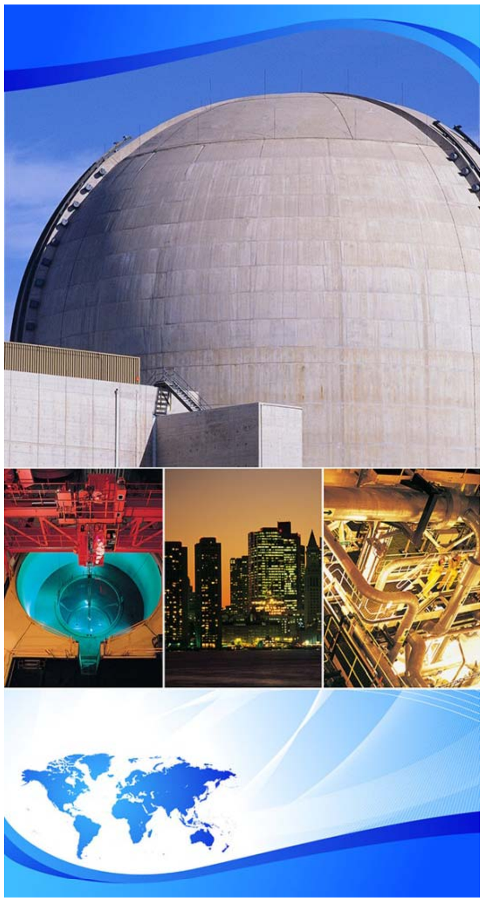

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA
Fire HRA Training Overview

Joint RES/EPRI Fire PRA Workshop 2011
San Diego CA and Jacksonville FL

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

Outline of the Presentation

1. **Overview of the EPRI/NRC Fire HRA Guidelines**
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

EPRI/NRC Fire HRA Guidelines Overview

- Purpose of the Fire HRA training course module
- Training objectives
- Background on the Fire HRA Guidelines
- Fire HRA development team, approach & timeline
- Fire HRA Guidelines, public review & path forward
- Summary of EPRI/NRC Fire HRA Guidelines scope & contents

SRL2

EPRI/NRC Fire HRA Guidelines

Purpose of Training Course

- Provide training on guidance from EPRI/NRC Fire HRA Guidelines (NUREG-1921/EPRI 1019196)
- Opportunity for face-to-face, real-time interactions between authors and potential future users
- Opportunity to improve training
  - This is the first time a full separate fire HRA session has been presented in the Fire PRA Workshop
  - It is important for us to get student/audience feedback for future presentations

Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate a knowledge of ASME/ANS PRA Standard **high level requirements** related to HRA**.**

4: Be able to identify **context and performance shaping factors** used in the analysis of post-fire human failure events.

5: Be able to list the **quantification methods** available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between post-fire HRA events.

Background on the Issue of Fire HRA

- Almost 50% of USA plants transitioning to NFPA-805
  - Using NUREG/CR-6850 [EPRI 1011989] for the Fire PRA Guidance
- NUREG/CR-6850 [EPRI 1011989] addresses:
  - Identifying human failure events (HFEs)
  - Assigning conservative screening human error probabilities (HEPs)
  - Post-fire Performance Shaping Factor (PSF) information
- NUREG/CR-6850 [EPRI 1011989] does not:
  - Describe a methodology for developing best-estimate HEPs (given fire related effects)
  - Address the requirements of:
    - ASME/ANS RA-Sa-2009, "Addenda to ASME/ANS RA-S-2008, Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," Chapter 4 for fires
- Consequently, there was a need for fire-specific guidance for best-estimate HRA quantification in fire PRA

EPRI/NRC Fire HRA Guidelines
High Level Objectives

- Through joint NRC and industry efforts, address the need for HRA guidance, especially for best-estimate quantification, for use in fire PRAs
    - Address methodology
    - Address guidance for implementing the methodology

- Develop a joint EPRI/NRC report (similar to NUREG/CR-6850 [EPRI 1011989])

- Consider ASME/ANS PRA Standard requirements and user needs

EPRI/NRC Fire HRA Guidelines
Development Team

EPRI | **NRC**

Stuart Lewis (Bob Kassawara)
EPRI Project Manager

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NRC-RES Project Manager

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<u>RES</u>
Susan Cooper (Lead)
John Forester
Stacey Hendrickson & Mary Presley

Independent Review Team
NRC Reps
Utility HRA Reps

Fire HRA Guidelines Development Approach

1) Fire Generic Data Review
   - Existing guidance & literature
   - Historical & experiential plant fire data
2) Fire HRA Methodology & Guidelines Development
   - Examined HRA process & identified how process and tasks would change for the fire environment and accident response scenarios in response to a fire
3) Fire HRA Review & Test
   - NRC and industry peer review team (7 people)
   - Two plants tested Scoping method flowcharts

Fire HRA Guidelines Development Timeline

– Started March 5, 2007
– First integrated draft - May 2008
– Peer review - June 2008
– Testing at 2 plants - Summer/Fall 2008
– Revised draft - April 2009
– Quick review by NRR & NRO – April 2009
– ACRS sub-committee presentation for info – June 2009
– Piloting by PWR Owner's Group – Summer 2009
– Public comment period - December 2009 to March 2010
– *Guidelines Update – March through November 2010*
– *Training Courses – September & October 2010*
– *ACRS sub-committee presentation – late 2010*
– *Publication of final report - December 2010*

Fire HRA Guidelines Public Review & Comment

- NUREG-1921/EPRI 1019196 issued in November 2009 for public review and comment
- Prior to public review period, obtained comments during presentation to ACRS PRA Subcommittee
- Received 265 public comments, 75 of which were editorial, from
  - PWROG
  - BWROG
  - EPRI HRA User's Group
  - Exelon
- Revision underway
  - Approach is not fundamentally different, but
  - Some important changes (e.g., reduced requirements for assessing feasibility of operator actions during screening and scoping analyses)

Fire HRA Guidelines Path Forward

- Final Guidelines document to be issued by end of 2010
- It is anticipated that this guidance will be used by the industry as part of transition to NFPA 805 and possibly in response to other regulatory issues
- This is the first report addressing fire-related HRA for fire PRA that goes beyond the screening level
- As the methodology is applied at a wide variety of plants, the document may benefit from future improvements to better support industry-wide issues being addressed by fire PRA

Fire HRA Guidelines Summary
Objectives and Scope

- Identify/analyze **existing post-initiator** HFEs
  - Changes to previously modeled HFEs due to fire effects
- Identify/analyze **post-initiator fire response** HFEs
  - New category of HFE to be analyzed
    - Procedures, training, cues typically different from existing post-initiator HFEs
  - Includes alternative shutdown (such as MCR abandonment due to habitability or transferring command and control to outside the MCR)
- Identify/analyze **post-initiator HFEs in response to spurious actuations and indications**
  - New category of HFE to be analyzed

Fire HRA Guidelines Summary
Objectives and Scope (continued)

- Implement post-initiator fire HEPs in fire PRA model(s)
  - Initial quantification using screening or scoping approach
  - Identification of risk significant events for later detailed HRA (e.g., to meet ASME/ANS Part 2 supporting requirement HR-G1, Capability Category II)
  - Including dependency analysis
- Out of Scope
  - Pre-initiators (per NUREG/CR-6850 [EPRI 1011989])
  - Fire brigade response (except for impacts on fire PSFs)

Fire HRA Guideline Summary
Major Topic Areas

1. Standard HRA **process** used for Fire HRA modeling:
   - Based on other processes and guidance
     - ASME/ANS PRA Standard
     - NUREG-1792
     - Fire Manual Actions, NUREG-1852
     - SHARP1
     - ATHEANA
2. Fire HRA **process steps**:
   – **Identification & definition** of human failure events (HFEs):
     - Substantial guidance provided, including feasibility test
     - Feasibility Evaluation (Go / No-Go) example criteria
       – Sufficient time available to complete action
       – Procedures & cues exist
       – Sufficient manpower

Fire HRA Guideline Summary
Major Topic Areas (continued)

2. Fire HRA **steps**: (continued)
   - **Qualitative analysis**
     - Certain activities required for all analyses; others only for specific detailed HRA method
     - Iterative process that continues throughout quantification steps
     - Further evaluation of HFE feasibility under fire conditions
     - As fire PRA develops, fire HRA must consider additional fire scenario-specific details that become available
   - **Quantification Methods – three levels**
     - **Screening Quantification**
       - Refinement/relaxation for areas identified in NUREG/CR-6850 [EPRI 1011989] implementation
       - Typically used in NUREG/CR-6850 [EPRI 1011989] Task 7 first/screening quantification

Fire HRA Guideline Summary
Major Topic Areas (continued)

2. Fire HRA **steps**: (continued)
   – **Quantification (cont'd, 2nd of 3 methods)**
     - **Scoping Fire HRA** method added (new):
       – Developed to address the majority of HFEs, thereby conserving HRA resources
       – Decision tree format
       – Guidance being developed to aid reproducibility & reviewability
       – Typically used during NUREG/CR-6850 [EPRI 1011989] Tasks 7 or 8 or early quantification of detailed fire scenarios in Tasks 11/14

Fire HRA Guideline Summary
Major Topic Areas (continued)

2. Fire HRA **steps**: (continued)
   - **Quantification (cont'd, 3rd of 3 methods)**
     - **Detailed Fire HRA**
       - Uses existing methods
       - Performance shaping factors modified for the fire context:
         - EPRI Cause-Based Decision Tree & HCR/ORE; & THERP
         - ATHEANA
       - Typically used in NUREG/CR-6850 [EPRI 1011989] Tasks 11/14 quantification of detailed fire scenarios as needed
   - **Dependency**: Typically part of NUREG/CR-6850 [EPRI 1011989] Tasks 11/14 quantification of detailed fire scenarios
   - **Uncertainty**: Typically used in Fire Risk Evaluation of separation issues as part of the transition to NFPA-805.

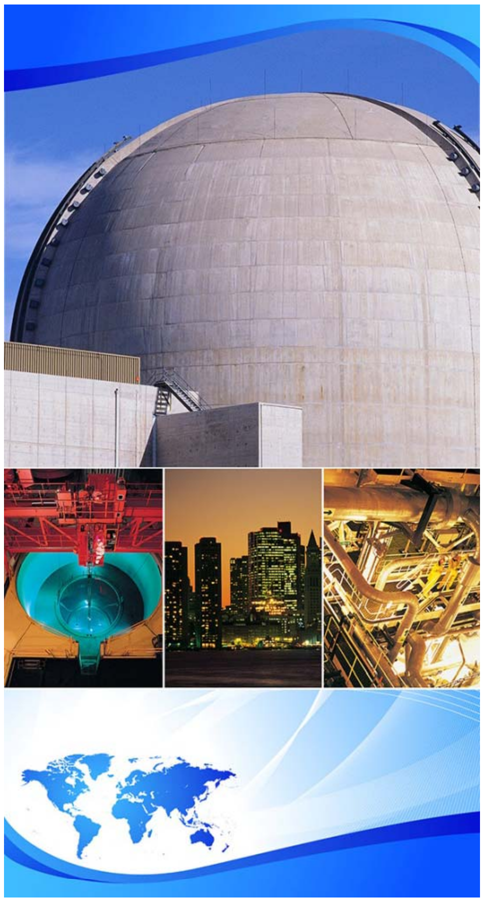
Fire HRA Process Steps

NUREG/CR-6850 [EPRI 1011989] Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification** of previously existing HFEs & potential response to spurious
Task 5 – Fire-Induced Risk Model	**Identification and Definition** of fire response HFEs
Task 12 – Post-Fire HRA	**Qualitative Analysis -** context & performance shaping factors
Task 7 – First/Screening Quant.	**Quantification –** typically screening or scoping
Task 8 – Scoping Quantification	**Quantification –** typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Fire HRA Technical Overview

- **<u>Fire HRA Process Summary:</u>**
  - Identification and Definition
  - Qualitative Analysis
  - Quantification Methods:
    - Screening
    - Scoping
    - Detailed
  - Recovery, Dependency, & Uncertainty

- Each Fire HRA process step is further described in subsequent presentations



EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA – Part 1

Identification & Definition of Post-Fire Human Failure Events

Kaydee Kohlhepp (Scientech) & Stuart Lewis (EPRI)
Joint RES/EPRI Fire PRA Workshop 2011
San Diego CA and Jacksonville FL

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

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. **Identification and Definition of post-fire human failure events**
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
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   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
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Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate knowledge of ASME/ANS PRA Standard **high level requirements (HLRs).**

- **For the HLRs associated with Identification & Definition**

4: Be able to identify **context and performance shaping factors** used in the qualitative analysis of post-fire human failure events.

5: Be able to list the **quantification methods** available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between post-fire HRA events.

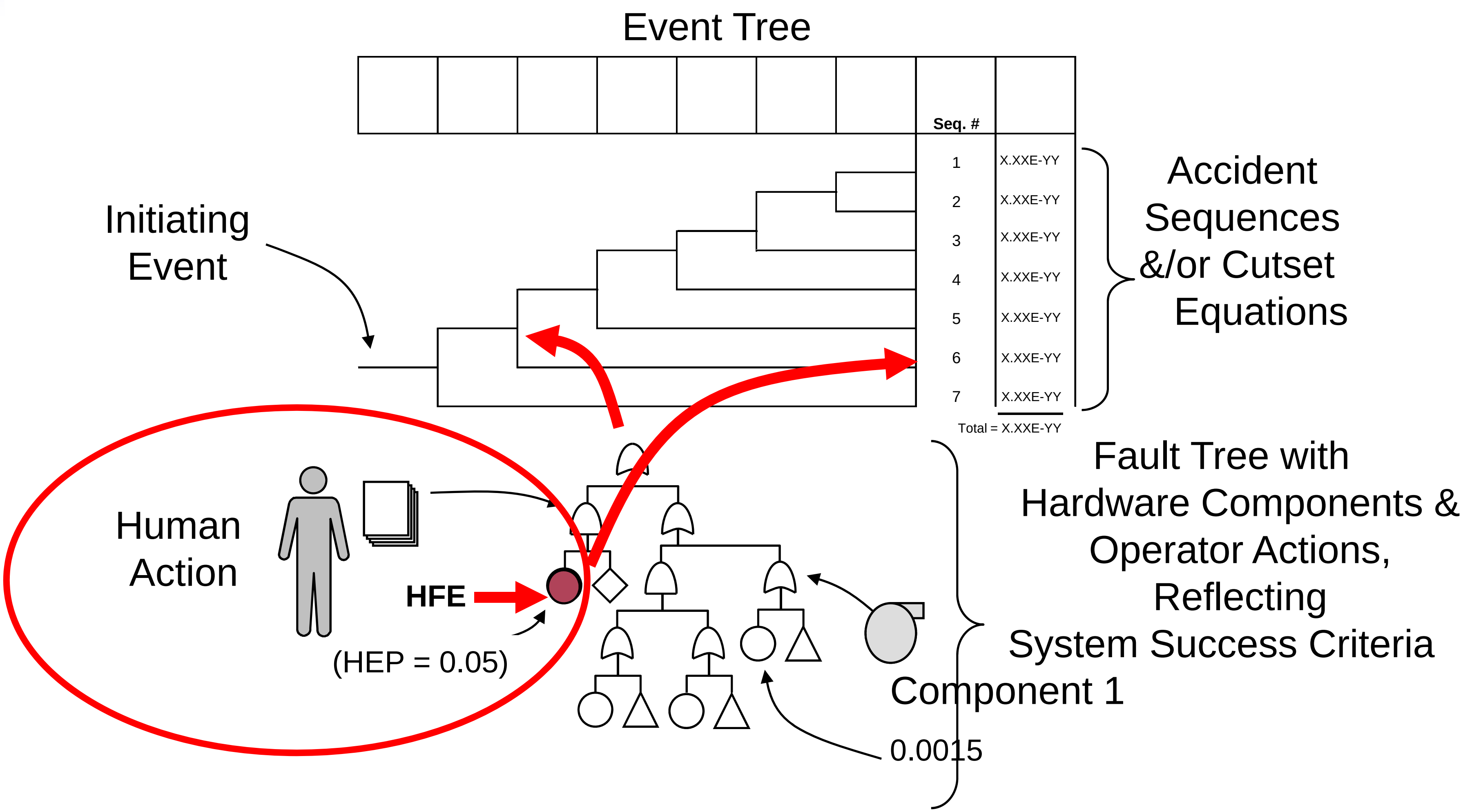
Outline of the Identification/Definition Module

- Introduction/Relation to NUREG/CR-6850 (EPRI 1011989) Tasks
- Applicable PRA Standard High Level Requirements
- Identification
- Categories of Fire Human Failure Events
- Definition & Fire Context
- Feasibility – Initial Assessment
- Summary

Introduction – What is *Identification*?

- Human Reliability Analysis starts with developing understanding of role(s) of operators in responding to an event
- Actions relevant to post-initiator (or post-fire) response are identified via
  - Review of plant emergency and other operating procedures
  - Review of PRA Event trees, Fault trees, & Results (sequences and/or cutsets)
  - Operator interviews
- Once relevant actions are understood, corresponding ***human failure events*** are ***identified*** for the PRA models

Introduction – Depiction of Identification



PRA Standard Requirements for Identification

Relevant HLRs from Internal-Events Section (Ch. 2 of Standard)

HLR-**HR**-E

A **systematic review** of the **relevant procedures** shall be used to identify the set of operator responses required for each of the accident sequences

Relevant HLRs from Fire Section (Ch. 4 of Standard)

HLR-**HRA**-A (from the HRA element)

The Fire PRA shall identify human actions relevant to the sequences in the Fire PRA plant response model

HLR-**ES**-C (from the Equipment Selection element)

The Fire PRA shall identify instrumentation whose failure including spurious operation would impact the reliability of operator actions associated with that portion of the plant design to be credited in the Fire PRA.

Introduction – What is ***Definition***?

- After HFE Identification, ***Definition*** gives the initial basis for justifying inclusion of the action in the PRA model.
- Consists of objective, qualitative data:
  - Procedures
  - Cues (the prompts to initiate actions)
    - Alarms, indications, and/or procedure steps
  - Timing (Time Window & Time Required)
  - Staffing (may require more than for internal event response)
- Provides input to the subsequent Qualitative Analysis of the factors affecting human reliability
- Requires Initial Feasibility Evaluation

PRA Standard Requirements for Definition

Relevant HLRs from Internal-Events Section (Ch. 2 of Standard)

HLR-**HR**-F

Human failure events shall be defined that represent the impact of not properly performing the required responses, consistent with the structure and level of detail of the accident sequences.

Relevant HLRs from Fire Section (Ch. 4 of Standard)

HLR-**HRA**-B

The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human response associated with the identified human actions.

Fire HRA Process Steps

NUREG/CR-6850 Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification of previously existing HFEs & potential response to spurious actuations/signals**
Task 5 – Fire-Induced Risk Model	**Identification & Definition of Fire Response Actions**
Task 12 – Post-Fire HRA	**Qualitative Analysis:** starts with **context definition**
Task 7 – First/Screening Quant.	**Quantification –** typically screening
Task 8 – Scoping Quantification	**Quantification –** typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Categories of Post-Fire Operator Actions

1. Existing operator actions from the internal events PRA
   – From the Level1/LERF PRA model used to develop the Fire PRA

2. Fire Response Actions
   – New actions contained in the fire procedures
   – New actions to address recovery of spurious actuation
   – MCR abandonment is a subset of fire response actions

3. HFEs Corresponding to Undesired Operator Responses
   – New actions to address undesired operator actions in response to spurious indications per Fires (Ch. 4) in the ASME/ANS Combined PRA Standard
   – EOCs are specifically addressed in FPRA

Identification of Fire PRA HFEs (General)

- Review Event Tree Sequences with applicable procedure/s:
  - Understand operator requirements to control plant response
    - Functions or systems manually initiated, controlled, or isolated
  - Typically a function of the initiating event
- Review System Fault Trees with applicable procedure/s:
  - Understand what is required of operators in controlling system or component response
    - Functions manually initiated or controlled
    - Potential recovery (e.g., align standby or alternate)
  - Typically independent of initiating event
- Review PRA Results sequences & cutsets
- Discussions with Operators to confirm operator response

Identification of Fire PRA HFEs (General cont'd)

Review ET sequences, system FT, and PRA results to:

1. Understand what the operators are doing
2. Identify **cue(s)** & **procedure steps, & time window**
3. Identify procedural path leading to the step with cue
4. Document the PRA **context** from Event or Fault Tree
   - Initiating event
   - Preceding operator actions in the sequence
   - Hardware/system successes and failures

Good Practice (collect if the data is available)

- Identify secondary cues or alternate success paths
  - Examples: Critical Safety Function Status Trees, alarms or indications.

Review of Plant Operations & PRA Data

- Best Practice for HRA analysts to confirm with plant **operations personnel** at the start of the HRA:
  – Staffing during fire (number of operators & roles)
  – Procedural usage for fire (EOPs, AOPs, & Fire Response)
  – Main control room (MCR) staff interaction with fire brigade
  – Expected MCR staff response after detection of fire
  – Review of plant-specific fire history for insights
- Review of **PRA Data**:
  – Additional information beyond Event & Fault Trees
  – Success criteria: Determine Time Window (Time Available)
  – Internal events HRA: to understand initial model basis

Identification:
Operator Actions in Internal Events PRA

- Identify fire-induced initiating events included the FPRA
  - Done in NUREG/CR-6850 (EPRI 1011989) Tasks 2 & 5
  - Examples of actions carried into the FPRA
    - General transients which may include spurious SI actuation
    - Loss of support system(s), e.g., loss of instrument air or loss of electrical bus
    - LOCA (e.g., due to spuriously opened relief valve)
    - Station blackout
- Identify operator actions modeled as delineating the plant response to the fire-induced initiators.
  - In event trees, fault trees, and in cutset recovery
- Includes manual start of safe shutdown components
  - Sometimes these are not “pre-existing” in the current PRA

Fire HFEs from Internal Events PRA - Examples

INCLUDE

- Open a steam dump or steam relief valve and conduct a post-LOCA cooldown
- Manual start of an emergency diesel generator
- Manual start of auxiliary feedwater following automatic actuation failure
- Manually align a back-up power supply

EXCLUDE

- Actions associated with internal events initiated not included in FPRA, for example:
  – Operators fails to diagnosis SGTR

Identification:
Fire Response Operator Actions

- Required in response to a fire, as directed by the fire procedure(s), such as
  - Mitigate or prevent damage to equipment (e.g., pump dead-heading from fire-induced spurious valve closure)
  - Mitigate the effects of spurious indications or actuations (e.g., shut off above pump)
  - Abandon main control room and perform safe shutdown outside the main control room
- Identification process can be
  - Iterative as required in fire PRA strategy
    - Often not credited during initial quantification
  - Comprehensive based on fire procedure/s
- Examples on next slide

Fire Response Action Examples

- Identify protected instrumentation channels (to mitigate spurious indications)
- Defeat solid state protection system (to prevent spurious safety injection)
- Control auxiliary feedwater locally by throttling valves manually and starting / stopping pumps
- Place remote shutdown location back-up indication panels in service
- Obtain steam generator level locally
- De-energize all ADS valves
- Close HPCI steam supply valve locally
- Align 4 kV bus by locally operating breakers

Identification:
MCR Abandonment Actions

- MCR abandonment actions are a sub-set of fire response
- Operators will abandon if control room becomes uninhabitable, or due to loss of required control
- Identification process can be
  - Iterative as required in fire PRA
  - Comprehensive based on review of the MCR abandonment procedure
- Some FPRAs credit scenarios where the operators remain in the control room for monitoring and announcing; but perform local actions
  - In this case the fire specific scenario is to be identified and defined by the FPRA analyst
  - HRA analysts identify the procedure guidance operators will follow

Identification: HFEs Corresponding to Undesired Operator Response to Spurious Signals

- An undesired operator action is a well intentioned operator action, taken in response to a spurious indication, that unintentionally exacerbates the scenario
  - Operators are generally trained to (1) believe their instrumentation and (2) follow their procedures
- Identified within the context of the accident progression
  - Review annunciator response procedures (primarily)
  - Review emergency operating procedures (best practice)
- Defined in terms of their impact on the function, system, train or component.
  - Although these actions are well-intended & not operator errors as such, the undesired consequences have the same impact as an error & are therefore modeled as HFEs

Identification & Definition of Factors for Undesired Operator Response to Spurious Signals

- Cue parameter/s
  - Single or multiple (redundant or diverse)
- Cue (procedural) hierarchy
  - Continuously monitored or procedurally checked only
- Cue verification
  - Required for immediate actions
- Degree of redundancy/diversity for a given parameter
  - Redundant/diverse channels mitigate consequences of single spurious indication

Examples of Potential HFEs Corresponding to Undesired Operator Responses based on Review of ARPs

Spurious Annunciator	Undesired Action	Consequence
ESW PUMP MOTOR INSTANT TRIP	Place the affected pump's control switch in LOCKOUT.	One train of service water stopped, thereby reducing ESW prob. of success in CCDP calculation. Can be restarted.
CCW PUMP MOTOR INSTANT TRIP	Place the affected pump's control switch in LOCKOUT.	Stopping one CCW pump increases operating temp. on many components in CCDP calculation. Can be restarted.
EAST RHR PUMP SUCTION VALVES NOT FULL OPEN	Immediately open 1-IMO-310, East RHR Pump Suction, or 1-ICM-305.	Depending on scenario (size of LOCA or not) could lead to cavitation of the pump. Loss of pump in Recirc. mode
RHR PUMPS MOTOR INSTANT TRIP	Place pump control switch in LOCK-OUT.	Delay start of RHR if not on or halts RHR if on. Impacts CCDP. Can be manually started.

Human Failure Event Definition (General)

- Define a set of HFEs as unavailabilities of functions, systems or components as appropriate to the level of detail in the accident sequence and system models
- Include in the definition:
  - Accident sequence specific timing of cues, and time window for successful completion, and
  - Accident sequence specific procedural guidance (e.g., AOPs, and EOPs), and
  - The availability of cues and other indications for detection and evaluation errors, and
  - The specific detailed tasks (e.g., component level) required to achieve the goal of the response. (Cat III)
- Cognitive and execution elements

Definition during Fire PRA Tasks

- HFE Definition starts during Identification with:
  - Cues/alarm or other indications, Procedure, Staffing, Time available
- Feasibility evaluation initially done during Definition, then expanded as HFE is developed
- Fire PRA Context typically varies with NUREG/CR-6850 (EPRI 1011989) Task
  - **Context starts in Definition & continues during Qualitative Analysis**
  - Task 7a – Screening HEPs often use qualitative info from Definition
  - Task 12 – Scoping HRA often uses qualitative info (context & PSF) associated with the scoping HRA trees
  - Task 14 – For risk significant HFEs perform Detailed HRA using qualitative context & PSFs associated with the detailed quant. method

Definition during a Fire PRA

- Definition of existing internal events HFEs should be reviewed & revised for fire-specific impacts
- New fire response HFEs require definition
- Definitions should include:
  - Fire impact on instrumentation & indications used for detection & diagnosis
  - Fire impact on timing of (1) cues, (2) response, (3) execution, and on (4) time available
  - Fire impact on success criteria
  - Fire impact on manpower resources, which affect recovery
  - Fire impact on local actions, e.g., accessibility, atmosphere, lighting
- Some data may not be initially available, but will be filled in during Qualitative Analysis

Initial Assessment of Feasibility

- Purpose: To decide whether an operator action can be accomplished or not, given the plant-specific & scenario-specific fire impacts.
- Feasibility Evaluation – Set HEP to 1.0 for any of the following (as the action would not be feasible)
  - Failed **instrumentation** (so no cues for operator action)
  - Insufficient **time available** to complete action
  - Insufficient **manpower**
  - **Procedural guidance** does not exist
  - Other Factors that may preclude credit
    - Fire is in same location as required actions
    - Inaccessible tools or equipment
- Feasibility is like a "continuous action step" that is re-visited as the NUREG-6850/EPRI 1011989 tasks progress.

Identification & Definition Summary

- HFE ***Identification*** finds where operator actions occur
  - In the plant response to initiating events & in the PRA model
- Identification consists of:
  - Review plant operating procedures & understand operator response
  - Review PRA Event trees, Fault trees, Results & Success Criteria
- HFE ***Definition*** gives the initial justification for inclusion of the action in the FPRA & provides input to Qualitative Analysis
- Definition consists of documenting objective, qualitative data:
  - Procedures
  - Cues
  - Timing
  - Staffing
- Initial Feasibility Evaluation is the Go/No-Go check

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. **Identification and Definition of post-fire human failure events**
3. Qualitative analysis **– NEXT!**
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
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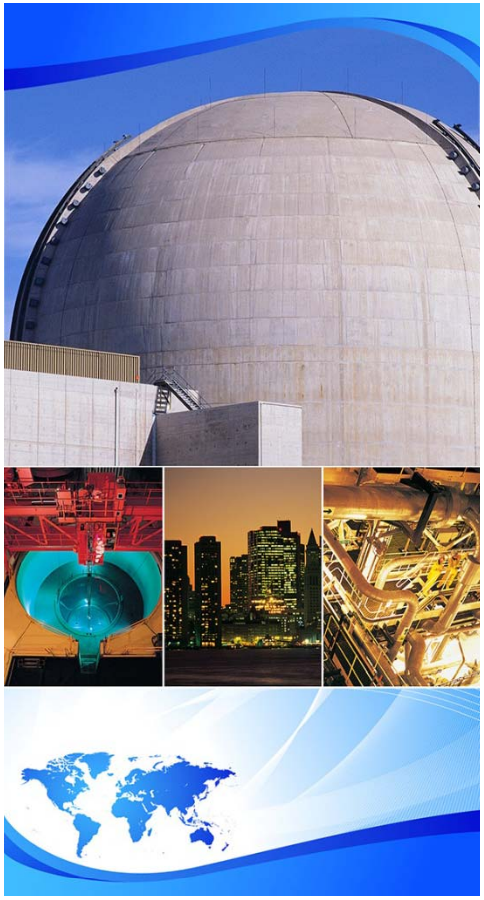

EPRI/NRC-RES FIRE PRA METHODOLOGY

Qualitative Analysis

Kaydee Kohlhepp (Scientech)

Joint RES/EPRI Fire PRA Workshop 2011

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Outline of the Presentation

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Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate a knowledge of ASME/ANS PRA Standard **high level requirements** for fire PRA.

4: Be able to identify **context and performance shaping factors** used in the analysis of post-fire human failure events.

5: Be able to list the **quantification methods** available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between post-fire HRA events.

Outline of the Qualitative Analysis Module

- Introduction
- Applicable PRA Standard High Level Requirements
- Definition & Fire Context
- Historical Experience Input
- Plant Operations Input
- Feasibility
- Performance Shaping Factors

Introduction

- Regardless of the HRA quantification method, qualitative information is needed to support evaluation
  - Provides the data “foundation” used in each Fire HRA process step
  - Objective information, called the FPRA context
  - Evaluated information, such as performance shaping factors (PSFs)
- Assumptions likely to be needed relative to the amount of information available at different stages of the FPRA model development
- All PSFs addressed in Part 2 of the ASME/ANS standard (high-level requirements HR-F & HR-G) need to be considered, but may or may not be explicitly used during quantification
  - Some contribute to the overall “story”
  - NUREG-1792 gives insights on good practices

Introduction (continued)

- Qualitative analysis includes:

  1. Developing fire-specific context
  2. Review of historical experience
  3. Review of plant operations
  4. Evaluating HFE feasibility
  5. Performance Shaping Factor identification/development

Applicable HLRs (from the PRA Standard*)
Qualitative Analysis

Relevant HLRs from Internal-Events Section (Part 2) of PRA Standard*

- HLR-AS-A: The accident sequence analysis shall describe the plant-specific scenarios that can lead to core damage following each modeled initiating event. These scenarios shall address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage (11 SRs)
- HLR-HR-E: A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the accident sequences (4 SRs)
- HLR-HR-F: Human failure events shall be defined that represent the impact of not properly performing the required responses, in a manner consistent with the structure and level of detail of the accident sequences (2 SRs)

* ASME/ANS RA-Sa-2009, “Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency PRA for Nuclear Power Plant Applications”

Applicable HLRs (per the PRA Standard)
Qualitative Analysis (Continued)

Internal Events (non-fire) HLRs (cont'd)

- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence. (8 SRs)

Relevant HLRs from Fire Section (Part 4) of PRA Standard

- HLR-HRA-B: The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human responses associated with the identified human actions (2 SRs; consistent with HLR-HR-F)
- HLR-HRA-C: The Fire PRA shall quantify HEPs associated with the incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fires (1 SR)

Review of Historical Experience

- To gain a better understanding of the plant response following an event, evaluate the effect of such incidents, and gain insight into the context in which accidents can occur
- May reveal potential influences on operator performances (e.g., plant conditions and associated gaps in procedures or training) and challenging conditions or situations the operators might encounter
- Review plant-specific events as well as industry-wide incidents (e.g., NRC Information Notices)
- Usually focuses on a specific type or class of events (e.g., a particular type of initiating event such as a fire or small LOCA)

Review of Plant Operations

- Prior to quantification, HRA analysts should review plant specific fire histories for insights and confirm with operational personnel:
  - Staffing during fire
  - Fire procedural usage during fire
  - How control room staff will interact with fire brigade
  - Expected staff response after detection of fire
- After preliminary quantification, analysts should conduct operator interviews and specifically address risk significant HFEs
  - Operator interviews should confirm:
    - Specific procedural usage for each action
    - Scenario and plant specific timing information
    - Expected operator response for specific scenario
  - Operator interviews could also include walkdowns and observation of simulator exercises

Definition and Fire-Specific Context

- HFE Definition starts during Identification with:
  - Cues/alarm or other indications
  - Procedure
  - Staffing
  - Time available
- Feasibility evaluation initially done during Definition, then repeated/updated as HFE is developed
- Fire PRA Context typically varies with NUREG/CR-6850 [EPRI 1011989] Task
  - Task 7a – Screening HEPs often use qualitative info from Definition
  - Task 12 – Scoping HRA often uses qualitative info (context & PSF) associated with the scoping HRA trees
  - Task 14 – For risk significant HFEs, perform Detailed HRA using qualitative context & PSFs associated with the detailed quant. method

Corresponding PRA Standard SRs: Part 2, HR-F2 & Part 4, HRA–B2

Feasibility Assessment

- The evaluation of HFE feasibility begins at the Identification and Definition stage and continues throughout the Qualitative and Quantitative analyses as further information becomes necessary and available
- Fire HRA should also address the particular feasibility considerations of ex-MCR actions given a fire.
- NUREG-1852 defines a feasible operator manual action as one "that is analyzed and demonstrated as being able to be performed within an available time so as to avoid a defined undesirable outcome."

Corresponding PRA Standard SRs: Part 2, HR-G4 & HR-G5; Part 4, HRA-C1

Preliminary Feasibility Evaluations

- There may be limited fire modeling or fire PRA model sequence information available for the HRA at the time screening or scoping is scheduled to be performed
- Existing information from previous analyses & demonstrations may be used to assess operator action feasibility at any point of the Fire HRA process
- Examples of existing timing data/demonstrations include:
  - Prior Appendix R walkdowns
  - Prior Operator Manual Action (OMA) feasibility analyses
  - Results of training exercises (simulator for MCR actions; Fire Response Actions outside MCR)
  - Established job performance measures (JPMs)

Feasibility Assessment for Scoping and Detailed Fire HRA

- Re-consideration of feasibility issues such as timing, staffing, tools, and accessibility are important as more information becomes available
  - Scoping for more reasonable estimates than screening
  - Detailed for risk-significant fire HFEs, including recovery actions
- Feasibility analysis at this stage typically examines further details regarding the action, context, scenario and timing
- Best evaluated through reliable existing information, structured interviews and, if possible, walkthroughs with operations and training personnel, including photo-documentation of locations to be accessed, equipment to be actuated & tools to be used

Influences on Feasibility

- There are a number of activities that may influence the feasibility, particularly time to respond. In general, if the following conditions are identified then HFE is considered not to be feasible.
  - Not enough crew
  - Not enough time
  - Equipment is in-accessible – This could include factors such as smoke and heat that prevent the operators from reaching the location.
  - Cues and indications are failed such that there is no operator success path
  - The execution has no training and walk-downs show that not all crew members could perform the execution
- In performing the assessment of feasibility, the time available needs to asses the key fire effects

Performance Shaping Factors (PSFs)

PSFs are those factors which can impact operator performance (no new ones for fire):

- Cues & Indications
- Timing (time required & time available)
- Procedures & Training
- Complexity
- Workload, stress, pressure
- Human-Machine Interface
- Environment
- Special Equipment
- Crew Communication, Staffing & Dynamics

Corresponding PRA Standard SRs: Part 2, HR-G3 to G5; Part 4, HRA–C1 Note 1

Cues and Indications

- Cues are the prompts to initiate actions
  - Alarms, indications, and/or procedure steps
- Need to evaluate availability of cues given the fire impact
  - Verify (by cable tracing if necessary) that either

    (1) instrumentation is not affected by fire, or

    (2) it is known that required instrumentation is sufficiently protected and can be identified (e.g., procedurally) as such
  - If primary cues or indications are impacted, identify diverse cues & indications that could be credited
    - From the procedure
    - From discussions with plant operators

Timing

- Obtain the following timing for each HFE
  - Total time available (thermal-hydraulic data)
    - Time to damage (core damage or component damage)
    - This is usually assessed with a bounding calculation that can be applied in many situations
  - Time that plant response cue occurs relative to the initiating event (thermal-hydraulic data)
  - Time it takes operators to formulate a response
    - Detection, diagnosis & decision-making
    - Data from operator interviews, generic simulator data or observations
  - Time it takes to execute response
    - Includes travel, equipment/tools, & manipulation
    - Data from operator interviews, JPMs, training records or observations

Procedures and Training

- Identify how operators implement fire procedures
  - Implemented in parallel or after completion of EOPs
  - Unlike EOPs, fire procedures might not be standardized or their use could be discretionary
  - Might require more judgmental, vs. “automatic,” decisions/actions due to dynamic nature of fires
- Identify critical procedure steps for both cognition and execution
- Identify if and how often operators are trained on both fire procedures and EOPs

Complexity

- For local and MCR abandonment actions, the crew may be required to visit various locations
  - As the number of locations increases, the complexity of the situation also increases
  - Multiple actions may require coordination among crew(s), which may increase complexity
  - The number and complexity of the actions and the availability of needed communication devices should be addressed

Workload, Pressure and Stress

- For HRA methods that categorize stress into different levels, such as low, moderate and high, a further increase in the level of stress may be considered for fire HRA
  - Due to the potential for larger combinations of negative PSFs that could occur during a fire and increase the stress above what is considered high stress for internal events HRA
  - Whether or not there is a need to assume higher stress is a major industry comment that is under discussion
- Example - the scenario may be unfamiliar, the procedures & training for the fire scenario may only be considered adequate, the time available to complete the action may be shortened due to fire, and/or the time required may be longer
  - The analyst may therefore decide that stress will have a significant impact on performance, where it may not have been as significant in the internal events HRA

Human Machine Interface

- For control room abandonment actions, the adequacy of the remote shutdown and local panels needs to be verified
  - Remote shutdown panels are plant specific and design reviews and improvements have not always been completed
  - Remote shutdown panels are typically not designed for mitigation of all initiating events
  - Additionally, the operators may not be as familiar with the panel layout as they are in control room scenarios
- Local actions that require the use of equipment that has been damaged such that manipulation could be difficult or unlikely to succeed should not be credited in the PRA
  - For example, a hot short on a control cable has caused a valve to close and drive beyond its seat, possibly making it impossible to open manually

Environment

- For local actions, there is the potential that the fire could impact ideal travel path to locations. Less direct routes and longer travel times need to be considered
- For control room actions, even if fire does not directly impact control room, environmental conditions outside the control room may still impact operator performance inside the control room. (ie. smoke entering CR from HVAC system)
- For main control room abandonment, actions may need to consider operators' use of SCBA gear
  - Consider effects of smoke, heat and toxic gas for main control room abandonment
    - NUREG/CR-6850 [EPRI 1011989] Section 11.5 provides guidance for impact of smoke

Environmental Effects on Feasibility

- Radiation
  - Fire could damage equipment in a way that radiation exposure could be an issue in the location in which the action needs to be taken, causing the need to don personnel protection clothing (extra time)
- Smoke and toxic gas effects
- Increased noise levels from fire fighting activities, operation of suppression equipment, or personnel shouting instructions
- Water on the floor, possibly delaying the actions
- Obstruction from charged fire hoses or large wheeled portable extinguishers
- Heat stress which requires special equipment, limiting time in the area & other precautions; or too many people (getting in each others' way)

Special Equipment

- Due to varying environmental conditions during a fire, the crew may require the use of special equipment such as:
  - Keys
  - Ladders
  - Hoses
  - Flashlights
  - Clothing to enter containment areas
- Tools need to be checked to ensure they can be located and accessed during a fire, and that they will likely be functional
- The call for abandoning the MCR might also require use of protective gear or self contained breathing apparatus (SCBA). The hindrance of the special clothing on the operators' actions needs to be addressed

Crew Communication, Staffing and Dynamics

- Per NUREG/CR-6850 [EPRI 1011989], most plants can be operated from the control room with two or three operators as the minimum, but a crew may consist of four or five licensed operators
  - thus assigning one to the fire brigade usually does not diminish the control room capability below what is required
- Crew credited for recovery in internal events may no longer be applicable for fire
- For MCR abandonment actions, verify that there are adequate control room members necessary to fulfill the needs of proper shutdown actions from RSP
- MCR abandonment actions as well as some local actions may require the use of SCBA and could impact communications

Factors That Could Impact MCR Crew

- MCR staff actions that can influence the time to respond; such as the time to
  - obtain the correct fire plan & procedures once the fire location is confirmed
  - inform the plant staff of the fire & call for fire brigade assembly & actions
  - alert and/or communicate with local staff responsible for completing various actions
  - provide any specific instructions to the responsible local staff for the actions

Factors That Could Impact Local Crew

- Timing considerations of Local staff actions can influence the time to respond; such as the time to
  - collect any procedures, establish communications, obtain needed special tools or don personnel protective equipment (PPE)
  - perform preparatory actions such as donning Self-Contained Breathing Apparatus (SCBA) or personnel protective clothing
  - travel to the necessary locations
  - implement the desired actions; if more than 1 action they may have to be coordinated or done sequentially
  - inform MCR staff and others that the actions have been successfully completed & the desired effect achieved

Crew to Crew Variability

- Physical size, strength and dexterity differences that may be important for performing the actions
- Cognitive differences (e.g., memory ability, analytic skills)
- Different emotional responses to the fire/smoke
- Different responses to wearing SCBAs to accomplish a task (i.e., some people may be more uncomfortable than others with a mask over their faces, thus affecting action times)
- Differences in individual sensitivities to “real-time” pressure
- If the action has training, it is typically assumed that all crew members could complete the action, and crew to crew variability is treated as a sensitivity.

Qualitative Analysis Summary

- Regardless of the HRA quantification method, qualitative information is needed to support evaluation.
  - Provides the data “foundation” used in each Fire HRA process step
  - Objective information, called the FPRA context
  - Evaluated information, such as performance shaping factors (PSFs)
- All PSFs addressed in Part 2 of the ASME/ANS standard (high-level requirements HR-F & HR-G) need to be considered, but may or may not be explicitly used during quantification
  - Some contribute to the overall “story”
  - NUREG-1792 gives insights on good practices
- **Qualitative analysis includes**:
  1. Developing fire-specific context
  2. Review of historical experience
  3. Review of plant operations
  4. Evaluating HFE feasibility
  5. Performance shaping factors identification/development

EXAMPLES

1. FIRE SPECIFIC CONTEXT DEFINITION
2. CUES AND INDICATION CONFIRMATION
3. PROCEDURES AND TRAINING
4. TIMING

Example of Fire Specific Context Definition

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

1. Initial Conditions: Steady state, full power
2. Initiating Event:
   - Fire in Area 5A2
   - The fire starts in transformer and impacts targets in the plume and vertical trays adjacent to the flames
   - PORV spuriously opens resulting in small LOCA
3. Accident sequence (functional failures and successes):
   - Reactor trip, Turbine trip
   - No ATWS
   - No containment spray required
   - AFW successful
   - SI actuates due to open PORV
   - Cooldown and depressurization required
   - Switch over to recirculation required

Example of Fire Specific Context Definition
(Continued)

4. Preceding operator error or success in sequence:
   - Operators fail to detect spurious PORV opening prior to auto SI actuation
   - Operators controlled ECCS flow to match make-up flow with leakage rate
   - RHR pumps tripped
   - Cooldown and depressurization either failed or failed to be completed before RWST reaches 33%
5. Operator action success criterion:
   - Recognize 8804A cannot be opened from the control room due to fire damage
   - Locally open 8804A located at 73' RHR Access or 100'
6. Timing (Typically determined from MAAP)
   - Time to RWST 33% = 180 minutes
   - Time to RWST 0% = 300 minutes
   - Time required to perform local valve operation = 25 minutes

Example of Fire Specific Context Definition *(Continued)*

7. Consequence of failure: Time to drain RWST
8. Availability of Cues and Indications:
   - RCS Pressure decreasing would be the primary cue operators would be focused on for diagnosing stuck open PORV; RCS pressure indicators are not failed by the fire
   - RWST Level indications are not impacted by fire
   - Monitor light boxes: The indicators at the switch would not be available to alert the operators that the valve failed to close but the monitor light boxes would be giving conflicting information and the operators tend to look at both the position switch and the monitor light boxes

Example of Cues and Indication Confirmation

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

- Operator interview insights
  - The operators stated that it would be obvious that 8804A failed to open when attempted from the control room. In addition to the position switches in the control room, the valve positions are also monitored on monitor light boxes. The cabling for the monitor light boxes are separate from the valve cabling
  - The operators stated that they are aware that switch-over to recirculation is imminent and they will have an operator preview E1.3 (step 13 of E-1 PREVIEW EOP E-1.3, TRANSFER TO COLD LEG RECIRCULATION). They anticipate that the preview will alert the operators to a failed valve.
- Review of Cable Tracing
  - The RWST level indicators are not failed by the fire
  - RCS pressure indicators are protected per Appendix R requirements and remain available during the fire
  - The indicator switch in the control room is failed by the fire

Procedures and Training Example

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

Procedures:

Cognitive: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26

Step: 8.g. - Check for charging pump (pp or pps) amps, Charging injection flow and SI Pp flow if pps are in operation

Execution: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26

Other: Fire Procedure Revision: 21A

Procedure Notes:

By the time switch over to cold leg recirc is required, the operators will also be looking at CP-M-10 (The fire procedure)

The procedure step in CP-M-10 reads:

Manually close 8804A Power will be isolated (by opening 480V MCC feeder breaker 52-1G-58 to preclude spurious operation of 8982A. If 8982A has opened, then locally close valve 8980 after opening its power breaker 52-1F-31

The operators are trained bi-annually on ES 1.3 but they are not specifically trained on ES 1.3 following a fire with various valve failures

Training – For Non Fire Scenario

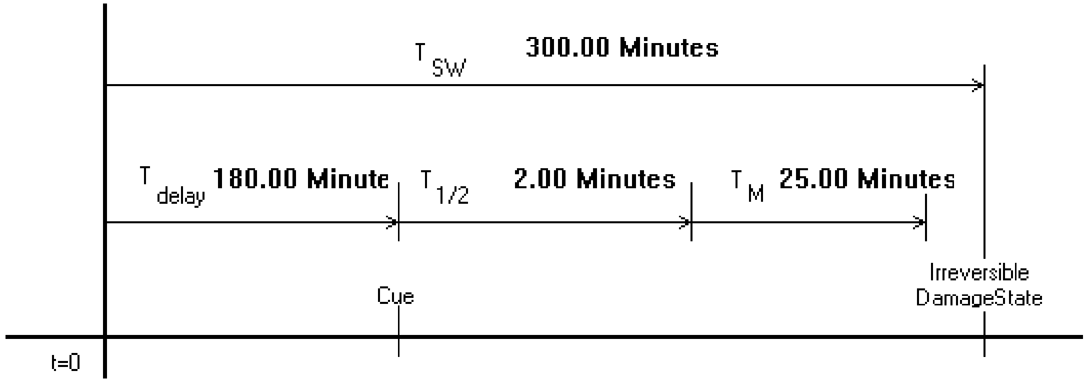
Classroom, Frequency: 0.5 per year

Simulator, Frequency: 0.5 per year

There is no fire specific training for this scenario.

