efficiency, economy and desired applications

EPRI/NRC-RES FIRE PRA METHODOLOGY

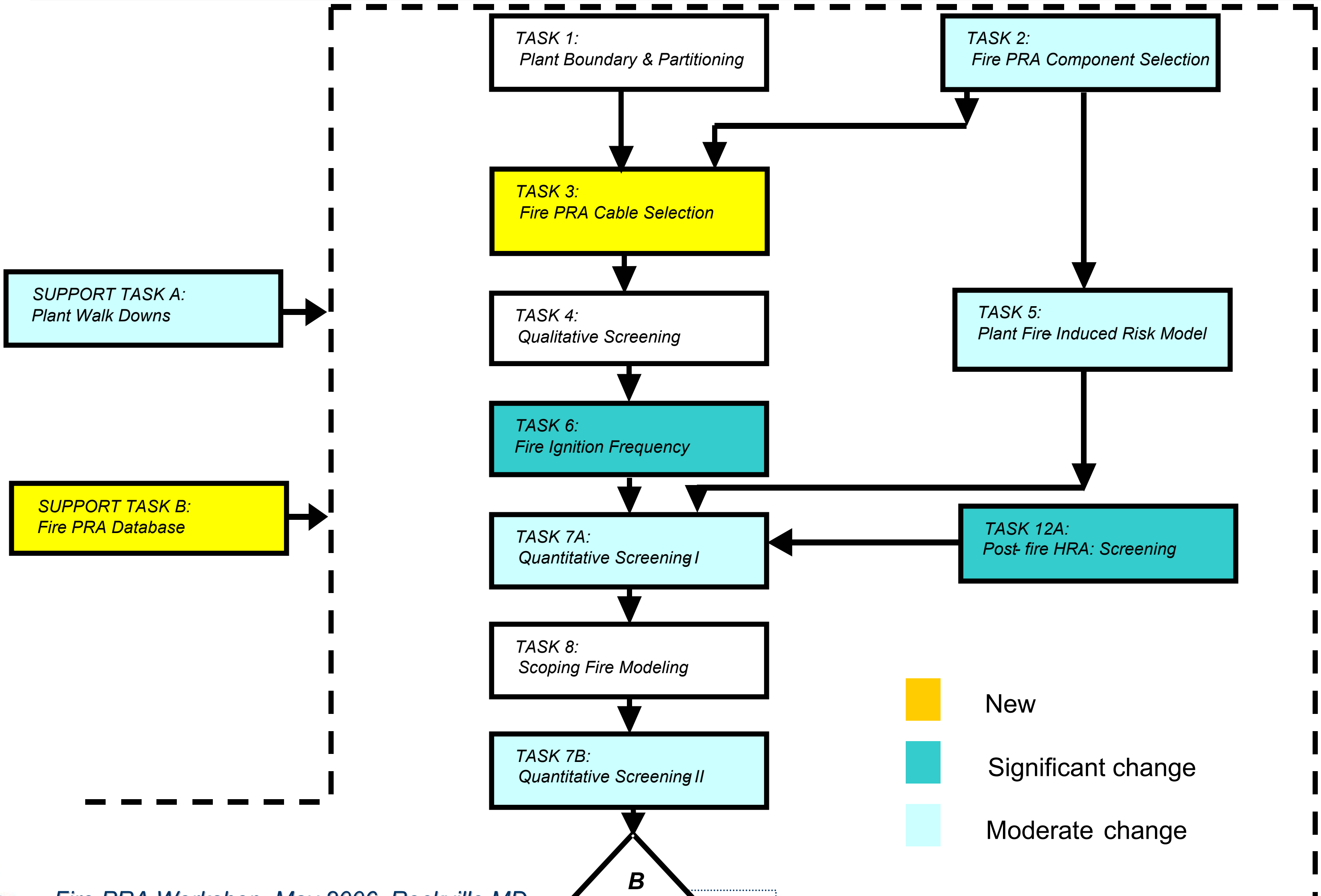
- Procedures cover the following technical areas
  - Plant analysis boundary and partitioning
  - Fire PRA component selection and risk model
  - Circuit/cable selection, routing and failure modes analysis
  - Screening, qualitative and quantitative
  - Fire ignition frequency
  - Fire modeling; fire growth, damage and detection/suppression
  - Post-fire human reliability analysis (HRA)
  - Seismic-fire interactions, and
  - Fire risk quantification, including uncertainties, and documentation

PROCEDURE CONTENT

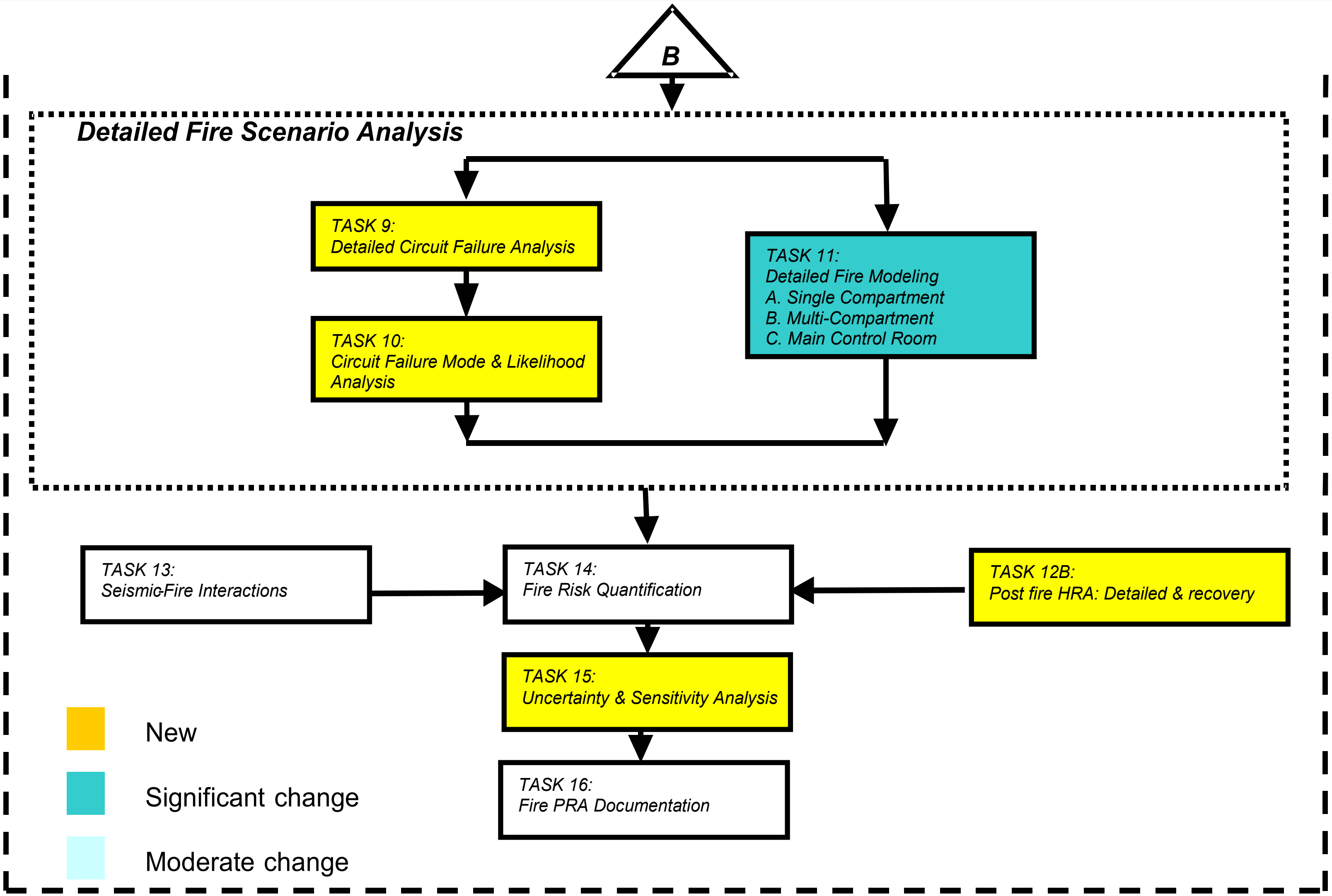
1. Purpose
2. Scope
3. Background information: General approach and assumptions
4. Interfaces: Input/output to other tasks, plant and other information needed, walk-downs
5. Procedure: Step-by-step instructions for conduct of the technical task
6. References

Appendices: Technical bases, data, examples, special models or instructions, tools or databases

OVERVIEW OF FIRE PRA PROCESS



OVERVIEW OF FIRE PRA PROCESS



IMPROVEMENTS

Improvement focused on:

- Areas critical to application, e.g.,
  - Circuit selection & analysis, including spurious actuations
  - Safe shutdown manual actions
- Resolving technical issues from review of the EPRI methods and IPEEEs, e.g.,
  - Fire severity
  - Fire detection and suppression
- Improved method and/or technical basis without need for significant research, e.g.,
  - Transient fire frequency model
  - Modeling of fire safe shutdown strategy

WHERE ARE THE IMPROVEMENTS
From FIVE & Fire PRA Guide

- New tasks
  - Circuit selection and analysis (tasks 3, 9 and 10)
  - Uncertainty (task 15)
- Significant changes: Change/addition of method
  - Ignition frequency (task 6)
  - Post-fire HRA (task 12)
  - Fire modeling (tasks 8 and 11)

WHERE ARE THE IMPROVEMENTS
From FIVE & Fire PRA Guide

- Moderate changes: Changes to improve the process
  - Component selection (task 2)
  - Fire-induced risk model (task 5)
  - Quantitative screening (task 7)
- Insignificant changes
  - Analysis boundary and partitioning (task 1)
  - Qualitative screening (task 4)
  - Seismic fire interactions
  - Quantification & documentation (tasks 14 and 16)

KEY AREAS OF IMPROVEMENTS (NEW):
Circuit/cable Selection, Routing and Failure Modes Analysis

- Stand-alone approach for cable selection and analysis within the context of risk
  - Past U.S. methods relied on existing plant analyses such as Appendix R safe shutdown analysis
  - This approach uses similar methods but with an expanded scope
  - Prepared with the recognition of other documents addressing related technical area(s)
- Multiple spurious actuations of equipment and instruments
  - Recommends up to 3 in component selection (more if needed for your application)
- Probabilistic Circuit Failure Modes and Likelihood
  - Important where redundant cables are affected by the same fire such as main control room
  - Use of fire testing (2002) by EPRI and NEI with NRC participation

KEY AREAS OF IMPROVEMENT (NEW):
Uncertainty

- FIVE and Fire PRA Guide did not explicitly address uncertainties
- Understanding and assessment of uncertainties, to the extent possible, is necessary part of PRA and risk-informed applications
- This method offers:
  - Systematic identification and evaluation of sources of uncertainty
  - Quantification limited to where possible
    - No new method offered

KEY AREAS OF IMPROVEMENT:
Fire Ignition Frequency

- EPRI FIVE and Fire PRA Guide used location/component-based frequency model
- This method uses component-based frequency model for most sources
  - This method allows for plant-to-plant variability in fire hazard location
  - Larger data set (since IPEEE) makes this more feasible
- Use of two-stage Bayesian as a means of addressing data quality/variability
- Improved transient fire frequency model to account for plant practice and administrative control

KEY AREAS OF IMPROVEMENT:
Post-fire human Reliability Analysis

- Previous methods
  - FIVE does not provide explicit instructions for assessment of operator response
  - Fire PRA Guide provide simplified rules for screening HRA
- This method: Primary focus is on the Screening HRA
  - Rule-based (in the absence of detailed fire scenario information) quantitative screening approach
  - Instructions provided to develop screening HEPs based on these conditions
- Detailed post-fire HRA defers to the use of existing HRA methods in fire conditions
  - Fire performance shaping factors (PSF) defined and described
- Quantitative link between these PSFs and best-estimate HEPs not developed (Post-fire HRA methodology)

KEY AREAS OF IMPROVEMENTS:
Fire Modeling

- Characterization of ignition source heat release rate (HRR)
  - Peak HRR value was used in FIVE and Fire PRA Implementation Guide
  - Distribution of fire intensity for various fire types is provided in this method
- Fire severity
  - FIVE had no SF, Fire PRA Guide treated as a fixed value
  - A method is provided to derive SF based of conditions specific to the fire scenario
- Fire suppression analysis
  - Manual suppression times based on event data – historical fire suppression time curves, same as Fire PRA Implementation Guide
  - Suppression curves provided based on ignition source and/or location

KEY AREAS OF IMPROVEMENTS:
Fire Modeling

- Special fire models
  - Needed to address fire scenarios important to NPPs but outside the capability of the most commonly used computational fire models
  - None where in FIVE, some where in Fire PRA Implementation Guide
    - New: Main Control Board fires, High-Energy Arcing Faults, Turbine Generator fires, Smoke damage
    - Improved: Cable fires, Hydrogen fires
    - Similar for the most part: Cabinet-to-cabinet fire propagation, Passive fire protection features

OTHER AREAS OF IMPROVEMENT

- Component Selection
  - Consideration of components critical to spurious (particularly multiple) spurious actuations
- Fire-specific plant response
  - Special models to address deviations from normal Emergency Operating Procedures
  - Large early release
- Quantitative screening
  - Use of a “floating” screening criteria to derive total fire risk profile (rather than vulnerabilities)

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 1: Plant Partitioning, Qualitative Screening, and an Introduction to Walkdowns

Steve Nowlen

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Plant Partitioning and Qualitative Screening
Scope of this Module

Module 1 covers three tasks:

- Support Task A: Plant Walkdowns
  - Role of walkdowns in Fire PRA
- Task 1: Plant Partitioning Analysis
  - Define Global Analysis Boundary
  - Partition into physical analysis units or Compartments
- Task 4: Qualitative Screening
  - First chance to identify very low risk compartments

Support Task A: Plant Walkdowns
Just a Quick Note….

- You *cannot* complete a Fire PRA without walkdowns
- Expect to conduct a number of walkdowns, especially for key areas (e.g., those analyzed in detail)
- Walkdowns can have many objectives and support many tasks:
  - Partitioning features, equipment/cable mapping, fire ignition source counting, fire scenario definitions, fire modeling, detection and suppression features, recovery actions HRA
- Walkdowns are generally a team activity so coordinate them to optimize personnel time and resources

Plant Partitioning and Qualitative Screening
General Comment/Observation

- The recommended practice for both Tasks 1 and 4 are little changed from prior methods
  - These were areas of consolidation for the methods development work
  - That means you can likely benefit from a previous analysis
    - e.g., your IPEEE fire analysis
    - However: watch out for new equipment/cables, new initiators when screening
  - We will cover material rather quickly

Task 1: Plant Partitioning
Key Definitions: Compartment vs. Fire Area/Zone

- We talk mainly about Fire Compartments which are defined in the context of the Fire PRA only
  - Defining Fire Compartments is an analysis convenience
- Fire Areas are defined in the context of your regulatory compliance fire protection program
- Fire Zones are generally defined in the context of fire protection features (e.g., detection, suppression, hazards)
  - Fire zones have no direct meaning to the Fire PRA context and we avoid using this term

Task 1: Plant Partitioning
Task Objectives and Output

- There are two main objectives to Task 1:
  - Define the Global Analysis Boundary
    - The maximum physical extent of the plant that will be considered in the Fire PRA
  - Divide the areas within the Global Analysis Boundary into analysis Compartments
    - The basic physical units that will be analyzed and for which risk results will be reported
- Task output <u>is</u> the definition of these two aspects of the analysis

Task 1: Plant Partitioning
Task Input

- No real input from any other task is required (it is, after all, Task 1)
  - There *is* a link to the equipment and cable selection Tasks 2 and 3
  - You may also find yourself iterating back to this task later in the analysis – that is fine, just be careful to track any changes
- What do you need to support this Task?
  - Layout drawings that identify major structures, walls, openings
    - Drawings that identify Fire Areas are especially helpful
  - Plan and elevation drawings are helpful
  - You *will* need to do a walkdown to support/verify decisions

Task 1: Plant Partitioning
Defining the Global Analysis Boundary

- Our guidance assumes that you are analyzing an entire unit
  - Some applications may focus on a specific portion of the plant
    - Example: NFPA 805 Change Analysis may impact as little as a single fire area
  - Our approach/guidance still works, but as an analyst, you will need to adjust the global analysis boundary to suit your intended application
  - However, if you goal is a plant-wide Fire PRA then…..

Task 1: Plant Partitioning
Defining the Global Analysis Boundary (2)

- We want a *Liberal* definition of the global analysis boundary
  - It's OK to include obviously unimportant areas, we'll drop them quickly, but better to do this formally
- Encompass all areas of the plant associated with both normal and emergency reactor operating and support systems, as well as power production
- Sister Units should be included unless they are physically and functionally separated
  - No shared areas, no shared systems, no shared components and associated cables, no conjoined areas (e.g., shared walls)

Task 1: Plant Partitioning
Defining the Global Analysis Boundary (3)

- Begin with your protected area: anything within the protected area should be included in the Global Analysis Boundary
  - In most cases that will capture all risk-important locations
- If necessary, expand the boundary to include any other locations that house any equipment or cable identified in Tasks 2 or 3
  - This is the Task 2/3 link mentioned before!
  - Example: If your turbine building is outside the protected area, you need to expand Global Analysis Boundary to capture it

Task 1: Plant Partitioning
Defining the Global Analysis Boundary (4)

- By the end of the analysis, you need to provide a fire risk disposition for all locations within the global analysis boundary
  - That may be anything from screened out qualitatively to a detailed risk quantification result

Task 1: Plant Partitioning
Defining Fire Compartments (1)

- We divide the Global Analysis Boundary into smaller pieces (compartments) for the purpose of tracking and reporting risk results
- A compartment can be many things, but when it comes down to it, a compartment is:

  A well-defined volume within the plant … that is expected to substantially contain the adverse effects of fires within the compartment.

Task 1: Plant Partitioning
Defining Fire Compartments (2)

- This task is often subjective – judgment *is* required
- Ideally: Compartments = Rooms
  - Locations that are fully defined by physical partitioning features such as walls, floors, and ceilings
- But the ideal is not the only solution - other features and elements may be credited in partitioning
  - That's where judgment comes into play!
  - What will you credit as a Partitioning Feature?

Task 1: Plant Partitioning
Defining Fire Compartments (3)

- A good starting point is your Fire Areas, but you are *by no means limited* to equating Fire Compartments to Fire Areas
  - A Fire Area may be partitioned to two or more Compartments
  - You may combine two or more Fire Areas into a single Compartment
- Map your Fire Compartments back to your Fire Areas!
  - Regulatory applications are Fire Area based so you want to have this mapping
- In the end: { ∑ Compartments } = { Global Analysis Bnd. }
  - No omissions – No overlap!

Task 1: Plant Partitioning
Defining Fire Compartments (4)

- So what can you credit as a partitioning feature:
  - Bottom line: anything you can justify – see text for examples
    - You do need to justify your decisions with the exception of structural elements maintained as a rated fire barriers
  - In the end, your partitioning decisions should not affect the risk results, but..
  - Don't go crazy – there are disadvantages to over-partitioning
  - General guideline: try to minimize the need to develop and analyze multi-compartment scenarios

Task 1: Plant Partitioning
Defining Fire Compartments (5)

- There are some things that you should not credit in partitioning:
  - Partial height walls
  - Radiant energy shields
  - Beam pockets
  - Equipment obstructions (e.g., pipes)
  - (ANS Draft Standard says: Raceway or other localized fire barriers *may not be credited* in partitioning)

Task 1: Plant Partitioning
Defining Fire Compartments (6)

- Final Point: You need a system to identify/name your Fire Compartments
  - Something both consistent and logical – but whatever works for your application and plant
  - Often makes sense to use Fire Area designations in naming schemes
    - Example: Fire Area 42 might become Fire Compartments 42A, 42B…
  - Use your naming scheme consistently throughout the Fire PRA
    - Documentation, equipment/cable tracing, database, etc.