Timing Example

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA



- T_{sw} = 300 min = time to RWST depleted
- T_{delay} = 180 min = switchover to recirc. RWST <33%
- T_{action} [availableTime Window] = 300 -180 = 120 min
- $T_{1/2}$ = 2 min = Estimated time to attempt to close CR switch and realize that valve must be closed locally
- T_m = 25 minutes from operator interviews

Time Margin Calculation

$$TM = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\%$$

$$\frac{120 - (2 + 25)}{2 + 25} * 100 \sim 360\%$$

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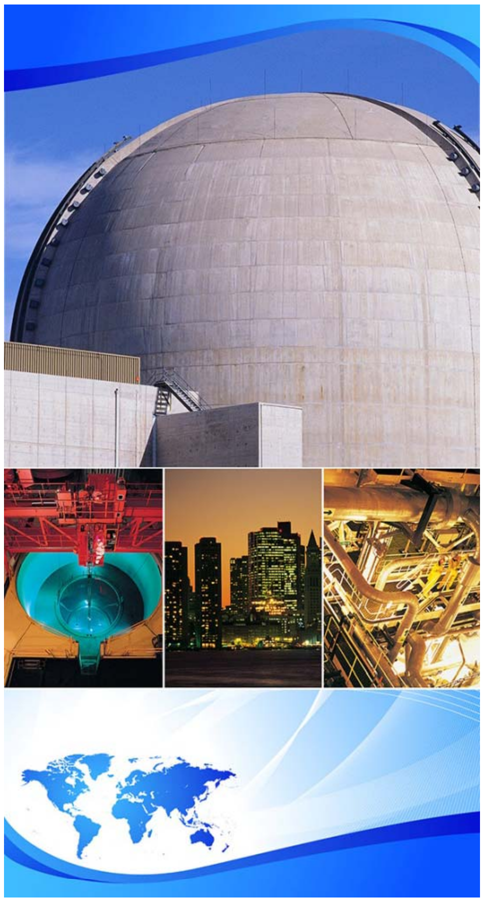

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA – Part 1

Joint RES/EPRI Fire PRA Workshop 2011
San Diego CA and Jacksonville FL

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

Applicable HLRs (per the PRA Standard)
Quantitative Analysis

- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence (8 SRs)
- HLR-HRA-C: The Fire PRA shall quantify HEPs associated with the incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fires (1 SR)

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analyses:
   - **a) Screening**
   - b) Scoping
   - c) EPRI approach (detailed)
   - d) ATHEANA (detailed)
5. Identification and evaluation of recovery actions
6. Treatment of dependency
7. Uncertainty analysis

HRA Screening - Post-Fire HRA Objectives

- To verify that reasonable and feasible human actions and associated post-fire human failure events (HFEs) are
  - Identified and evaluated for fire effects
  - Included in Fire PRA
- To simplify PRA fire model by appropriately assigning screening HEPs for fire induced accident scenarios
  - Establish HEP screening values for developing Fire PRA model
  - Help focus analysis resources on the higher risk sequences

PRA Standard Definitions

- Screening – “a process that eliminates items from further consideration based on their negligible contribution to the probability of an accident or its consequences.”
- Screening criteria – “the values and conditions used to determine whether an item is a negligible contributor to the probability of an accident sequence or its consequences.”

- Corresponding PRA Standard SRs: Part 2, HR-G1 and Part 4, HRA-C1

Fire HRA Screening Analysis

- Method similar to that presented in NUREG/CR-6850 (EPRI 1011989)
- Supports assignment of screening values by:
  - addressing the key conditions that can influence crew performance during fires,
  - ensuring that the time available to perform the necessary action is appropriately considered (given the other on-going activities in the accident sequence), and
  - evaluating potential dependencies among HFEs modeled in a given accident sequence
- To facilitate simplified level of analysis, HFEs are sorted into “screening sets”

Post-Fire HRA Screening
Inputs

- Mitigating equipment and diagnostic indications from Task 2 (Fire PRA Component Selection)
- Human actions carried over from Internal Events PRA from Task 5 (Fire-Induced Risk Model development)
- EOPs and Fire Emergency Procedures (FEPs) - to identify new potentially risk important human actions that support Appendix R assumptions
- Equipment failures, spurious operations and indications; timing and fire location information for feasibility assessment – if available when screening is performed:
  - Task 3 (Fire PRA Cable Selection),
  - Tasks 9 (Detailed Circuit Failure Analysis) & 10 (Circuit Failure Mode Likelihood Analysis)
  - Tasks 8 (Scoping Fire Modeling) and 11 (Detailed Fire Modeling)

Post-Fire HRA Screening
Outputs

- May identify other equipment and indications that are needed to carry out a human action for Task 2 (Fire PRA Component Selection)
- May identify HFE modeling additions needed in Task 5 (Fire-Induced Risk Model) to account for pre-emptive procedure-driven actions to avoid fire-induced spurious equipment actuations
- Provide screening HEPs for Task 7 (Quantitative Screening)
- Identify HFEs requiring additional analysis (scoping or detailed)

Post-Fire HRA Screening
Screening Criteria Sets

- NUREG/CR-6850 (EPRI 1011989) screening criteria produced HEPs for longer term actions (>1 hour after fire initiation and plant trip) that were overly conservative, even for screening, so this has been modified
- Criteria summary:
  - Set 1: Internal events PRA HFEs that are only indirectly affected by the fire scenario
  - Set 2: Internal events HFEs that have added complications from spurious actuations
  - Set 3:
    - new fire-related HFEs
    - HFEs modeled in internal events PRA that need to be significantly revised to reflect fire effects
  - Set 4: HFEs associated with Alternative Shutdown (including MCR Abandonment)

Post-Fire HRA Screening Criteria
Set 1 - Existing Level 1 IE PRA HFEs

- Plant trip with no significant damage to safe shutdown equipment or related instrumentation beyond IE PRA
- No spurious cues or equipment actuations for safety-related equipment
- Necessary immediate responses are not attributed to fire
- One train/division of safe shutdown-related equipment and instrumentation is completely protected from fire
- MCR crew responsible for safe shutdown have no significant additional responsibilities

Post-Fire HRA Screening Criteria

Set 1 - Existing Level 1 IE PRA HFEs (Continued)

- No significant environmental impact or threat to MCR crew (e.g., smoke)
- Time available to diagnose and implement the action(s) is not significantly different than IE PRA-related scenario(s) where HFE(s) apply
- Ex-MCR manual actions from IE PRA are not significantly affected by smoke or toxic gases, loss of lighting, radiation threat
- Staff, special tools and communication capability are available to perform ex-MCR actions
- Dependency between multiple HFEs in IE PRA sequences is still applicable to Fire PRA

Post-Fire HRA Screening Criteria

Set 2 - Modification to Existing HFEs for Spurious Effects

- Set 2 screening criteria same as Set 1, except when
  - Significant spurious electrical effects are likely occurring in one (and only one) safety-related train/division of equipment and/or instrumentation important to the critical safety functions
- Presumes that some corrective responses on the part of the crew may be needed
- In Set 2, the crew might have to attend and respond to the spurious activity in the affected train/division to make sure it does not affect their ability to reach safe shutdown (e.g., causing a diversion of all injection).
- However, the crew would likely detect the spurious activity quickly and not be confused by it

Post-Fire HRA Screening Criteria
Set 3 - New or significantly modified HFEs

- These criteria address
  - new HFEs added to the Fire PRA or
  - prior Internal Events PRA HFEs needing to be significantly altered or modified because of fire conditions
- In such cases, pre-existing Internal Events PRA HEPs either do not exist, or are not appropriate as a basis for the Fire PRA
- If action is within 1st hour of fire initiation, set HEP to 1.0 for screening
- If action is long term, apply 0.1 or 10 times IE HEP, whichever is lower

Post-Fire HRA Screening Criteria

Set 4 – Alternative Shutdown HFEs

- All HFEs involved in reaching safe shutdown from outside the MCR, including HFEs representing the decision to abandon the MCR, should be assigned screening values of 1.0 since more detailed analysis is needed
- As discussed in Section 11.5.2.10 of NUREG/CR-6850 (EPRI 1011989), an overall probability value to represent the failure of reaching safe shutdown using alternate means can be used if the value is evaluated conservatively and a proper basis is provided
  - this approach was used in several IPEEE submittals
  - in many cases, 0.1 was used as a point value estimate for the probability

Post-Fire HRA Screening
Basis for Screening Values

- Conservative HEP values have no direct empirical basis
- Qualitative basis comes from experience with
  - Range of screening values used and accepted in HRA
  - Quantifying HEPs for events in nuclear power plant HRAs
  - Applying range of HRA methods and values associated with those methods
  - Performing HRA for Fire PRAs, including pilots
- Other inputs
  - Peer review comments
  - Not so low so as to miss potential dependencies among HFEs

Post-Fire HRA Screening
Quantification

- Assign screening HEPs on a fire scenario specific basis
- Four sets of screening criteria :
  - Set 1 (Existing Level 1 HFEs) : multiply internal events HEP by 10 to account for effects of potential fire brigade interaction and other minor increased workload/distraction issues. Examine dependencies across scenario
  - Set 2 (Modification to existing HFEs re: Spurious events): Spurious events impact one critical safety-related train/division: increase internal events HEP to 0.1, or 10 times original value, whichever is greater. Examine dependencies across scenario
  - Set 3 (New or significantly modified HFEs): applies to new HFEs and existing HFEs not meeting Set 1 or 2. Use 1.0 if action has to be performed within one hour of fire initiation. Use 0.1, or 10 times existing HEP, if > 1 hour, whichever is lower (relaxation of original screening guidance)
  - Set 4 (Alternative Shutdown HFEs): Use screening value of 1.0 or use overall value of 0.1 with documented justification (relaxation of original screening guidance)

Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x IE HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as IE HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x IE HEP, whichever is greater		0.1, or 10x IE HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x IE HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

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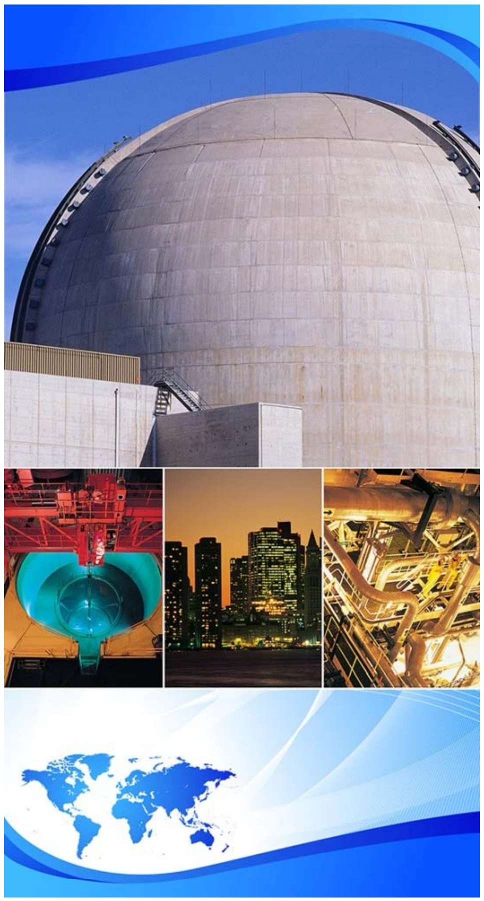

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA

Scoping Quantification Approach

Mary Presley (ARES)

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   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Three General Approaches to HRA Quantification

- Screening: Slightly modified from NUREG/CR-6850 (EPRI 1011989) to cover late (after fire is out) events
- **Scoping fire HRA quantification approach (new)**
  - Less conservative than screening, but designed to be slightly more conservative than detailed approaches
  - Some actions may not be able to meet some of the criteria (result in an HEP of 1.0)
- Two detailed fire HRA quantification approaches, modified for application in fire scenarios
  - EPRI Cause-Based Decision Tree (CBDT) & HCR/ORE; THERP
  - ATHEANA

Purpose of Scoping Approach

- Provide less conservative HEPs for HFEs surviving screening
  - Straightforward approach without requiring too much detailed analysis
- Intent is to provide HEPs that are more realistic, and therefore, some detailed analysis required
  - HEPs thought to be somewhat more conservative than might be obtained with more detailed analysis
  - Expected to limit need for detailed analyses for many HEPs
- Relies on assessment of feasibility of actions and a time margin to account for many of the uncertainties associated with fire scenarios (e.g., per NUREG-1852)
- Requires simple judgments about PSFs

Categories of Actions Addressed in Scoping Flowcharts

- New and existing main control room (MCR) actions
- New and existing ex-control room actions
- Actions associated with using alternative shutdown means due to MCR habitability issues or due to difficulties in controlling the plant from the MCR because of the effects of the fire
- Recovery of Errors of Commission (EOCs) or Errors of Omission (EOOs) due to spurious instrumentation
  - Supports addressing spurious instrument effects as described in Part 4 (Internal Fires) of ASME/ANS Combined PRA Standard (HLR-ES-C1 and C2)

Steps for Using Scoping Fire HRA Approach

1. Ensure minimum criteria are met
2. Assess feasibility of operator actions
3. Calculate time margin
4. Assess key conditions and PSFs
5. Use flowcharts to quantify - Search scheme directs to one of the following:
   - INCR = In MCR actions
   - EXCR = ex-MCR actions (actions normally performed locally)
   - ASD = Alternative Shutdown (including MCR Abandonment due to habitability or transferring command and control to outside the MCR due to an inability to control the plant)
   - SPI = recovery of errors due to spurious instrumentation

Minimum Criteria

1. Procedures
   - Plant procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action
   - Exceptions:
     - Execution of skill-of-the-craft actions
     - Recovery of EOO or EOC in some cases

2. Training – on the procedures and the actions

3. Availability and Accessibility of Equipment

Assessment of Feasibility

- Show that a given action or set of actions for a particular HFE can be diagnosed and performed within the time available

  time available > time required

- The time required for operator performance should consider 3 aspects:
  - Time at which the cue occurs relative to the initiating event
  - Time it takes the operators to formulate a response (detect, diagnose, decide)
  - Time to execute the response (including travel time and acquiring equipment, if necessary)
- Internal events that involve MCR actions can be assumed to be feasible and do not need to be re-evaluated for feasibility considerations, provided the fire does not affect MCR habitability or functionality

Determining Time Required for an Action for Assessment of Feasibility: Alternatives

- Job performance measures (JPMs)
- Demonstration through training exercises
- Appendix R feasibility demonstration
- Assessment of feasibility to meet criteria in NUREG-1852
- Assessment of feasibility of similar action
- Talk-through with operators and/or trainers
- Walk-through of action and/or procedures
- Simulation

Talk-Throughs and Walk-Throughs

- Talk-throughs with operators, trainers or other appropriate plant personnel can be used to estimate timing for determining feasibility for the scoping approach
  - Per Capability Category II as defined in ASME/ANS requirement HR-G2.
- Walk-throughs of actions and/or procedures (or simulation) are recommended when:
  - detailed HRA is needed for significant events
  - insufficient information is available to support a valid talk-through

Guidance for Performing Talk-Throughs

- Operators, trainers and other knowledgeable plant staff should be involved to the extent possible.
  - Those that would have to perform the action (or set of actions) should be interviewed.
  - More than one expert should be involved if possible, i.e., get more than one opinion.
- Do a thorough task breakdown so that the necessary actions and their locations, including access to and egress from, are clear.
- Evaluate relevant procedures (diagnosis and execution) in determining the time requirements.
  - How the procedures will be used, e.g., followed carefully in a step by step way or used more generally.

Guidance for Performing Talk-Throughs
(Continued)

- Determine the key indicators for the action
  - Assess how soon the operators would be expected to detect and begin responding to the cues.
  - Expected delays in detecting and responding to the cues should be included in estimating crew response time
- Consider list of factors that could influence performance (next slide) in conducting an assessment of feasibility
- The team should thoroughly discuss the tasks to be performed and the likely impacts on performance before making estimates about the time required.
- When reasonable, use an expert elicitation process such as that described in the ATHEANA Users Guide (NUREG-1880) to estimate the time requirements.

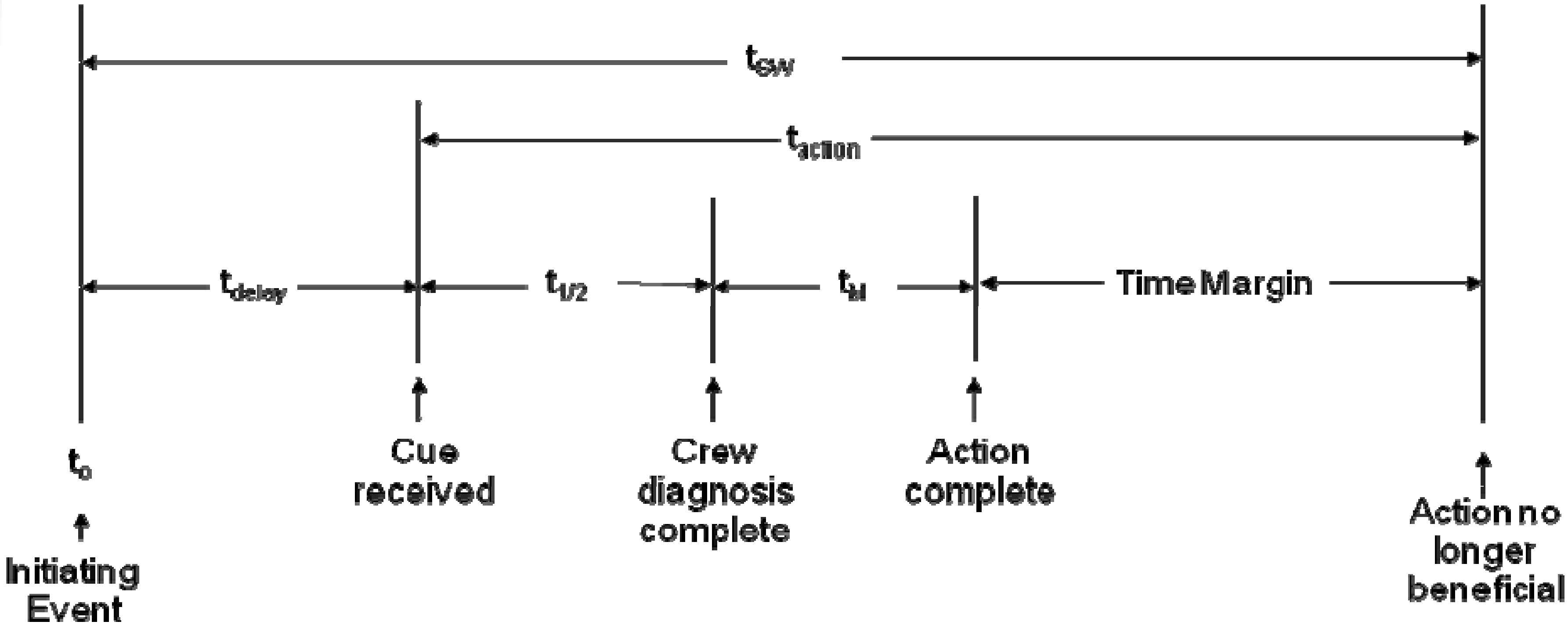
Considerations in Conducting Feasibility Assessment

- Environment
- Equipment functionality and accessibility
- Available indications and MCR response
- Communications
- Portable equipment
- Personnel protection equipment
- Procedures and training
- Staffing
- Other aspects (e.g., travel path, smoke)

Time Margin

- Extra time included to account for potential unexpected fire effects and variabilities such as:
  - Uncertainties in the demonstrations and conditions unable to be simulated
  - Potential variability in crew response times and individual differences
  - Variations in fire type and related plant conditions
- Within the scoping approach, time margins are required to be calculated for all actions or set of actions.
- Similar to guidance in NUREG-1852

Calculation of Time Margin



$$TM = \frac{t_{action} - (t_{1/2} + t_M)}{(t_{1/2} + t_M)} * 100\%$$

Calculation of Time Margin (2)

- Times used should be based on realistic (average) times, not the worst case analysis
- Some actions may involve either or a mix of both serial and parallel actions, with overlapping tasks. In these cases, determination of the time margin may not be as straightforward as illustrated. For more guidance, see Appendix A of NUREG-1852.

Assessing Key Conditions & PSFs within the Scoping Flowcharts

- How well the procedures match the scenario
  - The procedures should be relatively easy to follow given the pattern of indications
  - Serves as a proxy for diagnostic complexity

- Response execution complexity
  - Assessed as high or low
  - Complexity is usually considered **low** if:
    - Requires a single step
    - Performed by a single crew member
    - Multiple simple steps performed by single crew members working independently
    - Clear procedures or skill-of-craft
  - Complexity is usually considered **high** if:
    - Multiple steps that may be ambiguous or difficult
    - Multiple crew members performing coordinated steps
    - Multiple location steps if coordination/communication required
    - Multiple functions (e.g., both electrical and mechanical alignment)

Assessing Key Conditions & PSFs within the Scoping Flowcharts (2)

- Timing of cues for the action relative to expected fire suppression time.
  - If fire type unknown, fire suppression assumed to be 70-minutes ("all fires")
  - If fire type is known, may use the 99th %ile value (yellow) from FAQ 08-0050
  - Fire must be considered on-going for the fire types in red

Time (min)	T/G fires	High energy arcing	Outdoor transformers	Flammable gas	Oil fires	Electrical fires	Transient fires	PWR containment	Welding	Control Room	Cable fires	All Fires
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	0.883	0.947	0.836	0.881	0.684	0.602	0.531	0.687	0.392	0.189	0.446	0.714
10	0.780	0.897	0.698	0.776	0.468	0.362	0.282	0.472	0.153	0.036	0.199	0.510
15	0.689	0.850	0.584	0.683	0.320	0.218	0.150	0.325	0.060	0.007	0.089	0.364
20	0.609	0.805	0.488	0.602	0.219	0.131	0.080	0.223	0.024	0.001	0.040	0.260
25	0.538	0.762	0.408	0.530	0.150	0.079	0.042	0.153	0.009	*	0.018	0.186
30	0.475	0.722	0.341	0.467	0.102	0.048	0.023	0.105	0.004	*	0.008	0.133
35	0.419	0.684	0.285	0.411	0.070	0.029	0.012	0.072	0.001	*	0.004	0.095
40	0.370	0.647	0.238	0.362	0.048	0.017	0.006	0.050	*	*	0.002	0.068
45	0.327	0.613	0.199	0.319	0.033	0.010	0.003	0.034	*	*	*	0.048
50	0.289	0.581	0.166	0.281	0.022	0.006	0.002	0.024	*	*	*	0.035
55	0.255	0.550	0.139	0.248	0.015	0.004	*	0.016	*	*	*	0.025
60	0.226	0.521	0.116	0.218	0.010	0.002	*	0.011	*	*	*	0.018
65	0.199	0.493	0.097	0.192	0.007	0.001	*	0.008	*	*	*	0.013
70	0.176	0.467	0.081	0.169	0.005	*	*	0.005	*	*	*	0.009
75	0.155	0.443	0.068	0.149	0.003	*	*	0.004	*	*	*	0.006
80	0.137	0.419	0.057	0.131	0.002	*	*	0.002	*	*	*	0.005
85	0.121	0.397	0.047	0.116	0.002	*	*	0.002	*	*	*	0.003
90	0.107	0.376	0.040	0.102	0.001	*	*	0.001	*	*	*	0.002
95	0.095	0.356	0.033	0.090	*	*	*	*	*	*	*	0.002
100	0.084	0.337	0.028	0.079	*	*	*	*	*	*	*	0.001

Assessing Key Conditions & PSFs within the Scoping Flowcharts (3)

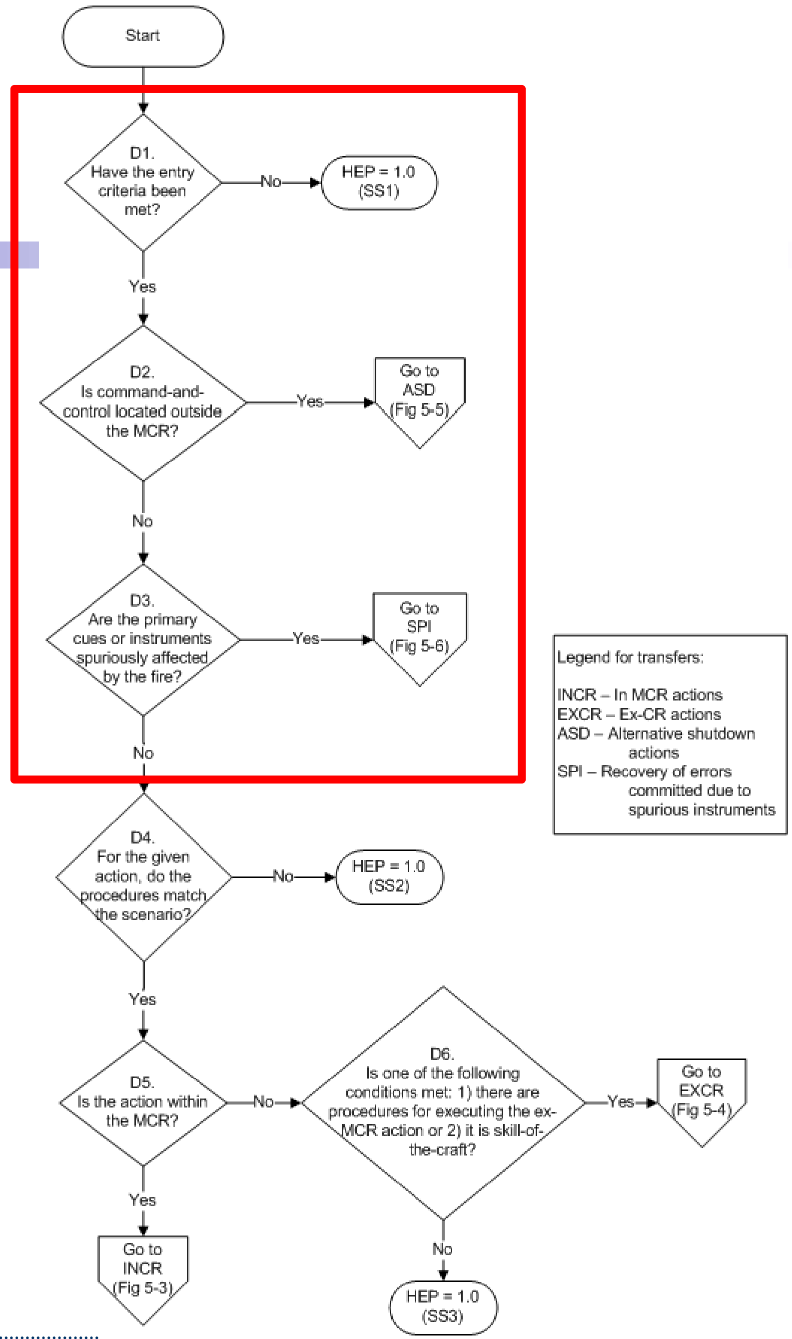
- Action time window
  - Time from the occurrence of the cues for action until the action is no longer beneficial
  - Short time window = 30 minutes or less
  - Long time window = greater than 30 minutes
- Level of smoke and other hazardous elements in the action areas
  - Need for special equipment (e.g., SCBA)
  - Impairment of vision or prevention of the execution of the action
- Accessibility
  - Location of action
  - Travel path

Use of Scoping Flowcharts

- HFEs quantified based on:
  - Assessment of key PSFs
  - Location of the actions associated with the HFE
  - Condition of relevant instrumentation
- A *Search Scheme* directs the analyst to the correct flowchart for quantification:
  - In-MCR action (INCR)
  - Ex-MCR action (EXCR)
  - Alternative Shutdown (ASD)
  - Recovery of error due to spurious instrumentation (SPI)
- Some HFEs quantified within the Search Scheme lead to HEP = 1.0

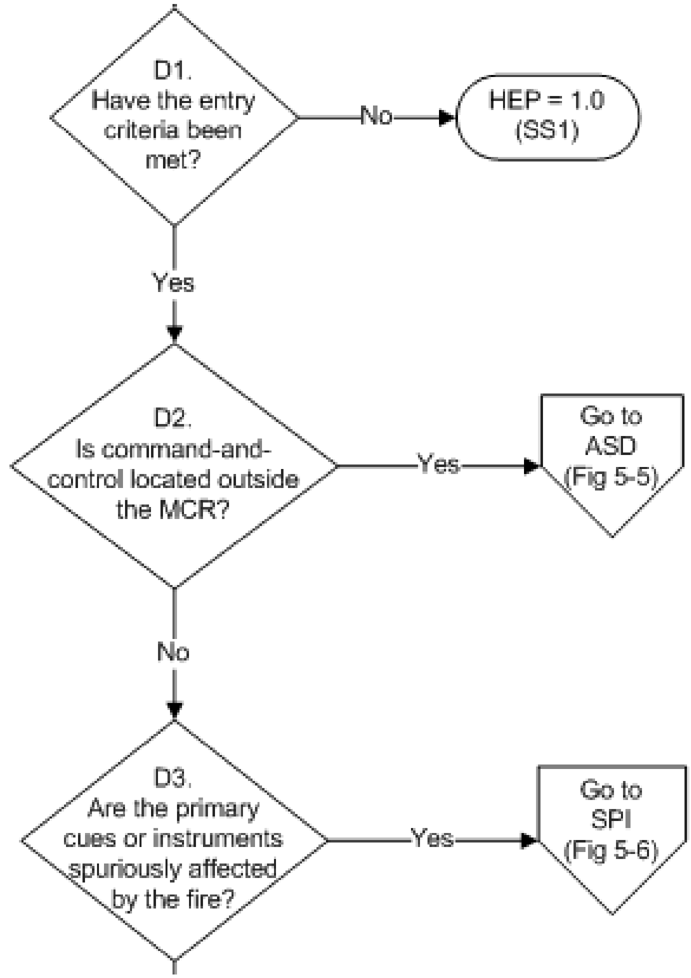
Search Scheme

- Directs analyst to correct quantification flowchart



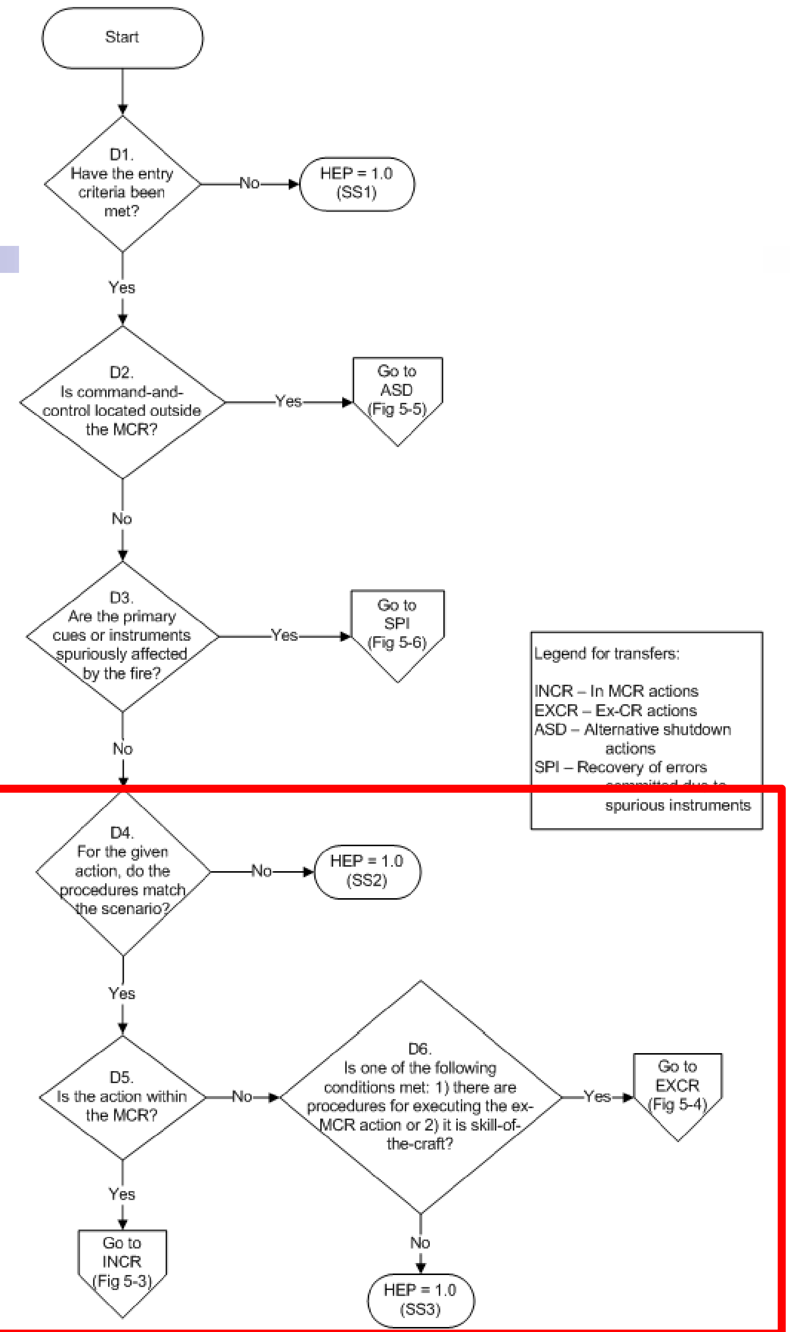
Search Scheme

- Direct to ASD or SPI tree
- Cues are not necessary to answer yes to D1, but likely their absence will still result in HEP = 1.0 later on

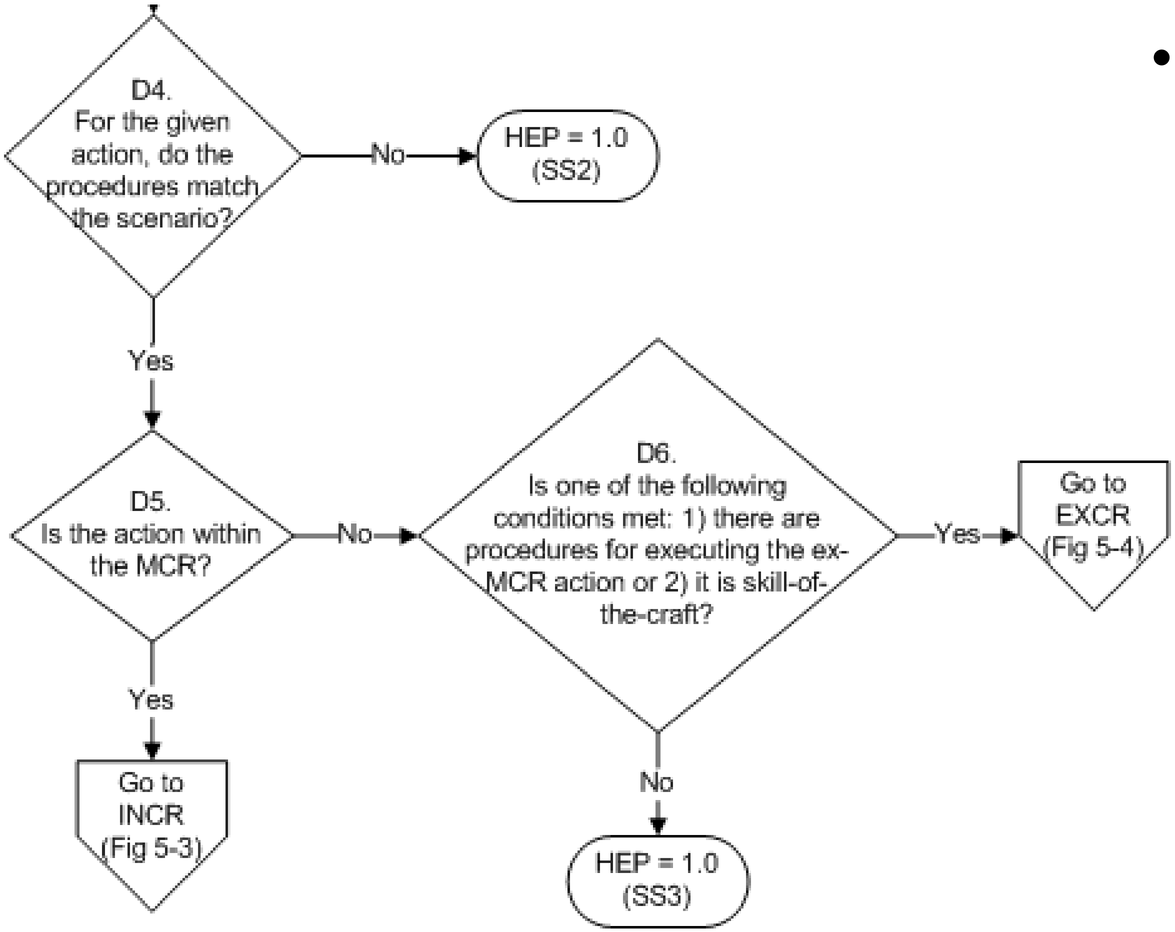


Search Scheme

- Directs analyst to correct quantification flowchart



Search Scheme



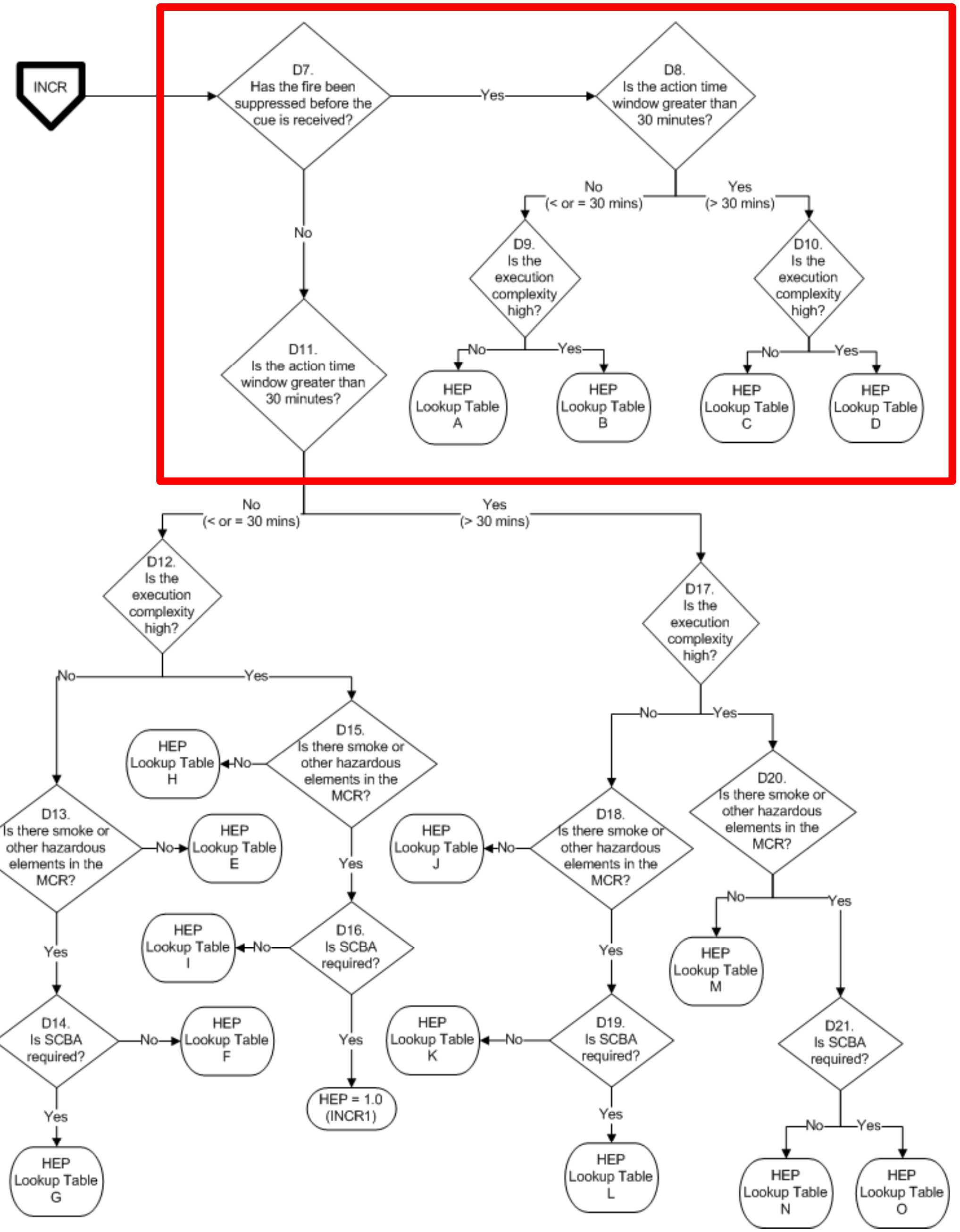
- Direct to INCR or EXCR

INCR – In-MCR Actions

- Used for the following HFEs:
  - New HFEs identified outside the Internal Events PRA
  - Existing HFEs from the Internal Events that survive quantitative screening
- Addresses diagnosis and execution of the action in the MCR
  - Presumes no challenge to MCR habitability or functionality from fire (see ASD)

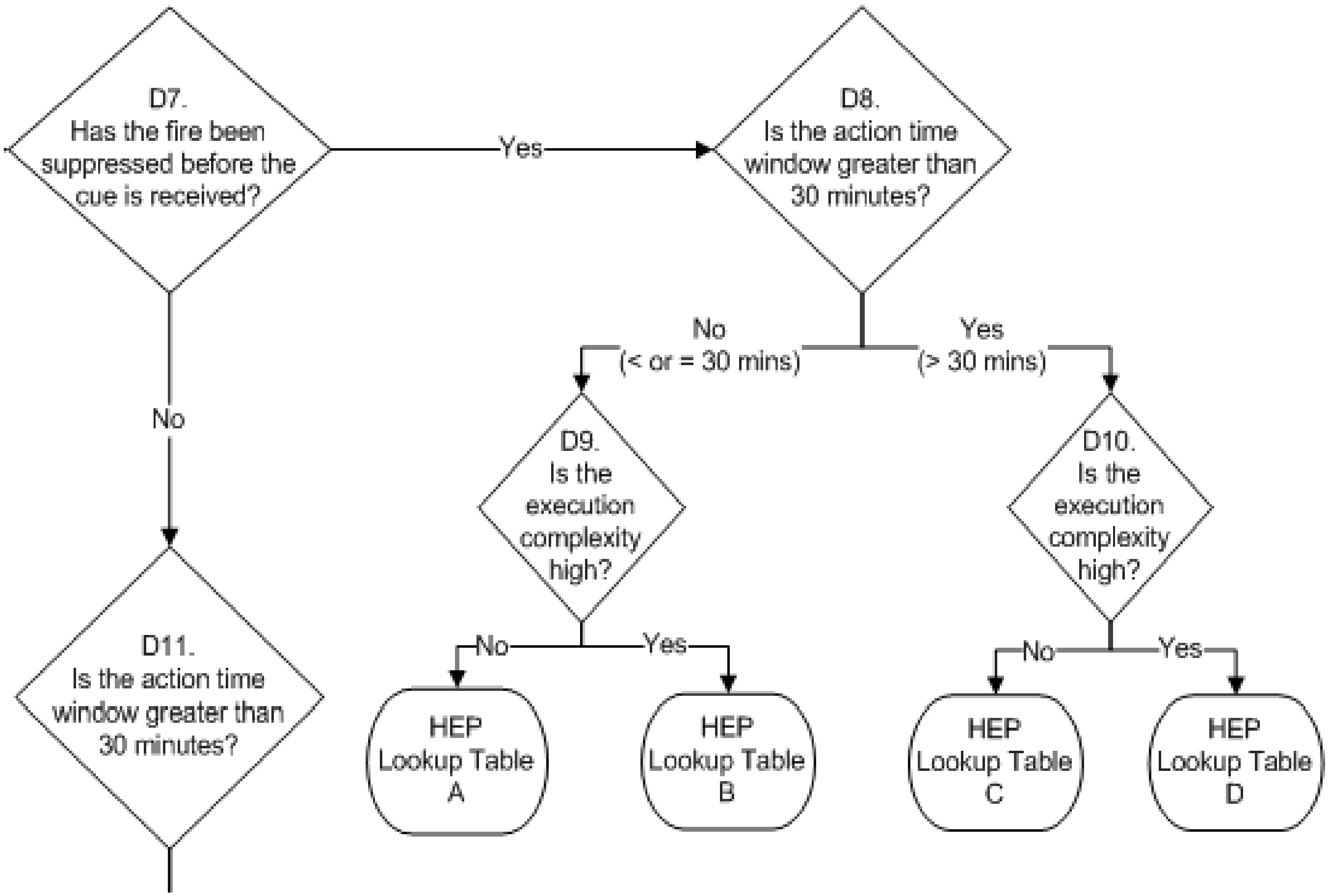
INCR

- Scoping HRA for in MCR Actions



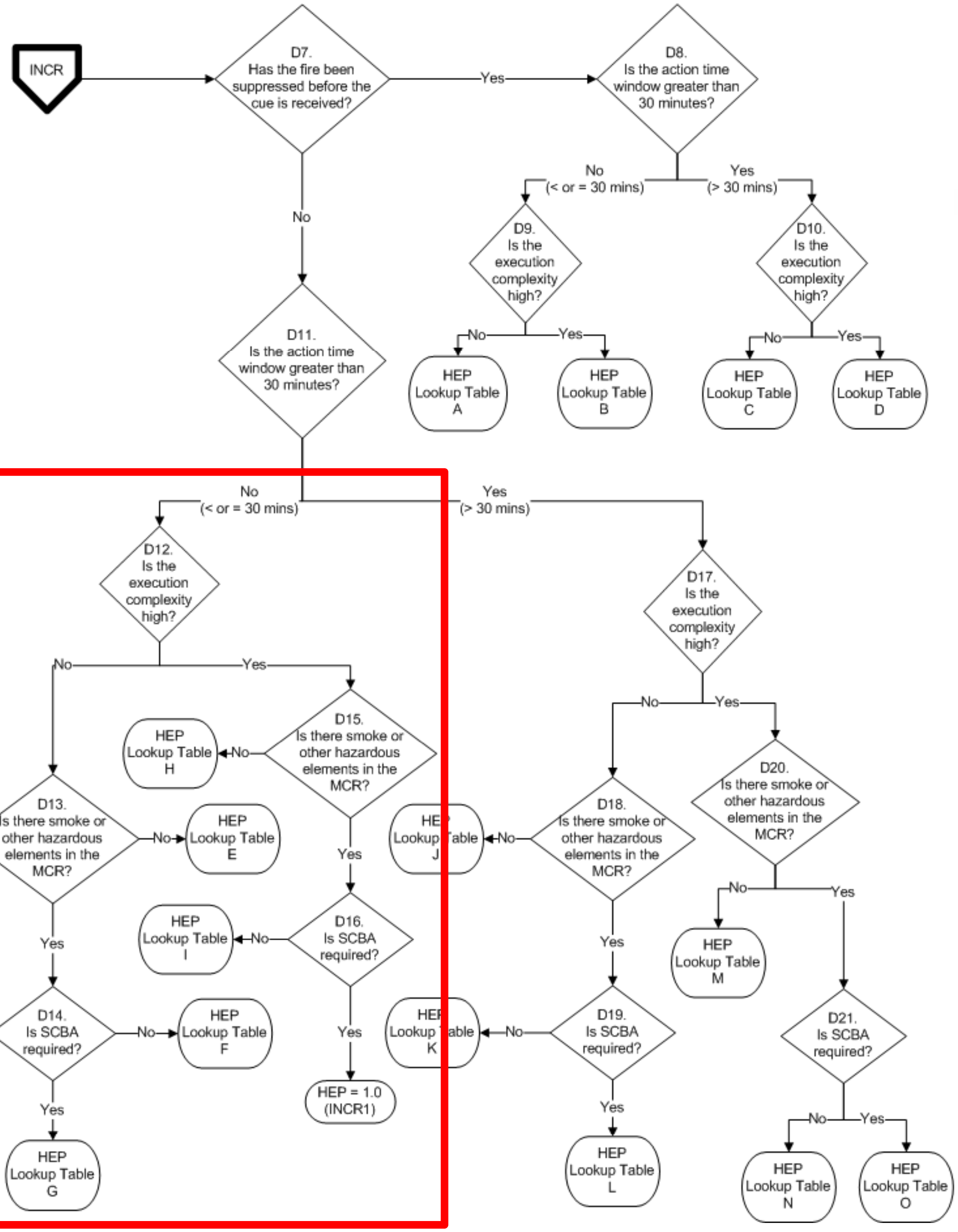
INCR

- Fire Suppressed?
  - 70 minutes from reactor trip
  - Fire specific timing [FAQ-08-0050]
  - Challenging fires (e.g., turbine generator fires) assume fire has not been suppressed.