Task 4: Qualitative Screening
Objectives and Scope

- The objective of Task 4 is to identify those Fire Compartments that can be shown to have a negligible risk contribution without quantitative analysis
  - This is where you drop the office building inside the protected area
- Task 4 *only* considers fire compartments as individual contributors
  - Multi-compartment scenarios are covered in Task 11(b)
  - Compartments that screen out qualitatively need to be re-considered as potential Exposing Compartments in the multi-compartment analysis (but not as the Exposed Compartment)

Task 4: Qualitative Screening
Required Input and Task Output

- To complete Task 4 you need the following input:
  - List of fire Compartments from Task 1
  - List of Fire PRA equipment from Task 2 including location mapping results
  - List of Fire PRA Cables from Task 3 including location mapping results
- Task Output: A list of Fire Compartments that will be screened out (no further analysis) based on qualitative criteria

Task 4: Qualitative Screening
A Note….

- Qualitative Screening is OPTIONAL!
  - You may choose to retain any number of fire compartments (from one to all) without formally conducting the Qualitative Screening Assessment for the compartment
  - However, to eliminate a compartment, you must exercise the screening process for the compartment
  - *Example 1*: Many areas will never pass qualitative screening, so simply keep them
  - *Example 2*: If you are dealing with an application with limited scope (e.g. NFPA 805 Change Evaluation) a formalized Qualitative Screening may be pointless

Task 4: Qualitative Screening
Screening Criteria

- A Fire Compartment may be screened out if:
  - No Fire PRA equipment or cables are located in the compartment, and
  - No fire that remains confined to the compartment could lead to:
    - An automatic plant trip, or
    - A manual trip *as specified by plant procedures*, or
    - A *near-term* manual shutdown due to violation of plant Technical Specifications*

*In the case of tech spec shutdown, consideration of the time window is appropriate

- No firm time window is specified in the procedure – rule of thumb: consistent with the time window of the fire itself
- Analyst must choose and justify the maximum time window considered

End of Module 1

- Questions?
- Discussion?
- Comments?

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-2: Task 2 - Fire PRA Component Selection & Task 5 - Fire-Induced Risk Model Development

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Component Selection and PRA Risk Model
Scope of this Module

Module II-2 covers two tasks:

- Task 2: Fire PRA Component Selection
  - Deciding what to model in the Fire PRA
- Task 5: Fire-Induced Risk Model Development
  - Constructing the PRA model

Component Selection and PRA Risk Model

General Comment/Observation

- Task 2 can represent an expansion of what needs to be considered over previous fire analyses
- Task 5 does not represent any changes from past practice, but what is modeled is based on Task 2
- Bottom line – just “tweaking” your IPEEE is probably NOT sufficient

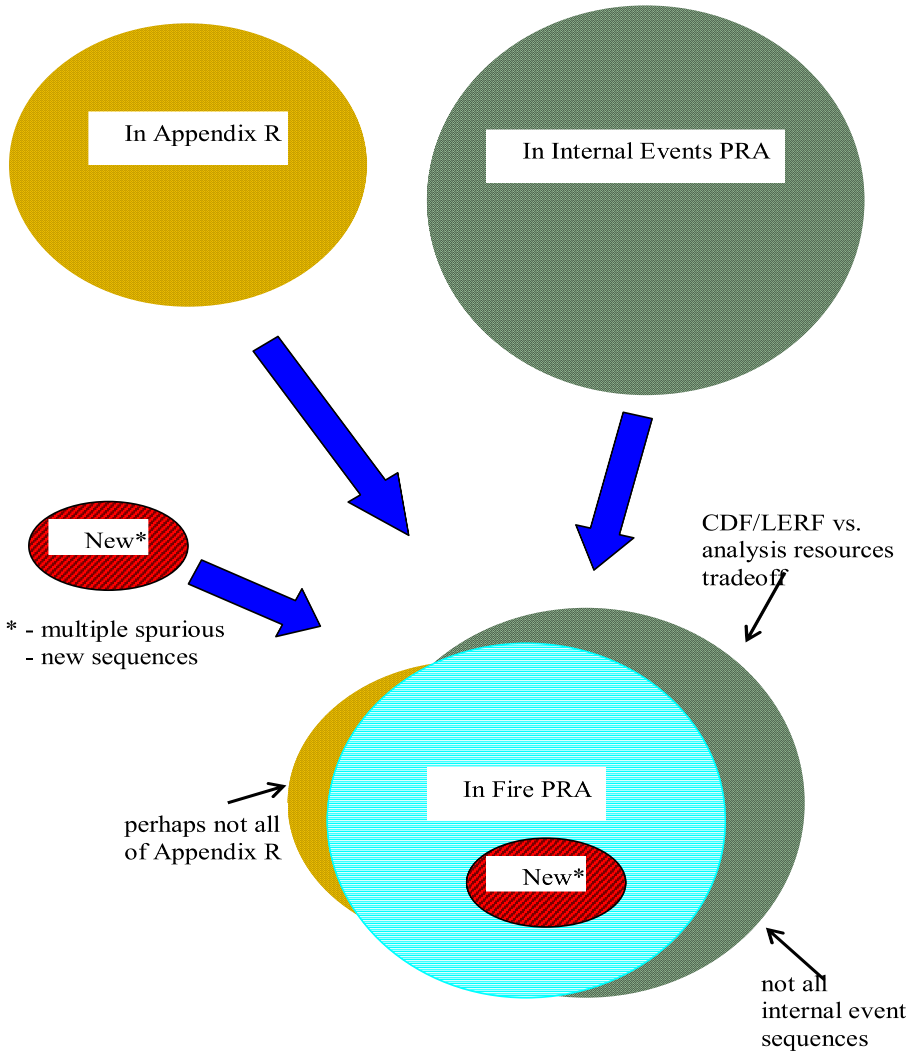
Task 2: Fire PRA Component Selection
General Objectives

Purpose: select plant components to be modeled for safe shutdown following fire in the plant

- See next slide for overview of scope
- WARNING: Just crediting Appendix R components may NOT be conservative
  - True that all other components in Internal Events PRA will be assumed to fail, but…
  - May be missing "new" components
  - May miss effects of non-modeled components on credited (modeled) systems/components and on operator performance
  - Still need to consider non-credited components as sources of fires

Task 2: Fire PRA Component Selection

Overview of Scope



Task 2: Fire PRA Component Selection
Scope of Component List

Should include following major categories of equipment:

- Equipment whose fire-induced failure causes an initiating event (need to identify worse-case initiator for each compartment)
- Equipment for mitigating safety functions and operator actions
- Equipment whose fire-induced failure or spurious actuation may adversely impact credited mitigating safety functions
- Equipment whose fire-induced failure or spurious actuation may cause inappropriate or unsafe operator actions

Task 2: Fire PRA Component Selection
Inputs/Outputs

Task inputs and outputs:

- Inputs from other tasks: equipment considerations for operator actions from Task 12 (Post-Fire HRA)
- Outputs to Task 3 (Cable Selection) and Task 5 (Risk Model)
- Choices made in this task set the overall analysis scope

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 1: Identify sequences to include and exclude from Fire PRA

- Some sequences can generally be excluded because of low frequency; e.g., fire with pipe-break LOCAs, SGTR, ATWS, vessel rupture
- Possible additional sequences: spurious SI, sequences associated with other spurious operation, MCR abandonment scenarios and other sequences arising from Fire Emergency Procedures (FEPs)

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 2: Compare Internal Events PRA model to App. R SSD list

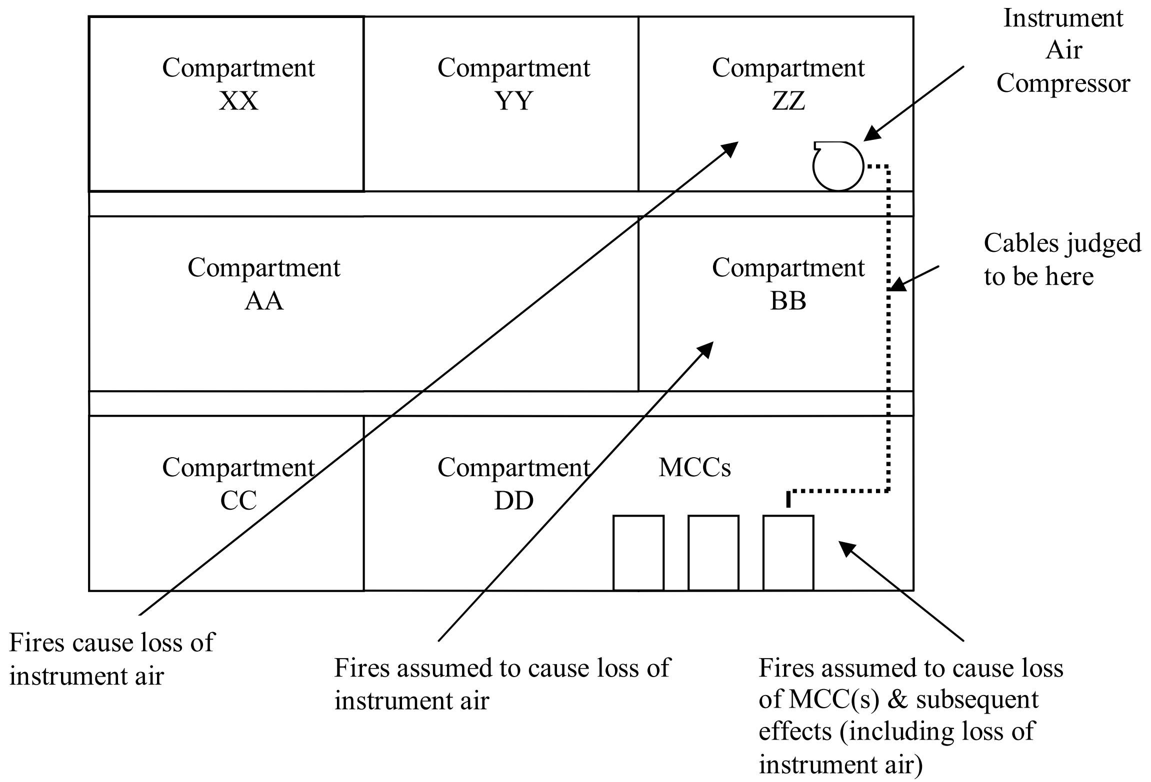
- Identify and reconcile differences in functions, success criteria, and sequences (e.g., App. R- no feed/bleed; PRA-feed/bleed)
- Identify and reconcile front-line and support system differences (e.g., App. R-need HVAC; PRA-do not need HVAC)
- Identify and reconcile system and equipment differences due to end state and mission considerations (e.g., App. R-cold shutdown; PRA-hot shutdown)
- Identify and reconcile other miscellaneous equipment differences. Include review of manual actions (e.g., actions needed for safe shutdown) in conjunction with Task 12

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 3: Identify fire-induced initiating events. Consider:

- Equipment whose failure will cause automatic plant trip
- Equipment whose failure will likely result in manual plant trip, per procedures
- Equipment whose failure will invoke Tech. Spec. LCO necessitating shutdown in < 8 hours
- Compartments with none of the above need not have initiator
- Since not all equipment/cable locations in the plant (e.g., all BOP) may be identified, judgment involved in ‘likely’ cable paths
- Identify worse-case initiator based on possible initiators and other mitigating equipment likely to be affected

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

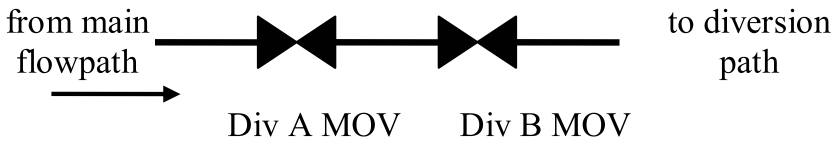


Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 4: Identify equipment whose spurious actuation may challenge SSD capability

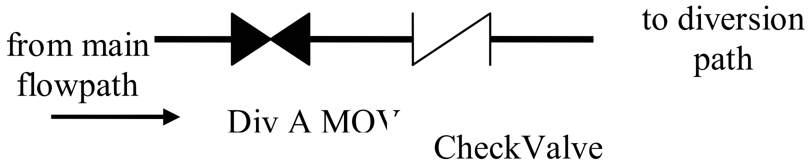
- Consider multiple spurious events within each system (as a practical matter, at least 2 to 3)
- Involves review of system P&IDs and other drawings
- Focus on equipment or failure modes not already on the component list (e.g., flow diversion paths)
- Any new equipment/failure modes should be added to component list for subsequent cable-tracing and circuit analysis

Task 2: Fire PRA Component Selection
Steps In Procedure/Details



takes 2 spurious hot shorts to open diversion path

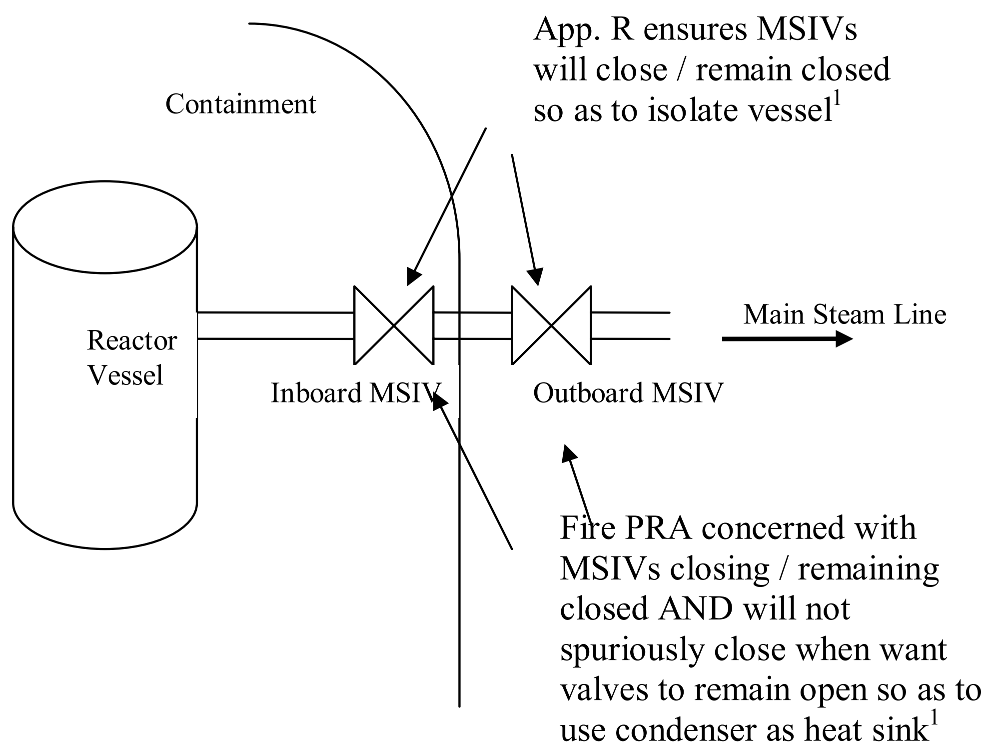
Included in model



takes 1 spurious hot short & failure of check valve to open diversion path

Screened from model if not potential high consequence event

Task 2: Fire PRA Component Selection
Steps In Procedure/Details



[1] different cables and corresponding circuits and analyses may need to be accounted for

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 5: Identify additional instrumentation/diagnostic equipment important to operator response (level of redundancy matters!)

- Identify human actions of interest in conjunction with Task 12
- Identify instrumentation and diagnostic equipment associated with credited and potentially harmful human actions considering at least a single spurious indication related to each action
  - Is there insufficient redundancy to credit desired actions in EOPs/FEPs/ARPs in spite of a failed/spurious indication?
  - Can a spurious indication cause an undesired action because action is dependent on an indication that could be 'false'?
  - If yes – put indication on component list for cable/circuit review

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 6: Include "potentially high consequence" related equipment

- High consequence events are one or more related failures at least partially caused by fire that, by themselves:
  - cause core damage and large early release, or
  - single component failures that cause loss of entire safety function and lead directly to core damage
- Example of first case: spurious opening of two valves in high-pressure/low pressure RCS interface, leading to ISLOCA
- Example of second case: spurious opening of single valve that drains safety injection water source

Task 2: Fire PRA Component Selection
Steps In Procedure/Details

Step 7: Assemble Fire PRA component list. Should include following information:

- Equipment ID and description (may be indicator or alarm)
- System designation
- Equipment type and location (at least compartment ID)
- PRA event ID and description
- Normal and desired position/status
- Failed electrical/air position
- References, comments, and notes

Task 2: Fire PRA Component Selection
Key Assumptions

The following key assumptions underlie this procedure:

- A good quality Internal Events PRA and App. R SSD analysis are available
- Analysts have considerable collective knowledge and understanding of plant systems and operator performance, and of the Internal Events PRA and App. R SSD analysis
- Reasonable bounds are applied in Steps 4 thru 6 to “limit” the number of spurious actuations considered
  - Configurations, timing, length of sustained spurious actuation, cable material, etc. among reasons to limit what will be modeled

Task 2: Fire PRA Component Selection
Inside the numbers (just like ESPN!)

Expect Task 2 to take 1.5 – 2.5 person-months

Expect the total number of components (not counting non-electrical components like check valves, heat exchangers, etc.) to be ~400 ± 100

Task 5: Fire Risk Model Development
General Objectives

Purpose: Configure the Internal Events PRA to provide fire risk metrics of interest (primarily CDF and LERF).

- Based on standard state-of-the-art PRA practices
- Intended to be applicable for any PRA methodology or software
- Allows user to quantify CDF and LERF, or conditional metrics CCDP and CLERP
- *Conceptually, nothing "new" here – need to "build the PRA model" reflecting fire induced initiators, equipment and failure modes, and human actions of interest*

Task 5: Fire Risk Model Development
Inputs/Outputs

Task inputs and outputs:

- Inputs from other tasks: [Note: inclusion of spatial information requires cable locations from Task 3]
  - sequence considerations, initiating event considerations, and components from Task 2 (Fire PRA Component Selection),
  - unscreened fire compartments from Task 4 (Qualitative Screening),
  - HRA events from Task 12 (Post-Fire HRA)
- Output to Task 7 (Quantitative Screening) which will further modify the model development
- Can always iterate back to refine aspects of the model

Task 5: Fire Risk Model Development
Steps in Procedure

Two major steps:

- Step 1: Develop CDF/CCDP model
- Step 2: Develop LERF/CLERP model

Task 5: Fire Risk Model Development
Steps in Procedure/Details

Step 1 (2): Develop CDF/CCDP (LERF/CLERP) models

Step 1.1 (2.1): Select fire-induced initiators and sequences and incorporate into the model