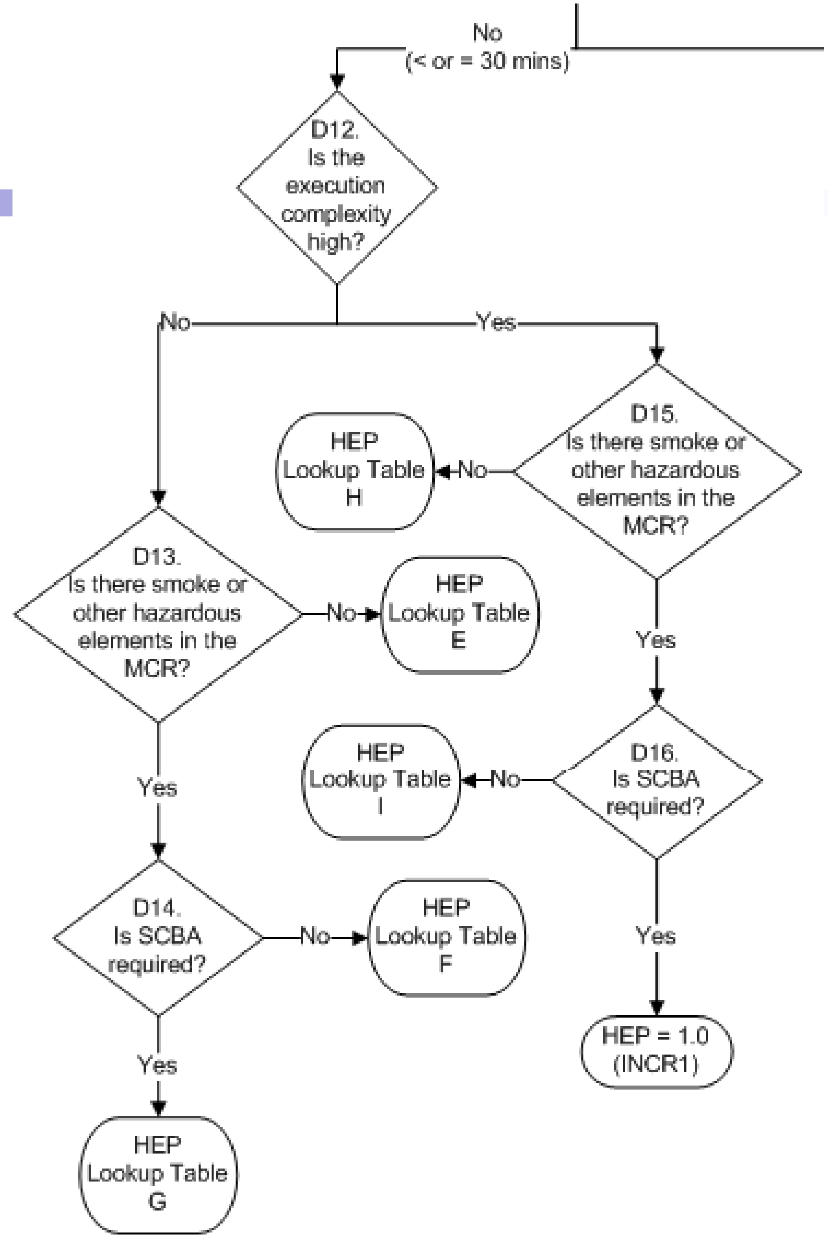
INCR

- Scoping HRA for in MCR Actions



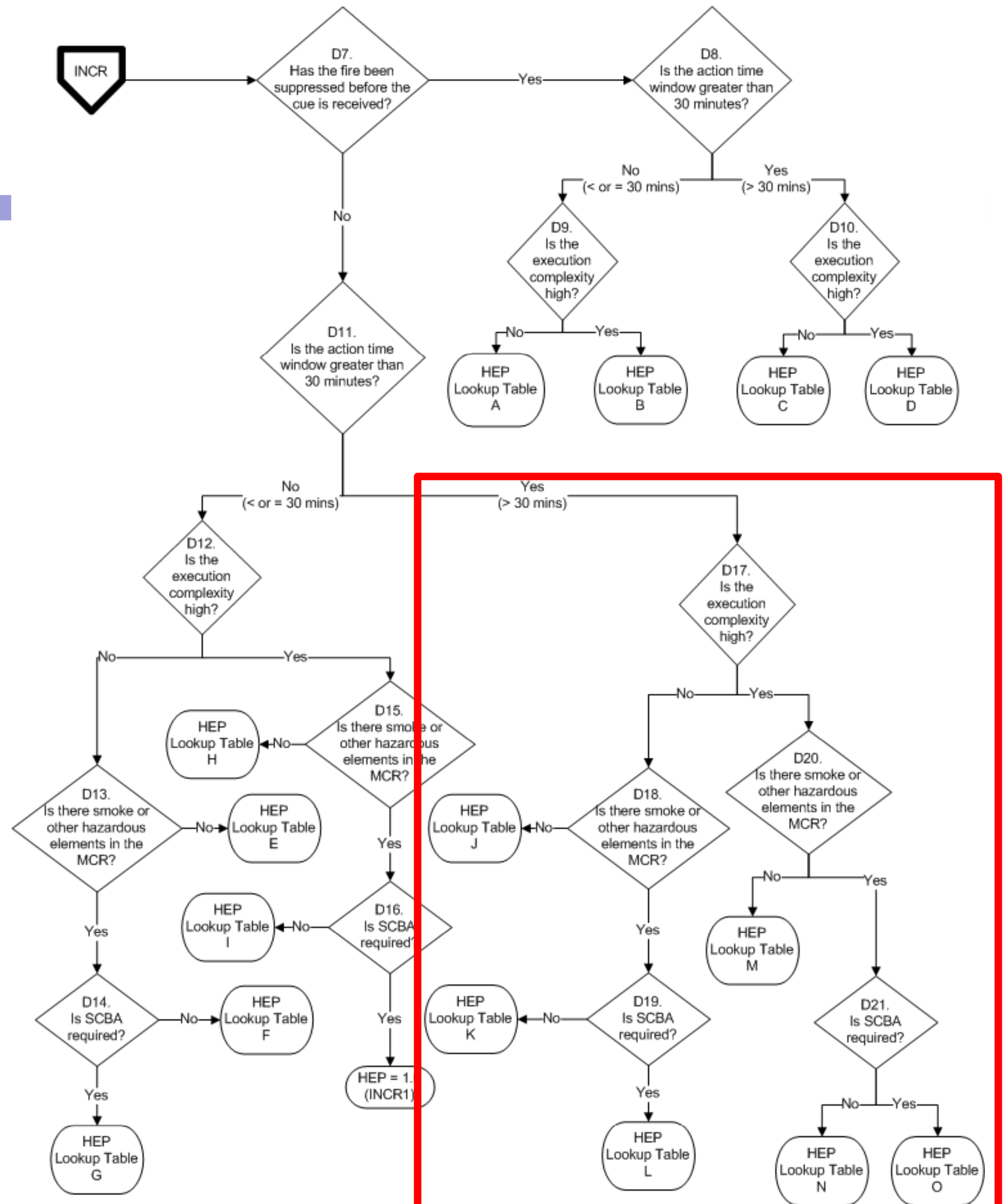
INCR

- Fire on-going
- Short time window (<30 min)



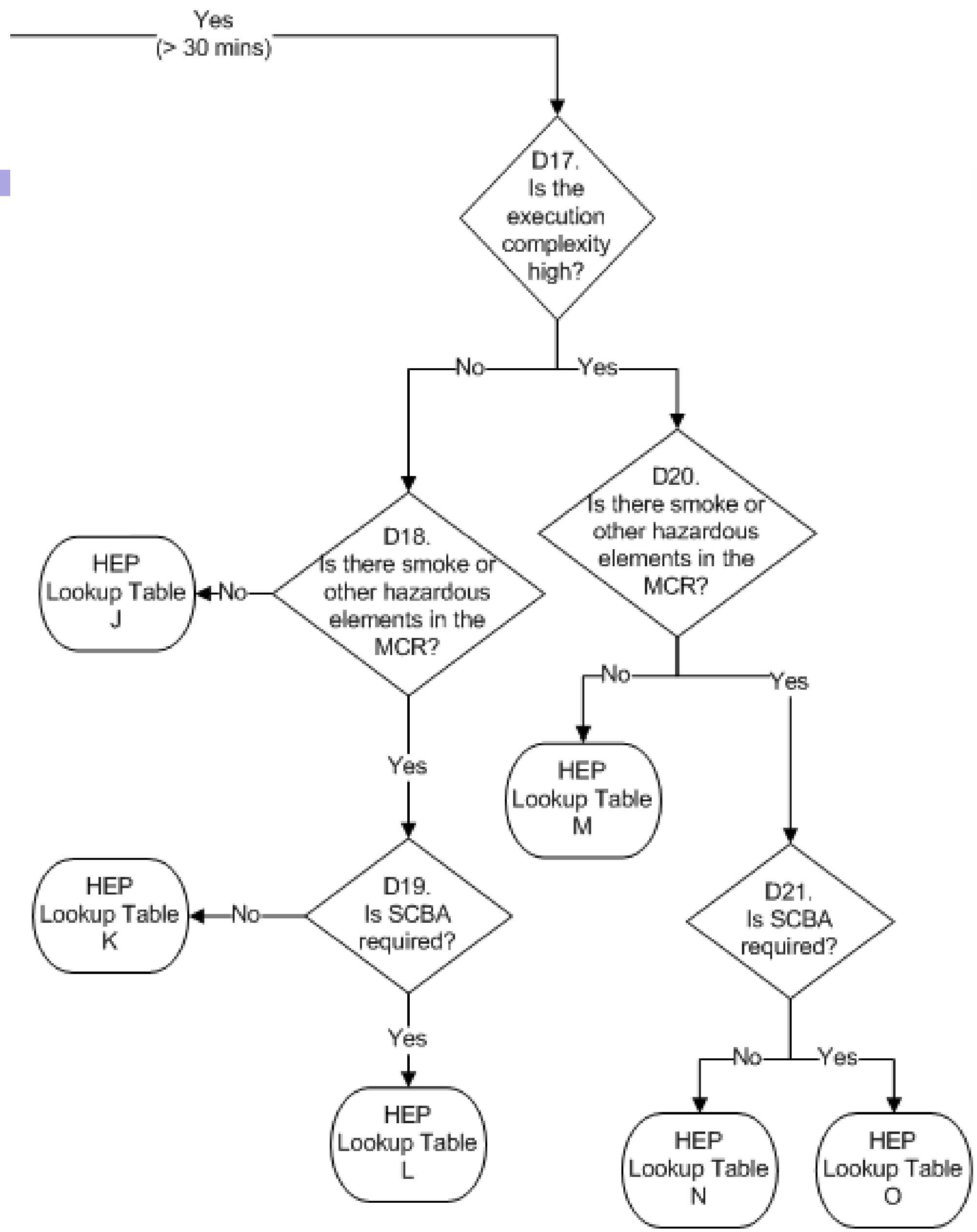
INCR

- Scoping HRA for in MCR Actions



INCR

- Fire on-going
- Long time window (>30 min)

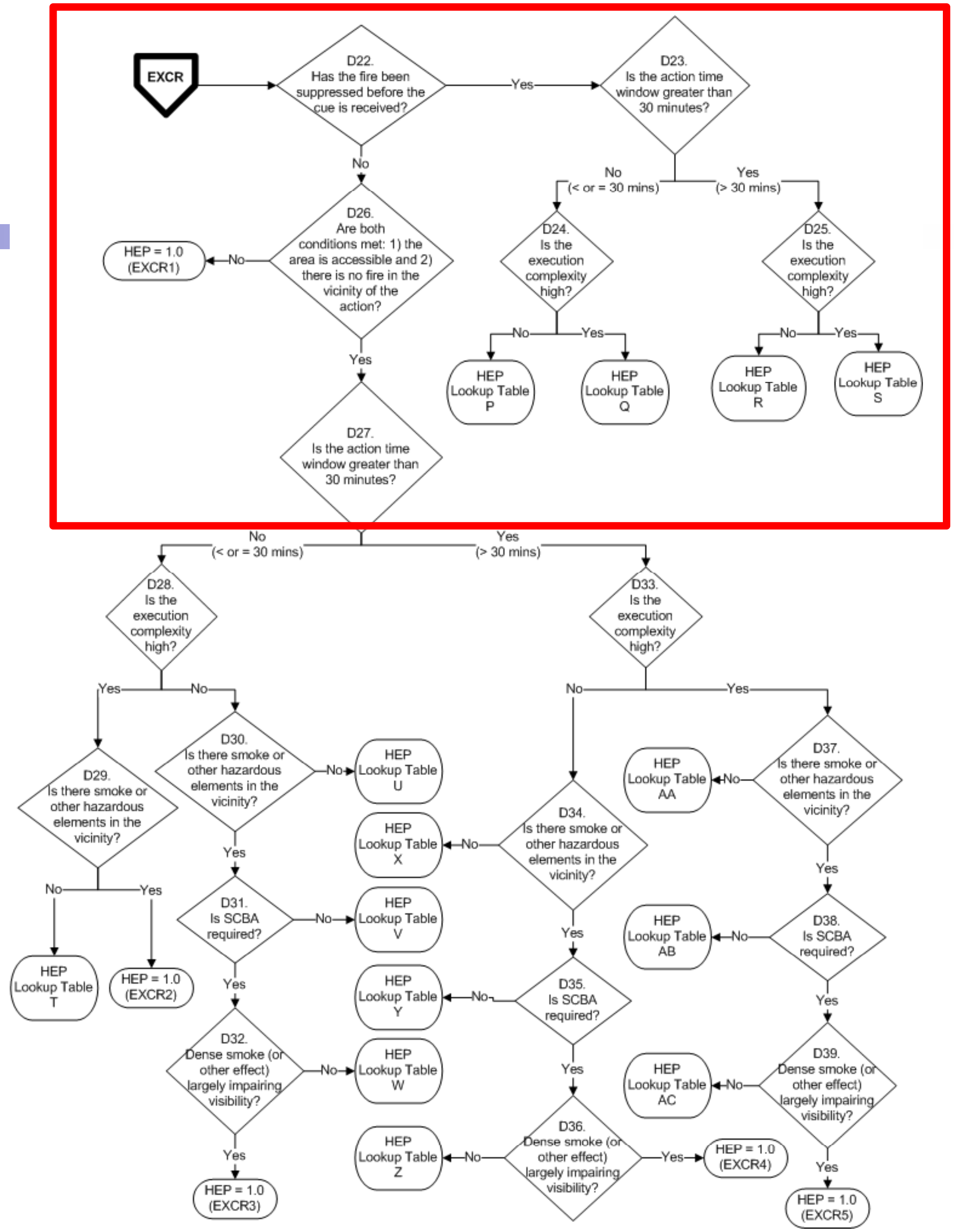


EXCR – Ex-MCR Actions

- Used for the following HFEs:
  - New HFEs identified outside the Internal Events PRA
  - Existing HFEs from the Internal Events that survive quantitative screening
- Addresses diagnosis and execution of the action(s)
  - Diagnosis within the MCR
  - Execution locally (i.e., ex-MCR)
    - If action is require both in the MCR and locally, this tree should be used

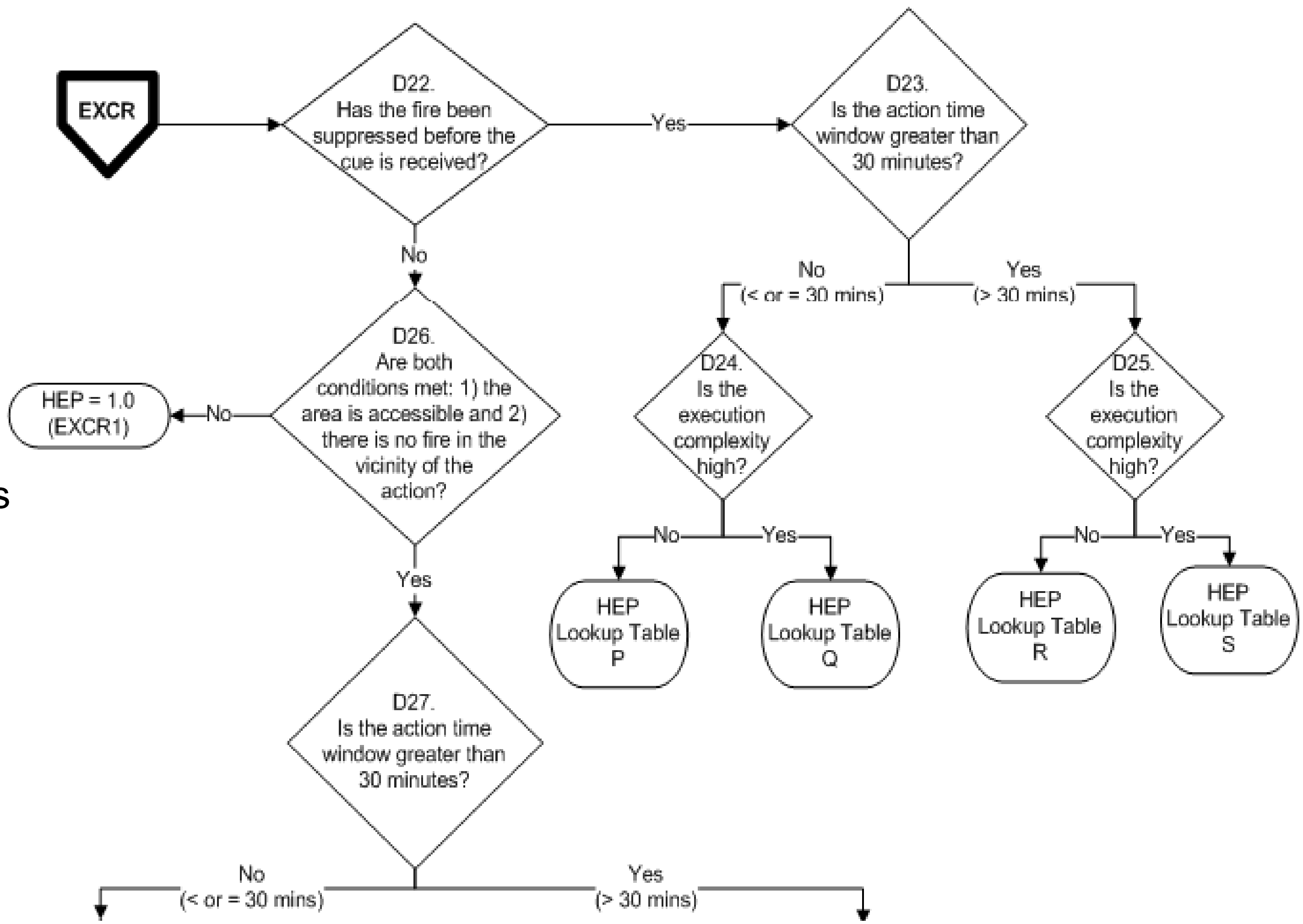
EXCR

- Scoping HRA for ex-MCR Actions



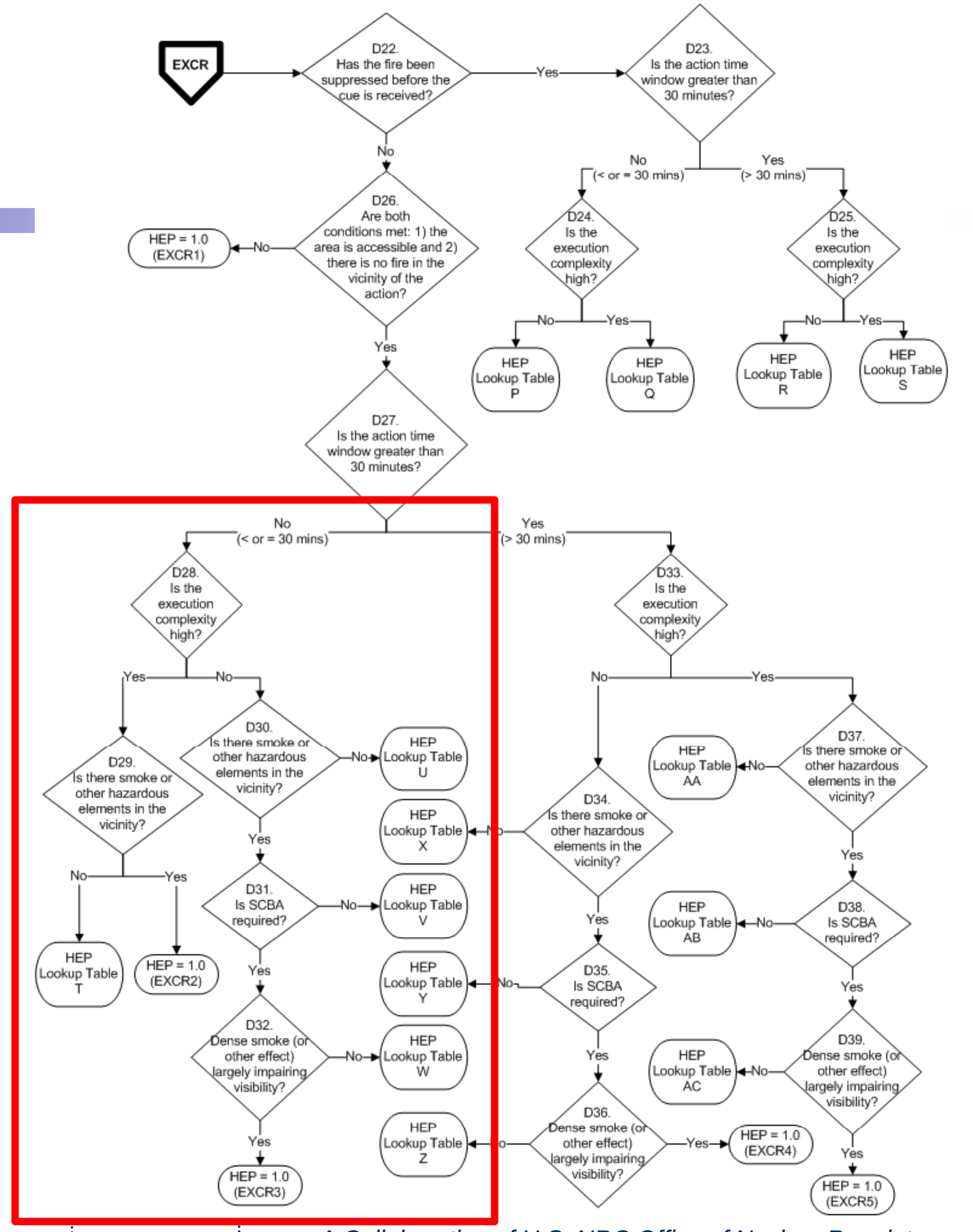
EXCR

- Fire Suppressed?
  - 70 minutes from reactor trip
  - Fire specific timing [FAQ-08-0050]
  - Challenging fires (e.g., turbine generator fires) assume fire has not been suppressed.



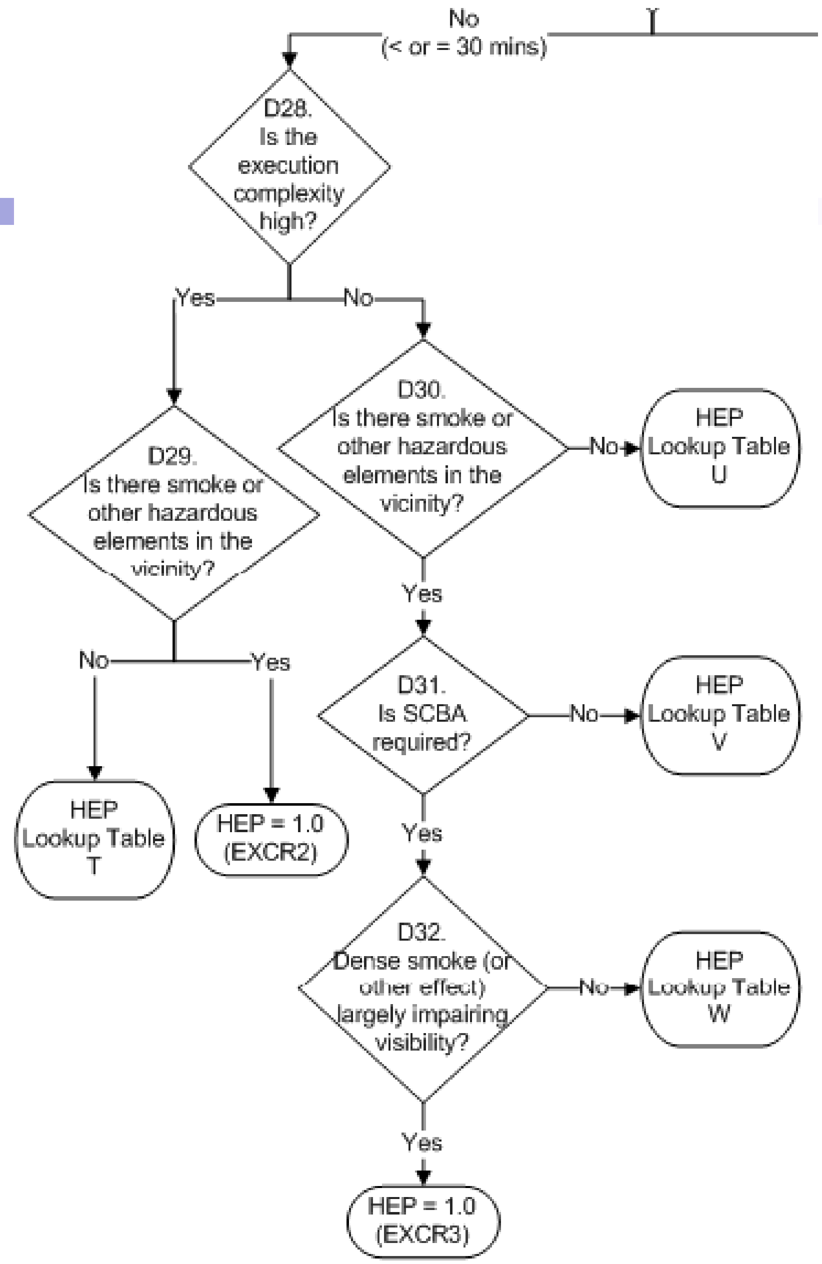
EXCR

- Scoping HRA for ex-MCR Actions



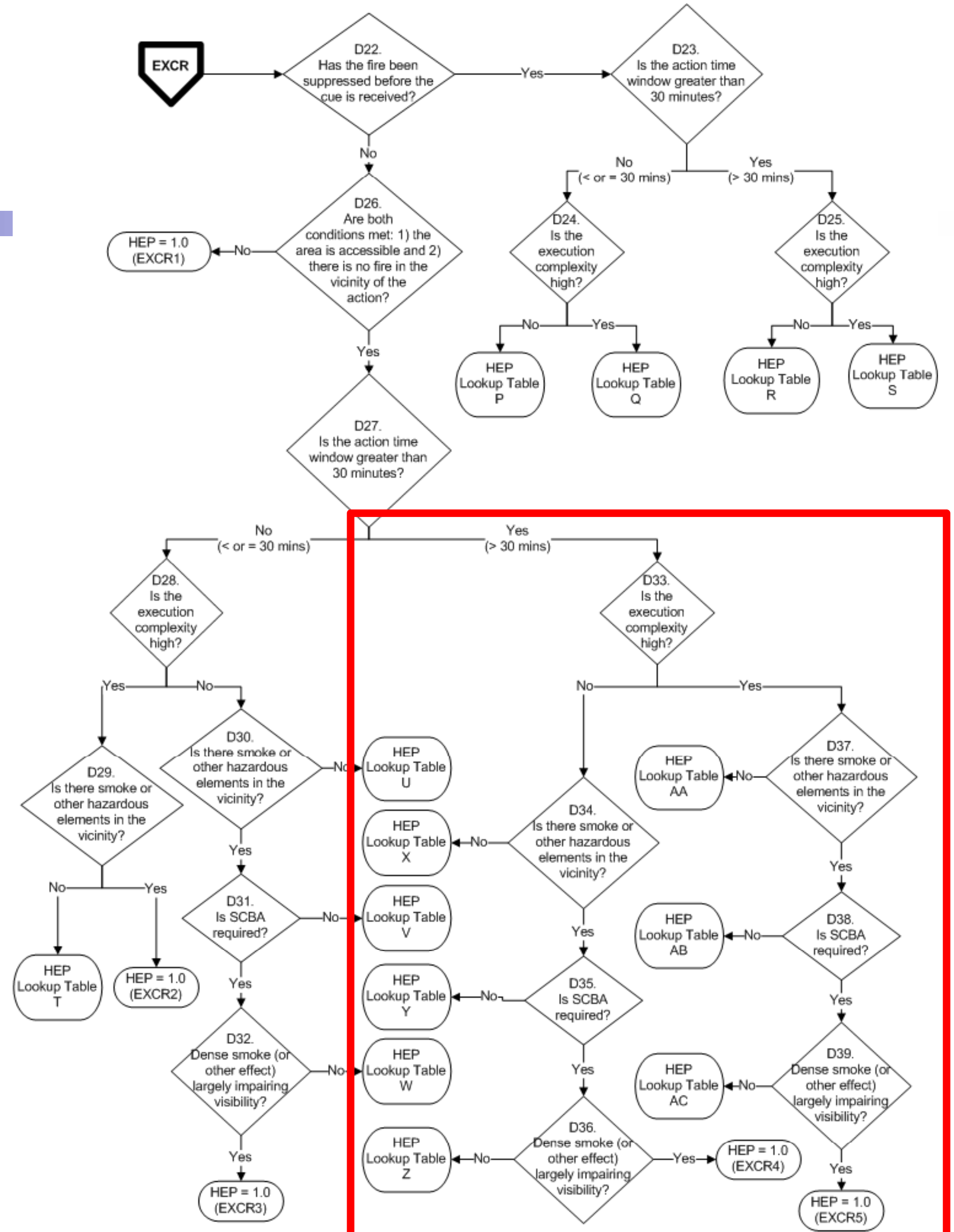
EXCR

- Fire on-going
- Short time window (< 30 min)



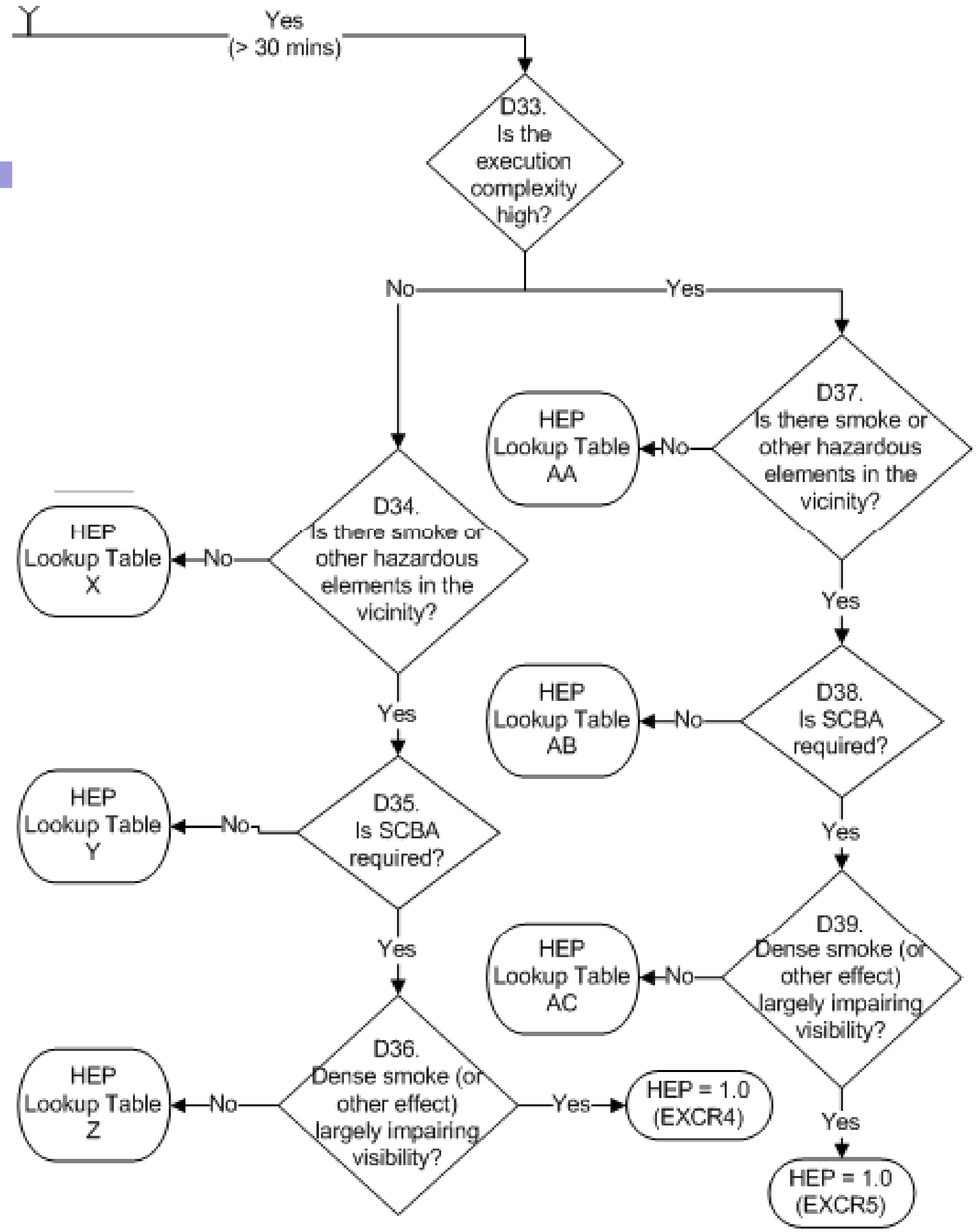
EXCR

- Scoping HRA for ex-MCR Actions



EXCR

- Fire on-going
- Long time window (> 30 min)

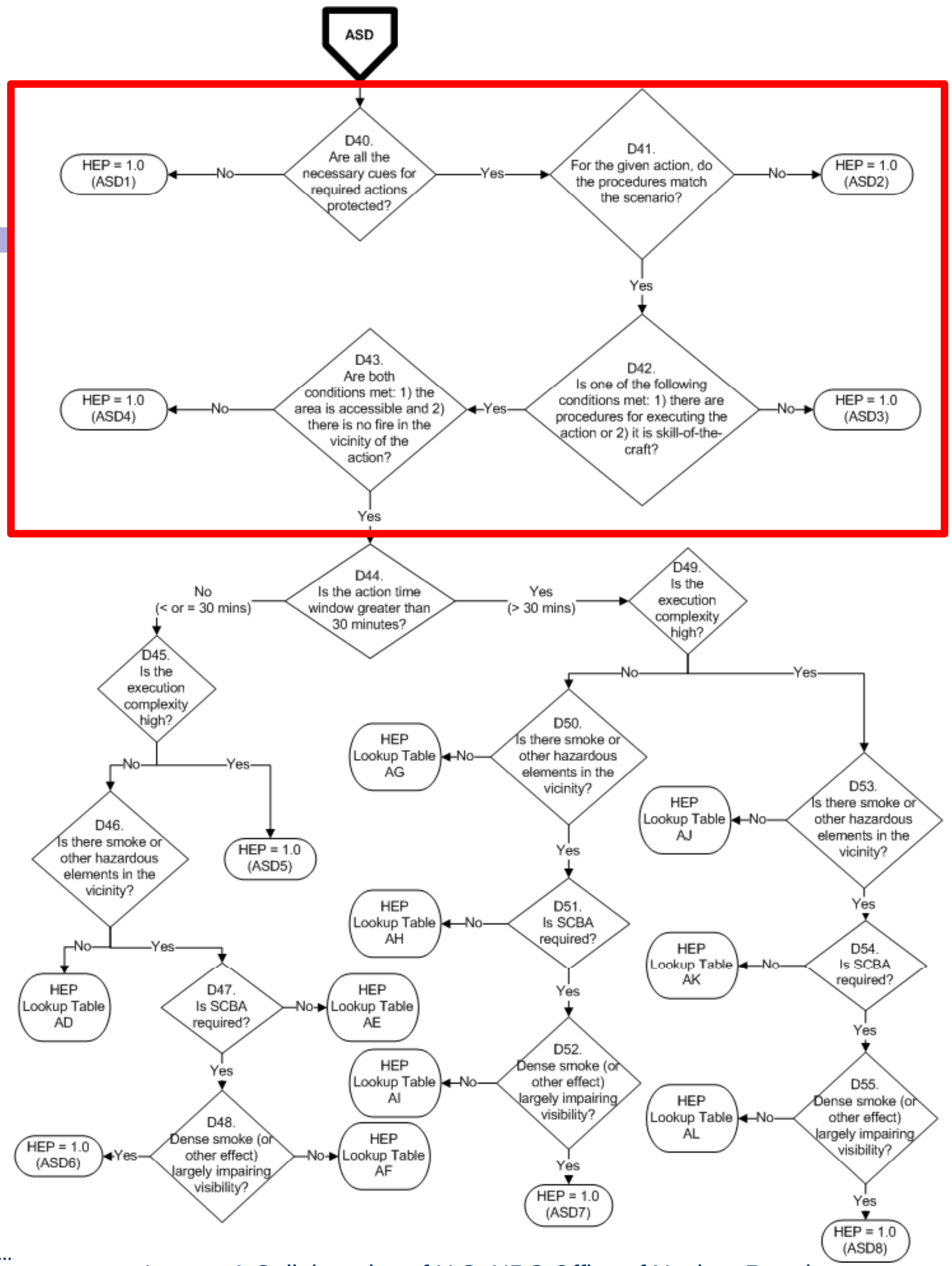


ASD – Alternative Shutdown

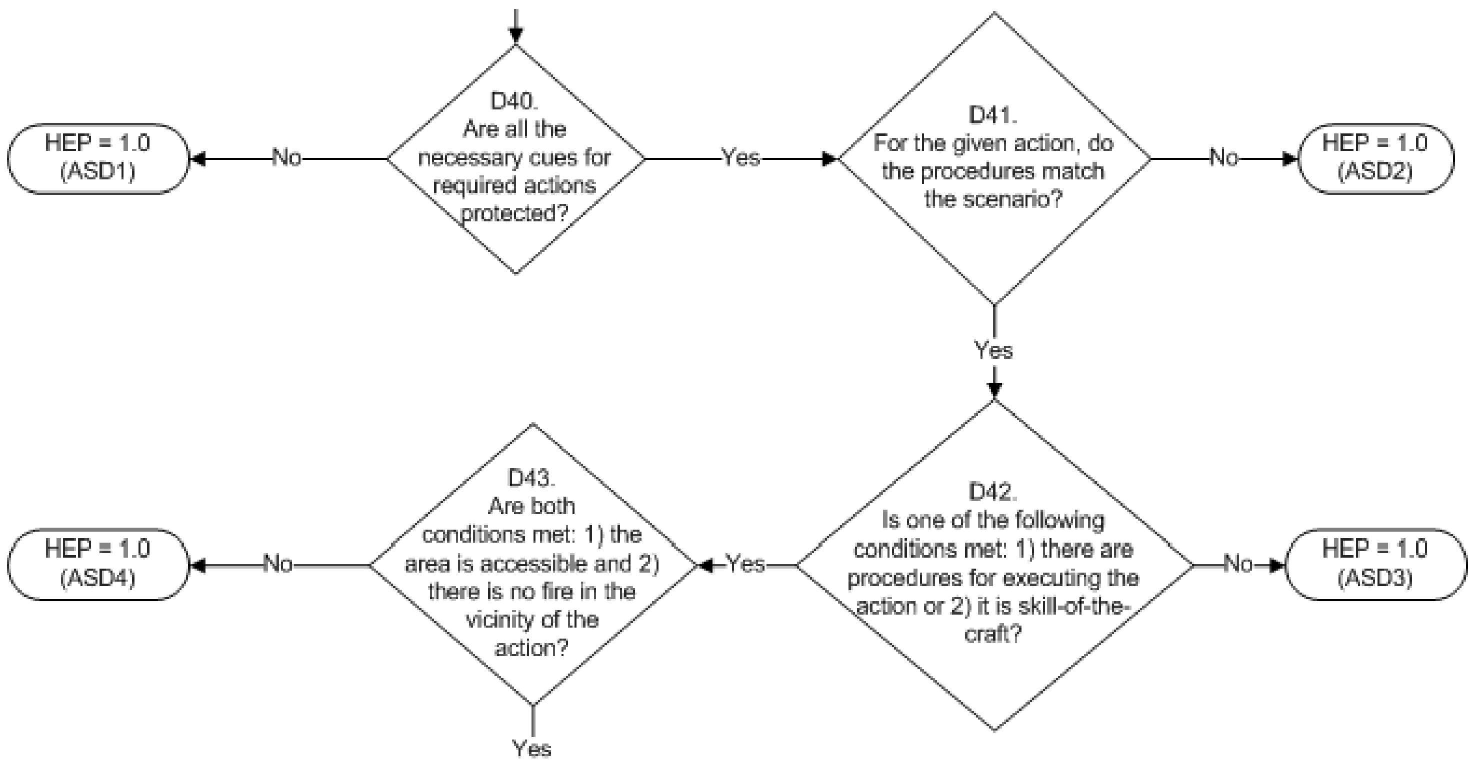
- Application to 2 situations:
  - Uninhabitable environment in MCR
  - Transfer of command and control to outside the MCR due to an inability to control the plant (loss of MCR functionality)
    - If the crew decides to stay in the MCR (i.e., direct the crew response and perform actions from the MCR to the extent possible), but collect some information or take some actions outside the MCR as necessary to reach safe shutdown (referred to as *remote shutdown*), actions should be quantified as ex-MCR actions and the EXCR flowchart should be used
- Additional information needed:
  - Identification of the cues necessary for diagnosis and verification that the instruments supporting these cues are protected from the fire effects
  - Determination of whether the action must take place in the direct vicinity of the fire.
  - Estimated level of smoke in the area

ASD

- Scoping HRA for Alternative Shutdown Actions



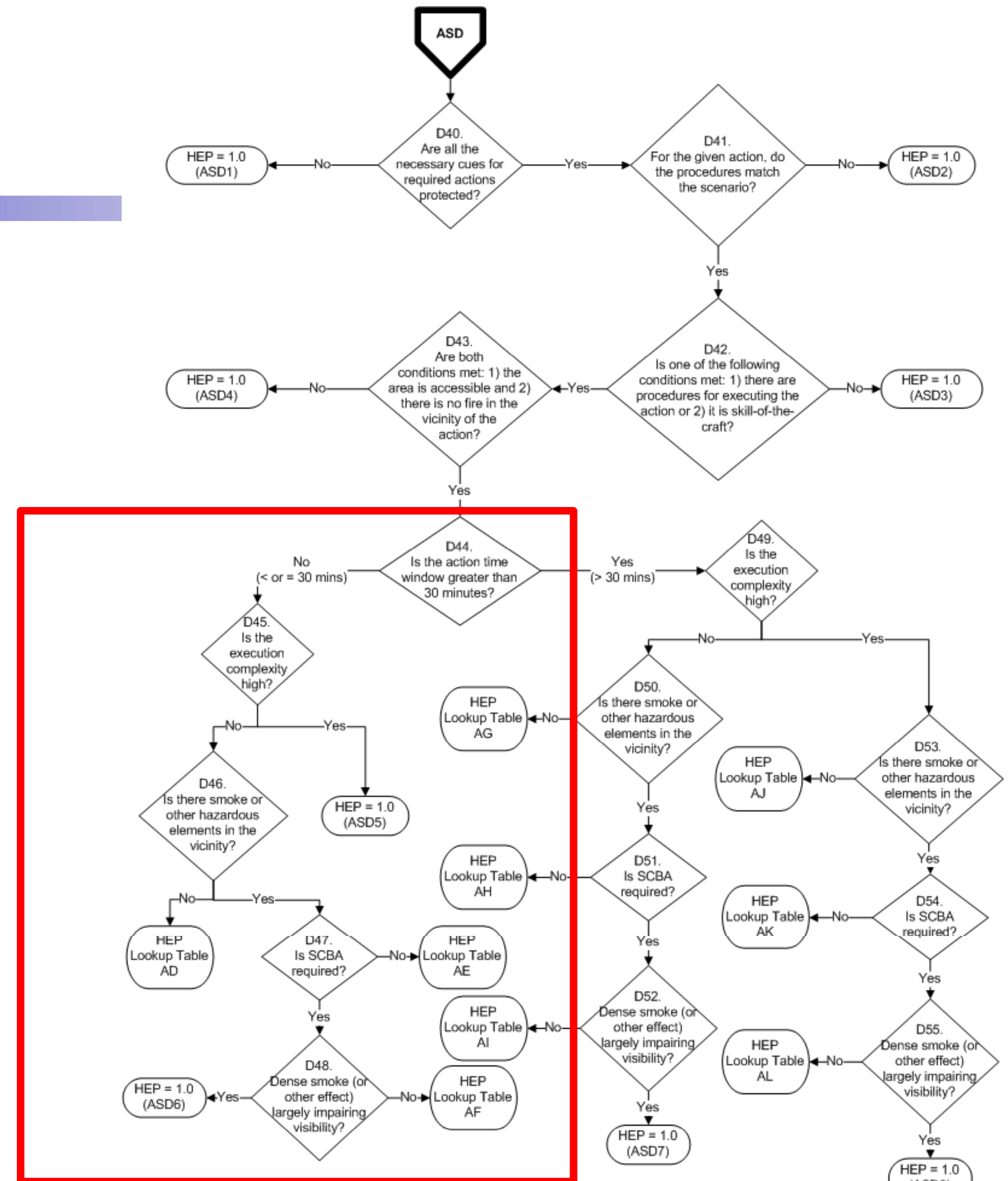
ASD



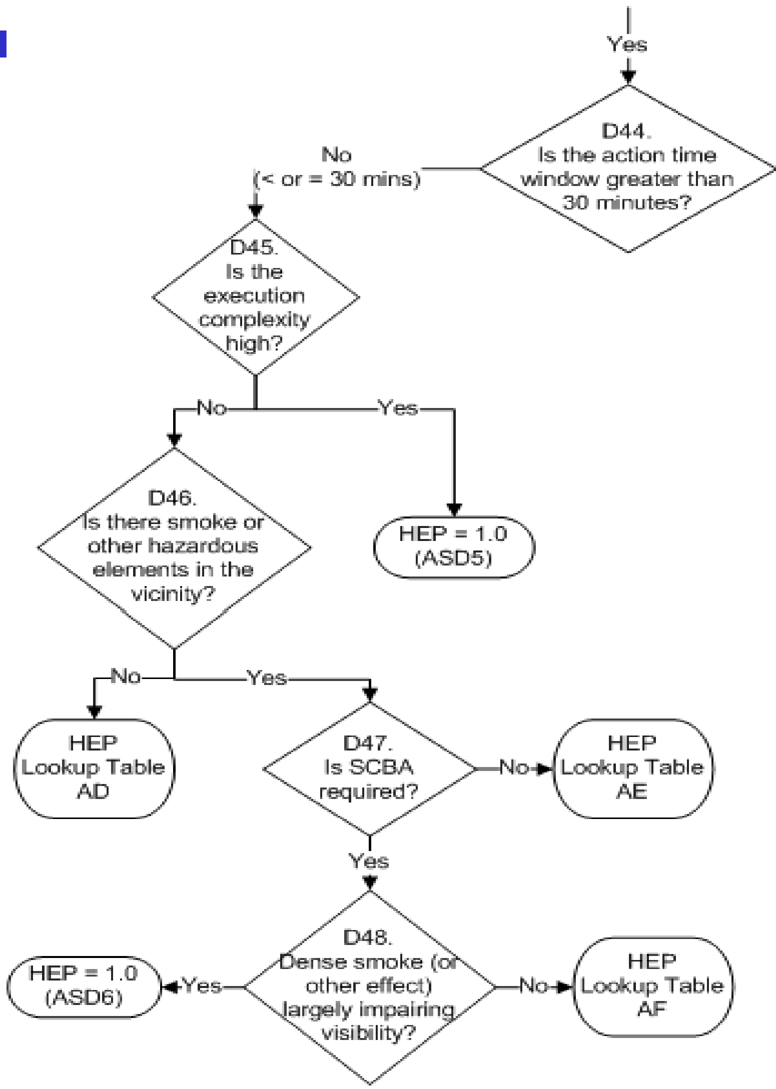
- D41 refers to diagnosis
- D42 refers to execution