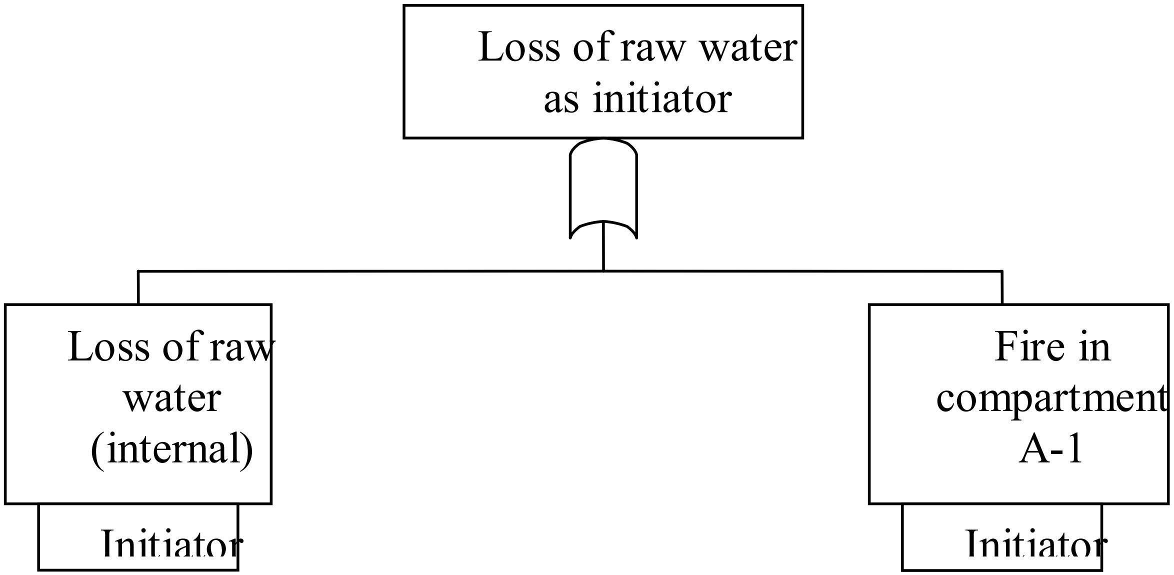
- Each fire-induced initiator is mapped to an internal initiator that mimics the effect on the plant of the fire initiator
- Internal events sequences form bulk of sequences for Fire PRA, but a search for new sequences should be made (see Task 2). Some new sequences may require new logic to be added to the PRA model

Task 5: Fire Risk Model Development
Steps in Procedure/Details

Step 1.1 (2.1) - continued

- Plants that use fire emergency procedures (FEPs) may need special models to address unique fire-related actions (e.g., pre-defined fire response actions and MCR abandonment).
- Some human actions may induce new sequences not covered in Internal Events PRA and can “fail” components
  - Example: SISBO, or partial SISBO

Task 5: Fire Risk Model Development
Steps in Procedure/Details



Example of new logic with a fire-induced loss of raw water initiating event

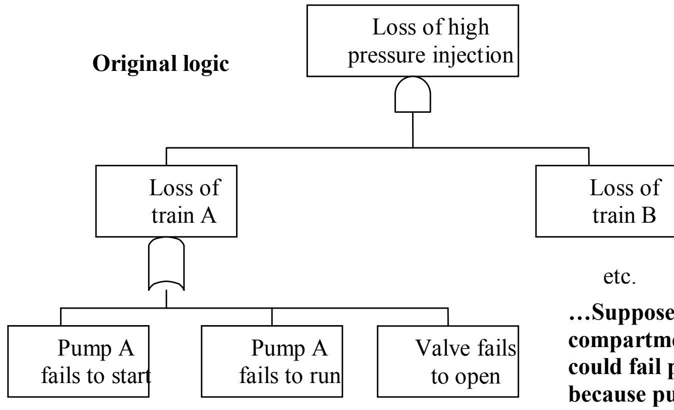
Task 5: Fire Risk Model Development
Steps in Procedure/Details

Step 1.2 (2.2): Incorporate fire-induced equipment failures

- Fire PRA database documents list of potentially failed equipment for each fire compartment
- Basic events for fire-induced spurious operation are defined and added to the PRA model
- Inclusion of spatial information requires equipment and cable locations
  - May be an integral part of model logic, or handled with manipulation of a cable location database, etc.

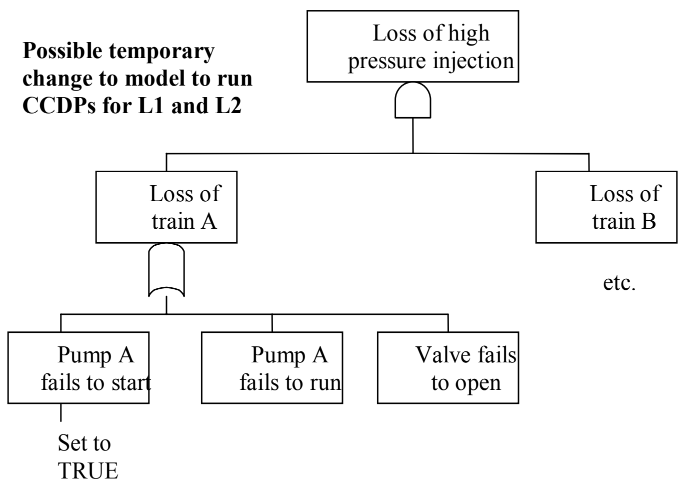
Task 5: Fire Risk Model Development
Steps in Procedure/Details

Original logic

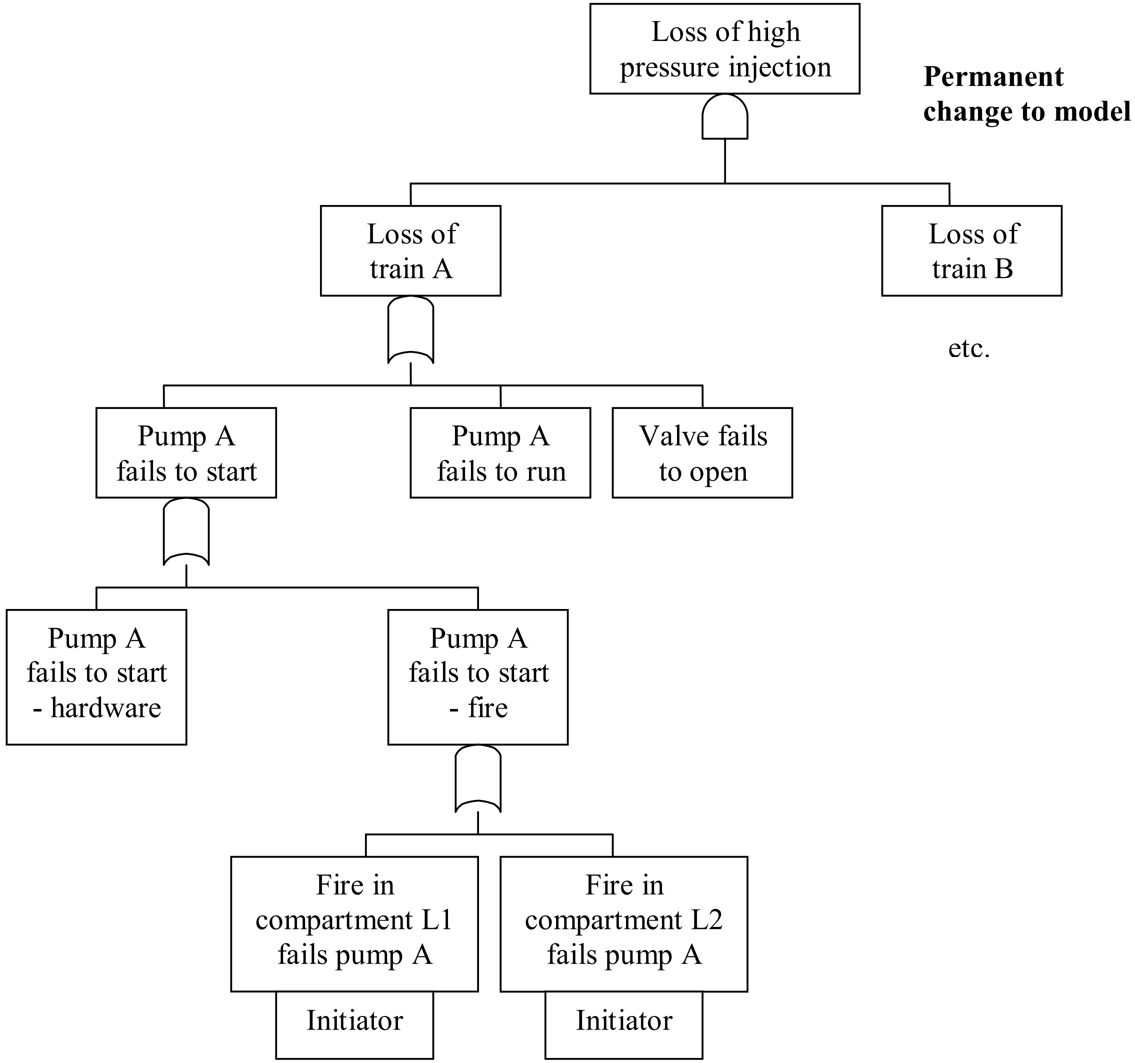


…Suppose fire in compartment L1 or L2 could fail pump A because pump A is in L1 and cable for pump A is in L2 …

Possible temporary change to model to run CCDPs for L1 and L2



Task 5: Fire Risk Model Development
Steps in Procedure/Details



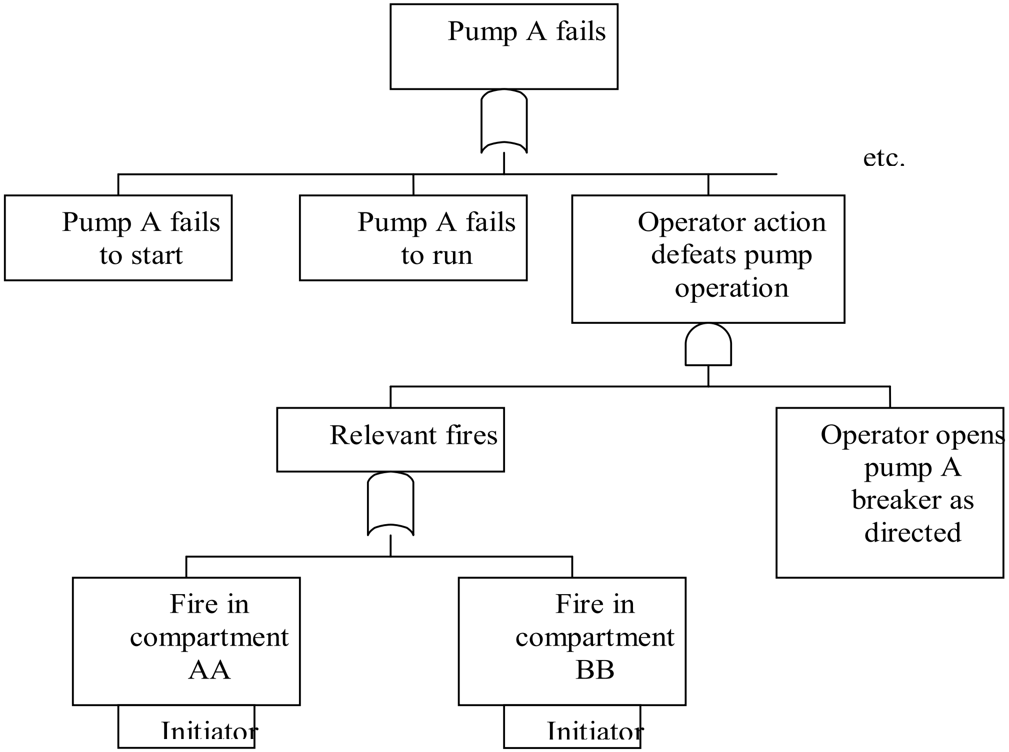
Task 5: Fire Risk Model Development
Steps in Procedure/Details

Step 1.3 (2.3): Incorporate fire-induced human failures

- New fire-specific HFEs may have to be added to the model to address actions specified in FEPs [Note: all HFEs will be set at screening values at first, using Task 12 guidance]
- Successful operator actions may temporarily disable ("fail") components

Task 5: Fire Risk Model Development
Steps in Procedure/Details

Suppose a proceduralized manual action carried out for fires in compartments AA & BB defeats Pump A operation by de-energizing the pump (opening its breaker drawer)…



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-3, Pt. 1: Fire PRA Circuit Analysis Overview

D. Funk - Edan Engineering Corp.

F. Wyant - Sandia National Laboratories

Joint RES/EPRI Fire PRA Workshop

May 24-26, 2006

Rockville, MD

CIRCUIT ANALYSIS
Presentation Road Map

- Circuit Analysis “Big Picture” Overview
- Circuit Analysis Strategy & Implementation
- Introduction to Key Considerations & Factors
- Review and Discussion of Tasks

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

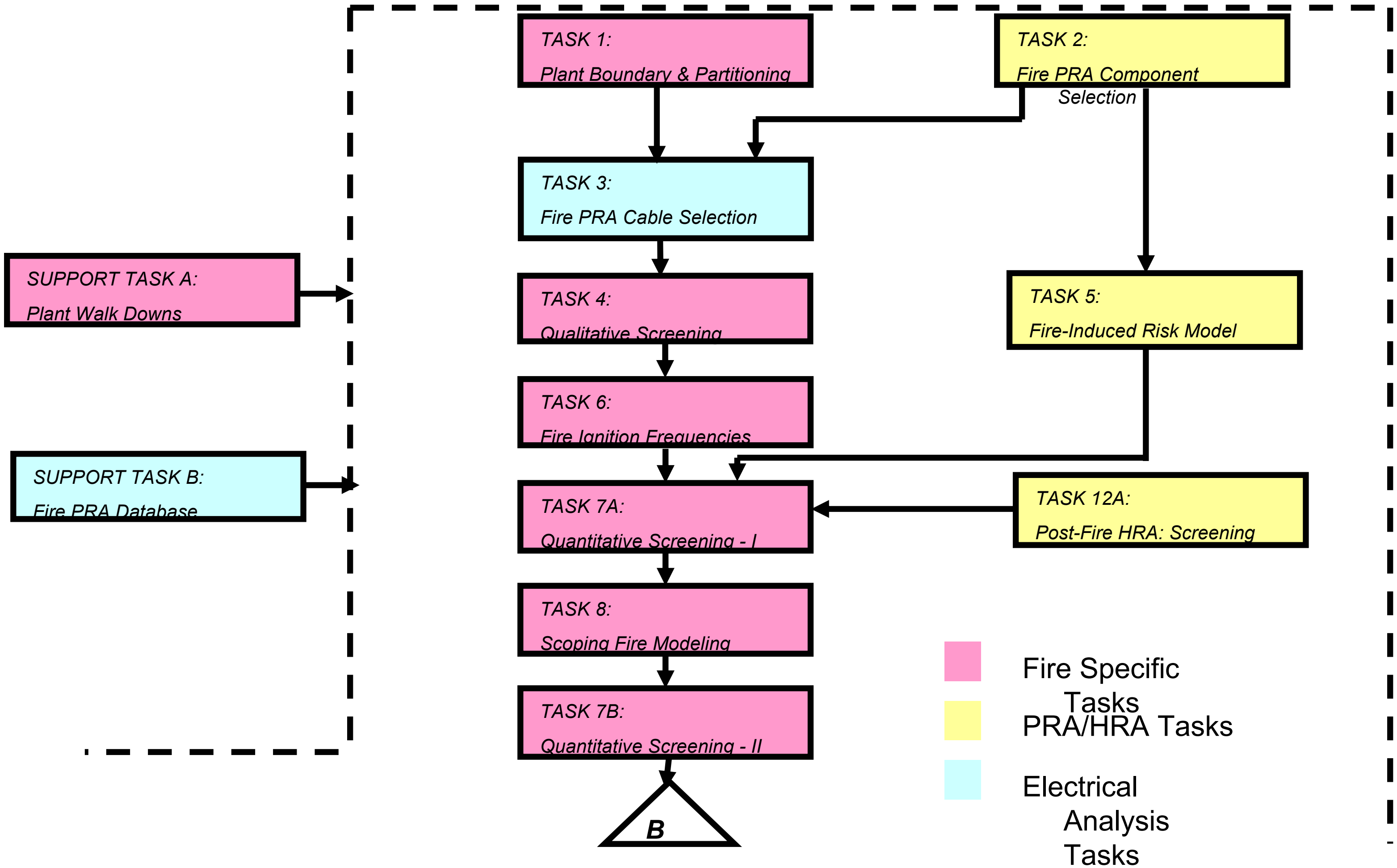
CIRCUIT ANALYSIS
Circuit Analysis Overview

- Substantial Technical and Process-Related Advances
- Collective Awareness of Circuit Failure Implications Greatly Improved
- Knowledge Base Improvements
  – EPRI/NRC Fire Tests: Prompt Jump in Understanding of Fire-Induced Circuit Failures
  – Working Knowledge in Applying Test Results

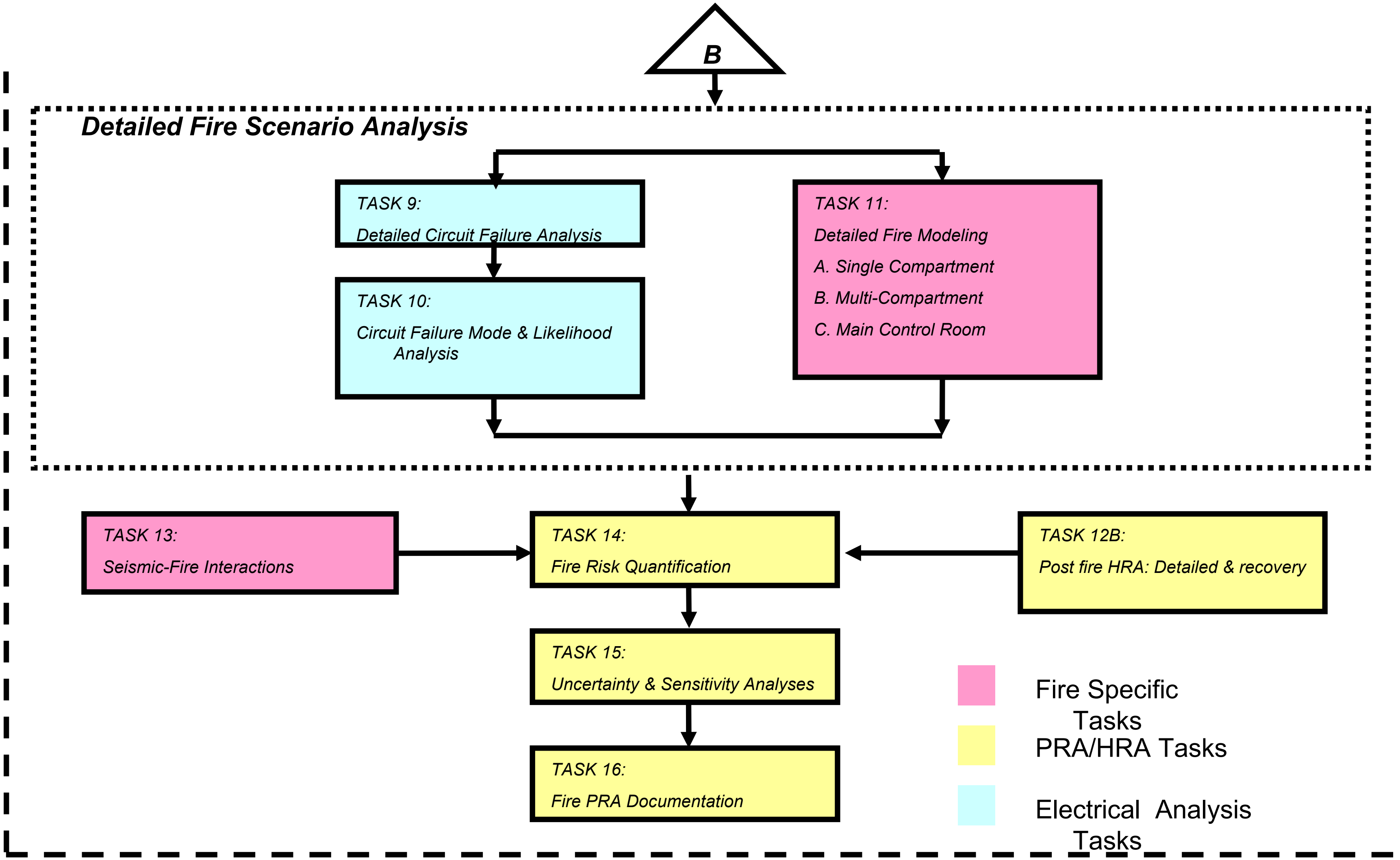
CIRCUIT ANALYSIS
Circuit Analysis Overview