ASD

- Scoping HRA for Alternative Shutdown Actions



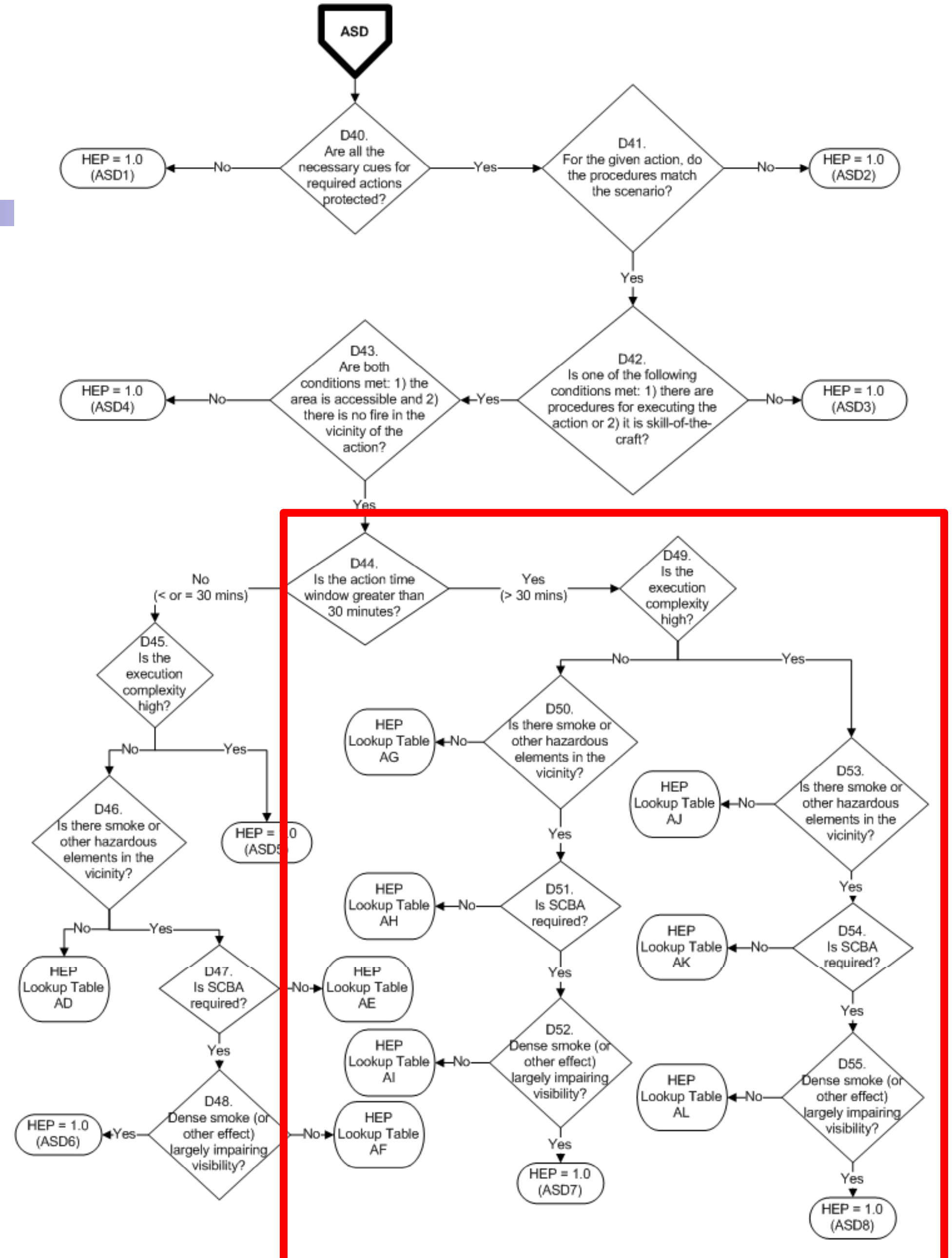
ASD



- Short time window (< 30 min)

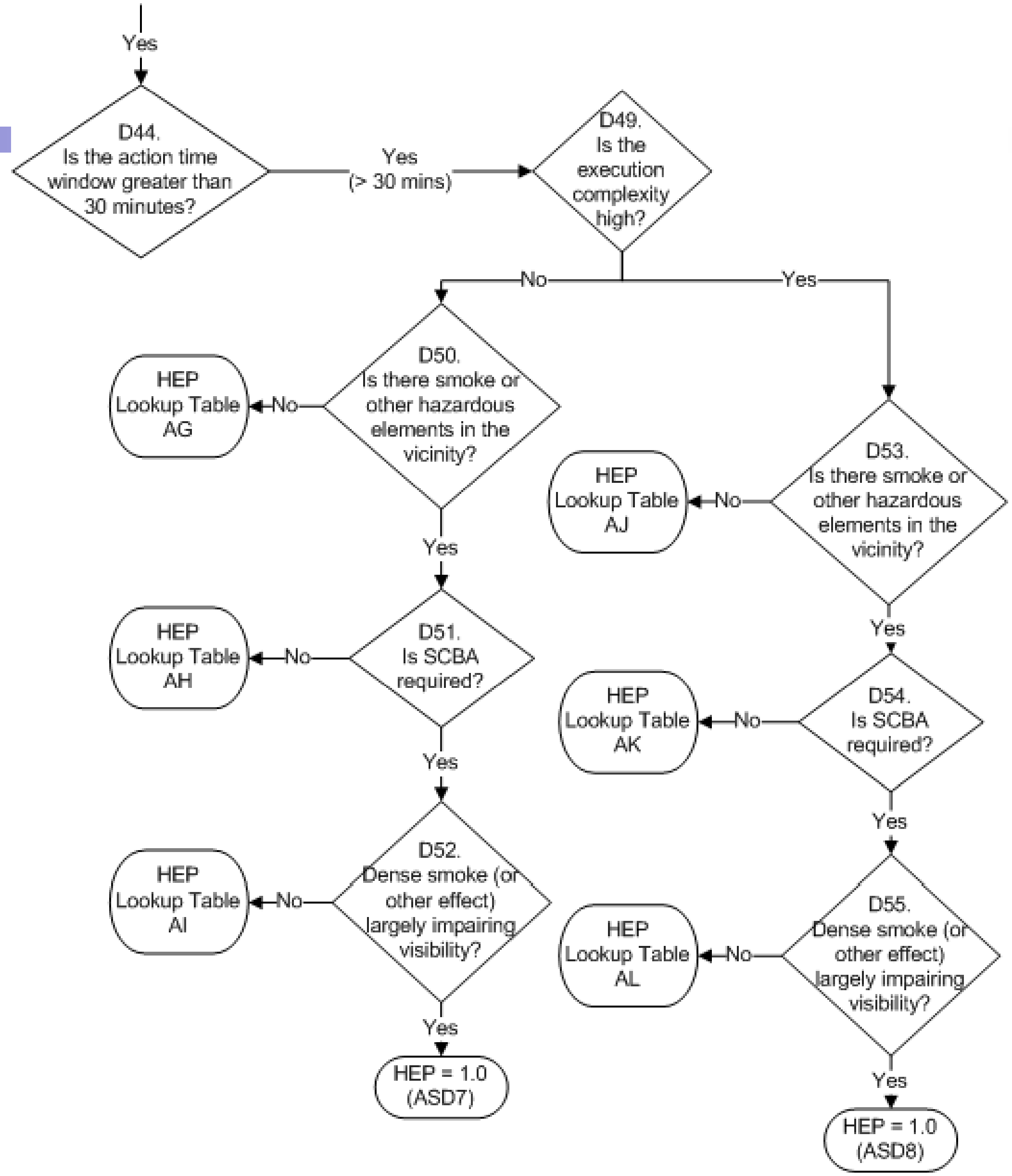
ASD

- Scoping HRA for Alternative Shutdown Actions



ASD

- Long time window (> 30 min)



SPI – EOC or EOO Due to Spurious Instrumentation

- Assumes the EOC or EOO has been committed & quantifies the probability that the error would remain uncorrected
- Assume an EOC or EOO if:
  - The cables are, or cannot definitively be known not to be (exclusion approach), routed through the fire area (Need cable routing information!)
  - The instrumentation is not required for an Appendix R action, such that it cannot be assumed to be protected by a fire barrier wrap
  - A single affected instrument can lead to the action
- Don't assume an EOC or EOO if:
  - Operator is suspicious of the equipment or instrument because it may be "suspect" due to location of fire
  - Demonstrated redundancy and diversity

SPI – Spurious Instrumentation

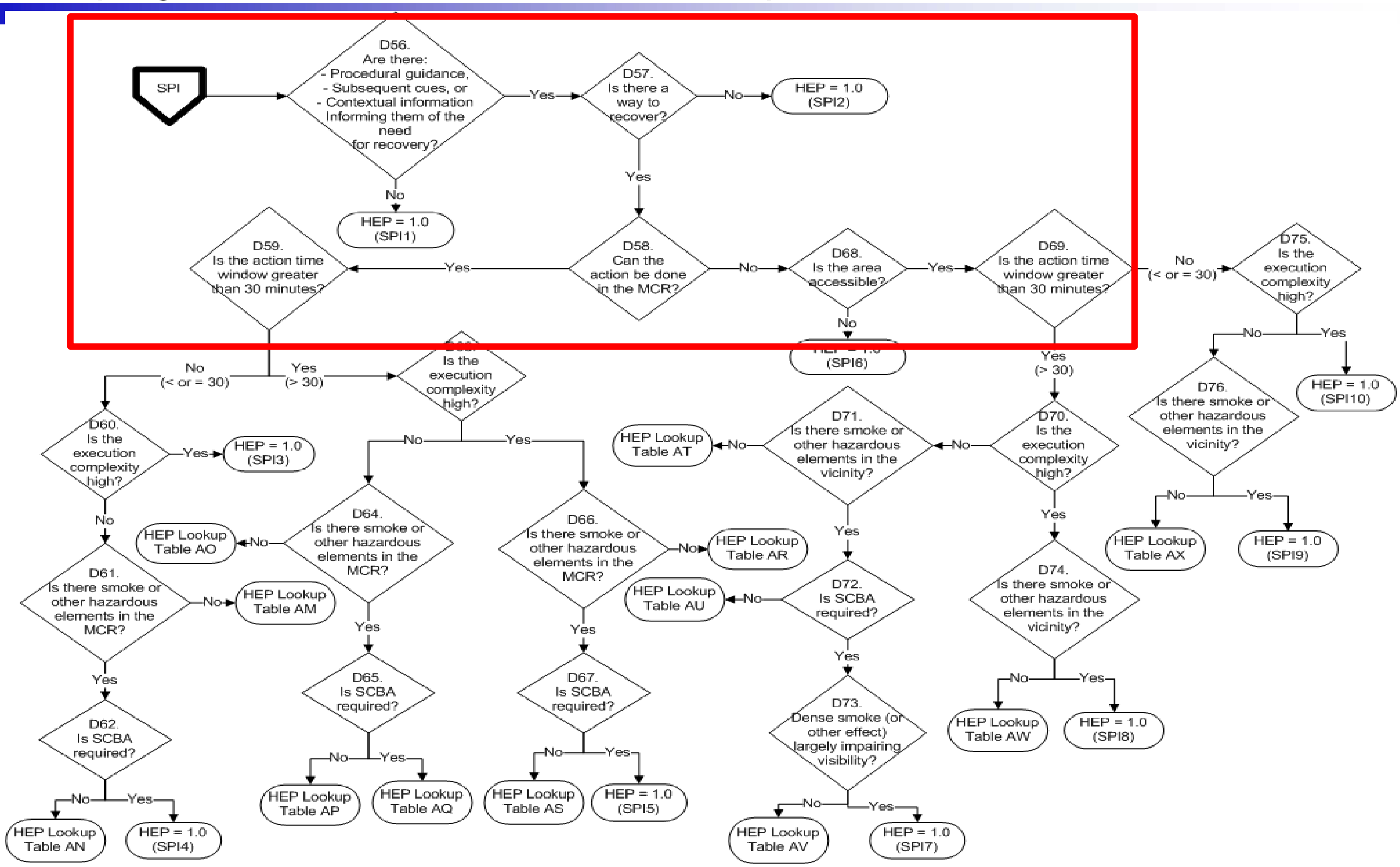
- Spurious instrumentation refers to the instrumentation necessary for the operator to diagnose the action (e.g., expected cues from the procedure)
- Analyst judgment required in cases of partial spurious indication (e.g., 2 out of 4 instruments fail vs. 2 out of 10 instruments fail). In these cases the analyst should consider:
  - How do the instruments fail?
  - Is it likely to cause the operator to fail to diagnose the problem?

SPI – Recovery of an EOC or EOO

- Recovery prompted by either:
  - Procedural guidance
  - Contextual information or subsequent cues in conjunction with existing procedures
- Recognition for need to recover may be either through:
  - Recognition of an error
  - Recognition of the need for the function
- Recovery possible by:
  - Reversal of the action (EOC)
  - Use of alternative system (EOC)
  - Performance of the necessary action (EOO)

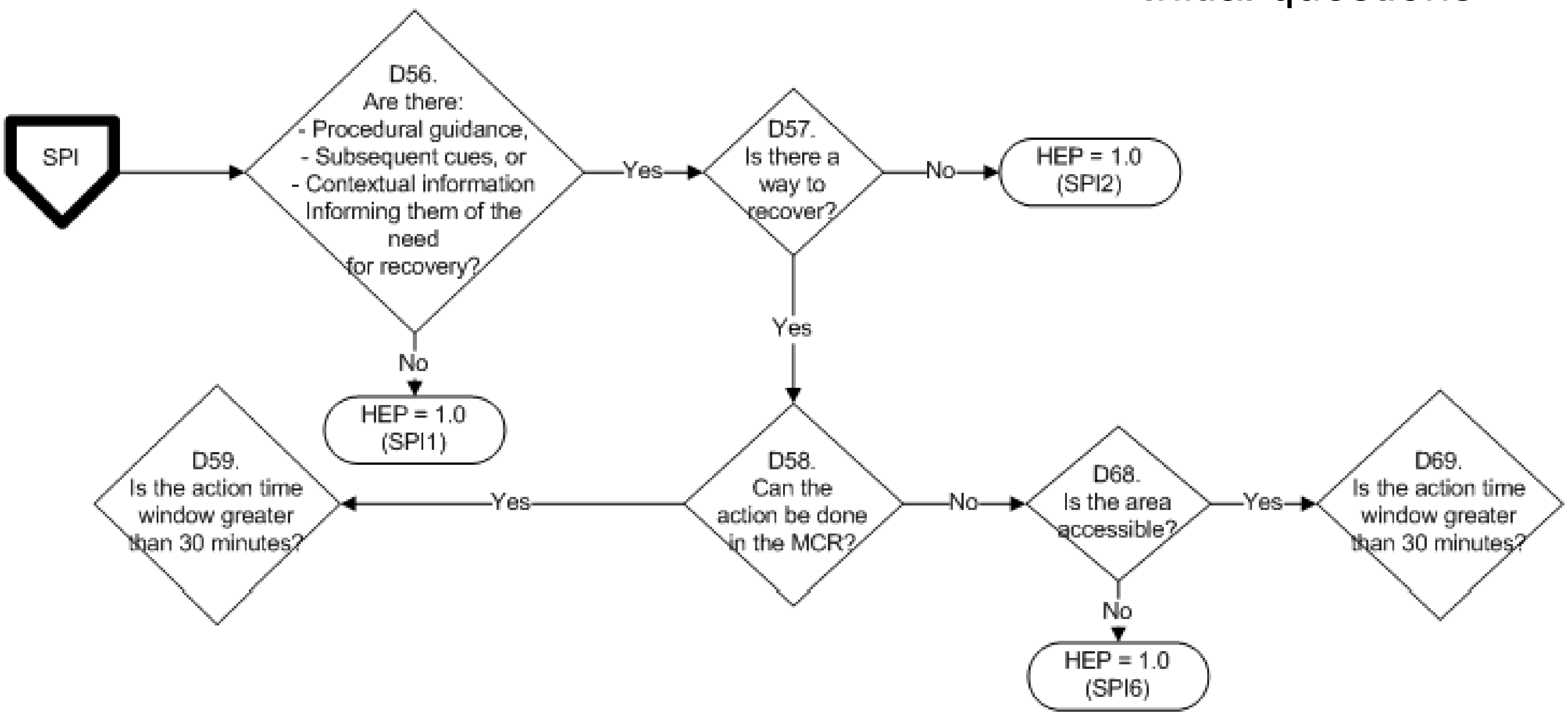
SPI

Scoping HRA for EOC or EOO due to spurious instrumentation



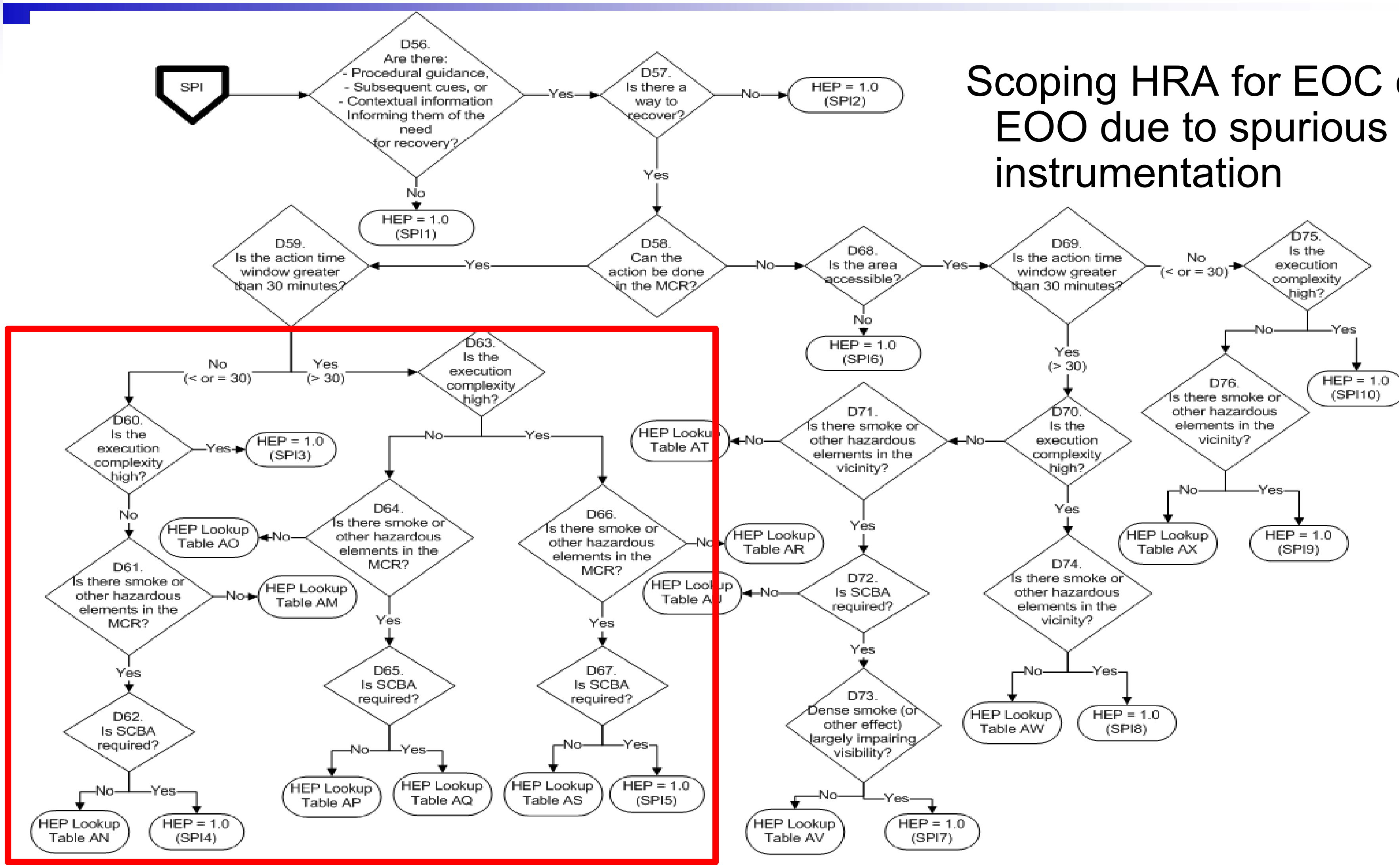
SPI

Initial questions

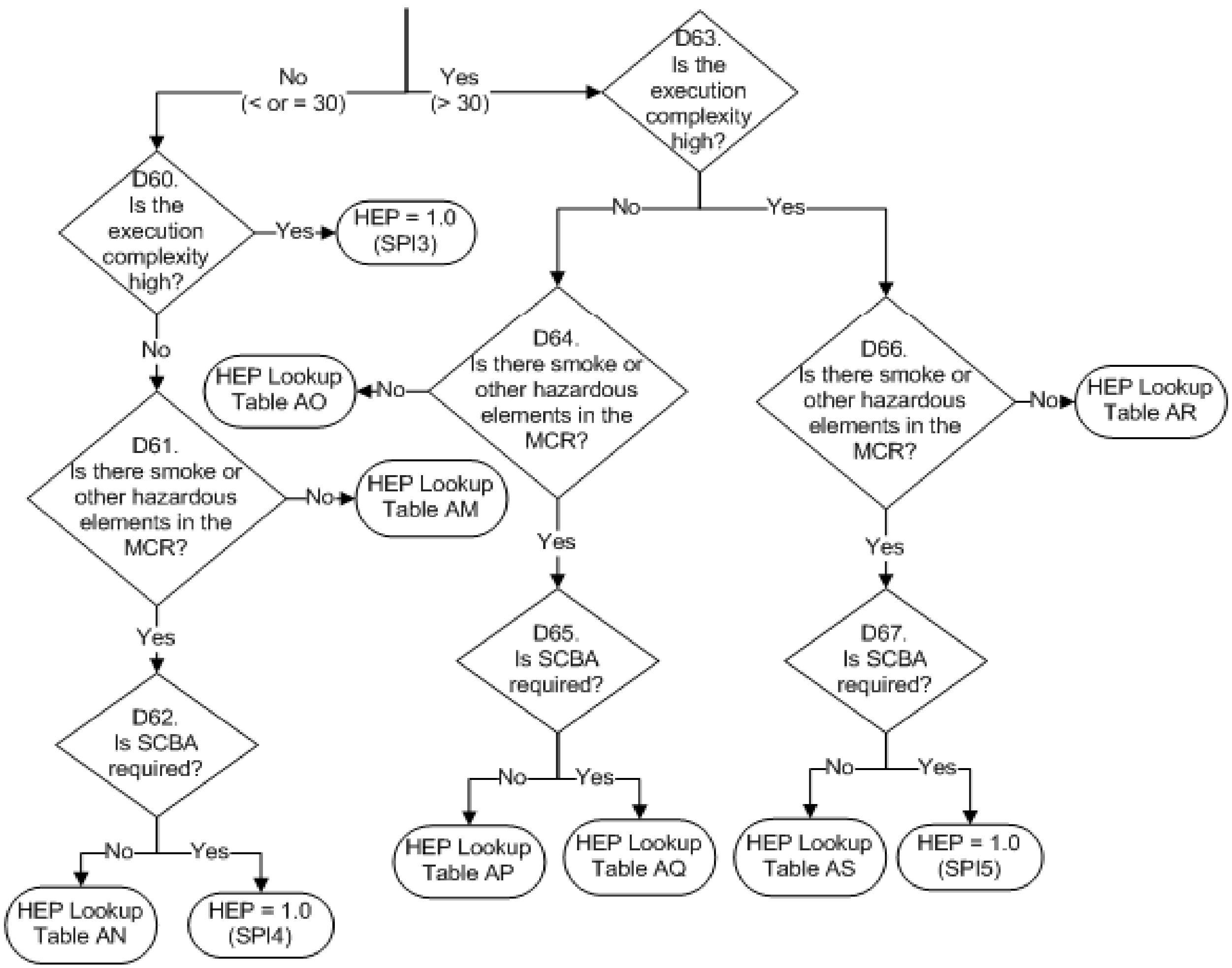


SPI

Scoping HRA for EOC or EOO due to spurious instrumentation



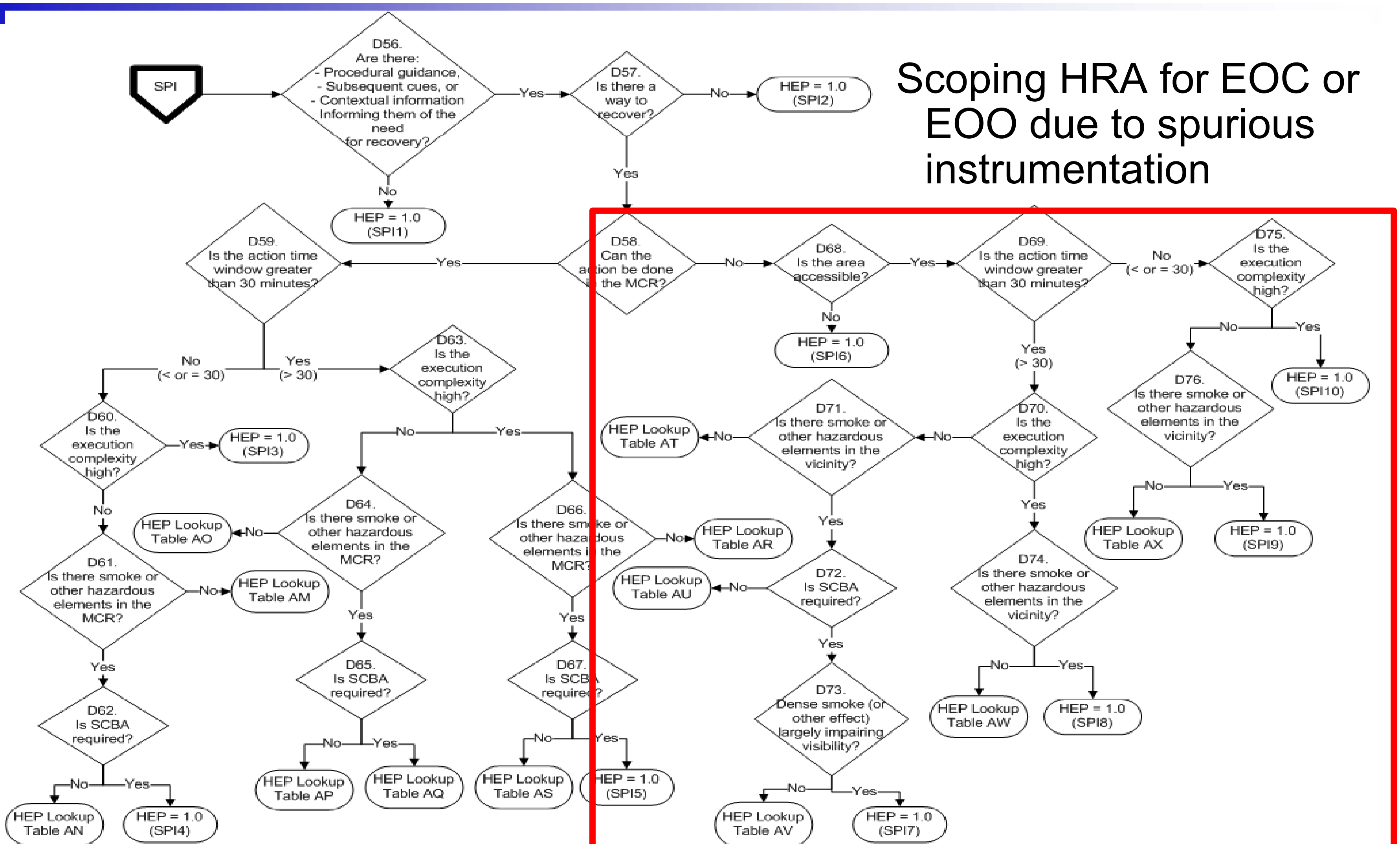
SPI



Action completed within the MCR

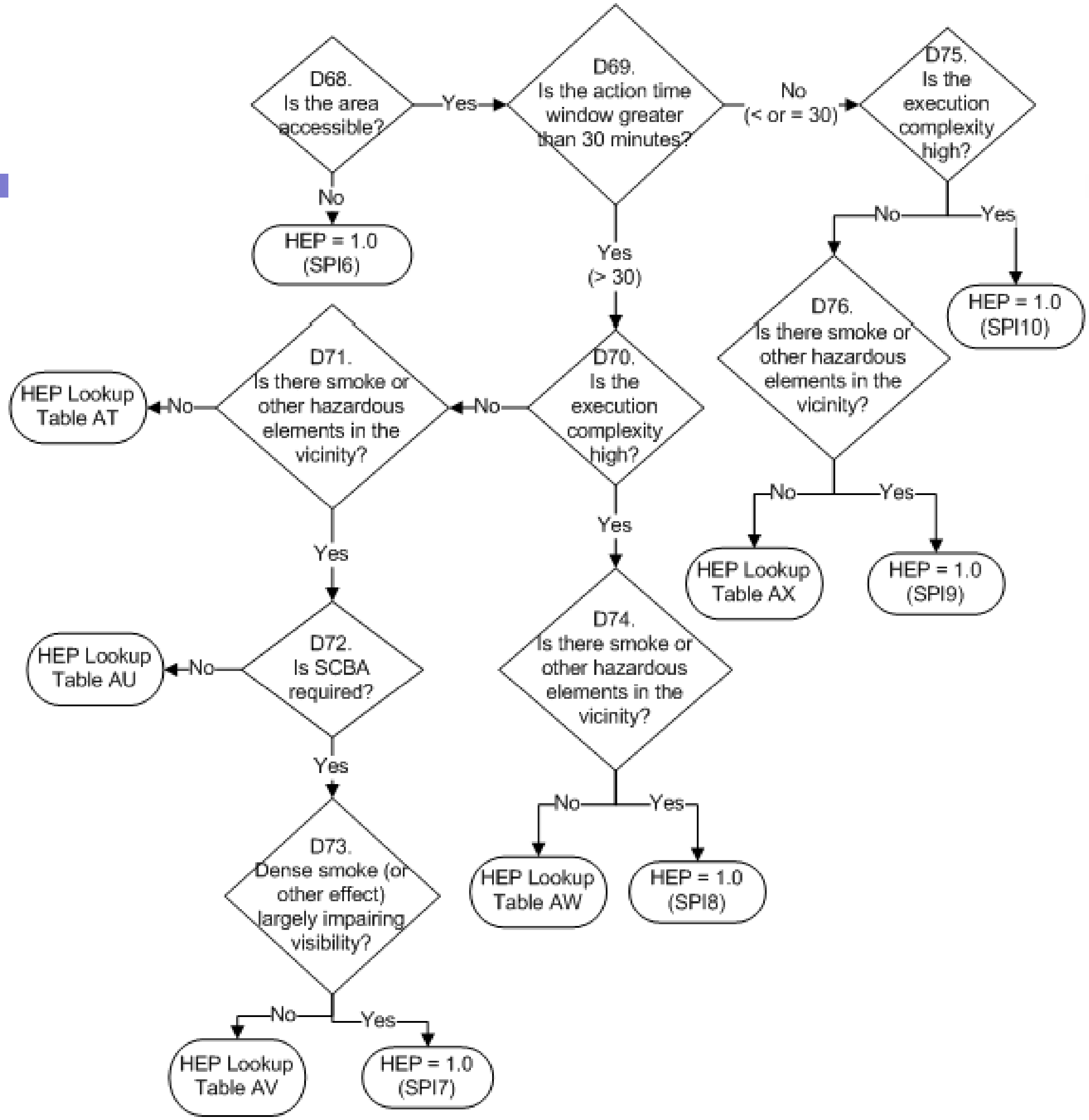
SPI

Scoping HRA for EOC or EOO due to spurious instrumentation



SPI

Action completed locally (ex-MCR)



HEP Values

- Base HEP = 1E-3 (minimally attainable value)
- Within a flowchart, HEP values are based on:
  - Timing of the cue for an action relative to start of fire
  - Length of action time window
  - Level of diagnosis complexity
  - Level of execution complexity
  - Level of smoke (area of action & travel path)
  - Accessibility of action site (area of action & travel path)

Multipliers Applied to HEPs Within Flowchart

- HEPs adjusted within a flowchart
  - Fire effects ongoing – significant increase
  - Action time window ≤ 30 mins – moderate increase
  - High execution complexity – moderate increase
  - Increases in smoke level – slight increase
  - Decrease in time margin – moderate increase
- HEPs based in part on amount of time margin (TM) available
  - TM < 50%
  - 50% < TM < 100%
  - TM ≥ 100%

Multipliers Applied to HEPs Across Flowcharts

HEP in Base Flowchart	Adjustment Value	HEP in Scoping Flowchart
INCR	2	EXCR
EXCR	2	ASD
INCR for in-MCR actions; EXCR for ex-MCR actions	5	SPI

Change in PSF	Scoping Approach Multipliers
Fire effects ongoing (i.e., < 70 minutes from the start of the fire)	10
Action time window $\leq$ 30 minutes	5
High execution complexity	5
Increases in smoke level	2
Decreases in time margin: from $\geq$ 100% to 50%-99% from $\geq$ 50% to < 50%	 5 Set HEP = 1.0

Summary of Scoping Quantification

- Purpose:
  - Offers less conservative and more realistic HEPs compared to the screening approach
  - More conservative but less resource intensive than more detailed HRA methods
- Categories:
  - In-MCR or local (ex-MCR) actions
  - Alternative shutdown
  - Recovery of errors due to spurious instrumentation
- Quantification:
  - Relies on assessment of feasibility of actions, time margin, and simple judgments about a few PSFs
  - Quantification is through the use of flowcharts

BACKUP SLIDES

INCR Look-up Table

HEP Lookup Table	Time Margin	HEP	HEP Label
A	≥ 100%	0.005	INCR2
	50 – 99%	0.025	INCR3
	< 50%	1.0	INCR4
B	≥ 100%	0.025	INCR5
	50 – 99%	0.125	INCR6
	< 50%	1.0	INCR7
C	≥ 100%	0.001	INCR8
	50 – 99%	0.005	INCR9
	< 50%	1.0	INCR10
D	≥ 100%	0.005	INCR11
	50 – 99%	0.025	INCR12
	< 50%	1.0	INCR13
E	≥ 100%	0.05	INCR14
	50 – 99%	0.25	INCR15
	< 50%	1.0	INCR16
F	≥ 100%	0.1	INCR17
	50 – 99%	0.5	INCR18
	< 50%	1.0	INCR19
G	≥ 100%	0.2	INCR20
	< 100%	1.0	INCR21
H	≥ 100%	0.25	INCR22
	< 100%	1.0	INCR23
I	≥ 100%	0.5	INCR24
	< 100%	1.0	INCR25
J	≥ 100%	0.01	INCR26
	50 – 99%	0.05	INCR27
	< 50%	1.0	INCR28
K	≥ 100%	0.02	INCR29
	50 – 99%	0.1	INCR30
	< 50%	1.0	INCR31
L	≥ 100%	0.04	INCR32
	50 – 99%	0.2	INCR33
	< 50%	1.0	INCR34
M	≥ 100%	0.05	INCR35
	50 – 99%	0.25	INCR36
	< 50%	1.0	INCR37
N	≥ 100%	0.1	INCR38
	50 – 99%	0.5	INCR39
	< 50%	1.0	INCR40
O	≥ 100%	0.2	INCR41
	< 100%	1.0	INCR42

Note that some tables (e.g., G) “absorb” the 50-99% TM into one <100% because multiplying the >100% TM by 5 already causes HEP=1

EXCR Look-up Table

HEP Lookup Table	Time Margin	HEP	HEP Label
P	≥ 100%	0.01	EXCR6
	50 – 99%	0.05	EXCR7
	< 50%	1.0	EXCR8
Q	≥ 100%	0.05	EXCR9
	50 – 99%	0.25	EXCR10
	< 50%	1.0	EXCR11
R	≥ 100%	0.002	EXCR12
	50 – 99%	0.01	EXCR13
	< 50%	1.0	EXCR14
S	≥ 100%	0.01	EXCR15
	50 – 99%	0.05	EXCR16
	< 50%	1.0	EXCR17
T	≥ 100%	0.5	EXCR18
	< 100%	1.0	EXCR19
U	≥ 100%	0.1	EXCR20
	50 – 99%	0.5	EXCR21
	< 50%	1.0	EXCR22
V	≥ 100%	0.2	EXCR23
	< 100%	1.0	EXCR24
W	≥ 100%	0.4	EXCR25
	< 100%	1.0	EXCR26
X	≥ 100%	0.02	EXCR27
	50 – 99%	0.1	EXCR28
	< 50%	1.0	EXCR29
Y	≥ 100%	0.04	EXCR30
	50 – 99%	0.2	EXCR31
	< 50%	1.0	EXCR32
Z	≥ 100%	0.08	EXCR33
	50 – 99%	0.4	EXCR34
	< 50%	1.0	EXCR35
AA	≥ 100%	0.1	EXCR36
	50 – 99%	0.5	EXCR37
	< 50%	1.0	EXCR38
AB	≥ 100%	0.2	EXCR39
	< 100%	1.0	EXCR40
AC	≥ 100%	0.4	EXCR41
	< 100%	1.0	EXCR42

ASD Look-up Table

HEP Lookup Table	Time Margin	HEP*	HEP Label
AD	≥ 100%	0.2	ASD9
	< 100%	1.0	ASD10
AE	≥ 100%	0.4	ASD11
	< 100%	1.0	ASD12
AF	≥ 100%	0.8	ASD13
	< 100%	1.0	ASD14
AG	≥ 100%	0.04	ASD15
	50 – 99%	0.2	ASD16
	< 50%	1.0	ASD17
AH	≥ 100%	0.08	ASD18
	50 – 99%	0.4	ASD19
	< 50%	1.0	ASD20
AI	≥ 100%	0.16	ASD21
	50 – 99%	0.8	ASD22
	< 50%	1.0	ASD23
AJ	≥ 100%	0.2	ASD24
	< 100%	1.0	ASD25
AK	≥ 100%	0.4	ASD26
	< 100%	1.0	ASD27
AL	≥ 100%	0.8	ASD28
	< 100%	1.0	ASD29

SPI Look-up Table

AM	≥ 100%	0.25	SPI11
	< 100%	1.0	SPI12
AN	≥ 100%	0.5	SPI13
	< 100%	1.0	SPI14
AO	≥ 100%	0.05	SPI15
	50 – 99%	0.25	SPI16
	< 50%	1.0	SPI17
AP	≥ 100%	0.1	SPI18
	50 – 99%	0.5	SPI19
	< 50%	1.0	SPI20
AQ	≥ 100%	0.2	SPI21
	< 100%	1.0	SPI22
AR	≥ 100%	0.25	SPI23
	< 100%	1.0	SPI24
AS	≥ 100%	0.5	SPI25
	< 100%	1.0	SPI26
AT	≥ 100%	0.1	SPI27
	50 – 99%	0.5	SPI28
	< 50%	1.0	SPI29
AU	≥ 100%	0.2	SPI30
	< 100%	1.0	SPI31
AV	≥ 100%	0.4	SPI32
	< 100%	1.0	SPI33
AW	≥ 100%	0.5	SPI34
	< 100%	1.0	SPI35
AX	≥ 100%	0.5	SPI36
	< 100%	1.0	SPI37

Conclusions on Scoping Analysis

- Useful to address actions for which
  - Screening analysis is inadequate
  - Additional resources required for detailed analysis may be unwarranted
- More detailed analyses should be pursued when
  - Conditions are beyond those addressed by scoping approach
  - Resulting HFEs continue to be significant contributors to risk
- Examples via Handouts

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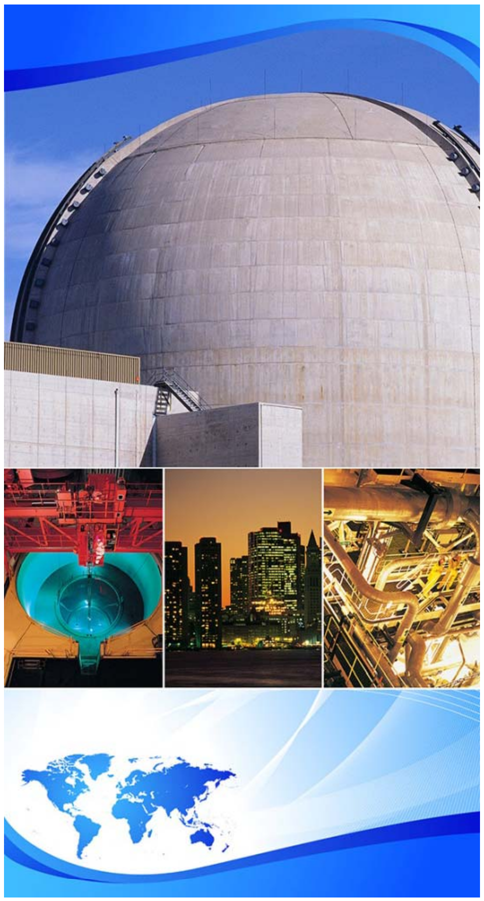


EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA

EPRI Approach to Detailed Fire HEP Quantification

Kaydee Kohlhepp (Scientech) & Stuart Lewis (EPRI)

Joint RES/EPRI Fire PRA Workshop 2011

San Diego CA and Jacksonville FL

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

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification & Definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) **EPRI approach (detailed)**
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate knowledge of ASME/ANS PRA Standard **high level requirements (HLRs).**

  - For the HLRs associated with Identification & Definition

4: Be able to identify **context and performance shaping factors** used in the analysis of post-fire human failure events.

5: Be able to list the quantification methods available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between post-fire HRA events.

Outline of the EPRI Approach to Detailed Fire HRA Module

- Introduction/Relation to NUREG/CR-6850 (EPRI 1011989) Tasks
- Applicable PRA Standard High Level Requirements
- Overview of Quantitative Methods in the EPRI Approach:
  - Cause-Based Decision Tree Overview (Cognitive)
  - HCR/ORE Overview (Cognitive for Time-Critical)
  - THERP (Execution)
- Definition & subsequent Qualitative Analysis
  - Fire Context
  - Performance Shaping Factor
- Method Selection & Quantification
- Summary

What is *Detailed Fire HRA*?

Consists of HRA tasks that develop human error probabilities (HEPs) for the modeled human failure events (HFEs)

- HEP used in FPRA quantification
- HEP development provides qualitative insights on results drivers

Typically done to PRA Standard Capability Category II

Uses most of the steps in the **HRA Process**:

1. Identification & Definition of HFE
2. Qualitative analysis – context & performance shaping factors
3. Quantitative analysis – method selection & quantification of HEP
    a) Screening
    b) Scoping
    c) Detailed HRA: EPRI approach or ATHEANA
4. Provides input to subsequent Fire HRA tasks
    - Dependency analysis
    - Uncertainty analysis

General Approaches to Quantification

1. Screening: Slightly modified from NUREG/CR-6850 (EPRI 1011989) to reduce the HEPs for late HFEs (after fire is out) – covered previously
2. Scoping FHRA quantification approach – covered previously
   - Less conservative than screening, but designed to be slightly more conservative than detailed approaches
   - Some actions may not be able to meet some of the criteria (result in an HEP of 1.0)
3. Two detailed fire HRA quantification approaches, modified for application in fire scenarios
   - EPRI – covered in this module
     - Cause-Based Decision Tree (CBDT) & HCR/ORE; THERP
   - ATHEANA – covered after this module

Fire HRA Process Steps

NUREG/CR-6850 Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification** of previously existing HFEs & potential response to spurious actuations/indications
Task 5 – Fire-Induced Risk Model	**Identification and Definition** of fire response HFEs
Task 12 – Post-Fire HRA	**Qualitative Analysis -** definition, context & performance shaping factors
Task 7 – First/Screening Quant.	**Quantification –** typically screening or scoping
Task 8 – Scoping Quantification	**Quantification –** typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Relationship of Detailed Fire HRA to FPRA Tasks

- Detailed Fire HRA supports FPRA quantification
  - Developed, and typically used, for detailed fire scenarios
    - Detailed Fire Scenarios (Tasks 11 & 14)
    - Uncertainty/Sensitivity (Task 15)
  - But can be used at any level, such as:
    - Screening / First Quantification (Task 7*)
    - Scoping (Task 8)
- Detailed Fire HRA uses inputs from most, prior FPRA tasks
  - Identification & Definition of HFEs (Tasks 2, 5, 7 & 8)
  - Qualitative Analysis (Task 12 – Fire HRA)

*** All task numbers refer to NUREG/CR-6850; EPRI 1011989**

PRA Standard Requirements for HRA Quantification

Relevant HLRs from Internal-Events Section (Ch. 2)

HLR-HR-G (from the internal events HRA element)

The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self consistent process that addresses the plant-specific and scenario-specific influences on human performances, and addresses potential dependencies between human failure events in the same accident sequence

Relevant HLRs from Fire Section (Ch. 4 of Standard)

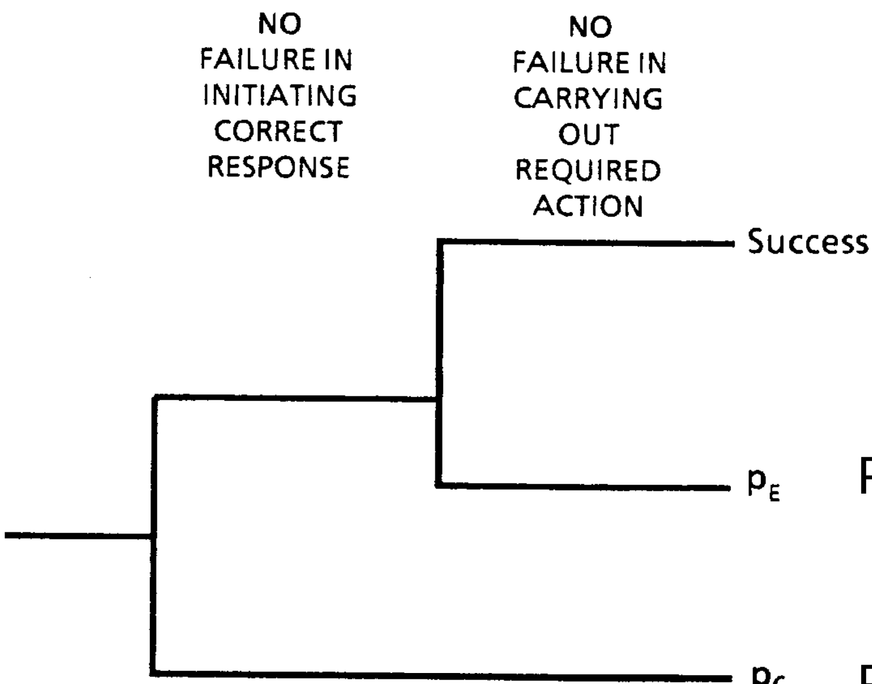
HLR-HRA-C (from the Fire HRA element)

The Fire PRA shall quantify HEPs associated with incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fire

EPRI Quantification Methods

- CBDTM (Cause Based Decision Tree Method)
  - 8 Decision trees based on simulator experiment insights
  - Default method for cognitive portion (detection/diagnosis)
- HCR/ORE Correlation (Human Cognitive Reliability / Operator Reliability Experiment)
  - Used for time-critical operator actions
  - Normalized time reliability correlation (function of $T_{available} / T_{required}$)
- THERP (NUREG/CR-1278) for execution
- Methods are implemented in EPRI *HRA Calculator*® software, but can be quantified on paper

Post-Initiator HFE Representation: EPRI TR-100259



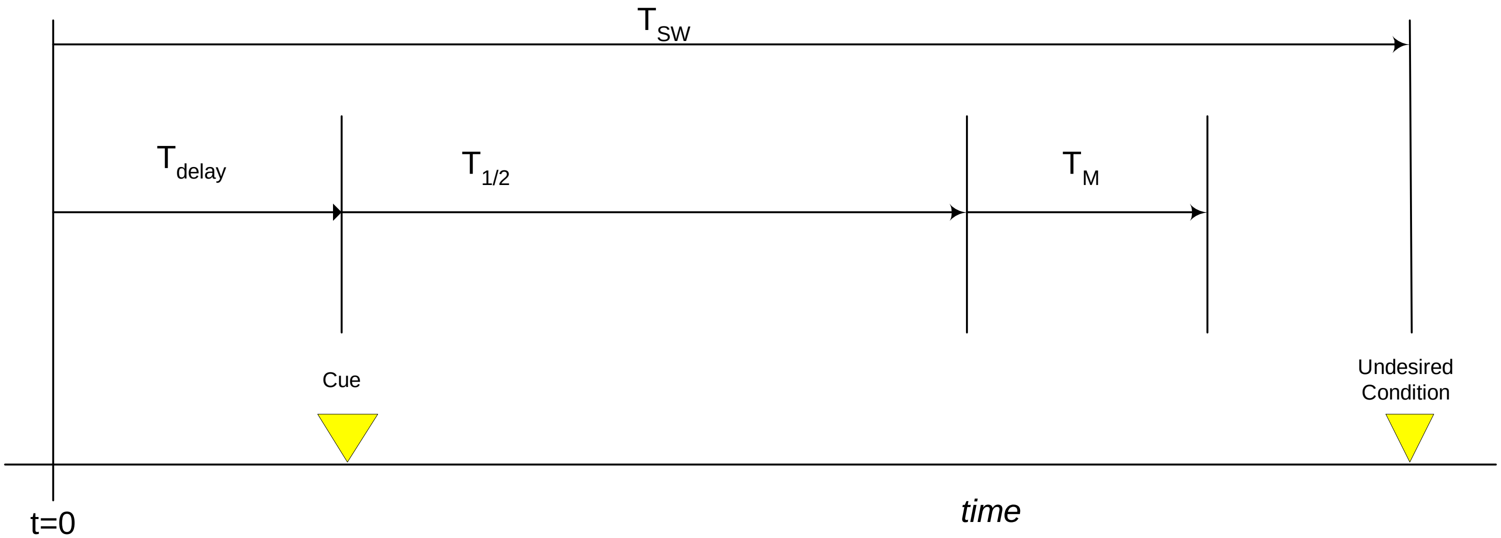
Pe = Execution is quantified using THERP

Pc = Cognitive is quantified using

CBDTM (default)

HCR/ORE (time critical HFEs)

EPRI Timeline for a Post-initiator HFE



T_{SW} = System time window

T_{delay} = Time from start of transient until cue is reached

T_{M} = Manipulation time (includes transit, tools, PPE & executing each task)

$T_{1/2}$ = Median response time (detection, diagnosis, & decision-making)

T_{W} = Time window for cognitive response = $T_{SW} - T_{delay} - T_{M}$

$T_{w} - T_{1/2}$ = Time available for recovery

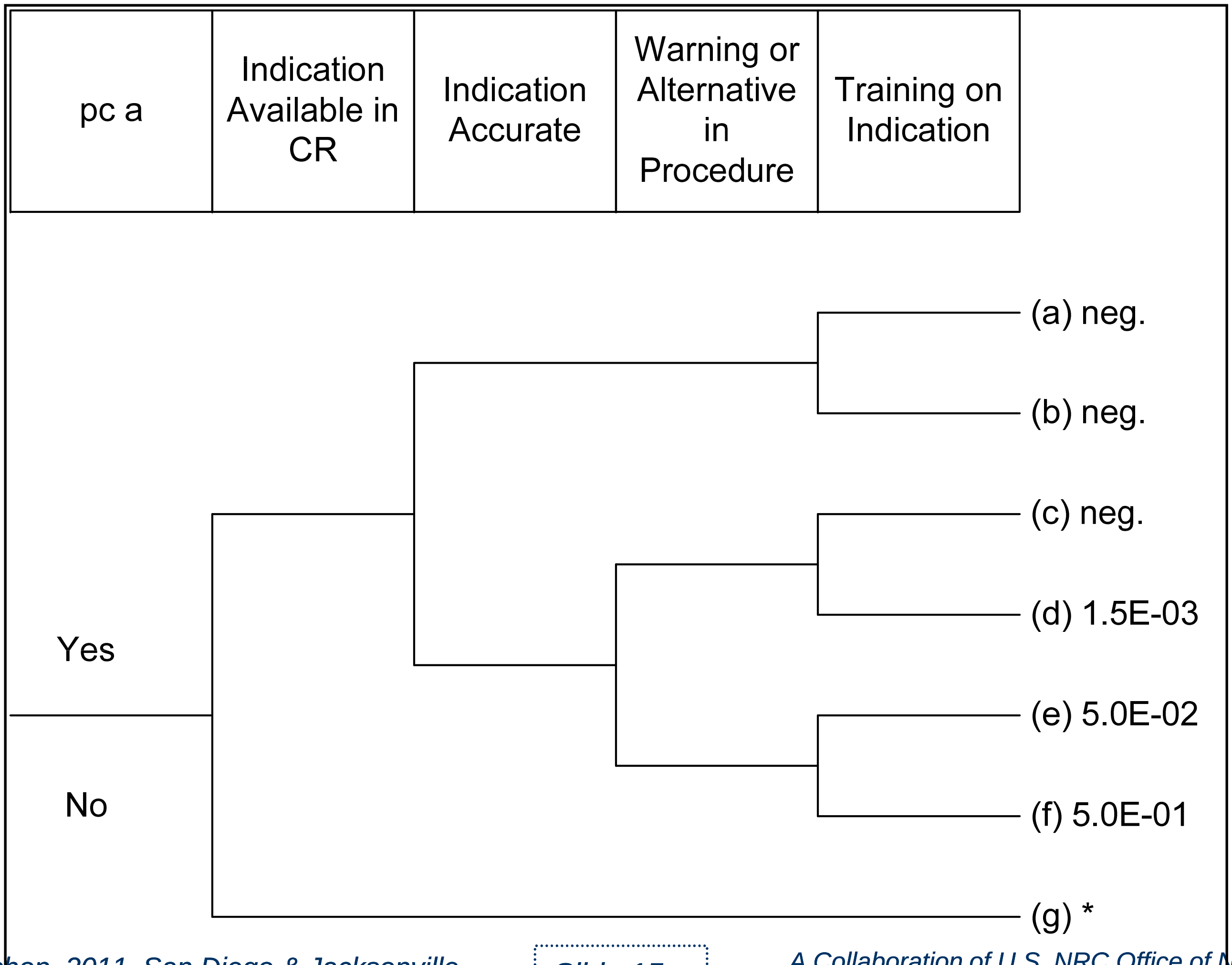
CBDTM Overview – Cognitive Method

- Analytical approach based on identification of failure mechanisms and compensating factors
- Applicable to rule-based behavior, such as when procedures are used
- Two high-level failure modes:
  - Plant information-operator interface failure
  - Operator-procedure interface failure
- Each failure mode is decomposed into contributions from several distinct failure mechanisms
- Default method, especially if not time-critical

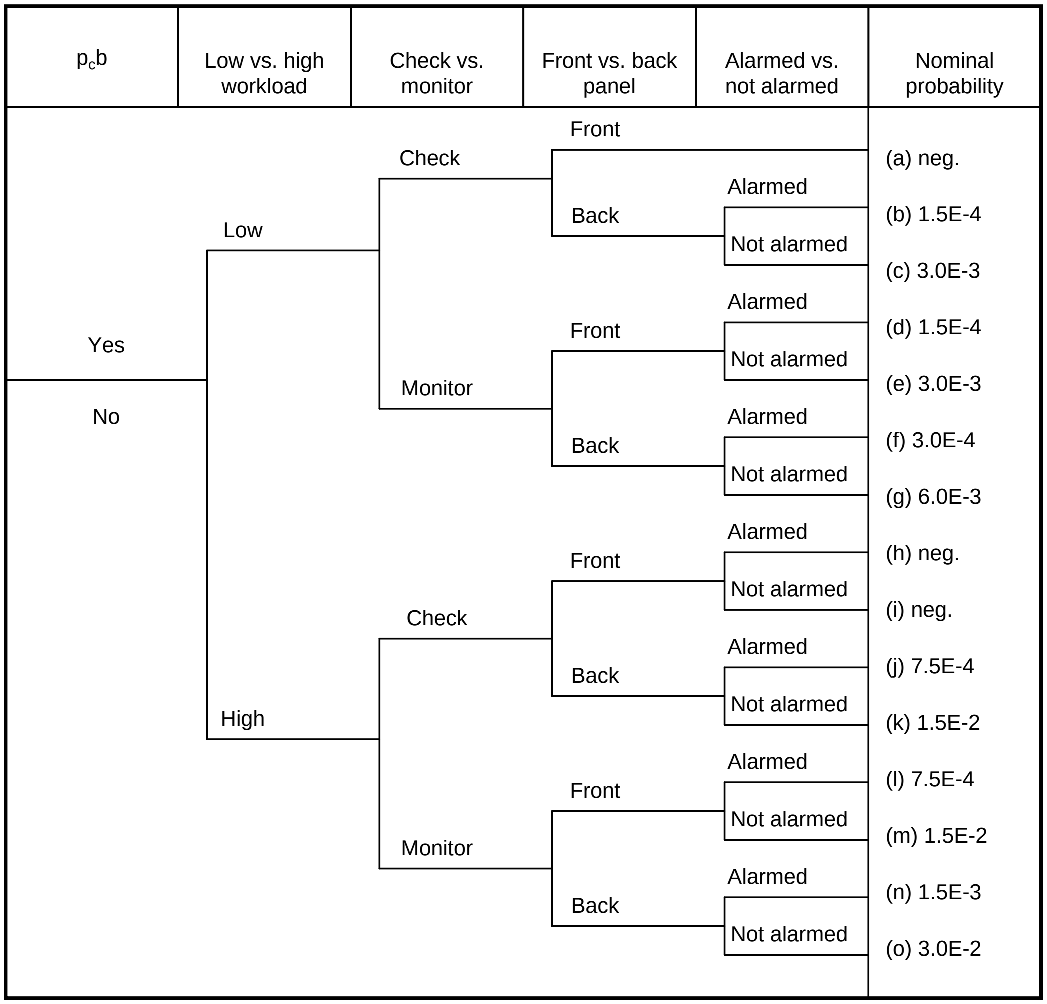
CBDT - Summary of Failure Mechanisms

Type	Designator	Description
Failures in the Operator–Information Interface	p_c a	Data not available
	p_c b	Data not attended to
	p_c c	Data misread or miscommunicated
	p_c d	Information misleading
Failures in the Operator-Procedure Interface	p_c e	Relevant step in procedure missed
	p_c f	Misinterpret instruction
	p_c g	Error in interpreting logic
	p_c h	Deliberate violation (not sabotage)

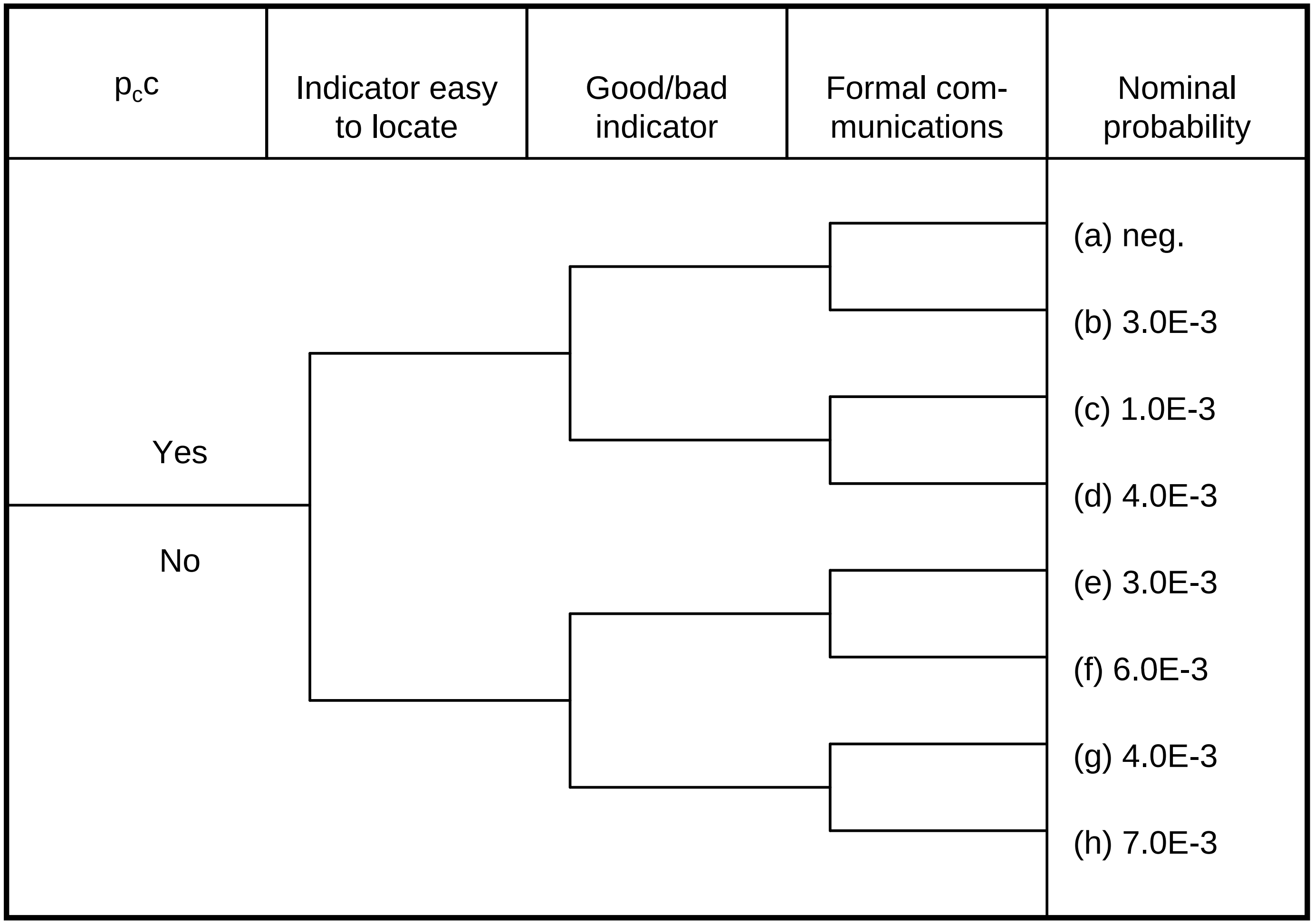
CBDTM decision tree:
pc-a Data not available



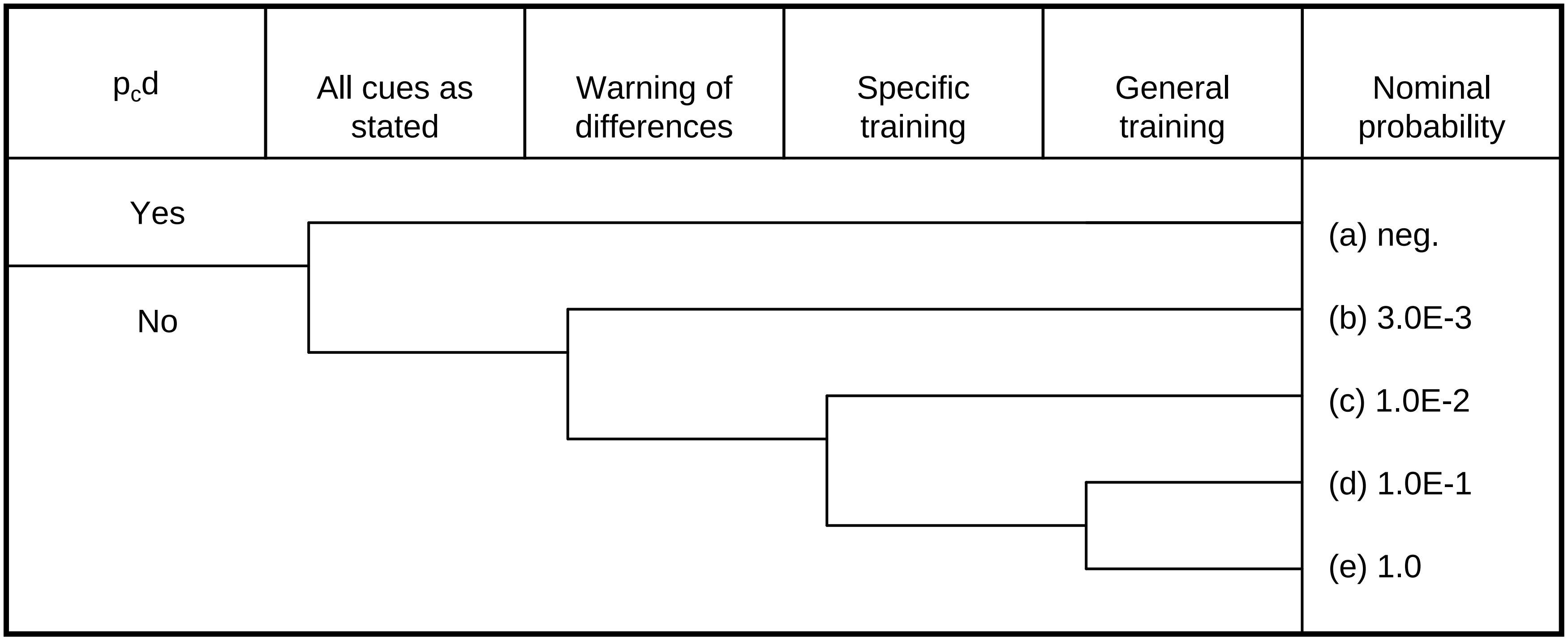
CBDTM decision tree: pc-b Data not attended to



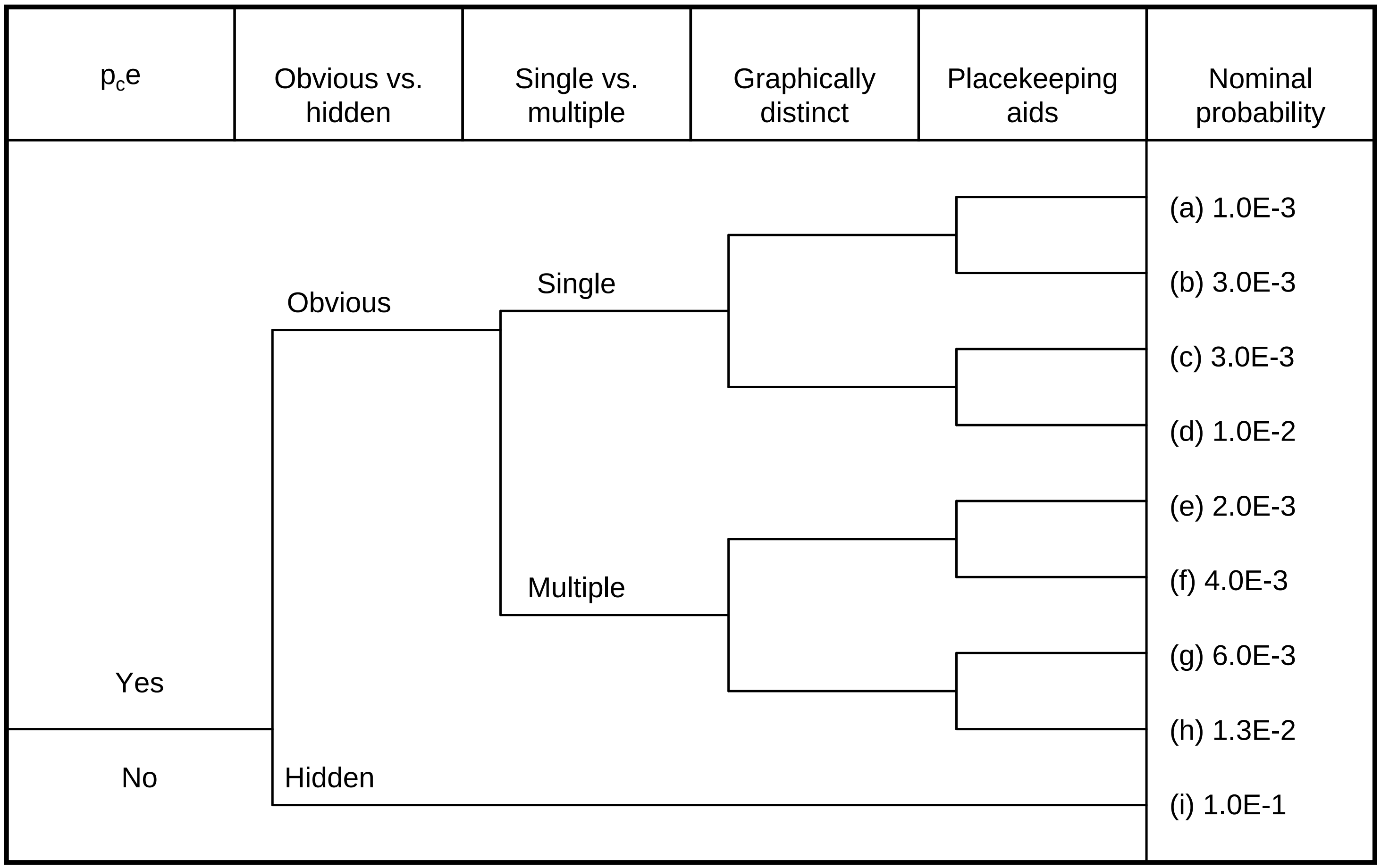
CBDTM decision tree:
pc-c Data misread or miscommunicated



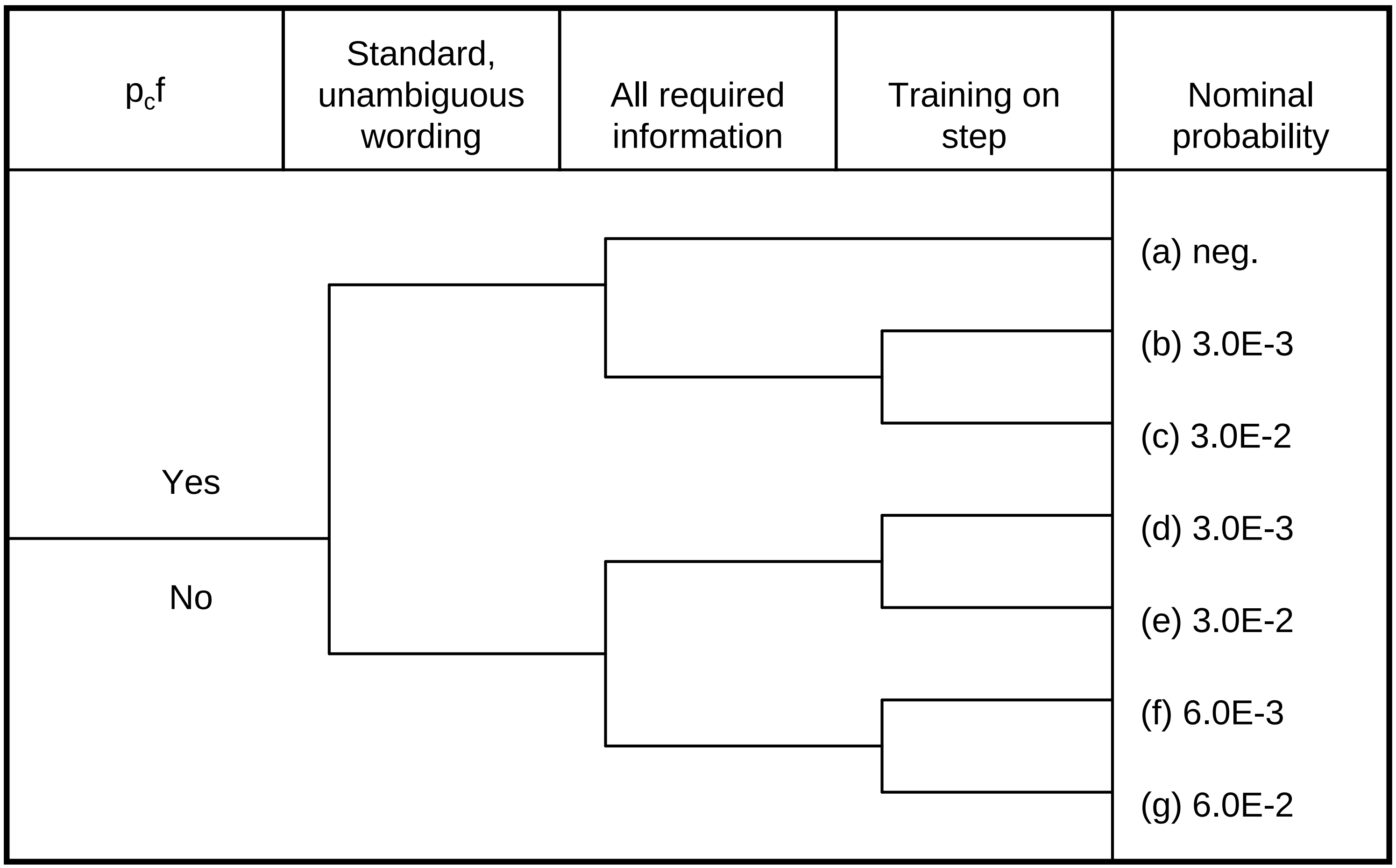
CBDTM decision tree:
pc-d Information misleading



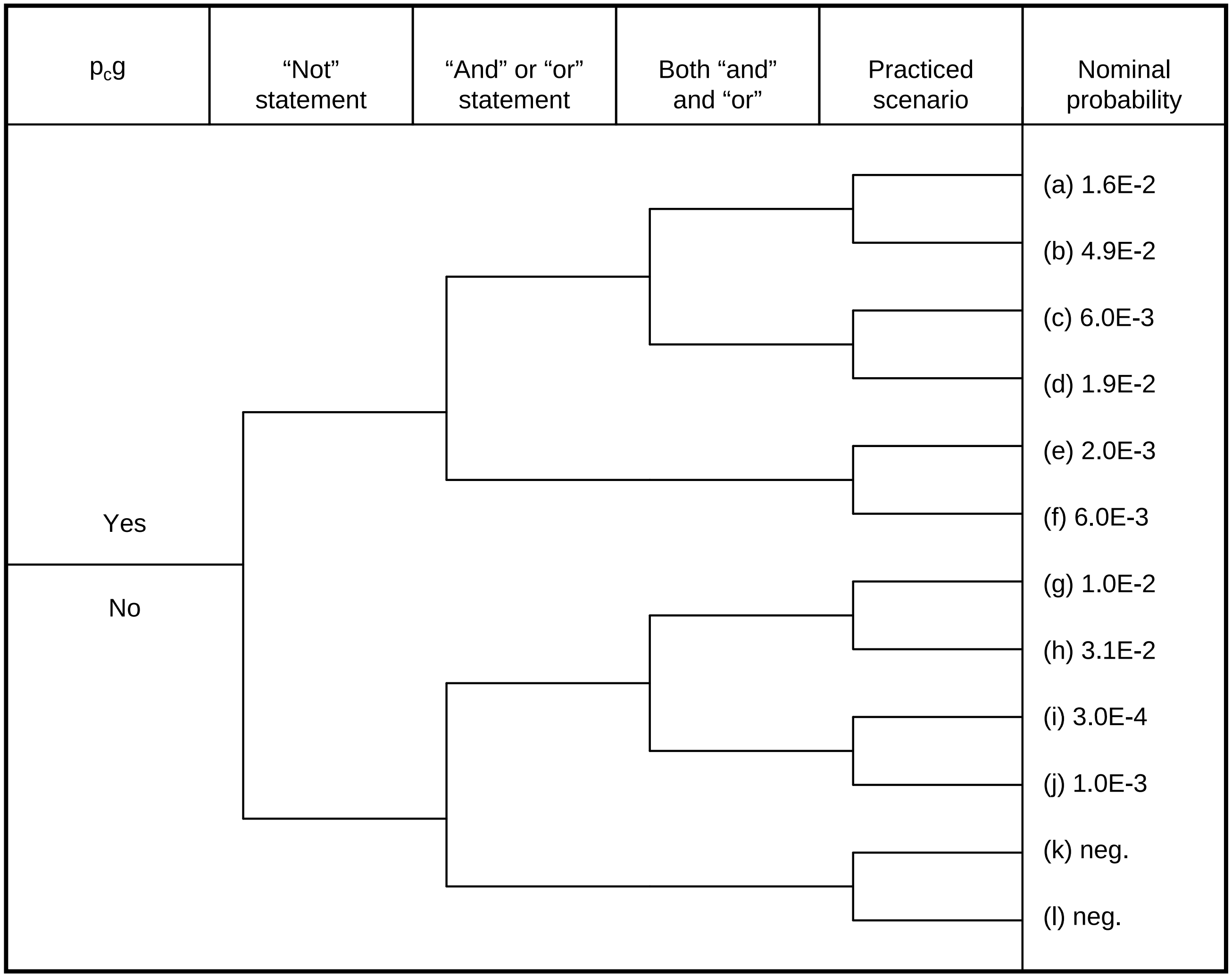
CBDTM decision tree:
pc-e Relevant step in procedure missed



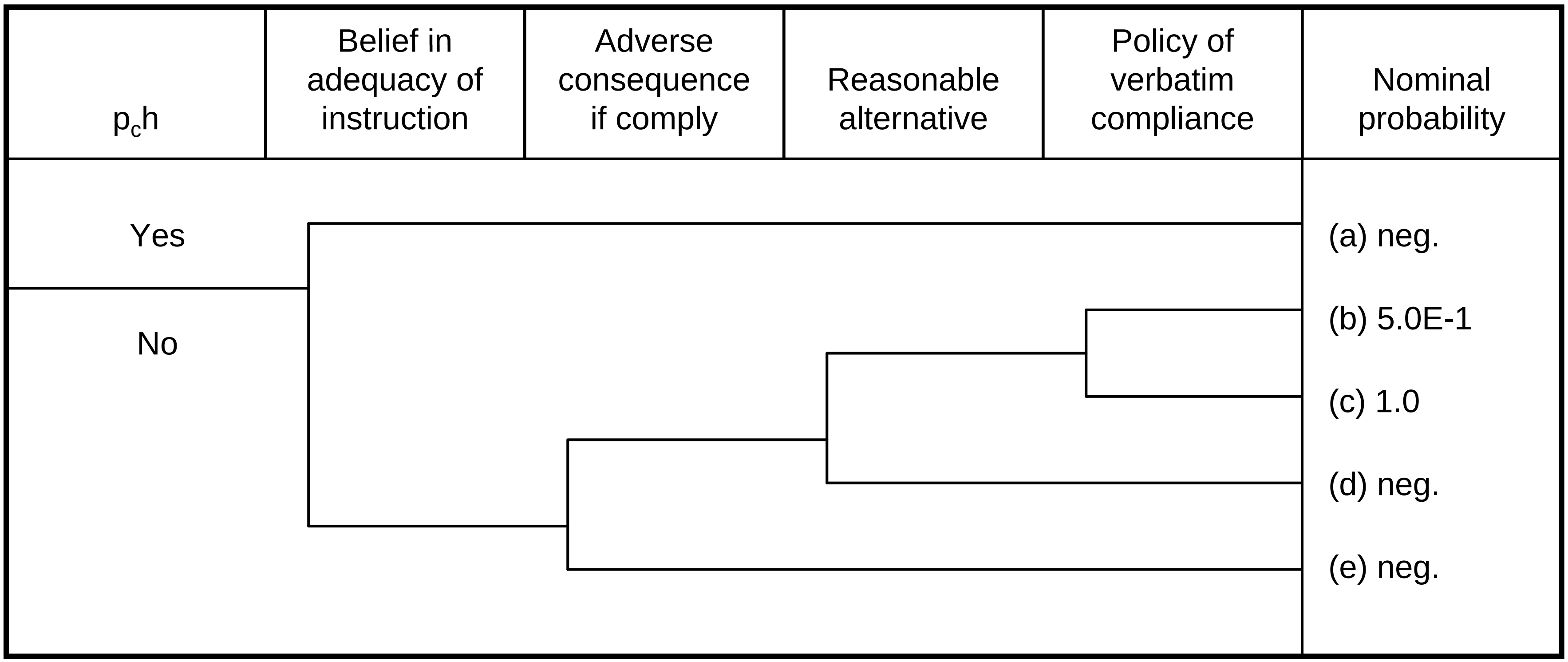
CBDTM decision tree:
pc-f Misinterpret instruction



CBDTM decision tree:
pc-g Error in interpreting logic



CBDTM decision tree:
pc-h Deliberate violation



Post-Initiators: CBDTM Recovery Factors

Tree	Branch	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review
Pca	all	NC	0.5	NC	0.5	0.5
Pcb	all	X	NC	X	X	X
Pcc	all	NC	NC	X	X	X
Pcd	all	NC	0.5	X	X	0.1
Pce	a-h	X	0.5	NC	X	X
Pce	i	0.5	0.5	X	X	X
Pcf	all	NC	0.5	X	X	X
Pcg	all	NC	0.5	X	X	X
Pch	all	NC	X	X	NC	NC

CBDTM - Recovery Factors

Recovery Factor	Time Effective
Self Review	At any time there is a subsequent cue, other than the initial cue that would prompt the operator to revisit the decision OR Is there a procedural step that either returns the operator to the initial step where the error was made, or that repeats the initial instruction?
Other (Extra) Crew	At any time that there are crew members over and above the minimum complement present in the CR and not assigned to other tasks
Shift Technical Advisor	10 to 15 minutes after reactor trip.
Emergency Response Facility/ Technical Support Center	1 hour after reactor trip – if constituted
Shift Change	6 hours after reactor trip given 8 hour shifts 9 hours after reactor trip given 12 hour shifts

HCR/ORE Overview – Cognitive Method

- **Cognitive** modeling of **time-critical operator actions**
  - For example, less than 30 minute time window
- Empirical method, a **time-reliability curve**
- Fitted to successful response times
- Data points in which crews were totally on the wrong path not included in the fitting (“outliers”)
- P_c therefore conditional on a correct decision, or the initial error was discovered in a timely manner
- Normalized time to be limited to time windows on which observations were made. Extrapolation not valid
- Guidance in **EPRI-TR100259**:
  - If P_c < 1E-02, use the CBDTM
  - If P_c believed to be conservative, use CBDTM

HCR/ORE – Equation

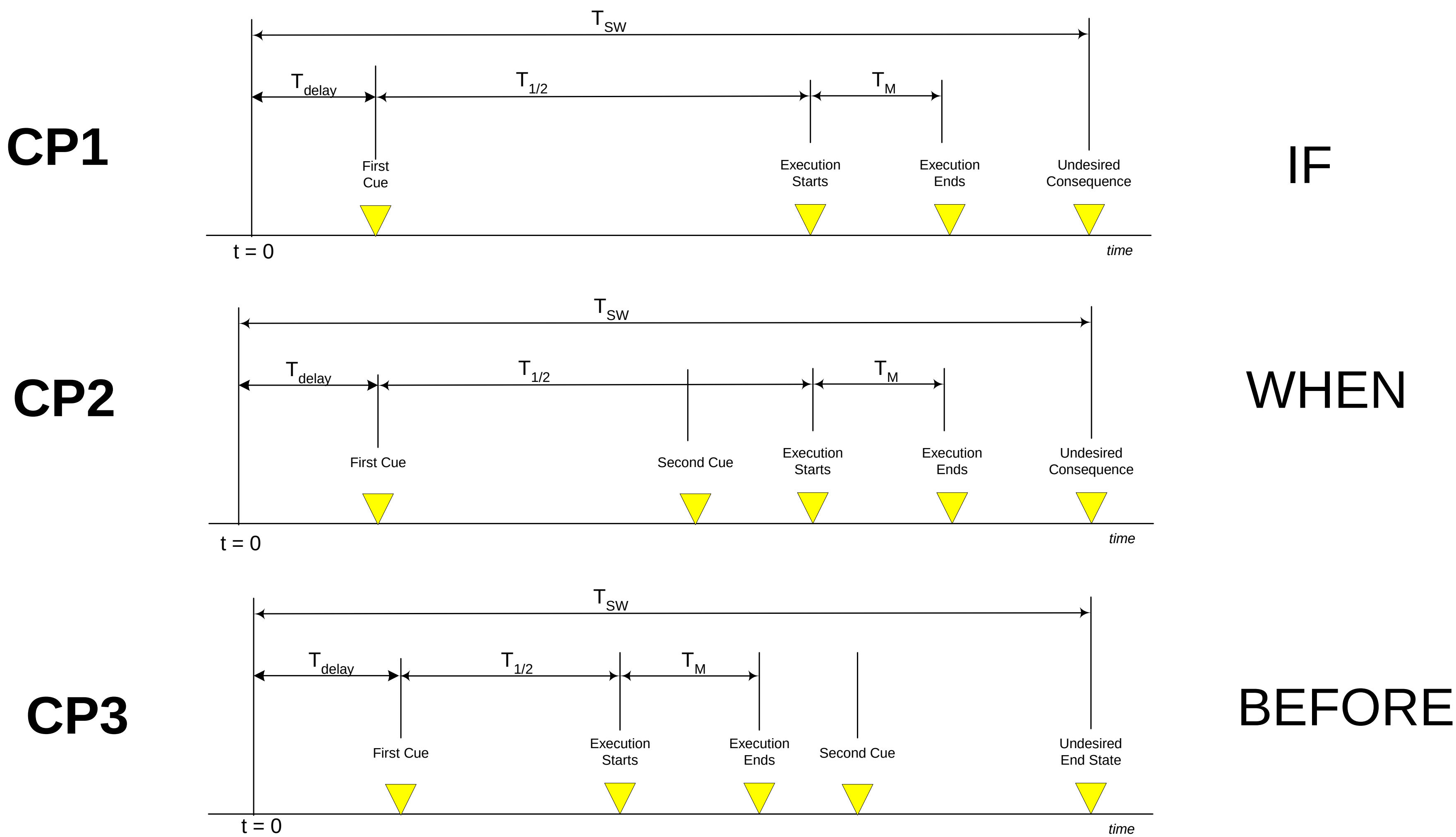
$$P_C = 1 - \Phi\left[\frac{\ln(\frac{T_W}{T_{1/2}})}{\sigma}\right]$$

- ***P_C* = Probability of cognitive non-response**
- σ = Logarithmic standard deviation (Determined based on cue response structure – next slide)
- Φ = Standard normal cumulative distribution
- $T_W = T_{SW} - T_{delay} - T_M$ = time window available for cognitive response
- $T_{1/2}$ = Crew median response time

HCR/ORE - Sigma Values based on cue-response structure

Plant Type	Cue-Response Structure	Values for σ		
		Average	Upper Bound	Lower Bound
BWRs	CP1	0.70	1.00	0.40
	CP2	0.58	0.96	0.20
	CP3	0.75	0.91	0.59
PWRs	CP1	0.57	0.88	0.26
	CP2	0.38	0.69	0.07
	CP3	0.77	*	*

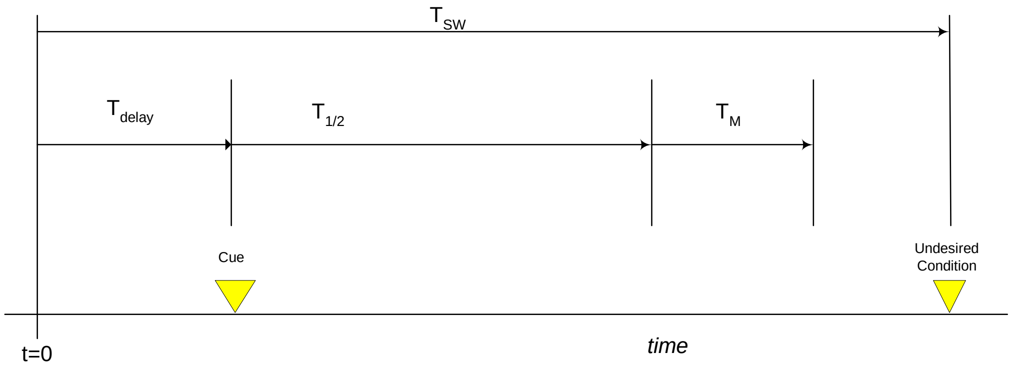
Categorization of Type CP Actions



Quantification:
Fire HEPs for HFEs from the Internal Events PRA

- If HFE has been quantified using EPRI HRA Approach for internal events, quantification for fire is a relatively simple modification in following areas:
  - **Timing**
  - **Cue** and indications impacts
  - Increase in **stress**
  - Increase in **workload**
  - Use of multiple **procedures**
  - For local actions, consider alternate **routes** if fire impacts the normal or ideal travel path

Fire Impacts on Timing



T = 0 is considered the start of the fire – For existing HFEs T=0 is typically reactor trip. In most cases, the FPRA assumes the fire and reactor trip coincide.

T_{delay} = Time from start of transient until cue is reached. If the cue is considered to be procedure step the **fire may cause delays in the procedure implementation**.

$T_{1/2}$ = If the fire impacts some but not all of the **instrumentation** $T_{1/2}$ will be increased from the internal events case to account for the time required for the operators to asses the situation & determine which instrumentation is correct or diagnose based on secondary cues.

T_m = For **main control room** actions in which there is no fire in the control room, T_m is considered to be the **same for the internal events case and the fire case**.

For **local actions, T_m will account for any detours caused by the fire**. T_m must also account for PPE & tools.