- Circuit Analysis is Now an Integral and Formal Part of the Fire PRA Process
  - Generally Dealt with in a Cursory Manor by IPEEE
  - Now a Rigorous and Formal Process for Correlating Cables-to-Equipment-to-Affected Locations
    - Definitive Data and Criteria has Replaced Estimations and Judgment
    - A More Structured Set of Rules
  - Further Improvements to State-of-the-Art Techniques Realistic

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
- 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
  - Potential Implications Confirmed at **ALL** Participating Plants
- 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 Consistent with Industry Best Practices
- Risk Perspectives 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
- Maximize Use of Appendix R Data and Other Analyses
- Do NOT begin Electrical Analysis Without Fire PRA Database Functional

CIRCUIT ANALYSIS
Key Considerations

- Availability, Quality, and Format of Cable Data
- Existence of Cable Location Data
- Usability of Appendix R Circuit Analysis Data
  - Recent Re-Analysis
  - Automated Tools
- 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
- Interaction with Systems Analysts Critical
- Compilation and Management of Large Volume of Data
  - Automated Tools Important for Efficient Process
  - Prudent Configuration Management

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-3, Pt. 2: Task 3 - Fire PRA Cable Selection

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Joint RES/EPRI Fire PRA Workshop

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Rockville, MD

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

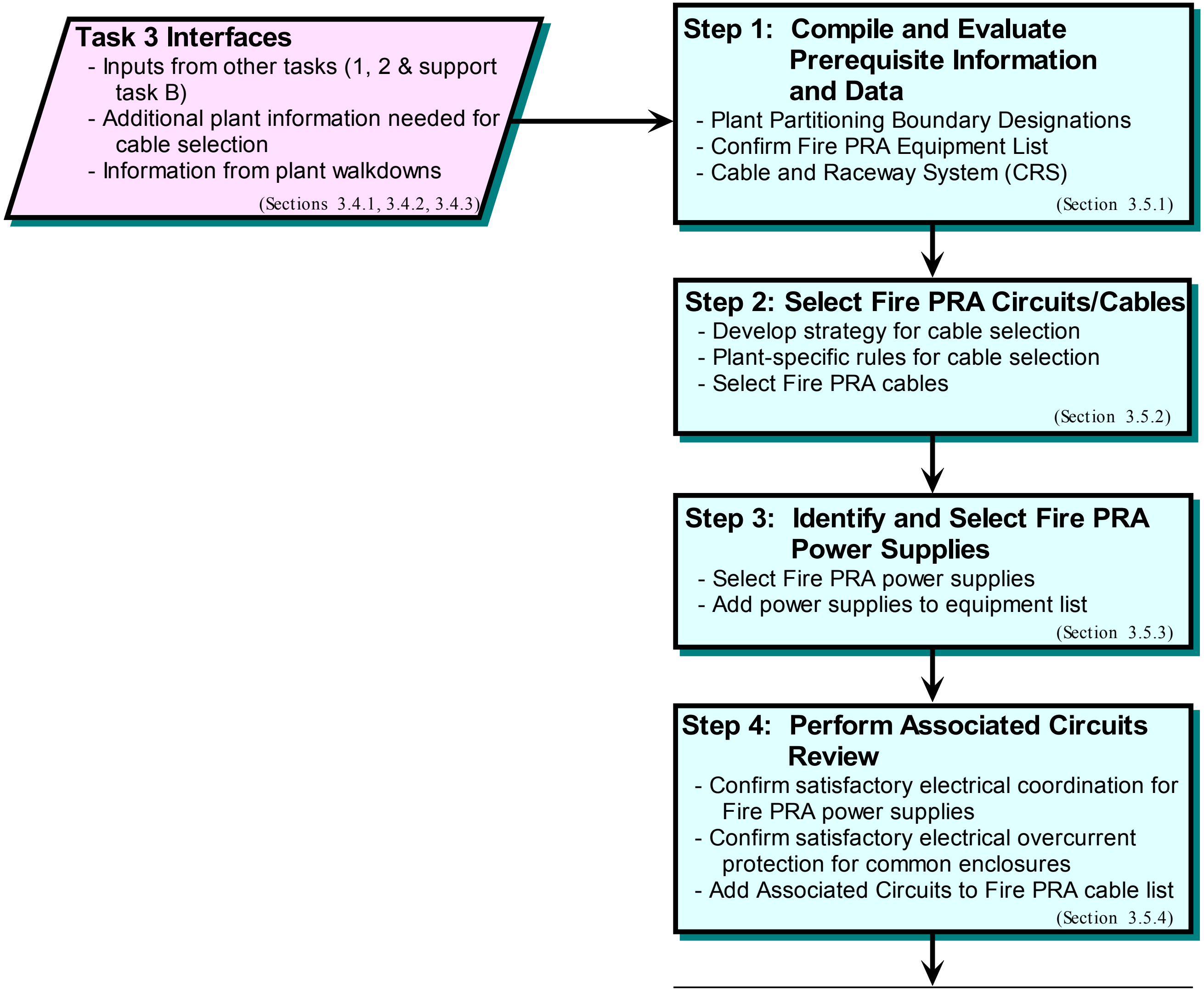
  Note: Scenario can be Fire Area, Room, Raceway, or Other Specific Location

- Identify Fire PRA Power Supplies

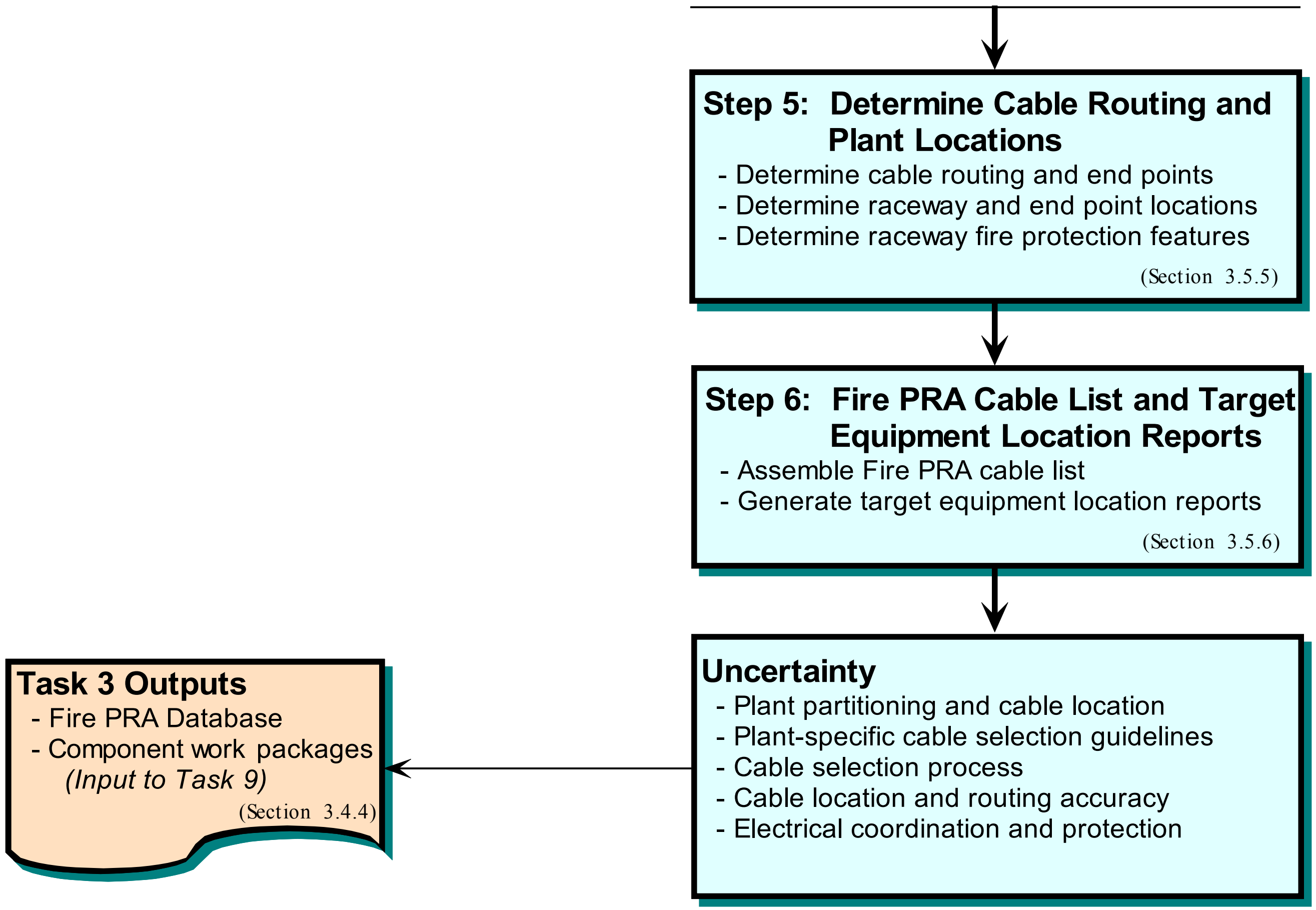
FIRE PRA CABLE SELECTION
Introduction

- Conducted for all Fire PRA Components
- Deterministic Process
- Associate Cables to Components Irrespective of Failure Mode
  - Some High-Level 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 Includes 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

FIRE PRA CABLE SELECTION
Step 1 – Compile Prerequisite Information

- Confirm Plant Partitioning is Compatible
- Confirm PRA Equipment List is Final
- Evaluate CRS Database Capability

FIRE PRA CABLE SELECTION
Step 2 – Select Fire PRA Cables

- Analysis Cases
  - Appendix R Component with Cable Data
  - Non-Appendix R Component with Cable Location Data
  - Non-Appendix R Component without Cable Location Data
- 3 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 Determine Rules
  - Indication & Alarm
  - Multiple Function Components
- Evaluate Appendix R Circuit Analysis Data
- Review Results of Fire PRA-to-Appendix R Equipment List Comparison
- How to Handle Off-Site Power

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy

- Minimal Effort to Obtain Necessary Information
- Revisit Past Assumptions
- 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

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- Case 1: Incorporate Existing Analysis

- Case 2: New Component w/ Cable Data
  - Collect Drawings
  - Identify Cables Following Plant Specific Rules
  - Identify External Circuit Influences
  - Document Cable Selection

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- Case 3: New Component w/o Cable Data
  - Same as Case 2, plus…
  - Determine Cable Routing and Associate with Plant Partitions

- Analysis Work Packages
  - Retrieve from Past Appendix R Analysis
  - Highly Recommended for New Components

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

- Identify Power Supplies as Integral Part of Cable Selection

- Add Power Supplies to Fire PRA Component List

- Do not Include if Not Required to Support Credited Function

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

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 PRA CABLE SELECTION
Step 6 – Target 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.