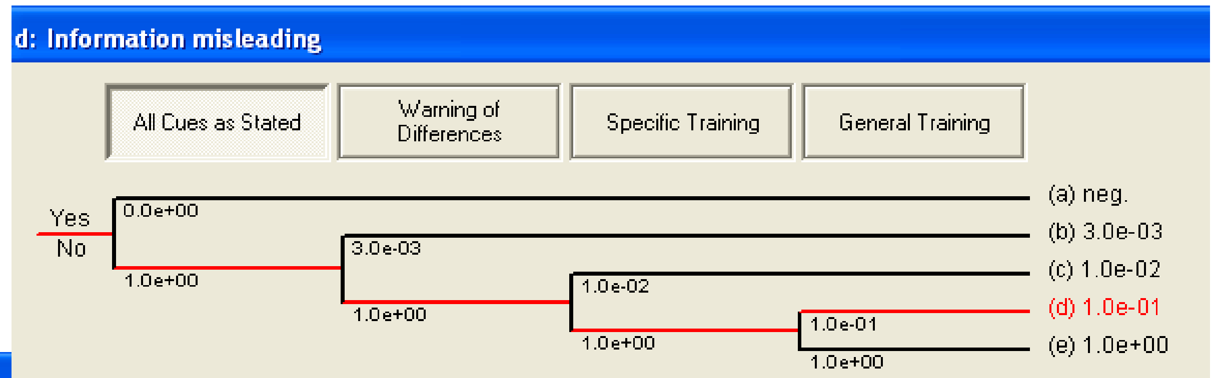
Fire Impacts on Timing (cont'd)

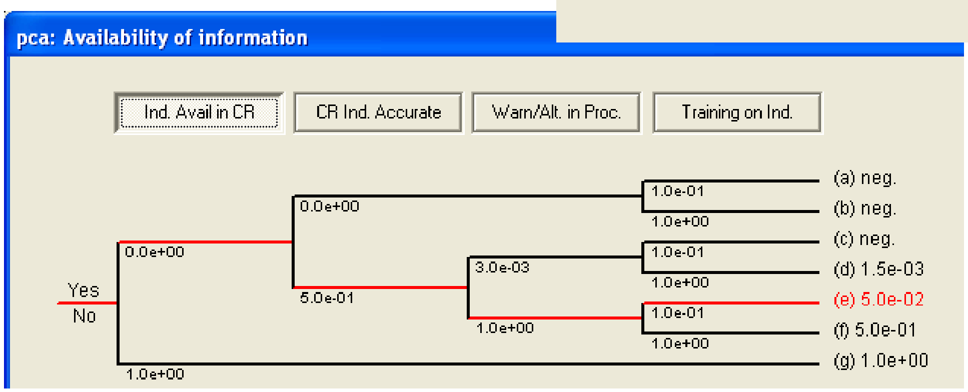
- If time available for recovery is reduced due to fire impacts on timing, then the recoveries previously credited in the internal events PRA within the CBDTM are to be revisited

- If time-critical action and cues/indications are impacted, then consider using upper bound for sigma when applying HCR/ORE

Fire Impacts on Instrumentation

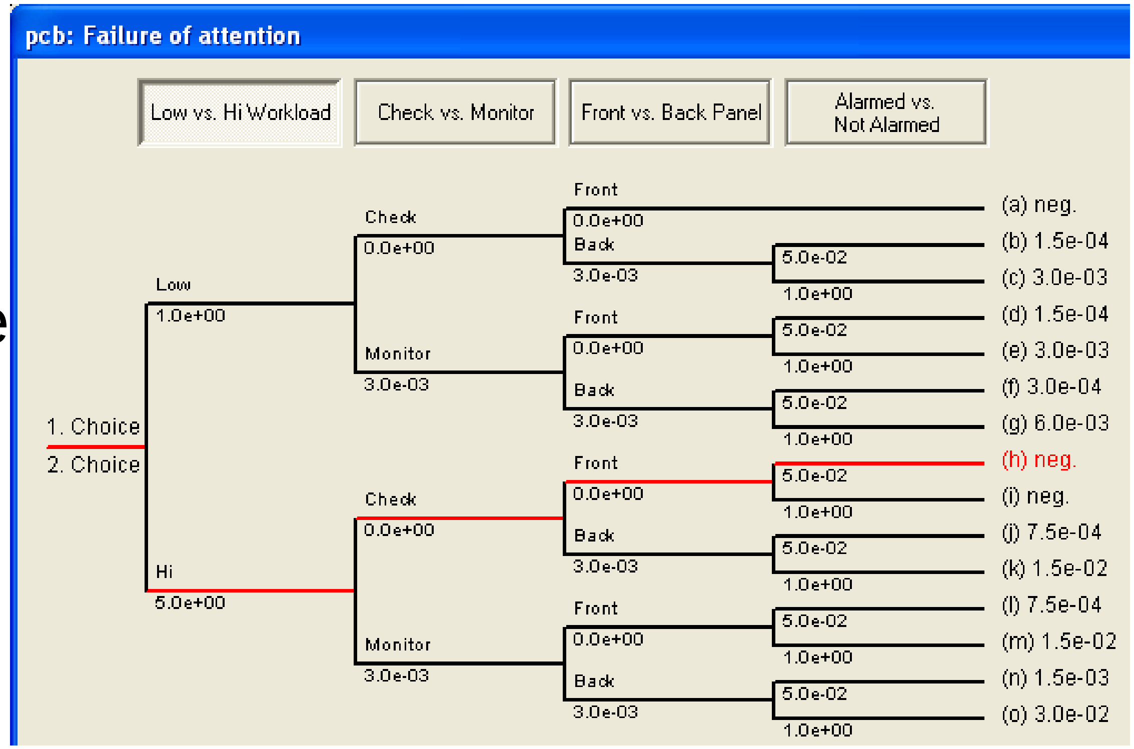
- If all **instrumentation is impacted** and there are no cues for diagnosis then HEP =1.0
- **Partial instrumentation** impacted is modeled in decision tree **Pc-a & Pc-d** (HEP range 1E-2 to 1.0)
- If the fire causes **no impact on instrumentation** then Pc-a and Pc-d typically evaluate to “Negligible”





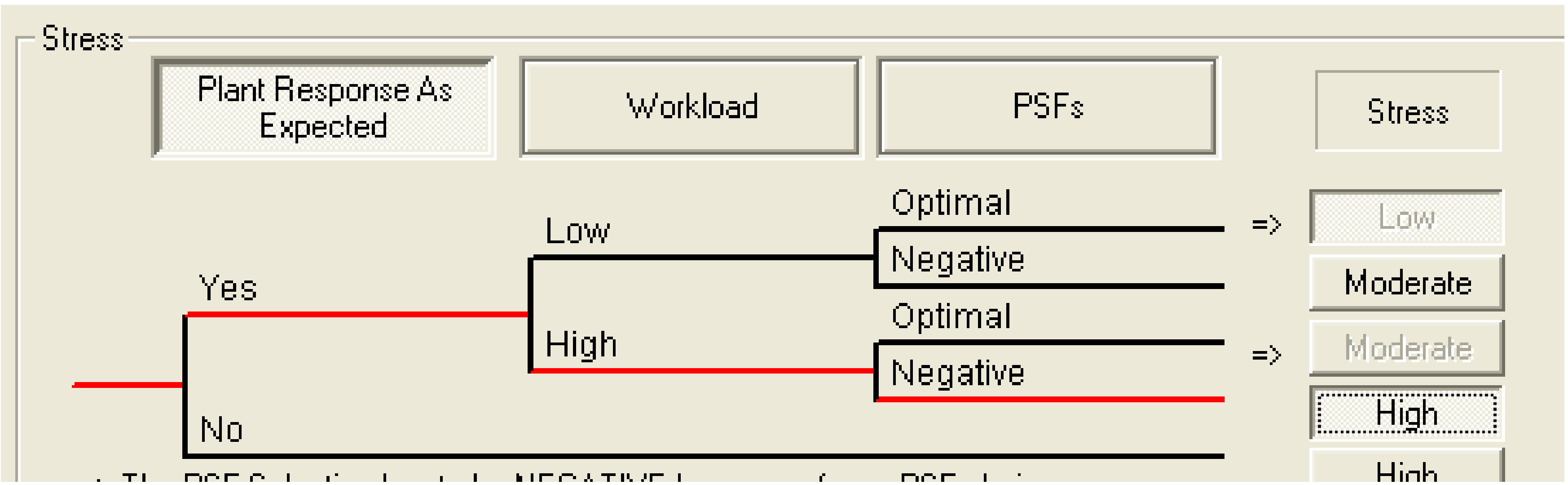
CBDT Example - Fire Impacts on Workload (Pc)

- Increased workload:
  - modeled explicitly
  - decision tree Pc-b
  - if fire causes increase in workload
  - select high workload
  - part of the cognitive phase (detection & diagnosis)
  - potentially recover if have additional staff



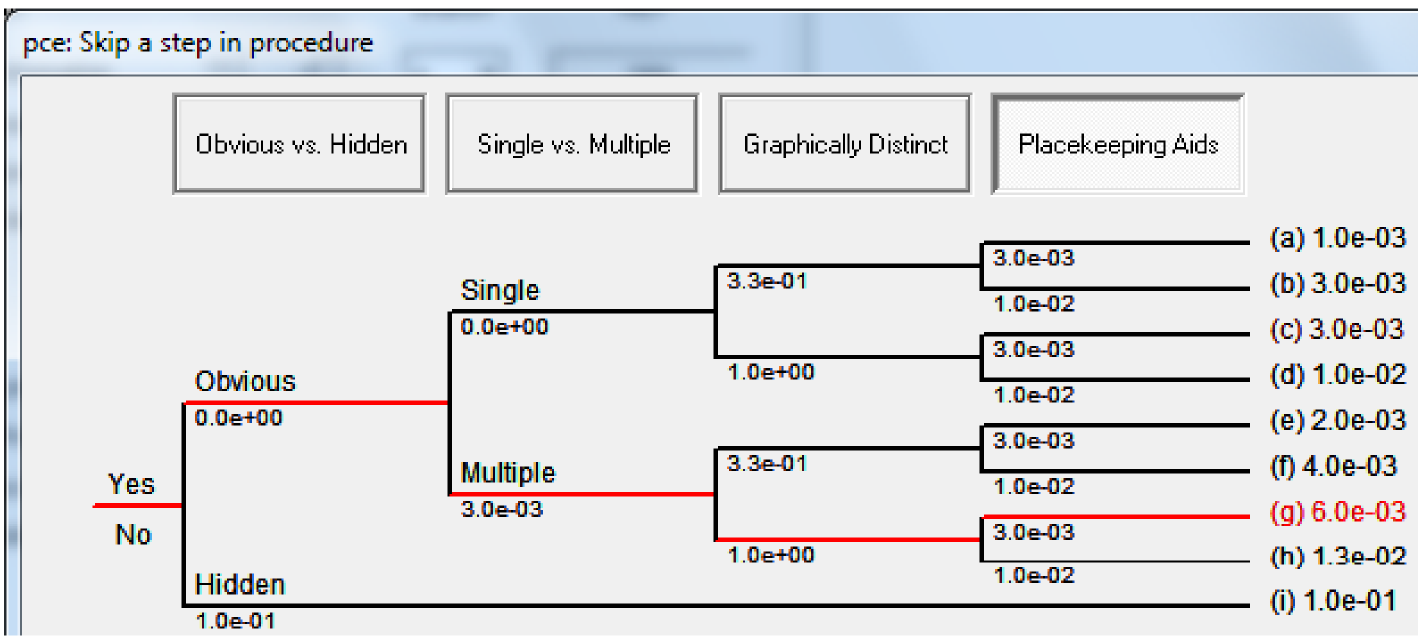
CBDT Example - Fire Impacts on Workload (Pe)

- Increase in workload is reflected by an increase in stress



Fire Impacts on Procedure Usage

- If EOPs are implemented in parallel to fire procedures, then multiple procedures are used
- If EOPs are suspended while fire procedures are being used, then only one procedure is credited and any time delays are accounted for in the timeline



Fire Impacts on Execution

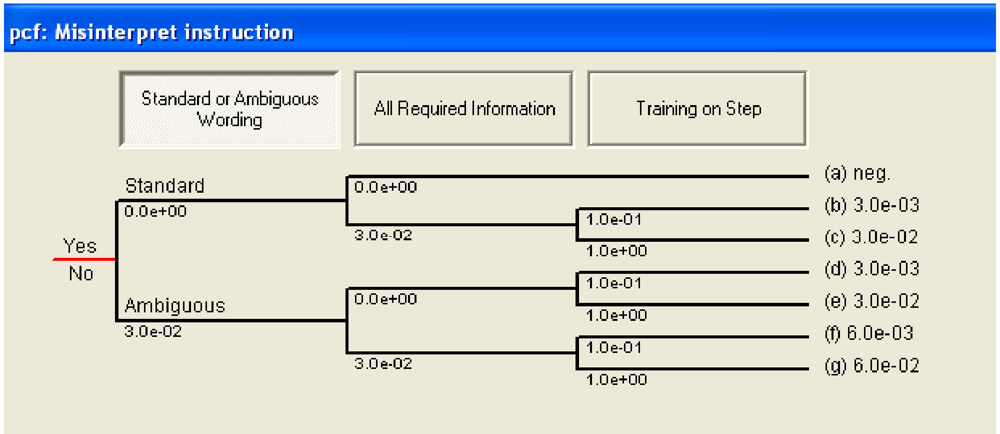
- Stress is often increased from internal events case
  - Except for control room actions when operator actions occurring more than 70 minutes after the fire started, because
    1. 99% of fires are extinguished within 70 minutes per FAQ 50
    2. On average, a fire is extinguished in 13 minutes
- For local actions, additional factor of 2 can be applied
  - Account for smoke, communication impacts, or
  - Additional equipment required by fire
    - Examples: SCBA, ladders, keys, tools

Fire Response HFEs

- Method selection depends on timing
  - CBDT approach to quantification applied first
  - HCR/ORE for time critical fire response actions
    - May se upper bound based on sigma value
- Ex-control room actions required due to loss of control are not substantially different from other local actions (e.g., during SBO) provided that local actions are not credited in close proximity to fire location
- No separate guidance for MCR abandonment
  - MCR typically is completely abandoned due to uninhabitability, not due to loss of control/functionality initial results show that frequency is low enough to not be a concern
    - If required, additional decision trees may be developed to model locus of control moving outside the control room

Fire Response HFEs

- Same considerations as internal events actions and the following **additional considerations**
  - **Ambiguously worded procedures**: Fire procedures are not standardized like EOPs. Modeled in decision tree $P_c f$. For internal events HFEs $P_c f$ typically evaluates to negligible.



  - **Local controls** may not be as easily accessible and as well trained on as for internal events actions. In this case, higher Error of Omission is selected from THERP
  - **No base case** from which to build the analysis, so entire analysis must be developed

Undesired Response to Spurious Indication or Actuation

- The following can be screened from consideration during identification:
  - Actions for which multiple indications are available for different parameters or via redundant channels
  - Actions that have a proceduralized verification step, if verification will be effective given the fire scenario

Quantification of Undesired Operator Responses to Spurious Signals

- HEPs for actions that do not screen from consideration are initially to be set to 1.0 (failed)
- EPRI approach to quantification
  - Assume the Error of Commission has occurred, then
  - Identify, define and quantify a recovery action

EPRI HRA Uncertainty

- For fire, the EPRI approach applies the same error factors (based on final HEP) as for internal events

HEP Error Factor		
HEP	Reference	EF
HEP < 0.001	THERP Table 20-20	10
HEP > 0.001	THERP Table 20-20	5
HEP > 0.1	Mathematical convenience	1

Detailed Fire HRA Summary

Consists of HRA tasks that develop human error probabilities (HEPs) for the modeled human failure events (HFEs)

- HEP used in FPRA quantification
- HEP development provides qualitative insights on results drivers

Uses most of the steps in the **HRA Process**:

1. Identification & Definition of HFE
2. Qualitative analysis – context & performance shaping factors
3. Quantitative analysis – **method selection** & quantification of HEP
    a) Screening
    b) Scoping
    c) Detailed HRA
        a) EPRI approach (CBDTM or HCR/ORE & THERP)
        b) ATHEANA
4. Provides input to subsequent Fire HRA tasks
    - Dependency analysis
    - Uncertainty analysis (HRA Calculator error factors are kept the same for fire HRA)

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and Definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
    a) Screening
    b) Scoping
    c) EPRI approach (detailed)
        a) EPRI Examples (See handouts)
    d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

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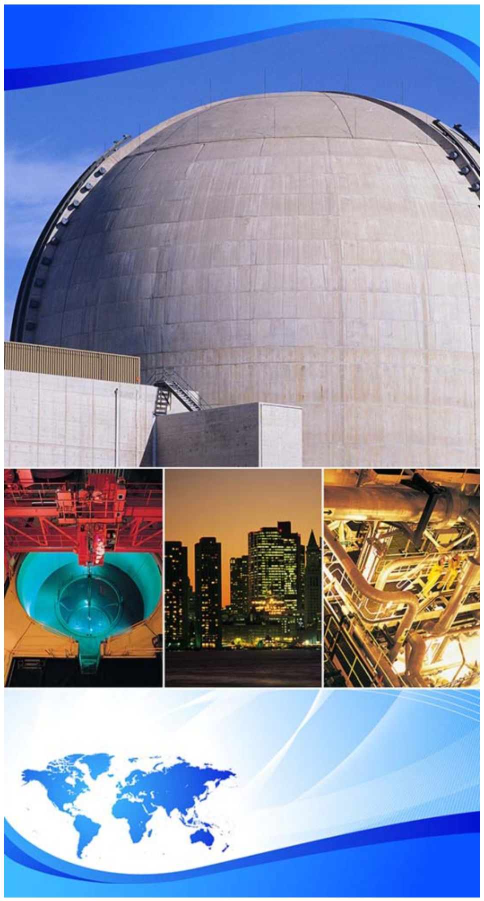

EPRI/NRC-RES FIRE HRA METHODOLOGY

Joint RES/EPRI Fire PRA Workshop 2011

San Diego CA and Jacksonville FL

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

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
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   a) Screening
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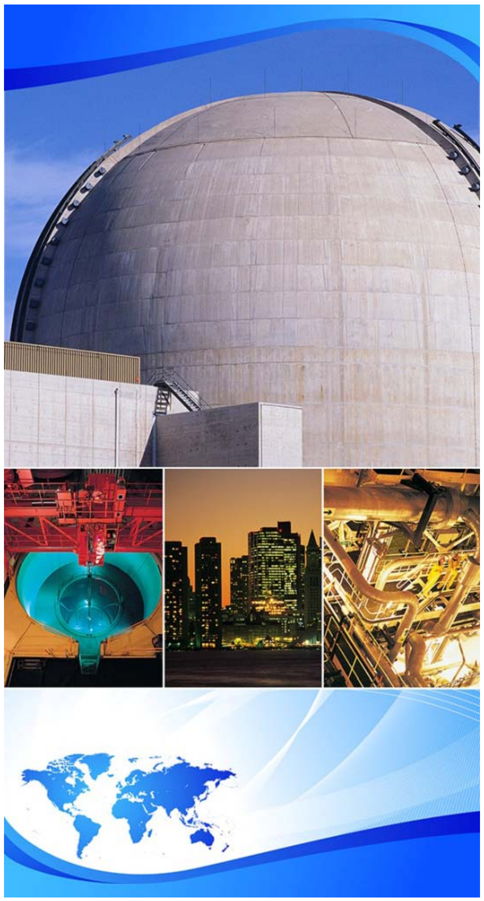


Detailed Quantification: ATHEANA

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

ATHEANA - Outline

1. Introduction to ATHEANA
2. ATHEANA – What's Going To Be Different For Fire PRA?
3. ATHEANA HRA Process
4. ASME/ANS PRA Standards Addressed
5. Steps For Performing ATHEANA
6. Addressing Fire-Specific Issues With ATHEANA
7. Fire HRA Exercises Using ATHEANA

Introduction to ATHEANA

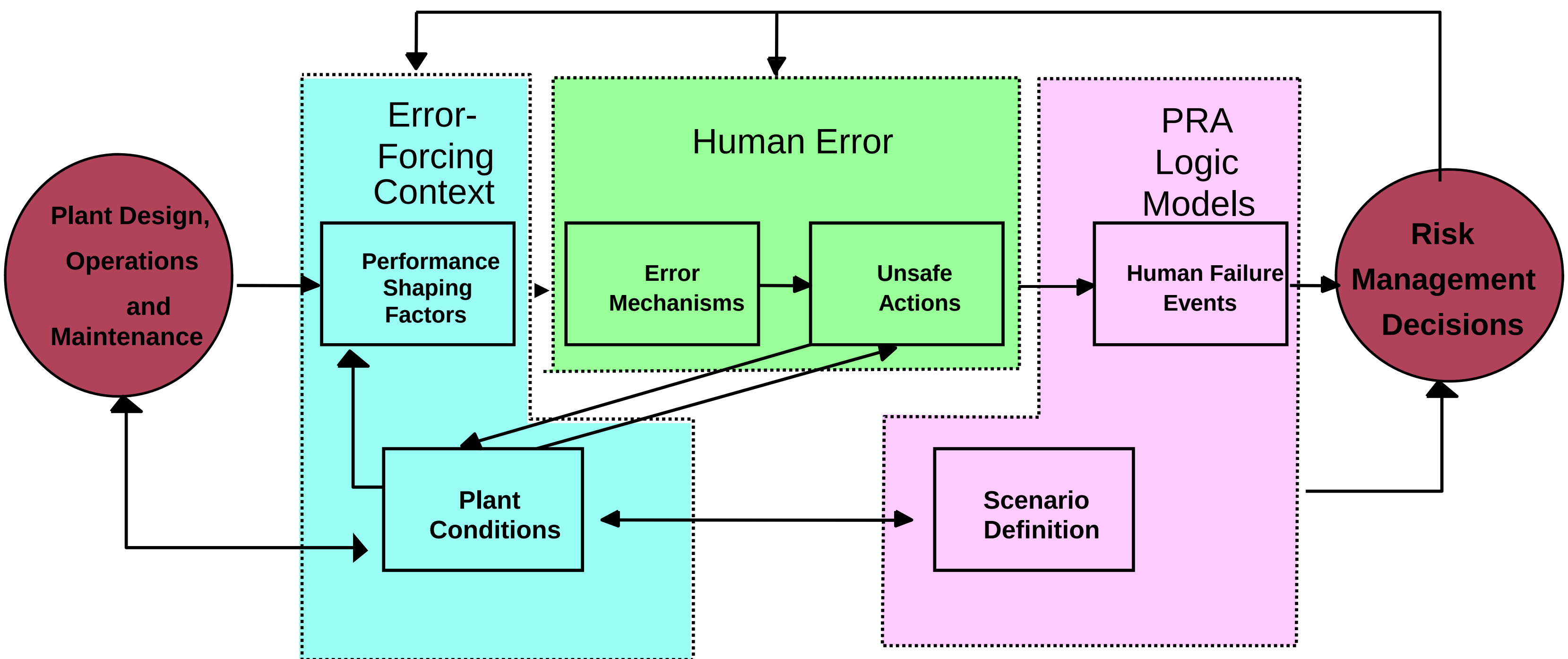
- ATHEANA is…
  - A Technique for Human Event ANAlysis
  - A second-generation HRA method
  - A development of NRC/RES and its contractors
  - An input to NRC's *Good Practices for Implementing Human Reliability Analysis (HRA)*, April 2005
- ATHEANA is documented in:
  - NUREG-1624, Rev. 1, *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)*, May 2000.
  - NUREG-1880, *ATHEANA User's Guide*, June 2007.

Introduction to ATHEANA (continued)

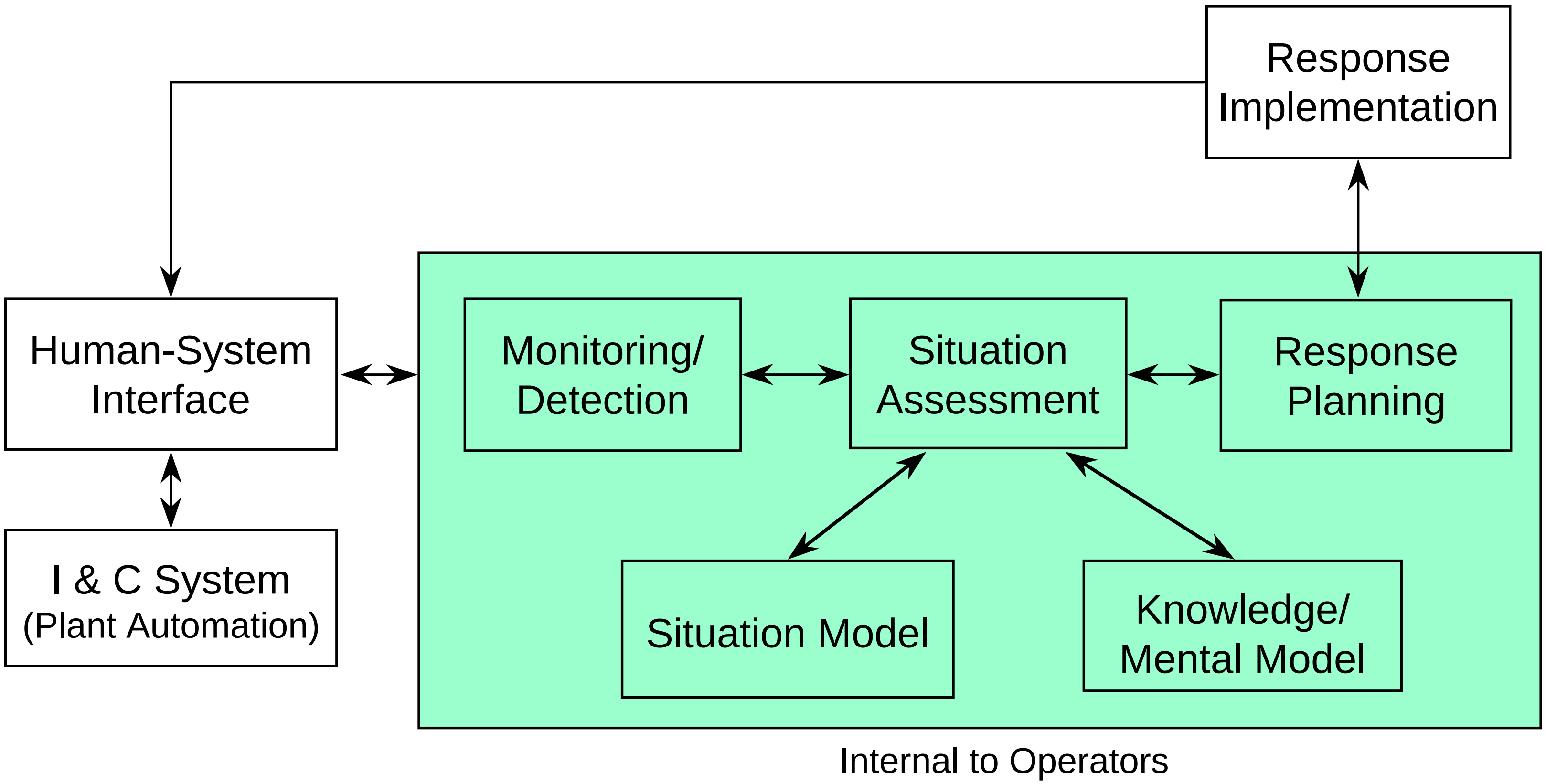
- ATHEANA is…
  - A knowledge-base* for (mostly) at-power, post-initiator HFEs, including:
    - Relevant psychological literature
    - Supporting analyses of historical events
  - A multidisciplinary framework for understanding human error
  - An HRA process (including detailed guidance for performing qualitative analysis)
  - A search scheme for HFEs (including errors of commission)
  - A quantification approach
- Also, ATHEANA provides a basis for performing retrospective analysis of historical events (including example analyses).

But, different knowledge bases* can be used or substituted.

Multidisciplinary Framework



Underlying Model of Operator's Behavior



Introduction to ATHEANA (continued)

- The basic premise of ATHEANA:
  - People behave “rationally,” even if reason for an action (or inaction) is wrong.
  - Often, when people make errors, they are “set up.”
  - People can be “set-up” by **contexts** that can create the *appearance* that the wrong response is correct when, in fact, it is not.
- Analyses of operating experience (particularly events with serious consequences) support this view, e.g.:
  - Nuclear power plant events (e.g., TMI 2, Browns Ferry, Chernobyl)
  - Incidents from a variety of other technologies (e.g., aviation, medicine, chemical processing, maritime)

Introduction to ATHEANA (continued)

Across industries, the following **contextual** factors often have been involved in serious events:

1. The plant behavior is outside the expected range (as represented by procedures, training, and traditional safety analyses).
2. The plant's behavior is not understood.
3. Indications of the actual plant state and behavior are not recognized (sometimes due to instrumentation problems).
4. Prepared plans or procedures are not applicable or helpful for the specific plant conditions.

Introduction to ATHEANA (continued)

Consequently, the principal motivators for developing ATHEANA were:

1. HFEs modeled in most HRA/PRAs are not consistent with the roles played by operators in actual operational experience.
2. The accident record and advances in behavior sciences both support a stronger focus on **context**.
3. Recent advances in psychology ought to be used and integrated with the disciplines of engineering, design, operations and training, human factors, and PRA in modeling HFEs.

Introduction to ATHEANA (continued)

…so, the principal objectives were:

1. To improve the HRA state-of-the-art , including:
   - To more realistically incorporate kinds of human-system interactions found important in accidents and near misses
   - To address dependencies among sequential human actions
   - To address errors of commission (EOCs), including their identification and quantification
2. To support the development of insights to improve plant safety and performance *__from HRA results__*
3. To support resolution of regulatory and industry issues *__from HRA results__*

Introduction to ATHEANA (continued)

Key characteristics are:

- Focuses on the **error-forcing context** (i.e., the context that sets up operators), but also addressed the nominal context
- Uses a structured search for problem scenarios (i.e., **error-forcing contexts**) and associated unsafe actions (i.e., operator failures)
- Links plant conditions, performance shaping factors (PSFs) and human error mechanisms through the **context**
- Is experience-based, both in its development and application (e.g., uses knowledge of domain experts such as operators, pilots, trainers)
- Uses multidisciplinary approach and underlying cognitive model of operator behavior
- Explicitly considers operator dependencies (including recovery actions) by developing entire accident sequences
- Uses a facilitator-led, expert elicitation approach for quantification (that allows the plant-specific experience and understanding from operators, operator trainers, and other operations experts to be directly reflected)

Introduction to ATHEANA (continued)

Example ATHEANA applications:

- HRA/PRAs in a prospective analysis of regulatory and industry issues such as pressurized thermal shock (PTS) (3 plants – Oconee, Beaver Valley, Palisades)
- International HRA Empirical Study (Steam Generator Tube Rupture and Loss of Feedwater scenarios)
- DOE's license application for Yucca Mountain waste repository (preclosure facility)
- Qualitative analyses of spent fuel handling (misloads and cask drops) (two NUREG/CRs – to be published)
- Retrospective event analyses and development of a knowledge-base for fire-specific human performance issues (NUREG/CR – to be published)
- HRA/PRA to evaluate design features of a facility to dismantle chemical weapons

ATHEANA – What's Going To Be Different For Fire PRA?

1. NUREG/CR-6850 [EPRI 1011989] and supporting documents indicate the need for adjustments for a fire-specific knowledge-base (e.g., fire-specific human performance issues).
2. EOCs are limited to those stated in the ASME/ANS PRA Standard.
3. Many *Fire HRA Guidelines* qualitative analysis tasks overlap; may already be performed or started before detailed quantification is performed.
4. The fire **context** may already be sufficiently challenging for operators; ATHEANA steps and activities related to finding an **error-forcing context** may not be needed.

The ATHEANA HRA Process

- Step 1: Define and interpret issue of concern
- Step 2: Define scope of analysis
- Step 3: Describe base case scenarios
- Step 4: Define HFEs and unsafe actions (UAs)
- Step 5: Identify potential vulnerabilities
- Step 6: Search for deviations from base case
- Step 7: Evaluate recovery potential
- Step 8: Quantification
- Step 9: Incorporation into PRA

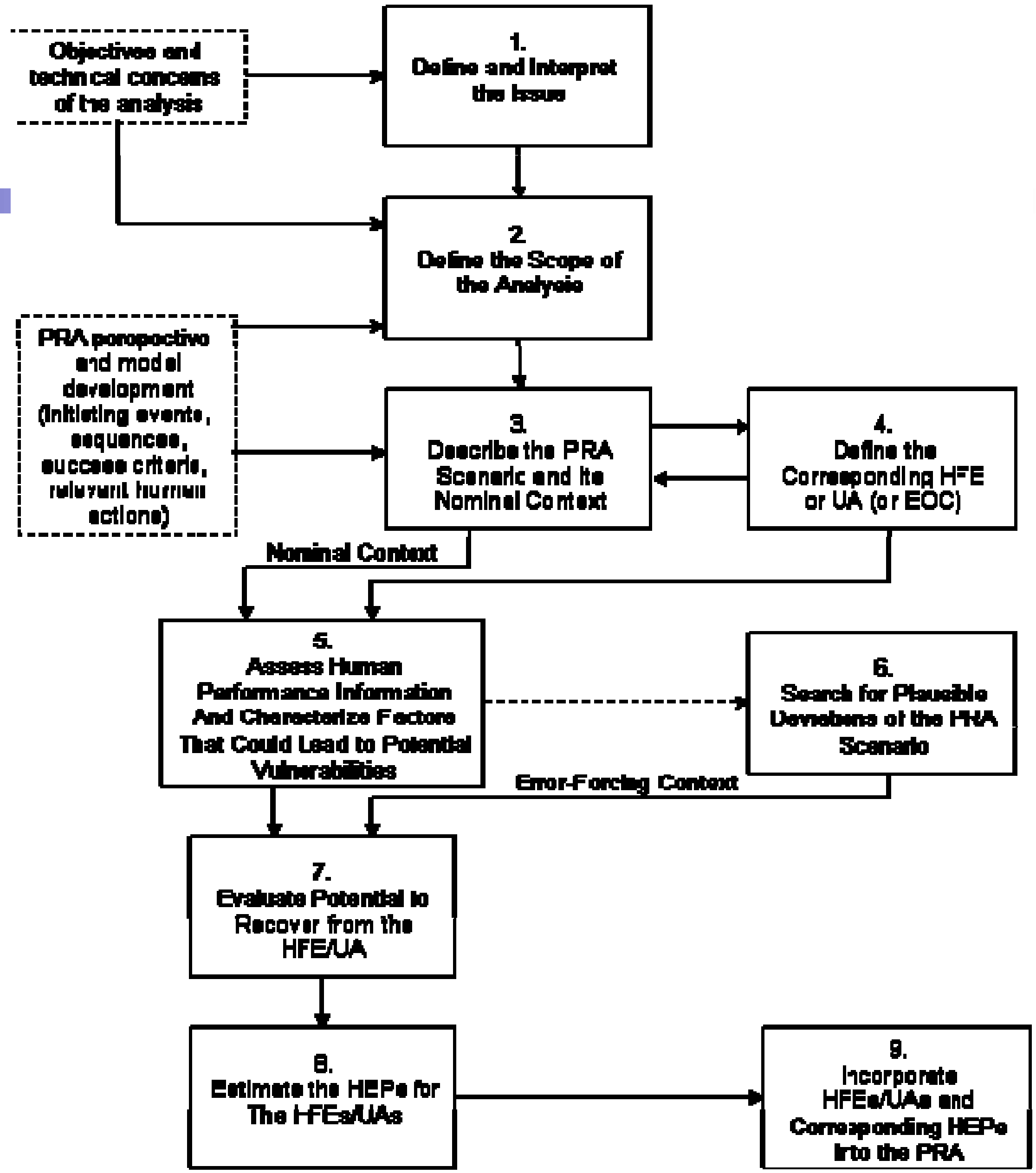
The ATHEANA HRA Process

- Not all of these steps are needed for every HRA/PRA job.
- For fire HRA/PRA, certain steps will not need to be performed by ATHEANA, e.g.,
  - NUREG/CR-6850 [EPRI 1011989] and the ANS/ASME PRA Standard already address Steps #1 and #2 (i.e., define and interpret the issue of concern, define the scope of analysis)
  - Deviations from the base case scenario (i.e., Step #6) are **usually** not needed for fire; most fire scenarios are generally challenging enough for operators that we do not have to look for even more unusual conditions
- So, later when we talk about ATHEANA steps, we'll highlight those needed specifically for fire HRA/PRA.

ANS/ASME RA-Sa-2009 Requirements for Fire – At Power High Level Requirements for HEP Quantification

- ATHEANA includes a fully capable detailed HRA quantification approach that satisfies requirements such as:
  - Part 2, HLR-HR-F: Human failure events shall be defined that represent the impact of not properly performing the required responses, in a manner consistent with the structure and level of detail of the accident sequences
  - Part 2, HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self consistent process that addresses the plant-specific and scenario-specific influences on human performances, and addresses potential dependencies between human failure events in the same accident sequence
  - Part 4, HLR-HRA-B: The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human responses associated with the identified human actions
  - Part 4, HLR-HRA-C: The Fire PRA shall quantify HEPs associated with incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fire
- …and supporting level requirements such as:
  - Part 2, SRs HR-F1, HR-G3, HR-G7, HR-G8; Part 4 SRs, HRA-B1 [Note 1] and HRA-C1

Steps in the ATHEANA Process



Mapping ATHEANA Process Steps to Fire HRA Guidelines Process

ATHEANA Process Step	Fire HRA Guideline Process Step
Steps 1 & 2: Define issue & scope of analysis	Defined by fire PRA & its scope of analysis – **no additional work needed**
Step 4: Define HFEs and unsafe actions (UAs)	**Covered*** by Chapter 3: Identification and Definition
Steps 3 & 5: Describe PRA scenario & assess human performance information, etc.	Some additional information needed for detailed HRA; but, **mostly covered** by Chapter 4: Qualitative Analysis
Step 6: Search for deviation scenarios	**Probably not needed**; fire scenarios are already "deviations"
Step 7: Assess potential for recovery	Similar to Chapter 6: Recovery
Step 8: Quantification (explicitly addresses dependencies & develops uncertainty distributions)	Different approach than scoping trees (Chapter 5) or CBDT (Appendix C); different approach to dependency & uncertainty (Chapters 7 & 8)

The ATHEANA HRA Process – Highlighting the needs for implementing Fire HRA Guidelines

- Step 1: Define and interpret issue of concern
- Step 2: Define scope of analysis
- Step 3: Describe base case scenarios
- Step 4: Define HFEs and unsafe actions (UAs)
- Step 5: Identify potential vulnerabilities
- Step 6: Search for deviations from base case
- Step 7: Evaluate recovery potential
- Step 8: Quantification
- Step 9: Incorporation into PRA

The ATHEANA HRA Process – Needs for implementing Fire HRA Guidelines (continued)

- So, in this presentation, we will only discuss the following steps in the ATHEANA process:
  - Step 3: Describe the base case scenario
  - Step 5: Identify potential vulnerabilities
  - Step 6: Search for deviations from base case (often not needed)
  - Step 7: Evaluate recovery potential
  - Step 8: Quantification
- As for the entire process in applying the Fire HRA Guidelines, these steps are **iterative**.

Note: If Step 6 is needed, HFEs may need to be redefined (as in any HRA/PRA, if warranted by plant conditions, timing of plant behavior, etc.). But, Fire HRA Guidelines can address this situation without using Step 2 of ATHEANA explicitly.

Step 3: Describe the PRA Scenario and its Nominal Context

- The base case scenario:
  - represents most realistic description of expected plant and operator behavior for selected issue and initiator
  - provides basis to identify and define deviations from such expectations (found in Step 6)
- Ideally, base case scenario:
  - has a consensus operator model (COM)
  - is well-defined operationally
  - has well-defined physics
  - is well-documented
  - is realistic
- Scenario description often based on FSAR or other well-documented analyses

  <u>In practice</u>, the available information defining a base case is usually less than ideal - analysts must supplement information deficiencies or simply recognize them.

Sources of Information Needed for Step 3

- Plant-specific FSAR (& other design basis documents)
- Safety analyses (e.g., plant-specific, vendor)
- Procedures (e.g., plant-specific EOPs, vendor, basis documents)
- Operator experience (actual & simulator)
- Operator training material & its background documentation
- Plant staff, especially operators, operator trainers, T-H experts
- Plant-specific & industry generic operating experience

Description of Base Case Scenario

- Initial plant conditions
- Sequence of events and expected timing before and following reactor trip
- Plant system and equipment response
- What the operators will see
  - usually trajectories of key plant parameters & indications
- Key operator actions during the scenario progression

Step 5: Assess Human Performance Information & Characterize Factors that Could Lead to Potential Vulnerabilities

- Identify and characterize factors (e.g., PSFs) that could contribute to crew performance in responding to the various accident scenarios
  - Factors that might increase the likelihood of the HFEs & UAs of interest
  - Helps focus later deviation searches
- Operators and trainers must play a role in this step
  - directly or through question/answer sessions
  - observation of simulator exercises (with relevant scenarios if possible)

Ways to Identify Potential Vulnerabilities

- Investigation of potential vulnerabilities due to biases in operator expectations (training, experience)
  - review training materials, interview trainers, operators
- Understanding of base-case scenario timeline and any inherent difficulties associated with required response
- Identification of operator-action tendencies based on
  - “standardized” responses to indications of plant conditions
  - informal rules
- Evaluation of formal rules and EOPs
  - critical decision points, ambiguities, sources of confusion, timing mismatches, special cases such as “preemptive actions,” etc.

Step 6: Search for Deviations From the Base Case

- Identify deviations from base case likely to result in risk-significant unsafe acts
- Deviations are plant behaviors or conditions that set up unsafe actions by creating mismatches between the proposed plant behavior and:
  - operators' knowledge, expectations, biases & training
  - procedural guidance & timing
- ATHEANA search schemes guide analysts to find real deviations in plant behavior and conditions
  - not just false perceptions in the operators' minds

Four Search Schemes for Step 6

- Identify deviations from the base case scenario using "HAZOP" guide words to discover troublesome ways that the scenario may differ from base case
  - more, less, quicker, slower, repeat ...
- Identify deviations for vulnerabilities associated with procedures & informal rules
  - e.g., changes in timing, sequencing of decision points, etc.
- Identify deviations caused by subtle failures in support systems
  - cause problems for operators to identify what's happening
- Identify deviations that can set up operator tendencies and error types leading towards HFEs/UAs of interest

Step 7: Evaluate Potential for Recovery

- Possibility of recovering from UAs is considered in this step
- However, when evaluated, recovery <u>always</u> considers both the complete EFC and the occurrence of the UA(s)
- Deviation description is extended to include the scenario characteristics up to the last opportunity for recovery
- Performance of this step linked with quantification - iteration between these steps is likely

Guidance for Recovery Analysis

- Define the possible recovery action(s) given the initial error corresponding to the HFE/UA has occurred
- Consider the time available to diagnose the need for and perform the recovery action so as to avoid a serious or otherwise undesired condition
- Identify the existence and timing of cues as well as how compelling the cues are that would alert the operators to the need to recover and provide sufficient information to identify the most applicable recovery action(s)
- Identify the existence and timing of additional resources (e.g., additional staff, special tools), if necessary, to perform the recovery

Step 8: Quantification

- Very structured, facilitator led, expert opinion elicitation process
  - leads to consensus distributions of operator failure probabilities
- Considerations in elicitation process (covered in NUREG-1880):
  - Forming the team of experts (include experts familiar with important relevant factors during fire conditions, operator trainers, etc.)
  - Controlling for biases when performing elicitations
  - Addressing uncertainty

ATHEANA Quantification: Asks the Experts Two Questions

1. Does the operational story make sense?
   - given the specific PRA scenario or sub-scenario
   - given what is known about operators & operations at this plant

2. What is the likelihood that operators will fail as described in the operational story?

Basic Formulation for Quantification Process

- $P\,(HFE|S) = \sum_{ij} P(EFC_i|S) \times P(UA_j|EFC_i, S)$
- HFEs are human failure events modeled in PRA
  - Modeled for a given PRA scenario (S)
  - Can include multiple unsafe actions (UAs) and error-forcing contexts (EFCs)
- First determine probability of the EFC (plant conditions and PSFs) being addressed
- Determine probability of UA given the identified EFC
- If multiple EFCs identified, then quantify a UA given each EFC separately

Six Steps to Quantification Process

1. Discuss HFE and possible influences / contexts using a factor “checklist” as an aid
2. Identify “driving” influencing factors and thus most important contexts to consider
3. Compare these contexts to other familiar contexts and each expert independently provide the initial probability distribution for the HEP considering:
   – “Likely” to fail ~ 0.5 (5 out of 10 would fail)
   – “Infrequently” fails ~ 0.1 (1 out of 10 would fail)
   – “Unlikely” to fail ~ 0.01(1 out of 100 would fail)
   – “Extremely unlikely” to fail ~ 0.001 (1 out of 1000 would fail)

Six Steps to Quantification Process (cont'd)

4. Each expert discusses and justifies his/her HEP estimate
5. Openly discuss opinions and refine the HFE, associated contexts, and/or HEPs (if needed) – each expert independently provides HEP (may be the same as the initial judgment or may be modified)
6. Arrive at a consensus HEP for use in the PRA

Addressing Fire-Specific Issues with ATHEANA

- ATHEANA should be applied in the same way for fire HRA, as for any other HRA/PRA.
- However, the fire-specific operator performance issues should be considered in performing ATHEANA steps (e.g., identifying potential vulnerabilities, quantification).
- Plus, some of the information needed to apply ATHEANA may be collected and analyzed already in order to have used either the screening values or scoping approach provided in the Fire HRA Guidelines.

Mapping ATHEANA Process Steps to Fire HRA Guidelines Process

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The ATHEANA HRA Process – Highlighting the needs for implementing Fire HRA Guidelines

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- Step 8: Quantification
- Step 9: Incorporation into PRA

Additional ATHEANA Needs for Fire HRA

1. Some additional qualitative analysis to support Steps 3, 5, (6), 7, and 8, including:
   - Information collection
   - Interviews of operator trainers
2. ATHEANA approach for quantification and recovery
   - With dependency considerations embedded
   - With uncertainty distribution being explicitly developed as part of quantification
3. Adjustments to knowledge-base (per considerations in NUREG/CR-6850 [EPRI 1011989] and others)

Example Qualitative Analysis Results - Chapter 4

- In applying the Fire HRA Guidelines, the following are examples of information already collected and/or analyzed:
  - Procedures used in fire scenarios
  - Usage of procedures
  - Potential fire effects and their impacts on human performance
  - Fire PRA scenarios with associated equipment and indication failures
  - Possible crew responses to fire scenarios
    - Errors of Commission
    - Errors of Omission

Examples of Additional Qualitative Analysis to Support ATHEANA

1. Identify:
   - important decision points or branching, and other possible places in procedures where operators may make different choices
   - plant-specific "informal rules" and other guidance that may supplement or slightly deviate from relevant procedural guidance
   - tradeoffs (e.g., impromptu choices between alternatives) or other difficult decisions that operators may need to make
   - potential situations where operators may not understand the actual plant conditions (e.g., spurious indications)
   - different ways by which an HFE could occur, starting with the fire PRA scenario description, different procedural paths or choices, and the reasons for these different choices

Examples of Additional Qualitative Analysis to Support ATHEANA (continued)

2. Develop:
   - insights from training, experience, or demonstration of fire-related operator actions (in- and ex-MCR), including use of specialized equipment
   - timelines or other ways of representing the time sequencing of events in fire scenarios
3. Objective or final result of ATHEANA qualitative analysis:
   - A full operational scenario description, or "operational story," including accident progression and as many "bells and whistles" as are reasonable, such that operator trainers can "put themselves into" scenario
     - Because, in quantification, you will be asking them, "what would your crews do in this situation?"

Examples of Additional Qualitative Analysis to Support ATHEANA (continued)

- The resulting operational scenario description may include:
  - Additional plant conditions that will need to be quantified as part of the HFE (unless accident sequence analyst wants to revise event trees or fault trees).
  - Distinctions on timing of plant behavior (that might need to be addressed as part of the HFE, unless logic is revised).
  - Instrument or indication issues (including failures) that will need to be reflected (for fire, might be explicitly part of PRA model, or may not).
  - Different possible procedure paths or response strategies that operators might rationally take.
  - Reasons why operators might take different procedure paths.
  - Credible **recovery actions**.

Likely to need help from operational experts on the last three elements.

Remember…Basic Quantification Formula?

First, let's simplify; only one EFC for each scenario, S.

So, we have:

$$P\ (HFE|S) = \sum_{j} P(UA_j|EFC,S)$$

- S = Full operational story (might not be equivalent to PRA scenario)
- UAs = Different procedure paths leading to undesired outcomes, and associated reasons for taking them
- EFCs = Plant conditions, behavior, PSFs, etc., that are not explicitly modeled in PRA, but needed to represent S

- Probability of each UA is conditional on EFC/S

ATHEANA – Iterating Between Qualitative Analysis and Quantification

- Development of operational scenario descriptions should be both for and by operational experts (e.g., trainers).
- Even "during quantification," the analyst should be alert to the need to modify, refine, and/or add details to the operational description of the scenario. For example:
  - During quantification, very different failure probabilities are provided by the expert panel of trainers.
  - When explaining answers, one trainer brings up a possible influence (e.g., a specific plant condition or equipment failure) that no one else has considered.
  - Because everyone agrees to the validity and importance of this factor, the analyst either:
    - Has everyone include this factor in their quantification, or
    - Defines a new HFE to address this newly defined scenario

ATHEANA – Iterating Between Qualitative Analysis and Quantification

- Based on experience in applying ATHEANA, most of the effort is in identifying and developing the elements of an "operational story" that represents what the experts think is important to operator behavior.
- Once this agreement is reached, reaching a consensus in final quantification by the operational experts is usually not difficult (if using the tools and techniques for facilitating expert elicitation, such as that given in the ATHEANA User's Guide.)

ATHEANA – Addressing Uncertainty in Fire HRA/PRA

- Performed as usually would, i.e.,
  - Expert elicitation process for quantification includes:
    - Detailed qualitative discussions to ensure all the available information (evidence) is brought to the table, shared, and agreed upon to the extent possible
    - Detailed identification of the key factors contributing to aleatory and epistemic uncertainty
  - The HEP developed for an HFE in a fire scenario (as for any other scenario) may be made up of combinations of distributions of multiple unsafe actions that have been evaluated separately.
  - Individual distributions combined mathematically into a single distribution.

Fire HRA Exercises Using ATHEANA

- TBD

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

EPRI

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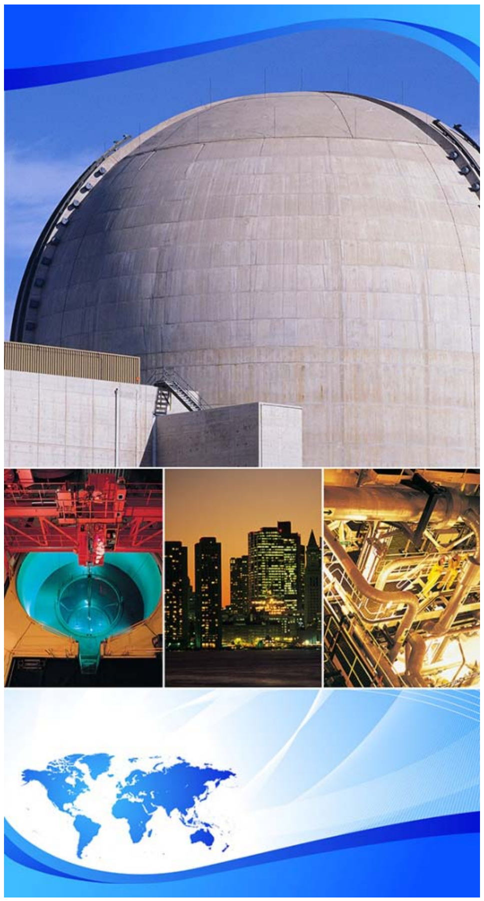


EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA – Part 2

Erin Collins (SAIC)
Kaydee Kohlhepp (Scientech)

Joint RES/EPRI Fire PRA Workshop 2011

San Diego CA and Jacksonville FL

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

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
    a) Screening
    b) Scoping
    c) EPRI approach (detailed)
    d) ATHEANA (detailed)
5. **Recovery analysis (as in cutset post-processing)**
6. Dependency analysis
7. Uncertainty analysis

Applicable HLRs (per the PRA Standard) *Recovery*

- HLR-AS-A: The accident sequence analysis shall describe the plant-specific scenarios that can lead to core damage following each modeled initiating event. These scenarios shall address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage (11 SRs)
- HLR-HR-H: Recovery actions (at the cutset or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario (3 SRs)
- HLR-QU-A: The level 1 quantification shall quantify core damage frequency and shall support the quantification of LERF (5 SRs, 1 specific to recovery)
- HLR-HRA-D: The Fire PRA shall include recovery actions only if it has been demonstrated that the action is plausible and feasible for those scenarios to which it applies, particularly accounting for the effects of fires (2 SRs)

Recovery per NFPA 805

- Recovery actions as defined under NFPA 805 are what used to be generally referred to in the fire protection community as "operator manual actions" (or OMAs).
- In this context, recovery refers only to actions performed outside of a primary control station (PCS). Note that the MCR is not the only PCS.
- Under NFPA 805, total transfer of control from the MCR to a dedicated or alternate shutdown location means there is a new PCS, and operations conducted there are not recovery actions (and neither are the actions required to transfer control).
- All actions away from a primary control station are considered recovery actions under NFPA 805, whether or not they are considered recovery actions in the PRA, and plant licensees must evaluate the additional risk of their use according to NFPA 805.
- **THIS IS NOT THE DEFINITION OF RECOVERY USED IN THE FIRE HRA GUIDELINES**

Recovery Types

There are three types of recovery actions of concern for fire HRAs. These are:

- Type 1 – Recovery within the same HFE, which is treated in the evaluation of the basic HEP
- Type 2 - Standard PRA concept of recovering cutsets by adding a new human action to the sequence

  (focus of this course segment)
- Type 3 - Modeling the fire brigade and their actions to extinguish the fire. According to NUREG/CR-6850 (EPRI 1011989), this type of recovery action is treated in the fire modeling task via statistical models derived from fire suppression event data (as updated via FAQ 08-0050)

Recovery within the Same HFE

- Treated in the evaluation of the basic HEP
- Examples include:
  - Self-review
  - Peer checking within a shift or after shift change
  - Shift Technical Advisor (STA) review
  - Procedure-related checks
- EPRI HRA Calculator – addressed via Cognitive Recovered and Execution Recovered modules - CBDTM recoveries applied consistent with EPRI TR-100259
  - Based on the time available for recovery, a minimum level of dependency applicable to recovery actions is suggested by the program
- ATHEANA - treated directly via conditional probabilities
  - When qualitative information is first converted into a quantitative estimate of the HEP, recovery of any initial error is addressed to the extent appropriate

Recovery at the Cutset Level

- PRA Standard definition – “Restoration of a function lost as a result of a failed system, structure, or component (SSC) by overcoming or compensating for its failure. Generally modeled by using HRA techniques.”
- Adding cutset level recovery actions is common practice in PRA
- Credits other reasonable actions the operators might take to avoid severe core damage and/or a large early release that are not already specifically modeled

- Corresponding PRA Standard SRs: Part 4, HRA-D1 and –D2

Recovery at the Cutset Level (continued)

- For example, in PRA modeling of an accident sequence involving loss of all injection, it would be logical and common to credit operators attempting to locally align an independent firewater system for injection
- Failure to successfully perform such an action would subsequently be added to the accident sequence model
- Further lowers overall accident sequence frequency because additional failures of these actions would be required before the core is actually damaged

Recovery vs. Repair (per RG 1.200)

- Recovery action is defined as:
  - a PRA modeling term representing restoration of the function caused by a failed system, structure, or component (SSC), by bypassing the failure.
  - Such a recovery can be modeled using HRA techniques regardless of the cause of the failure.
- Repair is defined as:
  - a general term describing restoration of a failed SSC by correcting the failure and returning the failed SSC to operability.
  - HRA techniques cannot be used since the method of repair is not known without knowing the specific causes

Recovery Analysis
Fire HRA

- Similar analysis process as for other fire HFEs
- Identification and Definition
  - Take note of existing Internal Event PRA recovery actions
  - From cutset review, identify risk-significant sequences with recovery potential
  - From fire and post-trip action procedures, use recovery-related steps to identify new recovery HFEs
  - Initial feasibility analysis
    - NUREG-1792, HRA Good Practices
    - NUREG/CR-6850 (EPRI 1011989)

Recovery Analysis
Fire HRA (continued)

- Qualitative Analysis
  - Review cutsets again to define key functional scenarios that the operators must address in each fire area (scenario)
  - Talk-through procedure-based recovery actions with operators or training personnel
- Quantification using same approaches
  - Screening
  - Scoping
  - Detailed (recommended to ensure thorough analysis of timing, PSFs and context)
- Incorporation into FPRA Model
  - Recovery Rules file

Recovery Actions
Considerations for Identification (per NUREG-1792)

- Cues are clear and provided in time to indicate need for recovery action(s) and failure(s) that need(s) to be recovered
- Sufficient time available for recovery action(s) to be diagnosed and implemented to avoid undesired outcome
- Sufficient crew resources exist
- There is procedural guidance
- Quality and frequency of training on recovery action(s)
- Equipment needed is accessible and in non-threatening environment (e.g., fire, extreme radiation)
- Equipment needed is available in context of other failures and initiator for sequence/cutset

Recovery Actions

Not to be Credited (per NUREG/CR-6850 [EPRI 1011989])

Actions should not be credited as recoveries that:

- require significant activity and/or communication among individuals while wearing SCBAs (unless SCBAs contain internal communication devices)
- require performing numerous and strenuous actions wearing SCBAs
- require operators or other personnel to travel through fire or areas where fire effects (e.g., smoke, heat) are severe
- involve restoring systems or equipment damaged by fire
- have insufficient time available

Recovery Actions

Relaxation from original 6850 guidance

- Reconsider Internal Event PRA assumptions (e.g., HRA recoveries of systems or components previously assumed failed)
  - re-evaluate WHY the component was assumed failed for internal events. If it was for conservatism, then may want to consider it for fire HRA
- Non-proceduralized HFEs <u>can</u> be credited, provided they meet the requirements of ASME/ANS SR HRA-H2
  - operator training includes the action, or justification for lack of procedures or training is provided
  - “cues” (e.g., alarms) exist to alert the operator to the recovery action
  - attention is given to the relevant PSFs
  - there is sufficient manpower to perform the action

Recovery Considerations

- Details of the fire context in a specific fire area are well defined for most areas via the Fire PRA model iteration that factors in fire modeling and circuit analysis
- Fire scenario complexity can then be understood from the cutsets and fire area components failed
- Evaluation of HFEs is sensitive to the types of conditions that appear to the operators in the MCR
  - For example, fire impact can range from:
    - all conditions are normal
    - some degraded cues
    - significantly degraded cues and additional spurious operations

Recovery and Use of Procedures

- Since the procedures generally address one type of functional loss at a time, the operators responding to severe fire conditions will often be in multiple procedures to address multiple impacts that fires have on the system
- Need to review postulated recovery scenarios with operations and training personnel to verify procedure steps used and interactions between fire procedures and EOPs

Recovery Analysis Consideration of Circuit Analysis *(per NUREG/CR-6850 [EPRI 1011989])*

- In some cases, electrical cable failures will result in permanent damage to electrical or mechanical equipment that precludes certain types of recovery actions
- For example, spurious operation of a valve due to a hot short that bypasses the valve's torque switch might cause permanent binding of the valve, precluding manual operation of the valve at a later time
- Cases of this nature should be documented and discussed with systems analysts to ensure recovery actions accurately reflect the prevailing conditions

- Corresponding PRA Standard SR: Part 4, HRA-D2, Note (1)

Qualitative Definitions of Fire Recovery Actions

Fire Initiated Scenario Type	Operator Objective (not recovery)	Selected HFE for recovery
Fire induced loss of DC power causes spurious ESFAS with normal cues	Override and control MSIS during fire, if nothing done then primary safeties lift in about 80 min.	OP FT control ESFAS and ADV given Fire
Fire induced trip with Loss of CST Makeup for AFW with normal cues	Provide makeup to CST 121 following a fire	OP FT Provide Makeup to CST given fire
Fire induced LOCA: Pzr valve 3/4 inch line open	Respond to loss of primary coolant and establish secondary cooling during fire	OP FT Depressurize to Containment Spray Pump Shutoff Head given fire with sample line open

Consideration of Procedures and Timing for Fire Recovery Actions

Fire scenario	Operator Actions for fire	HFE description	Action Time (diag. plus impl.)	Time Window (Tsw)	STD POST TRIP ACTIONS EOI SO23-12-1 R22	FIRE AOI SO23-13-21 R18
MSIS isolation (spurious from fire) with normal cues	Override and control MSIS during fire, if nothing done then primary safeties lift in about 80 min.	OP FT control ESFAS and ADV given Fire with **Normal Cues**	40	80	Step 8 VERIFY RCS Heat Removal criteria satisfied MSIS isolation OK use ADVs and AFW	Attachment 2- 12.0 AFW, MSS, MFW OPERATIONS then go to 3.0 ADV Operations (3.1.3) "When an ADV is needed, then OPERATE HV-8421 (for a Train A shutdown), or HV-8419 (for a Train B shutdown), in Local/Manual per SO23-3-2.18.1, Attachment for Local Manual Operation of HV-8419(HV-8421) Atmospheric Dump Valves."

Operator fails to stop spuriously started charging pump to prevent PORV lifting

- 1 charging pump is set to MANUAL, and is always set at 30 gpm.
- 1 charging pump is set to AUTO, so it varies between 0-60 gpm as required.
- 1 charging pump is in standby.
- If the charging pump in AUTO dials back to effectively 0 gpm when the third charging pump spuriously starts, then the increase in flow is only 30 gpm. Also, according to the PRA contact at the plant site, if all three charging pumps are running, the relief valve lifts. So it is assumed that the flow from the third charging pump is an additional 30 gpm (instead of the full 60 gpm capability).

Operator fails to stop spuriously started charging pump to prevent PORV lifting - 2

- Pressurizer Level is assumed to be at full power control level of 46%
- These are relevant parameters from MAAP parameter file. They are in metric units.
- VPZ 28.32 PRESSURIZER VOLUME
- APZ 3.575 PRESSURIZER CROSS-SECTIONAL AREA
- So just to check, the volume = 28.32 m3 = 1000 ft3. Agrees.
- So the cross-sectional area = 3.575 m2 = 38.5 ft2, and thus the radius = 3.5 ft.
- So the volume of the hemisphere is ~90 ft3 each (top and bottom), and the volume of the cylinder is 820 ft2.

Operator fails to stop spuriously started charging pump to prevent PORV lifting - 3

- If the water level is 46%, then the water volume is 0.46 x 820 + 90 = 467.2 ft3 = ~3495 gal
- At 55% there is 0.55 x 820 + 90 = 541 ft3 = ~4045 gal
- At 85% there is 0.85 x 820 + 90 = 787 ft3 = ~5885 gal
- Full = 1000 ft3 = 7480 gal
- So at 60 gpm, it takes ~9 min to get to 55%, ~40 min to get to 85% and reactor trip, and ~66 min to go solid.
- The time window would thus be 66 – 40 = 26 min between RT and water solid.
- So would get Alarm 1 in ~9 minutes, then Alarm 2 in ~38 minutes with Alarm 3 shortly afterwards at ~40 minutes when the second PZR channel satisfies the trip logic based on channel accuracy. The pressurizer goes solid in ~66 min.

Operator fails to stop spuriously started charging pump to prevent PORV lifting - 4

- At RX Trip, the operators would go to Procedure KW-PROC-000-E-0 for Reactor Trip or Safety Injection. At Step 4, CHECK If SI Is Actuated, the RNO Step a.4 states: IF SI is NOT required, THEN PERFORM the following:

a. INITIATE monitoring of CSF Status Trees per FR-0, CRITICAL SAFETY FUNCTION STATUS TREES.

b. GO TO ES-0.1, REACTOR TRIP RESPONSE.

- Once in ES-0.1, the operators will follow down to Step 4 CHECK Charging Flow Established: where they are directed to:

a. CHECK charging pumps - AT LEAST ONE RUNNING

b. ADJUST charging pump speed and START second charging pump as necessary to establish pressurizer level between 21% and 40%.

- This is conservatively considered to be the maximum timeframe required for operator action, since it is likely that pzr level would be noticed earlier and the third charging pump would be stopped.

Operator fails to stop spuriously started charging pump to prevent PORV lifting - 5

- However, since the pump is already in the off position in standby, it is likely that a local action would be required to shut off the pump. Therefore 10 minutes has been estimated for travel time. The actual local action is to actuate a push button to turn off the pump breaker.

Operator fails to stop spuriously started charging pump to prevent PORV lifting - 6

- The timing is therefore set up as follows:
- Tsw = 66 minutes (from spurious pump trip on fire to going solid)
- Tdelay = 40 minutes (to Rx trip)
- T1/2 (diagnosis) = 5 minutes (to go through procedures and get to charging step 4 in ES-01)
- Tm (execution) = 10 minutes to travel to Aux Building to charging pump
- In this scenario, the t=0 is presumed to be the fire that causes spurious pump actuation. Reactor Trip on high pzr level will occur when 85% pzr level is reached on 2/3 channels.

Editing Cutsets to Address Recovery

- The specific process of modifying models or results to account for recovery actions is PRA software-specific
- Some system, function, or sequence cutset equations may require editing before being used to quantify or merge event tree sequence equations
- Editing might include removal of disallowed cutsets, or the addition of recovery events
- Fire HRA analysts should work with the PRA model quantification team to understand the risk significant cutsets and how recovery actions are incorporated in the model in order to provide the appropriate inputs

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. **Dependency analysis (inter- vs. intra-dependence)**
7. Uncertainty analysis

Dependency Analysis
Evaluation Process

- Dependency evaluation
  - ASME/ANS PRA standard requires that multiple human actions in an accident sequence or cutset be identified, degree of dependency assessed, and joint HEP calculated
- Steps
  - Identify combinations of multiple operator actions in fire scenario (**regardless if screening, scoping or detailed quantification**)
  - Evaluate dependencies within scenario
  - Incorporate dependency evaluation into Fire PRA model
- Application
  - For Fire PRA, preliminary dependency analysis performed in combination with NUREG/CR-6850 (EPRI 1011989) Task 11, Detailed Fire Modeling and finalized as part of Task 14, Fire Risk Quantification

Applicable HLRs (per the PRA Standard) *Dependency*

- HLR-AS-B: Dependencies that can impact the ability of the mitigating systems to operate and function shall be addressed (7 SRs)
- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence (8 SRs)
- HLR-QU-C: Model quantification shall determine that all identified dependencies are addressed appropriately (3 SRs)
- HLR-FQ-C: [Fire Risk] Model quantification shall determine that all identified dependencies are addressed appropriately (1 SR)

Dependency Analysis
Scope

- Similar to Recovery, Dependency within the same HFE is treated in the evaluation of the basic HEP through
  - Consolidation at the basic event level, e.g., miscalibrations of redundant channels are modeled in one basic event
  - THERP rules ranging from zero dependence (ZD) to complete dependence (CD)
- Fire HRA Dependency analysis primarily focuses on post-initiator HFEs occurring in the same cutset (i.e., pre-initiator HFEs are not affected by fire context)

- Corresponding PRA Standard SRs: Part 2, AS-B2, HR-G7 and -H3, QU-C1 and –C2; Part 4, FQ-C1

Dependency Analysis
Approaches

1. Use actual data from simulators
   – Highly resource intensive
2. Analyze each HFE combination in detail
   – Highly resource intensive
   – Best results
3. Assume complete dependence (only credit 1 HFE per cutset)
   – Not resource intensive
   – Impact on risk metric could be unacceptably over-conservative
4. Apply a systematic set of rules to assign different levels of dependence
   – Moderate resource requirements
   – Impact on risk metric could be acceptable
   – Recommended approach

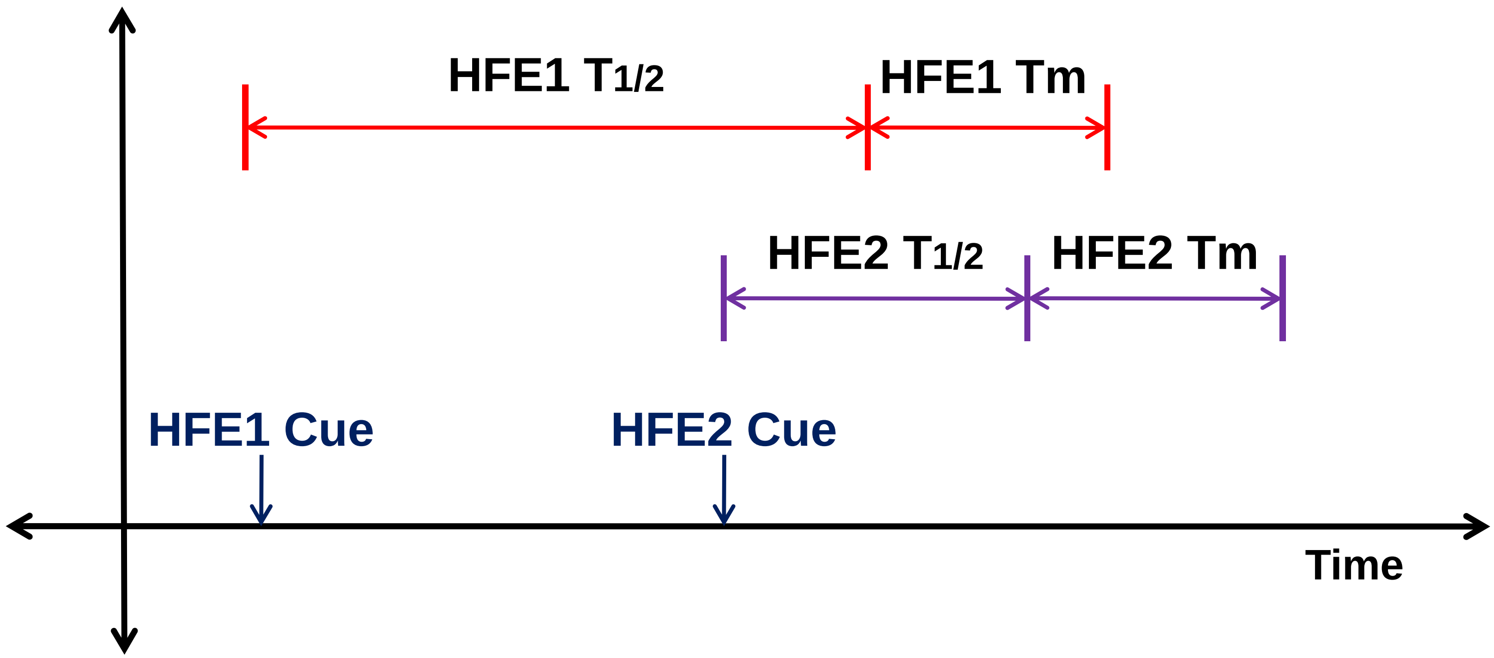
Dependency Analysis
Definitions

- Dependence Importance (DI) of HEP Combination
  - Risk metric given all HEPs in a given chronological combination, except the first HEP, are set to 1.0

- Risk Achievement Worth (RAW) of HEP Combination
  - Risk metric given all HEPs in the combination are set to 1.0

Dependency Analysis
Definitions (Continued)

- Simultaneous
  - For two HFEs in a chronological sequence, if the cue or requirement for a successive HFE occurs before the preceding HFE can be completed, the HFEs are *simultaneous.*



Dependency Analysis
Basic Dependency Rules

- Dependence impact is one-directional in chronological order
- The THERP positive dependence model is adopted, i.e., failure of an event increases the probability of failure of a subsequent event
- The first HFE in a sequence is always independent
- In a chronological sequence, an HFE depends only on the immediately preceding HFE (given no common cognitive element)
- An HFE is independent of an immediately preceding success

Dependency Analysis

THERP Dependency Formulas

Dependence Level	Equation	Approximate Value for HEP < 0.01
Zero (ZD)	HEP	HEP
Low (LD)	(1+19 X HEP) / 20	0.05
Medium (MD)	(1+ 6 X HEP) / 7	0.14
High (HD)	(1 + HEP) / 2	0.5
Complete (CD)	1.0	1.0

Dependency Analysis
Levels of Dependence

- **Dependency Factors**
  – Same Crew
  – Cognition (cues/procedure)
  – Simultaneity
  – Resources
  – Location
  – Timing
  – Stress

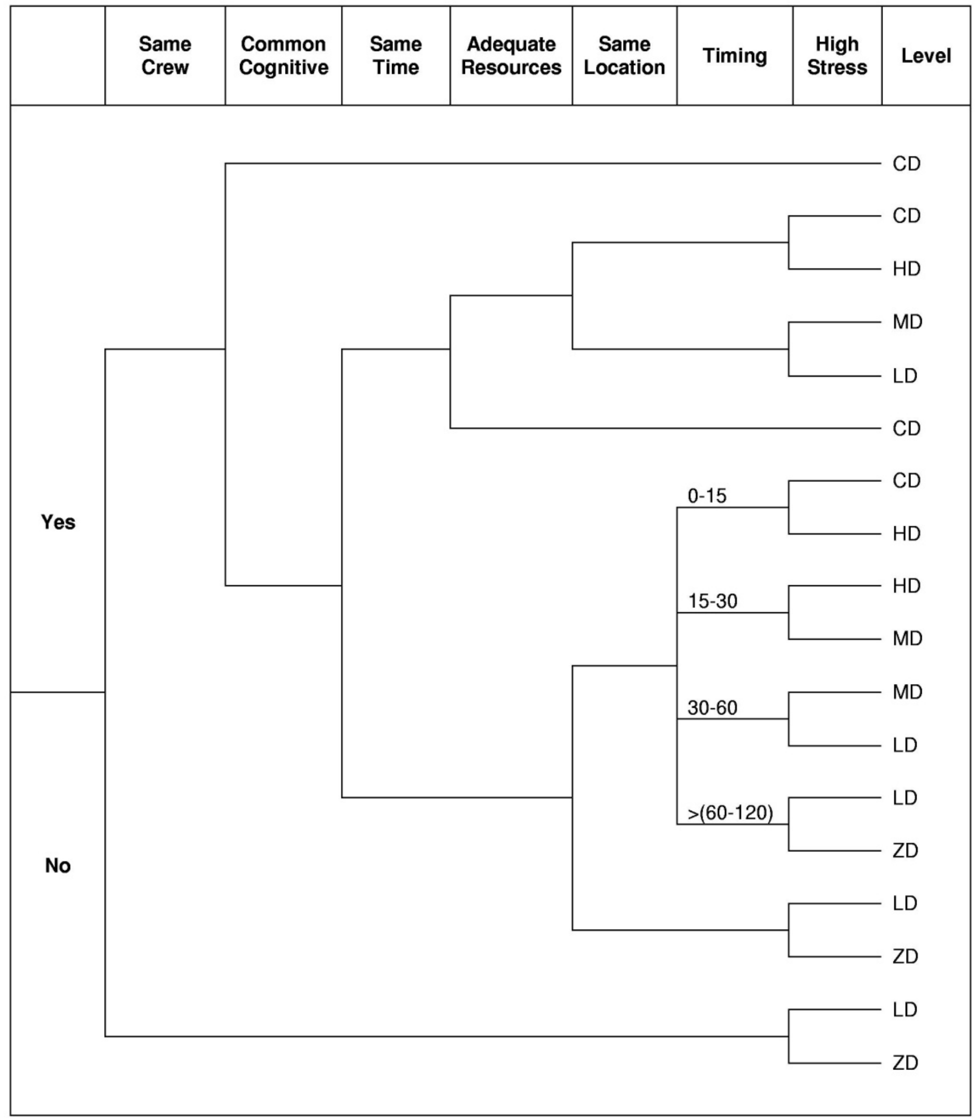


Figure 1: HRA Dependency Rules for Post-Initiator HFEs

ATHEANA Consideration of Dependency

- Unsafe Action (UA): Actions inappropriately taken (~ EOCs), or not taken when needed (~ EOOs), by plant personnel that result in a degraded plant safety condition
- In ATHEANA, the potential for multiple UAs contributing to a particular HFE is considered
- Modeling and analyzing at the UA level provides the means to explicitly investigate the potential impact of different UAs on the plant response, as well as on other human actions
- ATHEANA considers dependency when there is a significant perceived dependency between a particular UA associated with the HFE and some other human failure modeled in the PRA (either upstream or downstream in the chain of events depicted by the PRA sequence)

ATHEANA Consideration of Dependency *(continued)*

- By breaking the HFE into UAs, the specific dependency can be modeled more appropriately and explicitly
- If multiple human failures in the same sequence are not foreseen during the initial quantification of the various UAs and their contexts, then as with any PRA/HRA methodology, there will be an obligation of the analysts to identify such combinations once the PRA is initially "solved" and the human error combinations can be readily identified
- Based on this information, HEP evaluation may have to be revisited/redone if the results of these evaluations are potentially significant contributors to the risk and sufficiently strong dependencies are considered to likely exist among certain HFE/UAs

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7. **Uncertainty analysis**

Uncertainty Definitions
per the PRA Standard

- Uncertainty in the context of PRA and HRA is defined as the representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA
- Uncertainty analysis: the process of identifying and characterizing the sources of uncertainty in the analysis, and evaluating their impact on the PRA results and developing a quantitative measure to the extent practical
- Guidance now available via NUREG-1855 and EPRI 1016737 on parameter and modeling uncertainties in PRA

Applicable HLRs (per the PRA Standard)
Uncertainty

- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence (8 SRs)
- HLR-QU-E: Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and related assumptions shall be identified, and their potential impact on the results understood (4 SRs)
- HLR-UNC-A: The Fire PRA shall identify sources of CDF and LERF uncertainties and related assumptions and modeling approximations. These uncertainties shall be characterized such that their potential impacts on the results are understood (2 SRs)

Uncertainty Overview

- For fire HRA, uncertainties are addressed in the same manner as for internal events HRA
- The HRA should characterize the uncertainty in the estimates of the HEPs consistent with the quantification approach, and provide mean values for use in quantification
- In fire HRA, key assumptions may include timing or selections of performance shaping factors

- Corresponding PRA Standard SRs: Part 2, HR-G8, QU-E3

Qualitative Issues Contributing to FHRA Uncertainty

- Some actions use screening values in the Internal Events PRA and these may be carried over to the fire HRA model as screening values
- Operators dealing with fire scenarios may use multiple Emergency and Abnormal Operating Procedures (EOPs and AOPs) at the same time to deal with multiple failure conditions, such as loss of inventory and loss of heat sink due to electrical cable failures
- Operators rely on the plant computer information to supplement the primary safety related instruments as diverse information sources. However, the computer systems are not usually considered in the fire model

Qualitative Issues Contributing to FHRA Uncertainty (*continued*)

- The operators may not have specific procedures/plans for returning to the control room after a fire is out
- In case of fire, the MCR instrument response can degrade the flow of information to the operators
- Procedures dealing with fire are accurate in addressing Appendix R concerns, but can be complex for specific fire areas and may require some counterintuitive steps for the operators

Uncertainty Analysis

Examples

- Modeling Uncertainty
  - Alternate Shutdown/Main control room (MCR) abandonment actions
    - Unclear decision criteria for abandonment which are plant specific
    - When habitability is not an issue, crew may not completely abandon MCR even if their ability to control the plant (i.e., loss of MCR functionality) is hindered due to fire effects on control cables, etc.

Uncertainty Analysis

Examples

- Quantification of Data Uncertainty
  - A number of activities may influence time to respond and contribute to diagnosis and execution timing uncertainty
  - Situations or factors in fire context that may be difficult to recreate include:
    - MCR staff obtaining correct fire plan and procedures once fire location is confirmed
    - Collecting procedures, checking out communications equipment and obtaining any special tools or personnel protective equipment necessary to perform actions at local station
    - Traveling to necessary locations through smoke
    - MCR staff alerting and/or communicating with local staff implementing coordinated or sequential actions in multiple locations
    - Difficulties such as problems with instruments or other equipment (e.g., locked doors, a stiff hand wheel, or an erratic communication device)

Uncertainty Analysis
Examples (Cont'd)

- Completeness Uncertainty
  - According to Reg Guide 1.174, reflects an unanalyzed contribution due to:
    - Scope limitations
    - Methods not available
      - influences of organizational performance
    - Methods not refined to level of internal events analysis
      - analysis of some external events
      - low-power and shutdown modes of operation
  - Addressed through review process to either
    - expand upon original analysis, or
    - provide justification for scope constraints (risk-informed process described in RG 1.174)

Uncertainty in Detailed HRA
EPRI HRA Calculator

- EPRI HRA Calculator approach to addressing uncertainty
  - is based on THERP Table 20-20 and guidance in THERP Chapter 7
  - applies the same error factors as for internal events
  - THERP's assessment of uncertainty
    - assumes a lognormal distribution
    - assigns an error factor solely based on the final HEP
  - Since the approach is not based on the initiating event, it can be applied to all initiators including fire
- Contrast with ATHEANA, which develops probability distributions using expert elicitation

EPRI HRA Calculator Uncertainty Categories for Detailed Analysis

Estimated HEP	REFERENCE	ERROR FACTOR
< 0.001	THERP Table 20-20	10
> 0.001	THERP Table 20-20	5
> 0.1	Mathematical convenience	1

Uncertainty in Detailed HRA
ATHEANA

- ATHEANA uncertainty analysis is performed by developing probability distributions using expert elicitation
- The facilitator, with the assistance of the experts, puts forth two questions that progressively move the entire group from a qualitative evaluation to a quantitative estimate of the HEP and its uncertainty distribution:
  1. Given all the relevant evidence, how difficult or challenging is the action of interest for the scenario/context and why?
  2. Hence, what is the probability distribution for the HEP that best reflects this level of difficulty or challenge considering uncertainty?
- Applications of ATHEANA have found it useful to first provide a calibration mechanism for the experts to begin to interpret their qualitative conclusions into a probability

ATHEANA - Suggested Set of Initial Calibration Points for the Experts

Circumstance	Probability	Meaning
The operator(s) is "Certain" to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
The operator(s) is "Likely" to fail	~ 0.5	5 out of 10 would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
The operator(s) would "Infrequently" fail	~ 0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crews/operators were to experience this scenario.
The operator(s) is "Unlikely" to fail	~ 0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
The operator(s) is "Extremely Unlikely" to fail	~ 0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

Uncertainty Analysis References

- NUREG-1855, “Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making,” March 2009
- EPRI 1016737, “Treatment of Parameter and Model Uncertainty for Probabilistic Risk Assessments,” December 2008
- NUREG-1880, “ATHEANA User’s Guide,” June 2007
- EPRI 1009652, “Guideline For Treatment of Uncertainty In Risk-Informed Applications,” December 2005
- NUREG-1792, “Good Practices for Implementing Human Reliability Analysis (HRA),” Sandia National Laboratories, 2005
- NUREG/CR-1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," (THERP) Swain, A.D. and Guttmann, H. E., August 1983

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EPRI

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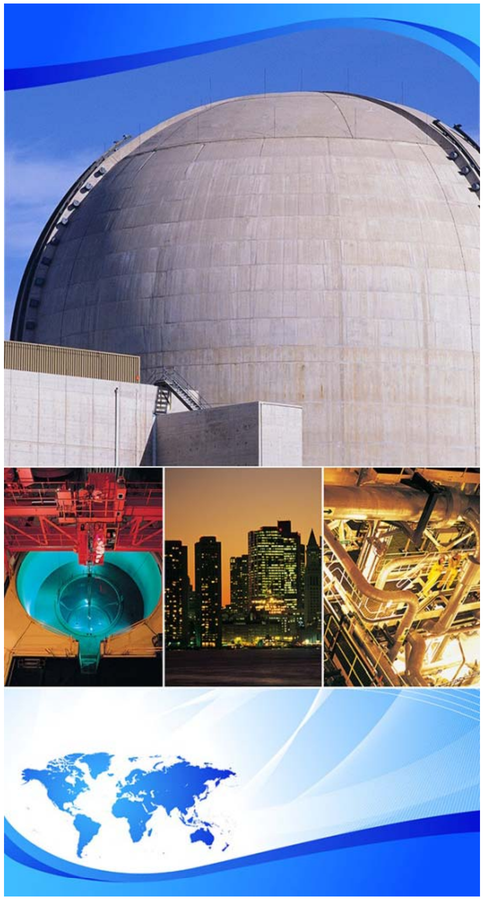

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Post-Fire HRA
EPRI Approach to
Detailed Fire HEP Quantification
Examples

Kaydee Kohlhepp (Scientech) & Stuart Lewis (EPRI)
Joint RES/EPRI Fire PRA Workshop 2011
San Diego, CA and Jacksonville, FL

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

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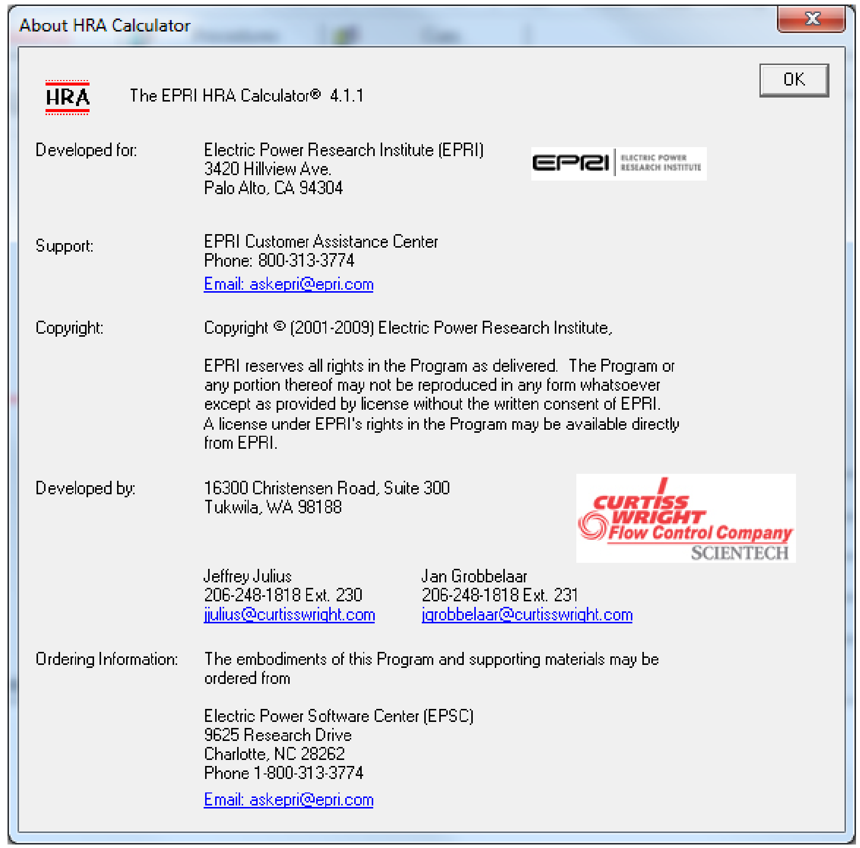
      i. Theory
      ii. Example
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

EPRI HRA Calculator^{TM}

- EPRI software was used, but is not required.
- EPRI HRA Calculator ^{TM} version 4.1.1 was used for following examples.



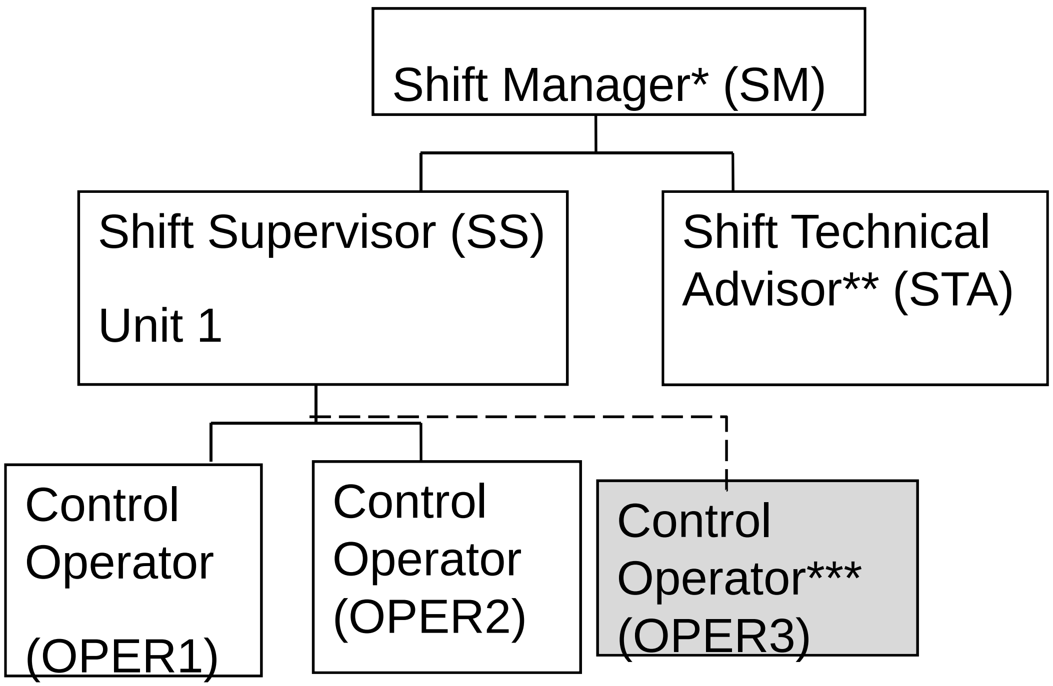
Assumptions for Examples

- Example Plant is a 2-loop Westinghouse PWR using Standard Westinghouse EOPs
- Fire PRA modeling is developed sufficiently
  - Detailed scenario descriptions & information available
- Fire Response Procedures
  - Implemented in parallel to the EOPs, and
  - Operators enter the fire procedures at the same time as they enter the EOPs
- Fire & reactor trip modeled to occur at the same time (T=0)

Crew Composition For Example Problems

- **Staffing**: Minimum staffing of the plant is as follows:

Inside Control Room:



Outside Control Room:

Local Plant Operators	Crew #
Auxiliary Operators	3
Turbine Hall Operator	2
Aux bldg/Water Treatment	2

Crew composition and titles are plant specific

*Dealing with high-level management issues (e.g., communicating with NRC)

**Can be outside CR. Will be in CR within 10 minutes of reactor trip.

***Normally available but not considered to be minimum staffing

Division of Labor During Fire Scenario

Following detection of fire, some crew members become members of the fire brigade and are unable to assist in actions directed by the control room. The fire brigade's only duty is to extinguish the fire.

Crew Member	Total Available Before Fire	# assisting with fire*	# Available for EOP actions
Shift Manager	1	1	0
Shift Supervisor	1	0	1
STA	1	0	1
Control Room Operators	2	1	1
Plant operators	7	4	3

*This includes members of fire brigade and staff occupied with FPs or otherwise occupied due to the fire

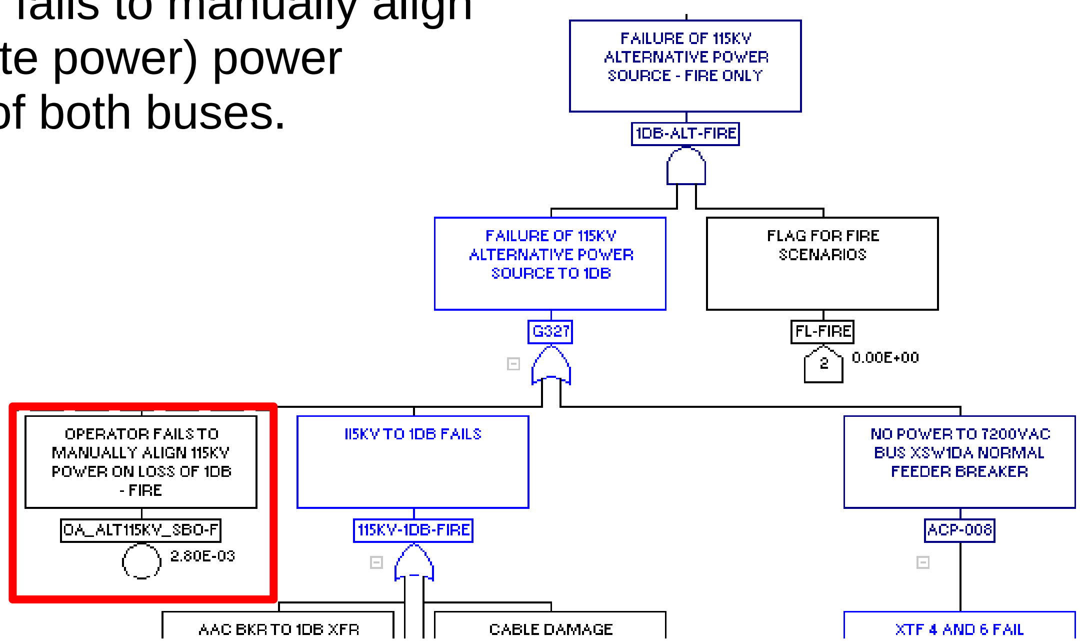
The EPRI approach reflects the plant practice that while the fire is ongoing no members of the fire brigade are available to assist with local or control room actions.

Generic Fire Response Timeline

Time (Minutes)	
T=0	Fire causes reactor trip
T=0	Control room receives fire alarm and actives fire brigade Control room sends local operator to investigate fire
T=5	Control room starts implementing Fire procedures in parallel to EOPs
T=10	Fire brigade is expected to be assembled and fighting fire within 10 minutes of activations
T=15	ERF activated and unusual event declared. Typical, plant policy states that if a fire is not under control within 15 minutes must declare unusual event.
T=70	Fire is out 99% of all fires are extinguished per FAQ 50

Example 1 - Operator fails to manually align 115kV bus (SBO)

- **Initial Conditions**:
- Steady state, full power operation.
  - Minimal staff on shift.
  - No out-of-service safe shutdown equipment.
- **Initiating Event**: Fire in turbine hall causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power following loss of both buses.



Accident Sequence & Success Criteria

Accident Sequence

- o Fire cause reactor trip
- o Turbine trip successful.
- o AFW failed due to the fire.
- o Primary PORV spuriously opens due to the fire.
- o The Main Generator breaker opens and the BOP busses are powered through XTF0001 (reverse) and XTF0002.
- o EDG B starts and the ESF Loading Sequencer loads onto bus.
- o EDG B trips due to fire damage. The ESF Loading Sequencer is still sending a signal to trip the normal and alternate feeder breakers (for EDG protection) to the bus.
- o All diesels failed – SBO
- o DC power remains available until batteries deplete. Batteries will last for 4 hrs

Operators Success Criteria

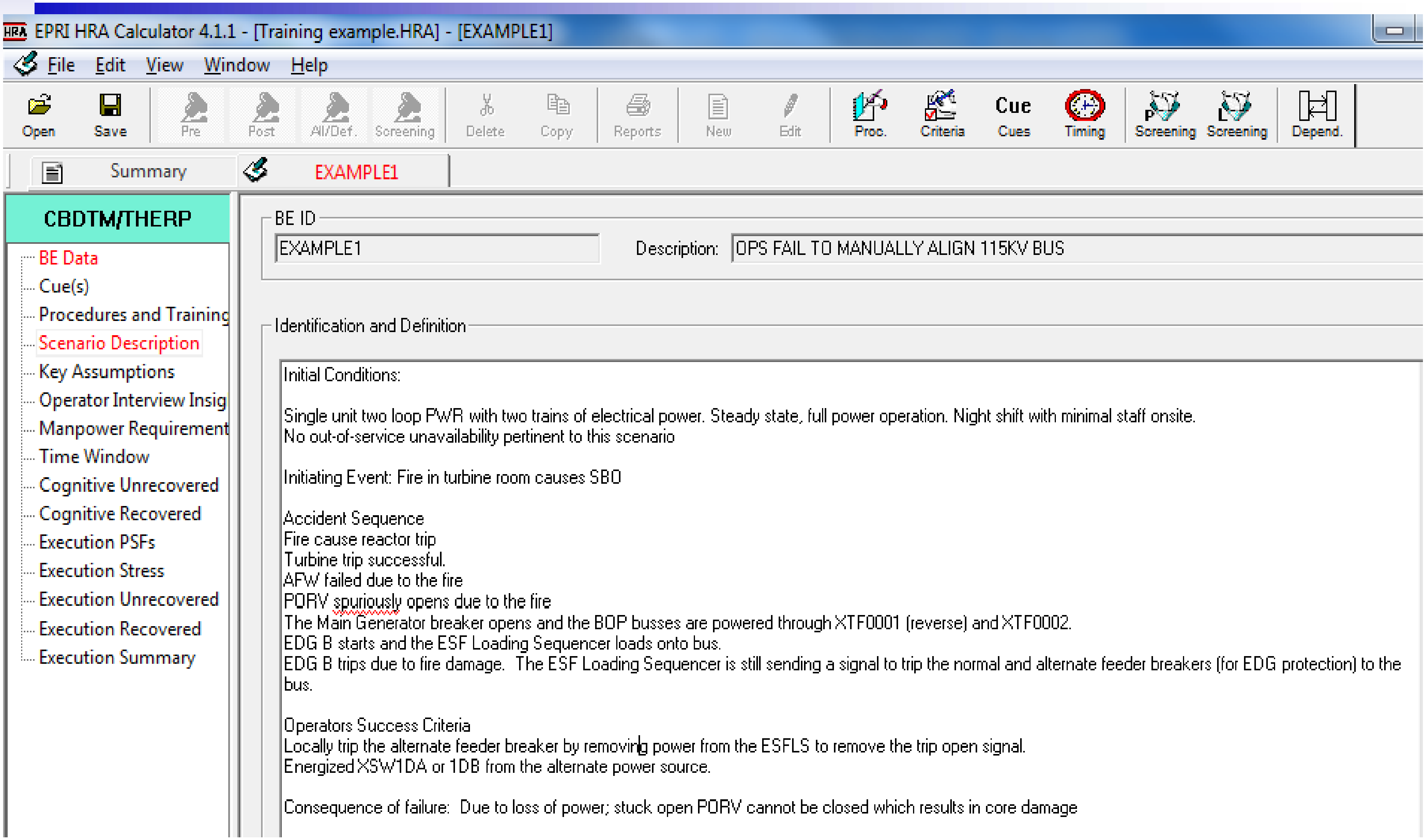
- o Locally trip the alternate feeder breaker by removing power from the ESFLS to remove the trip open signal.
- o Energized 1DB from the alternate power source.