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-3, Pt. 3: Task 9 - Detailed Circuit Failure Analysis

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Joint RES/EPRI Fire PRA Workshop

May 24-26, 2006

Rockville, MD

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 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
- Generally Reserved for Cases 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)
- Objective is to Screen Out Cables that Cannot Impact the Ability of a Component to Complete its Credited Function

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)

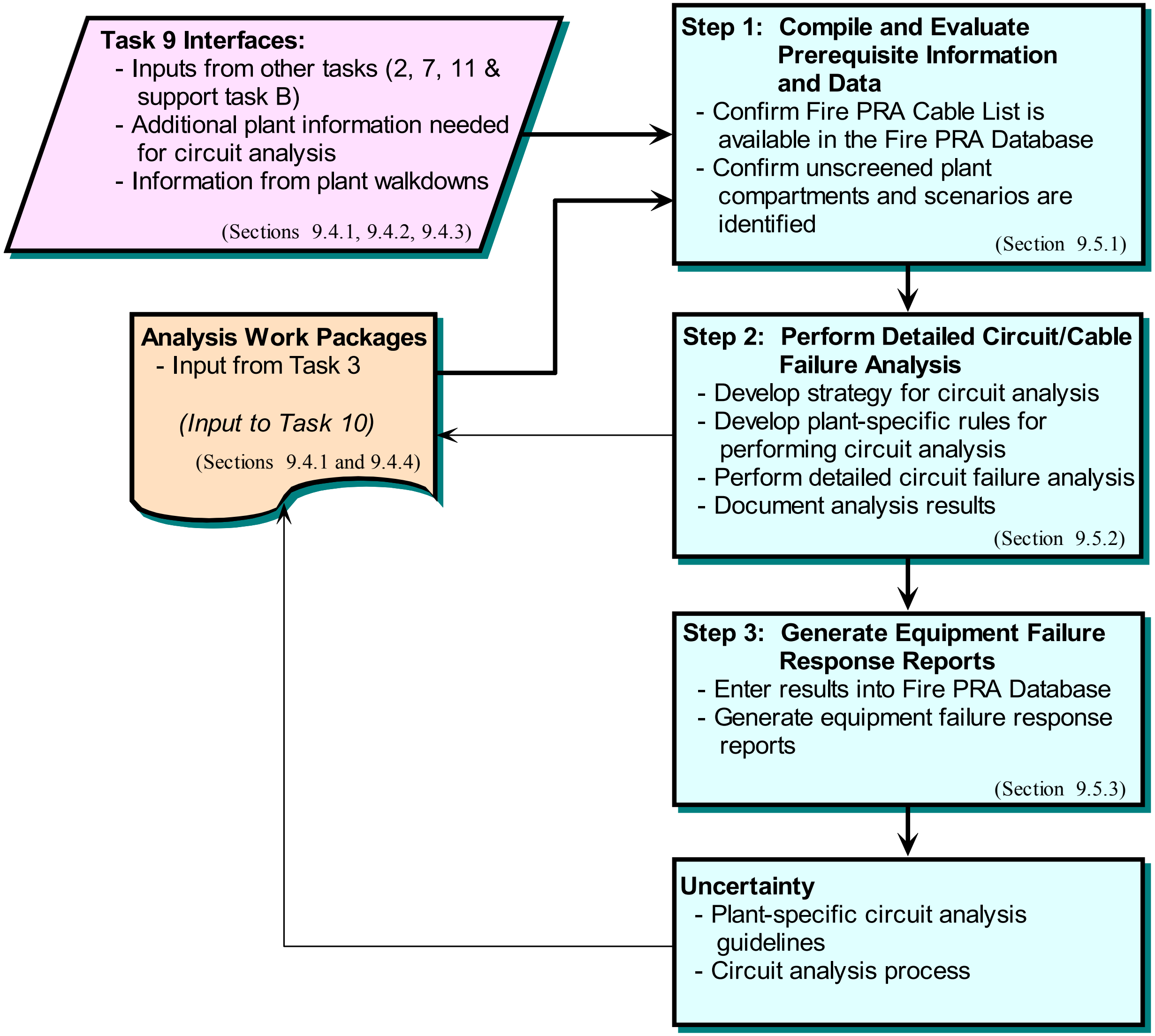
- Failure Modes NOT Considered
  - 3-Phase Proper Sequence Hot Shorts (except high consequence equipment and thermo-plastic conductor)
  - Inter-Cable Hot Shorts for Armored Cable and Cable in Dedicated Conduit
  - Open Circuit conductor failures
  - Multiple High-Impedance Faults

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
- Equipment is Assumed to be 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

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

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Outputs

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

DETAILED CIRCUIT FAILURE ANALYSIS
Step 1 - Compile Prerequisite Information

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

- 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 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 for Circuit Analysis
- Step 2.2: Develop Plant-Specific Rules for Performing 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 Compartment, of Equipment and Associated Cables Affected by Fire in the Compartment
  - Provides specific Equipment Responses that are Possible as a Result of Fire Damage to the Cables
  - May Need to Track Only Equipment Responses of Concern to the PRA Model

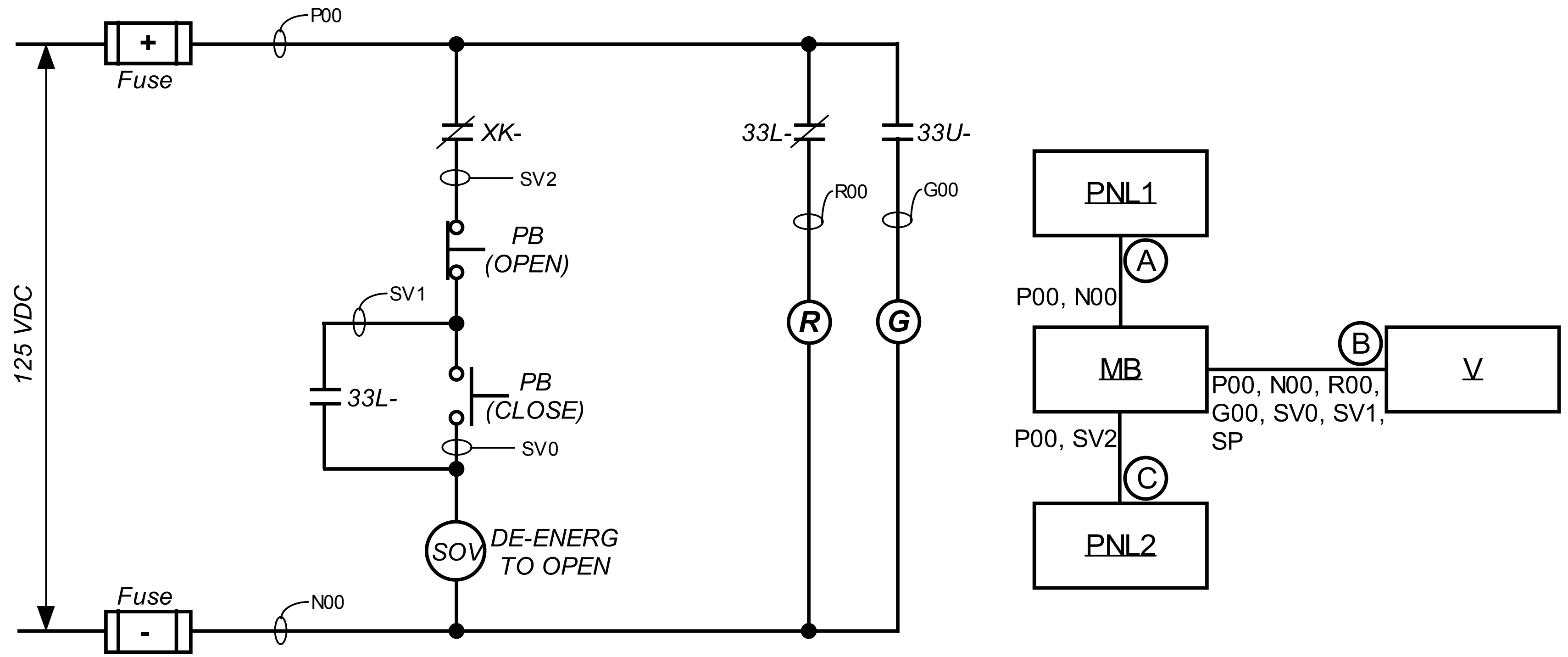
DETAILED CIRCUIT FAILURE ANALYSIS
Caveats & Recommendations

- 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/Fields Requirements
- Coordinate with the Fire PRA Modelers/Analysts Early-On to Define the Fire PRA Component Failure Modes of Concern

DETAILED CIRCUIT FAILURE ANALYSIS

Example - Typical SOV Control Circuit

QUESTION: What circuit failure responses are *possible* given cables A, B and C are damaged?



Valve Shown in Open Position

Answers will be provided in a later presentation