Consequence of failure: Core damage due to stuck open PORV

Expected Crew Response

Time	Event	Comment
T=0min	Fire and Reactor Trip	
T=0min	Control Room dispatches fire brigade to fight the fire; immediate memorized actions (steps 1-3 EOP 0) performed	Fire brigade comprised of 3 Local Plant Operators
T=3min	EOP 3, step 3 indicates SBO. Procedure transition brief held by SS to alert all control room staff that they have an SBO and fire. They will be entering ECA 0.0	OPER1 designated to perform ECA 0.0; OPER2 designated to start reviews of FP
T=5min	OPER1 begins ECA 0.0	
T=7min	Step 4 ECA 0.0 dispatch Local Plant Operator to investigate failure of AFW	Assume this Local Plant Operator will be tied up restoring AFW and not available to assist in additional actions
T=10min	STA arrives	Begins monitoring critical safety functions
T=15min	OPER1 reaches step 10 ECA 0.0, notifies SS that they need to transition to AOP 304	By this time OPER2 has finished reading through FP
T=15min	SS briefs control room staff on the AOP coordination with the FPs	7 contingent time critical action (need in the first hr) in FP; 2 necessary. Confirmed: FP actions will not interfere with AOP actions; sufficient personnel available to do both in parallel. Late actions (>4hr) are postponed until SBO is recovered.
T=20min	OPER1 begins AOP 304; OPER2 begins directing FP actions	OPER2 dispatches 1 Local Plant Operator to perform FP actions
T=35min	OPER1 arrives at step 17 of AOP 304 (locally remove power from ESFLS)	Cue for action

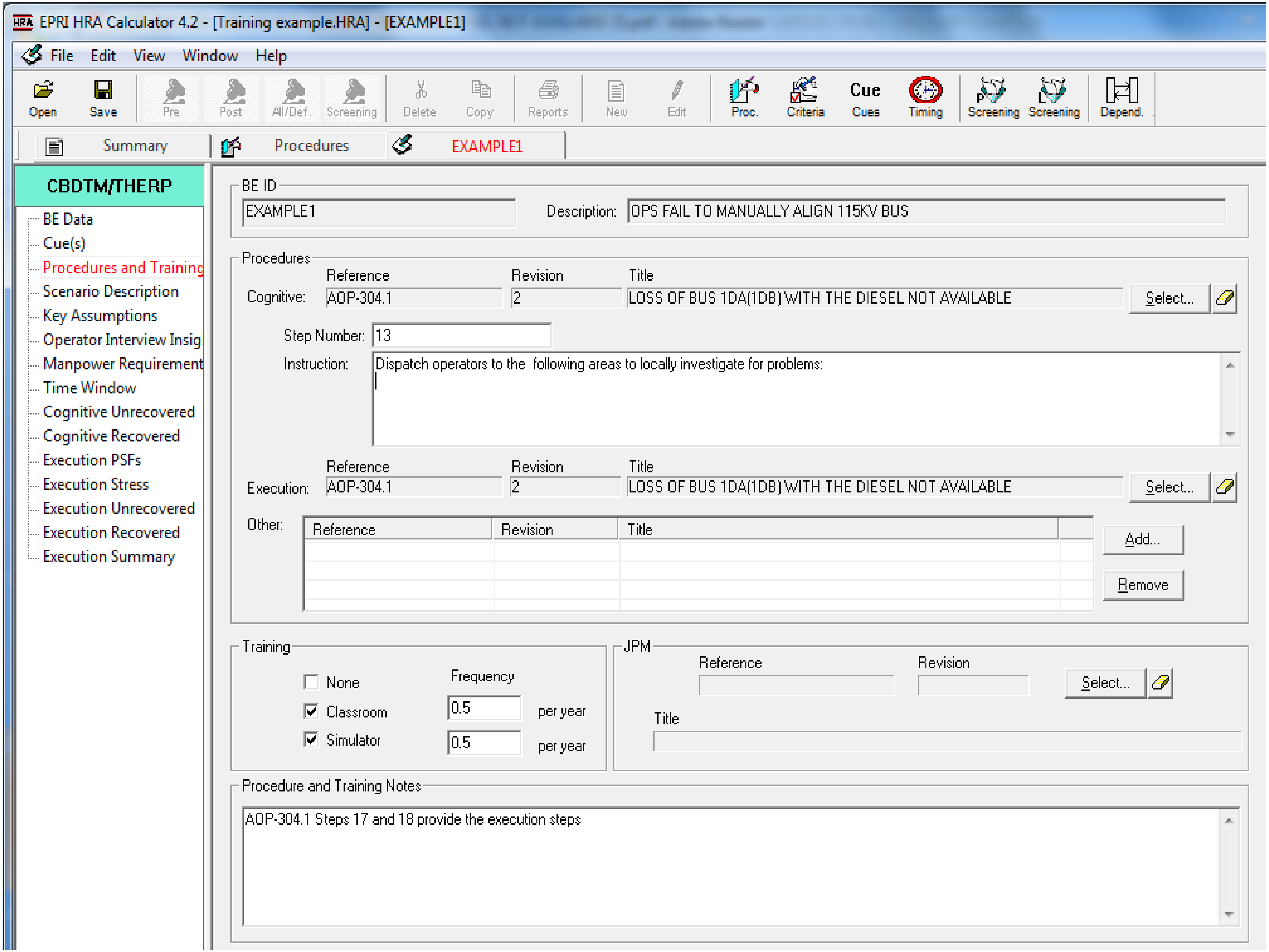
Scenario Description Using EPRI HRA Calculator



Procedures

- **Procedures**:
  - o Upon Reactor Trip, enter EOP-0
    - Step 3 of EOP-0 verifies that buses are energized. Buses are de-energized; this will take the operator to ECA 0.0 [Station Blackout Procedure]
    - Step 10 of ECA 0.0 checks that buses 1DB and 1 DA are energized. Both buses are de-energized; this will take the operator to AOP 304 due to loss of bus with no EDG.
    - Steps 17 and 18 of AOP 304 are the relevant response actions for this HFE:

ACTION/EXPECTED RESPONSE	ALTERNATIVE ACTION
17 **Locally remove power from the Train A ESF Loading Sequencer (XPN-6020 CB-436).** ☐	
18 **Energize XSW1DA from the normal power source:** a. Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b. Close BUS 1DA NORM FEED Breaker. ☐ c. Verify BUS 1DA potential lights are energized. ☐	18 <u>IF</u> XSW1DA normal power source is <u>NOT</u> available, <u>THEN</u> energize XSW1DA from the alternate power source: a) Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b) Close BUS 1DA ALT FEED Breaker. ☐ c) Verify BUS 1DA potential lights are energized. ☐


EPRI HRA Calculator 4.2 - [Training example.HRA] - [EXAMPLE1]
File Edit View Window Help
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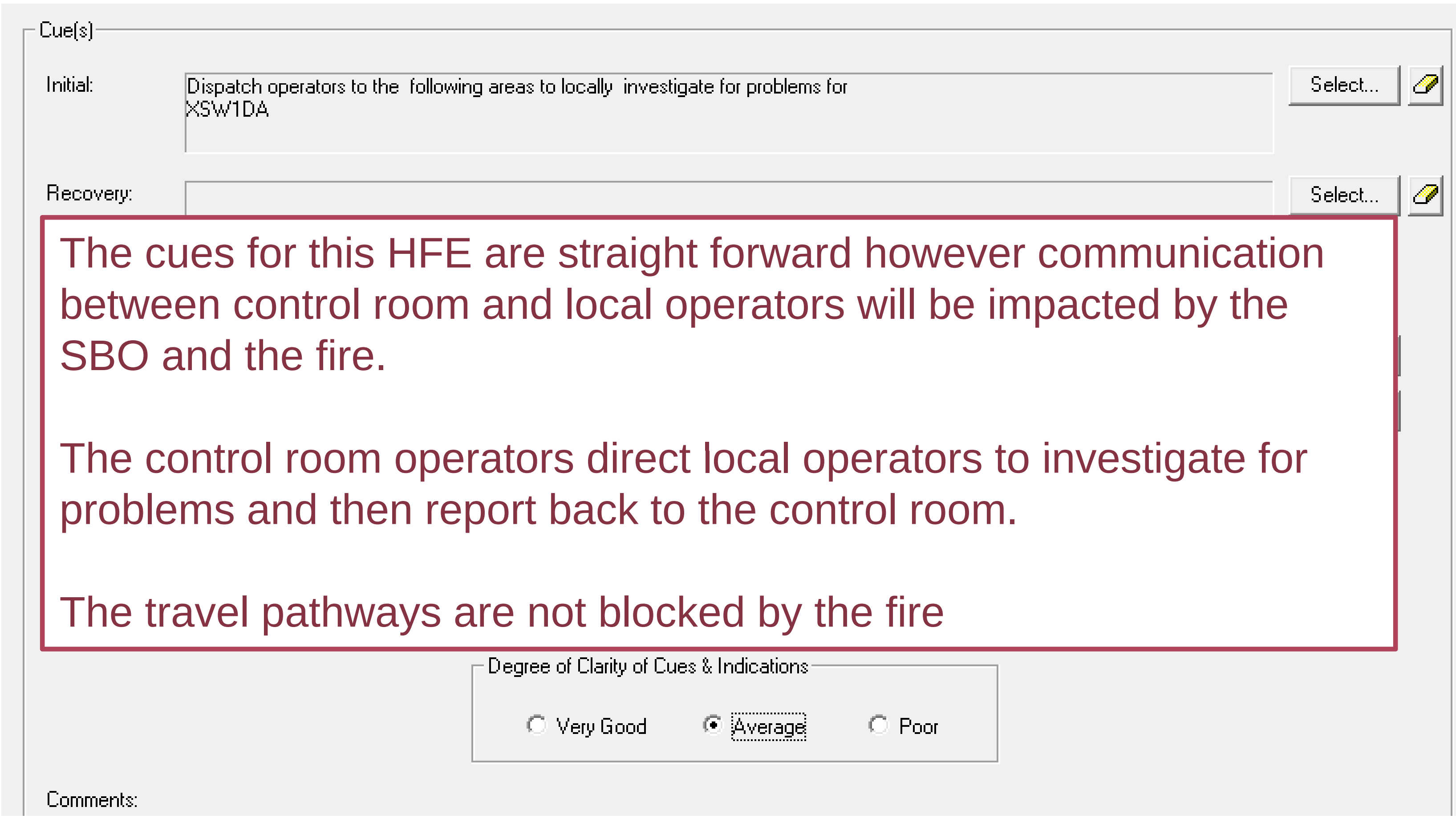
Summary Procedures EXAMPLE1
CBDTM/THERP
BE Data
Cue(s)
Procedures and Training
Scenario Description
Key Assumptions
Operator Interview Insig
Manpower Requirement
Time Window
Cognitive Unrecovered
Cognitive Recovered
Execution PSFs
Execution Stress
Execution Unrecovered
Execution Recovered
Execution Summary
BE ID
EXAMPLE1
Description: OPS FAIL TO MANUALLY ALIGN 115KV BUS
Procedures
Reference Revision Title
Cognitive: AOP-304.1 2 LOSS OF BUS 1DA(1DB) WITH THE DIESEL NOT AVAILABLE
Select...
Step Number: 13
Instruction: Dispatch operators to the following areas to locally investigate for problems:
Reference Revision Title
Execution: AOP-304.1 2 LOSS OF BUS 1DA(1DB) WITH THE DIESEL NOT AVAILABLE
Select...
Other: Reference Revision Title
Add...
Remove
Training
None
Classroom
Simulator
Frequency
0.5 per year
0.5 per year
JPM
Reference
Revision
Select...
Title
Procedure and Training Notes
AOP-304.1 Steps 17 and 18 provide the execution steps

Cues

LOSS OF BUS 1DA WITH THE DIESEL NOT AVAILABLE

ACTION/EXPECTED RESPONSE	ALTERNATIVE ACTION
13 **Determine the cause for loss of the ESF Bus:** a. **REFER TO ARP-001 XCP-633 through 641, ANNUNCIATOR RESPONSE PROCEDURE,** for annunciator(s) in alarm. ☐ b. Dispatch operators to the following areas to locally investigate for problems: • XTF0004 and XTF0005, ESF Transformers. ☐ • XTF0031, Emergency Aux Transformer #1. ☐ • XSW1DA. ☐ • XCX5201, Diesel Generator A Local Control Panel. ☐ • GENERATOR & XFMR ELECTRICAL RELAY BOARD (CB-463), XCP6221A-EG and XCP6225-EG. ☐	

Cues



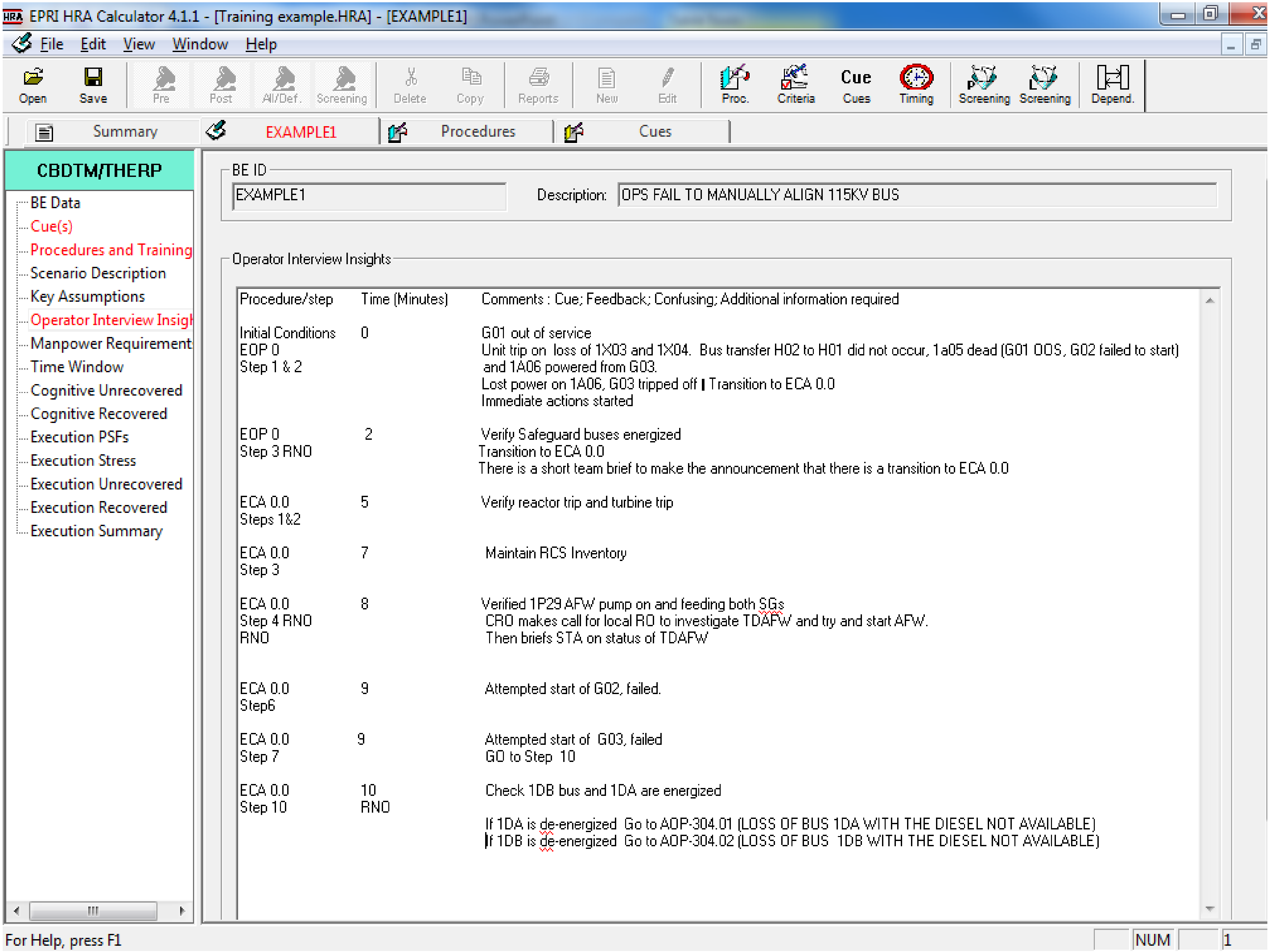
The cues for this HFE are straight forward however communication between control room and local operators will be impacted by the SBO and the fire.

The control room operators direct local operators to investigate for problems and then report back to the control room.

The travel pathways are not blocked by the fire

Simulator Observation (SBO non-fire scenario)

Procedure/step	Time (Minutes)	Comments : Cue; Feedback; Confusing; Additional information required
Initial Conditions	0	G01 out of service
EOP-0 Step 1 & 2	0	Unit trip on loss of 1X03 and 1X04. Bus transfer H02 to H01 did not occur, 1a05 dead (G01 OOS, G02 failed to start) and 1A06 powered from G03. Lost power on 1A06, G03 tripped off – Transition to ECA-0.0 EOP-0 Immediate actions started
EOP-0 Step 3 RNO	2	Verify Safeguard buses energized Transition to ECA 0.0 There was a short team brief to make the announcement that there was a transition to ECA 0.0
ECA-0.0 Steps 1&2	5	Verify reactor trip and turbine trip
ECA-0.0 Step 3	7	Maintain RCS Inventory
ECA-0.0 Step 4 RNO	8	Verified 1P29 AFW pump on and feeding both SGs CRO makes call for local RO to investigate TDAFW and try and start AFW. Then briefs STA on status of TDAFW
ECA-0.0 Step6	9	Attempted start of G02, failed.
ECA-0.0 Step 7	9	Attempted start of G03, failed – GO to Step 10
ECA-0.0 Step 10	10	Check 1DB bus and 1DA are energized RNO If 1DA is de-energized Go to AOP-304.01 (LOSS OF BUS 1DA WITH THE DIESEL NOT AVAILABLE) If 1DB is de-energized Go to AOP-304.02 (LOSS OF BUS 1DB WITH THE DIESEL NOT AVAILABLE)


EPRI HRA Calculator 4.1.1 - [Training example.HRA] - [EXAMPLE1]
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Procedures
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BE Data
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Scenario Description
Key Assumptions
Operator Interview Insigl
Manpower Requirement
Time Window
Cognitive Unrecovered
Cognitive Recovered
Execution PSFs
Execution Stress
Execution Unrecovered
Execution Recovered
Execution Summary
BE ID
EXAMPLE1
Description: OPS FAIL TO MANUALLY ALIGN 115KV BUS
Operator Interview Insights
Procedure/step Time (Minutes) Comments : Cue; Feedback; Confusing; Additional information required
Initial Conditions 0 G01 out of service
EOP 0 Unit trip on loss of 1X03 and 1X04. Bus transfer H02 to H01 did not occur, 1a05 dead (G01 OOS, G02 failed to start)
Step 1 & 2 and 1A06 powered from G03.
Lost power on 1A06, G03 tripped off | Transition to ECA 0.0
Immediate actions started
EOP 0 2 Verify Safeguard buses energized
Step 3 RNO Transition to ECA 0.0
There is a short team brief to make the announcement that there is a transition to ECA 0.0
ECA 0.0 5 Verify reactor trip and turbine trip
Steps 1&2
ECA 0.0 7 Maintain RCS Inventory
Step 3
ECA 0.0 8 Verified 1P29 AFW pump on and feeding both SGs
Step 4 RNO CRO makes call for local RO to investigate TDAFW and try and start AFW.
RNO Then briefs STA on status of TDAFW
ECA 0.0 9 Attempted start of G02, failed.
Step6
ECA 0.0 9 Attempted start of G03, failed
Step 7 GO to Step 10
ECA 0.0 10 Check 1DB bus and 1DA are energized
Step 10 RNO
If 1DA is de-energized Go to AOP-304.01 (LOSS OF BUS 1DA WITH THE DIESEL NOT AVAILABLE)
If 1DB is de-energized Go to AOP-304.02 (LOSS OF BUS 1DB WITH THE DIESEL NOT AVAILABLE)
For Help, press F1
NUM 1

Timing

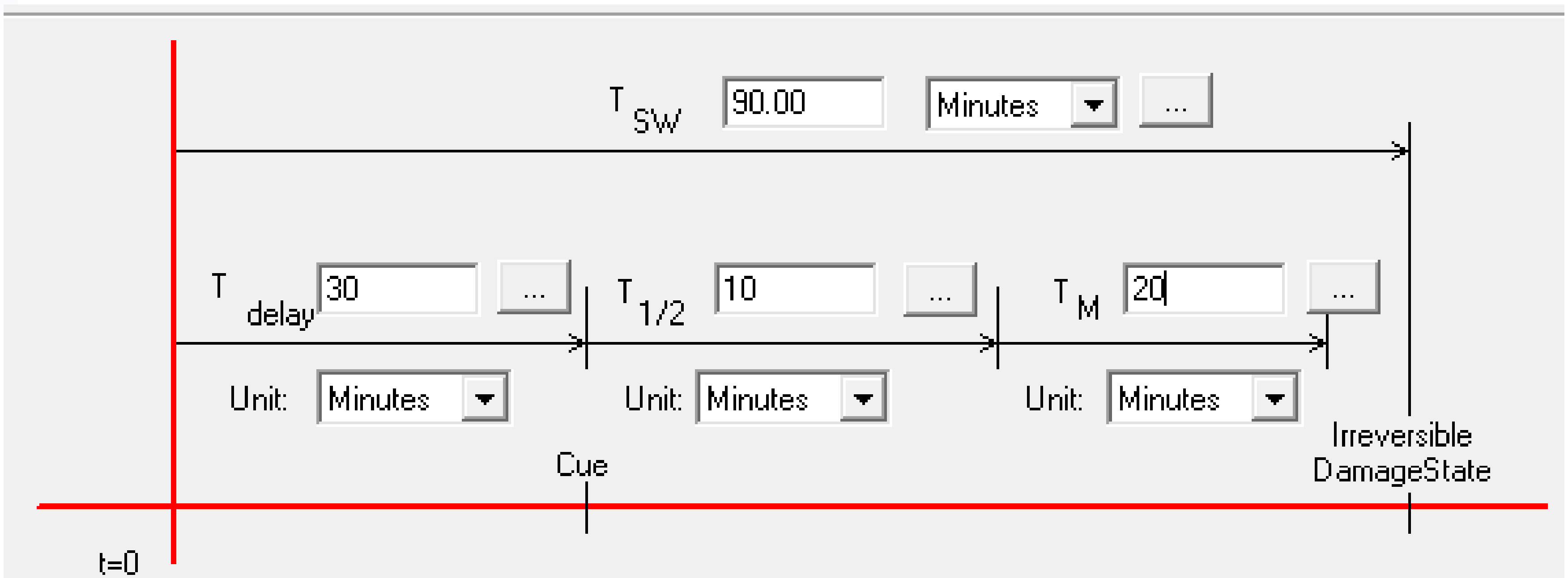
- o T = 0 Start of fire and reactor trip
- o T_{SW} = 90 minutes
  Time to core damage based on an IPE thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open.
- o T_{delay} = 30 minutes from reactor trip unit operators reach step 13
  - Based on simulator observation for a similar scenario for SBO it took operators 10 minutes to get through ECA 0.0 step 10
  - Simulation based on non-fire SBO so an additional time has been added to account for fire impacts.
  - It is estimated that it will take about 10 minutes to reach step 13 of AOP-304
  - Tdelay=20+10 minutes
- o T1/2 = 10 minutes based on operator interviews. This is the time operators estimated it would take to locally investigate status of breaker.
  - This includes time for the SS and STA to confer, coordinate with the fire procedures, approve the action and communicate to control room operators to commence steps 17 and 18.

Timing (cont'd)

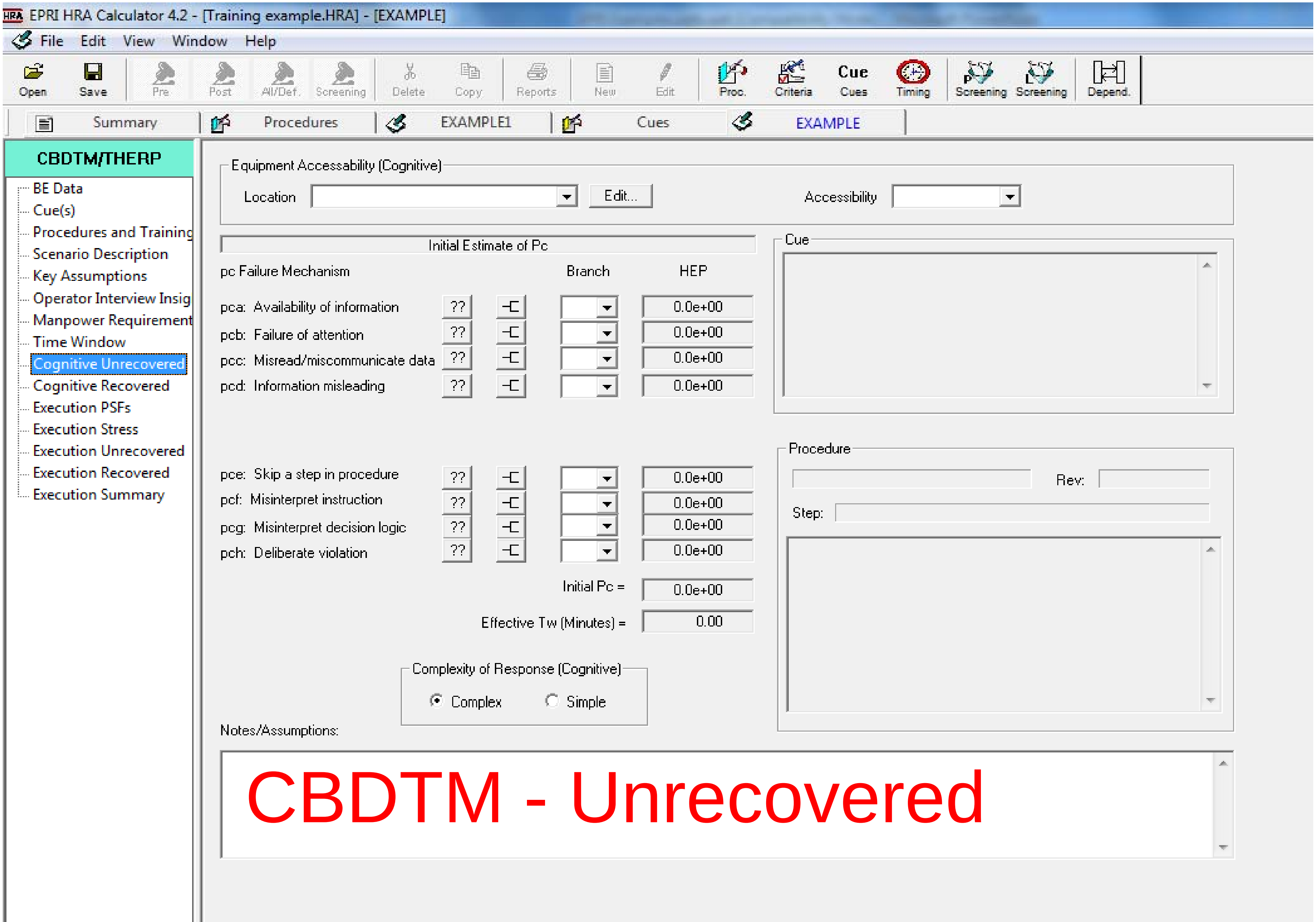
Tm = 20 minutes

- The action to locally remove power from the Train B ESF Loading Sequencer is trained on using Job Performance Measure (JPM) 12654 – Align ALT Feed Breaker. This JPM has a time requirement to be able to complete the local portion of the actions within 15 minutes, and this has been verified by observations of the JPM. The timing starts once the operator is given the instructions to perform this action and ends once the MCR action had been complete (end of step 18).
  - As part of this JPM the operators train on putting on flash gear which is required to locally remove power from the Train B ESF Loading Sequencer. The flash gear is stored in a cabinet at the entrance to the relay room.
- After the operators complete the local action they will need to return to the control room to tell the control room operators they were successful. This additional travel time is expected to take 5 minutes.
  - Under ideal conditions the Local Plant Operator could use the phone to call the control room. However, for fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable.
- Tm = 15 minutes + 5 minutes = 20 minutes

Timeline



Based on timeline a moderate dependency is considered for recovery


EPRI HRA Calculator 4.2 - [Training example.HRA] - [EXAMPLE]
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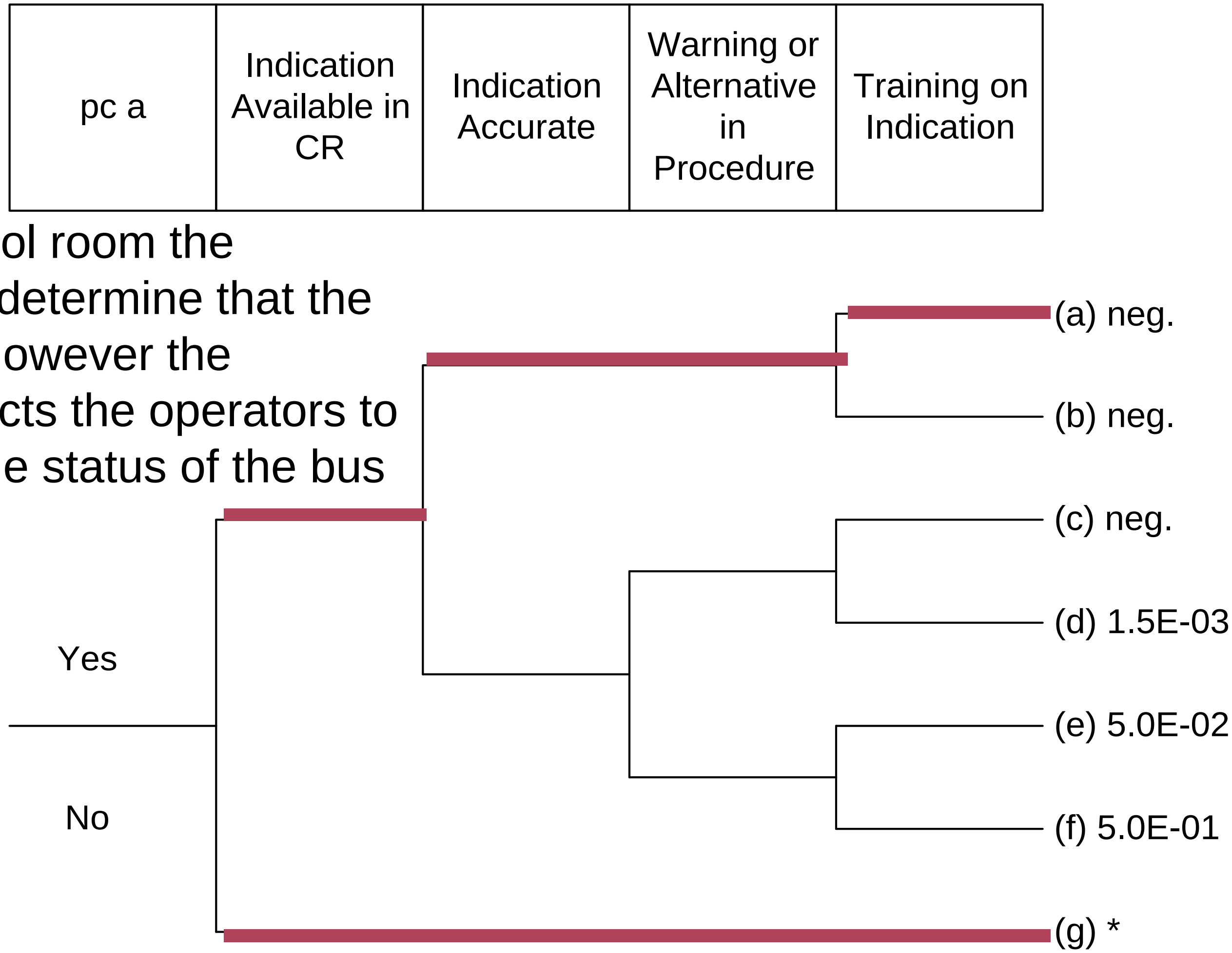
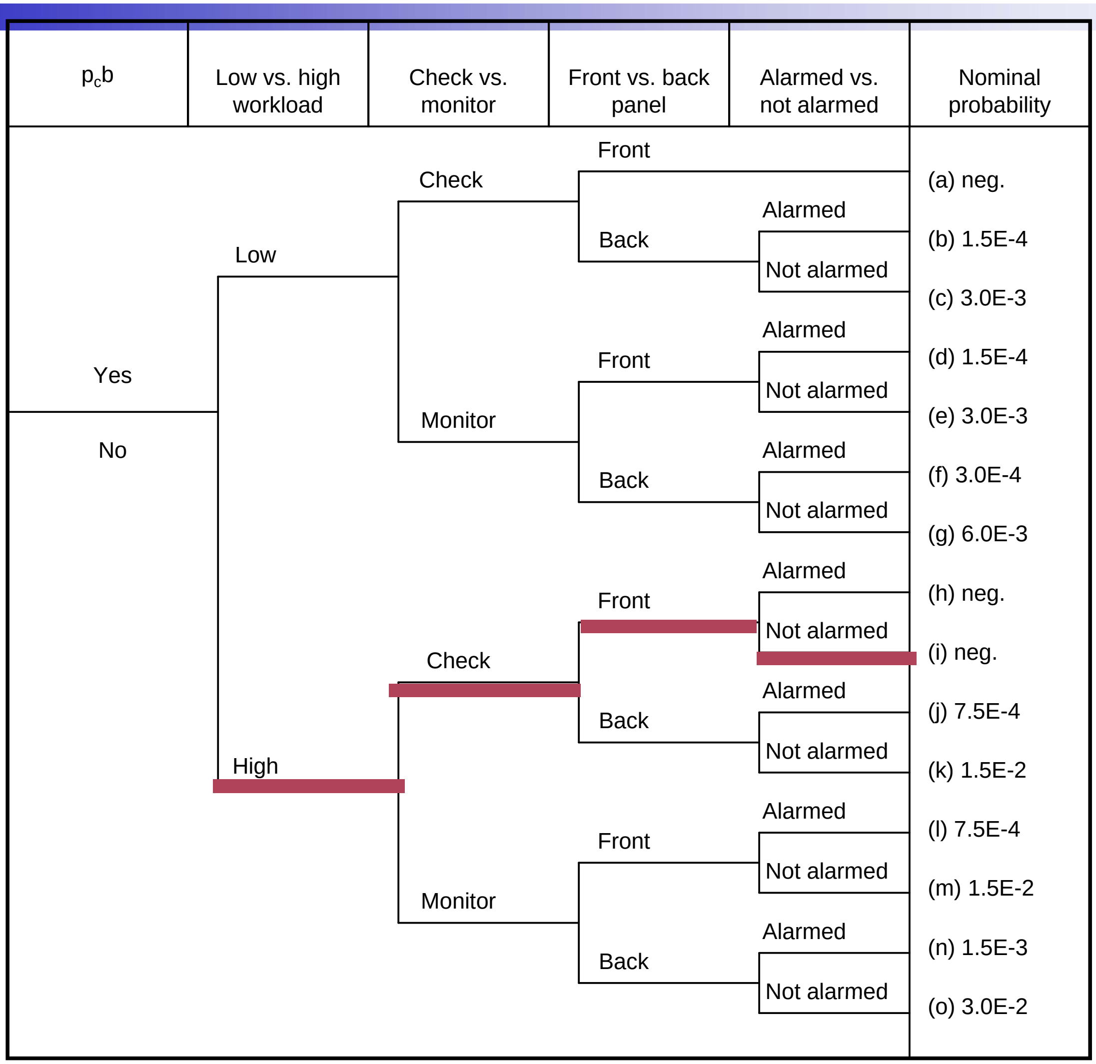
Manpower Requirement
Time Window
Cognitive Unrecovered
Cognitive Recovered
Execution PSFs
Execution Stress
Execution Unrecovered
Execution Recovered
Execution Summary
Equipment Accessability (Cognitive)
Location
Edit...
Accessibility
Initial Estimate of Pc
pc Failure Mechanism
Branch
HEP
pca: Availability of information
pcb: Failure of attention
pcc: Misread/miscommunicate data
pcd: Information misleading
pce: Skip a step in procedure
pcf: Misinterpret instruction
pcg: Misinterpret decision logic
pch: Deliberate violation
??
0.0e+00
Initial Pc =
Effective Tw (Minutes) =
0.00
Complexity of Response (Cognitive)
Complex
Simple
Notes/Assumptions:
Cue
Procedure
Rev:
Step:
CBDTM - Unrecovered

CBDTM decision tree:
pc-a Data not available

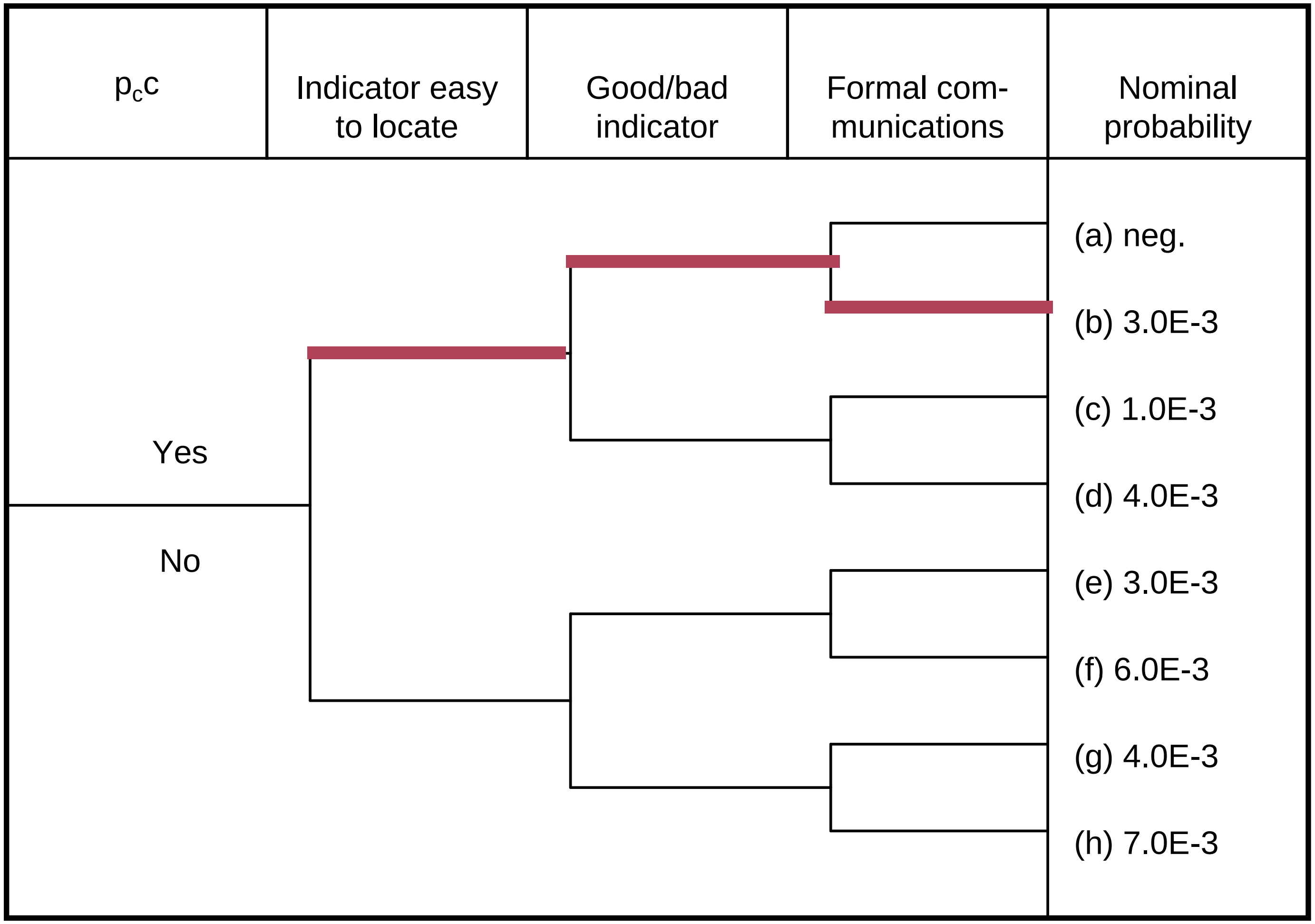
From the control room the operators can determine that the bus is failed. However the procedure directs the operators to locally verify the status of the bus



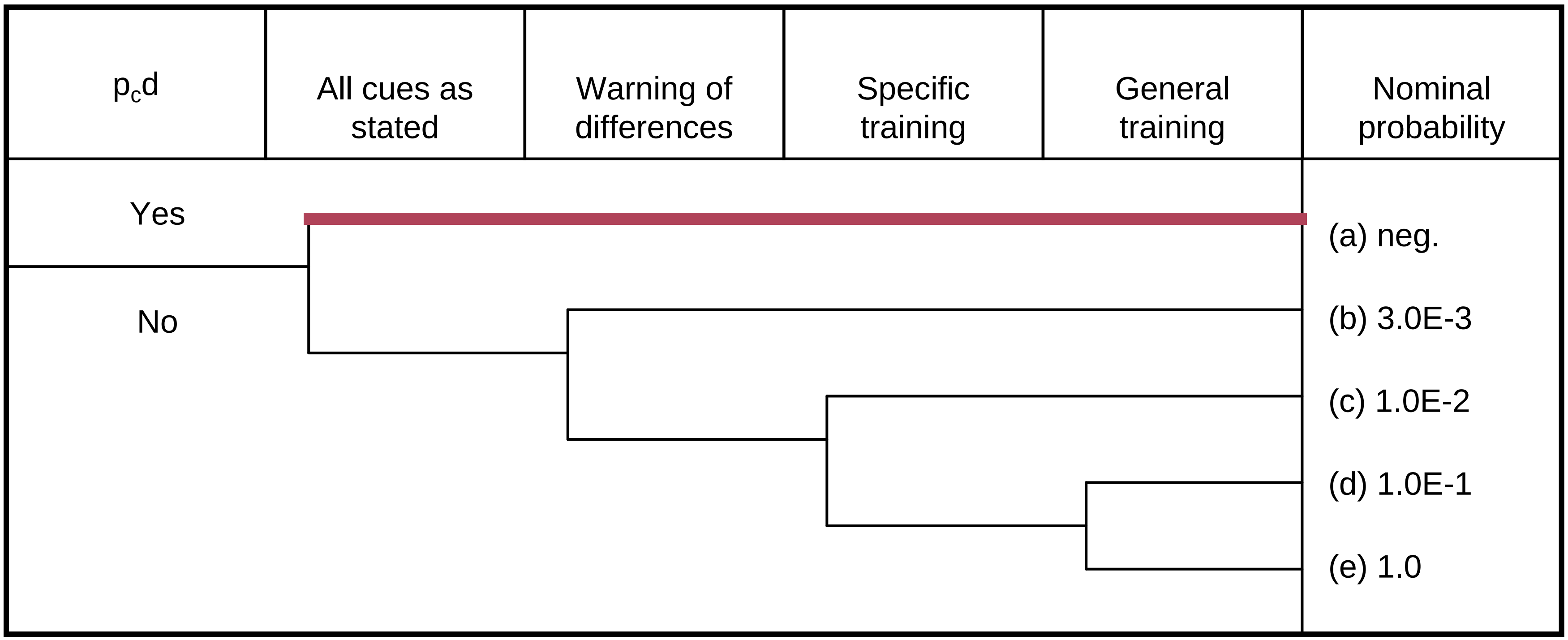
CBDTM decision tree: pc-b Data not attended to



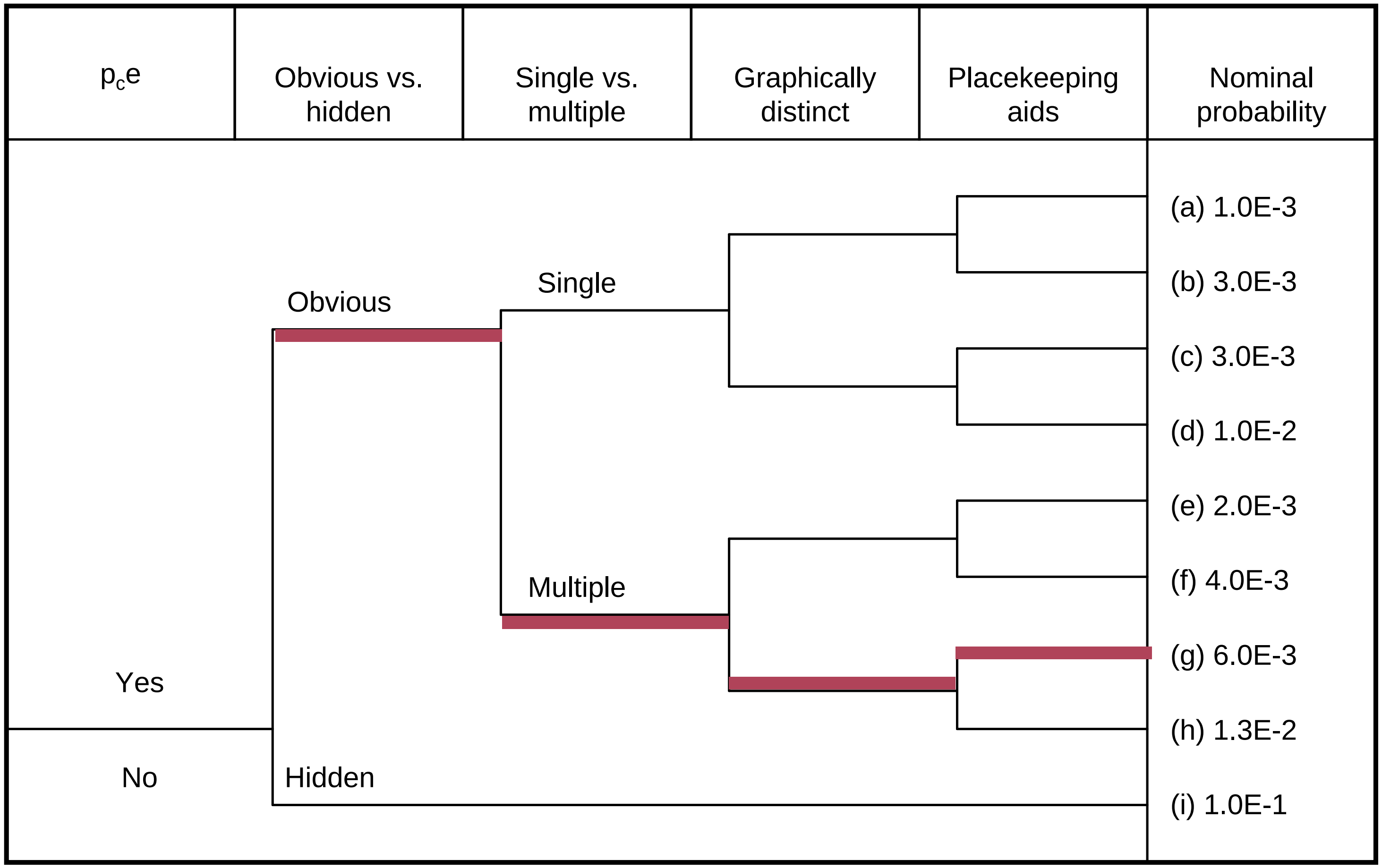
CBDTM decision tree:
pc-c Data misread or miscommunicated



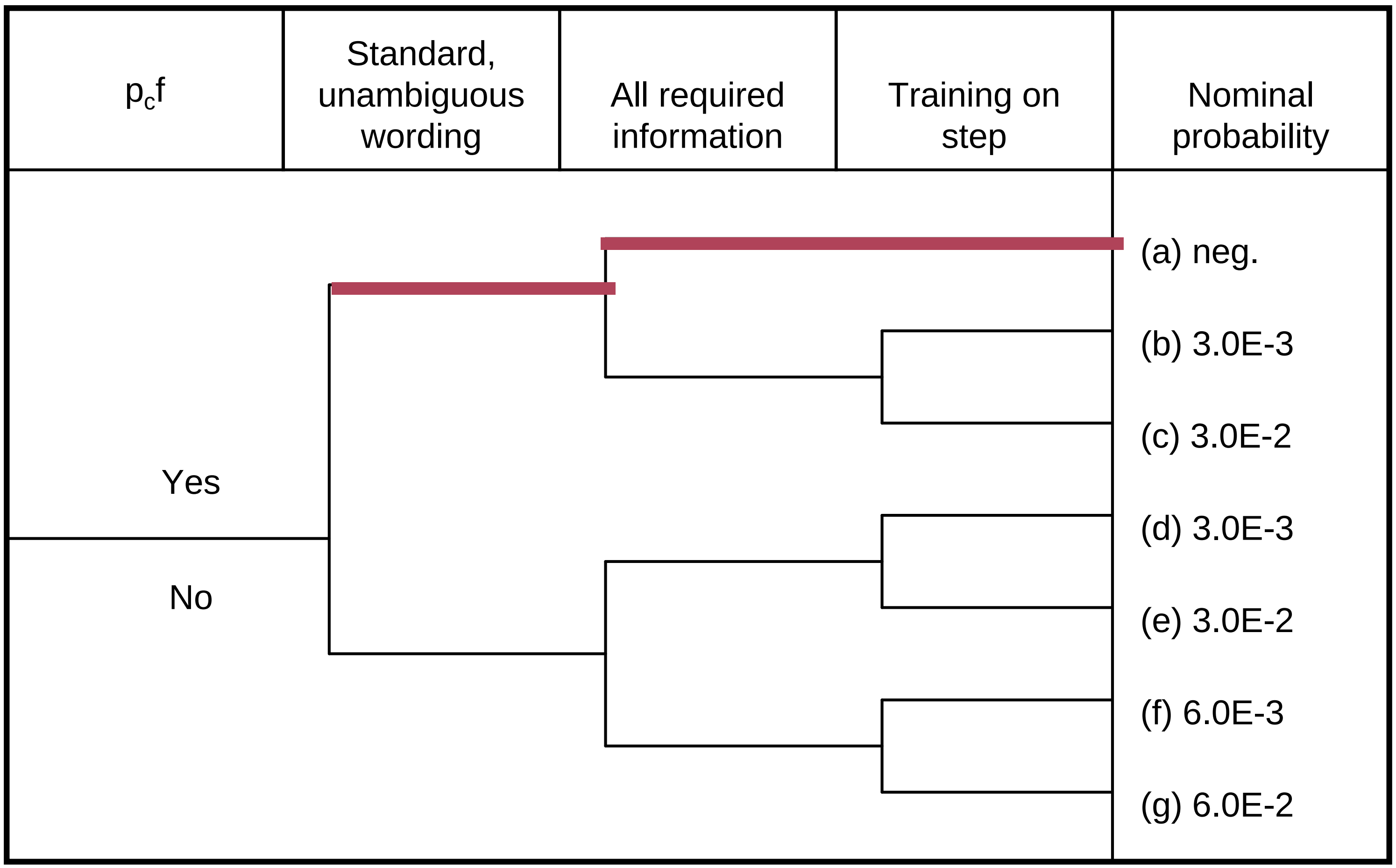
CBDTM decision tree:
pc-d Information misleading



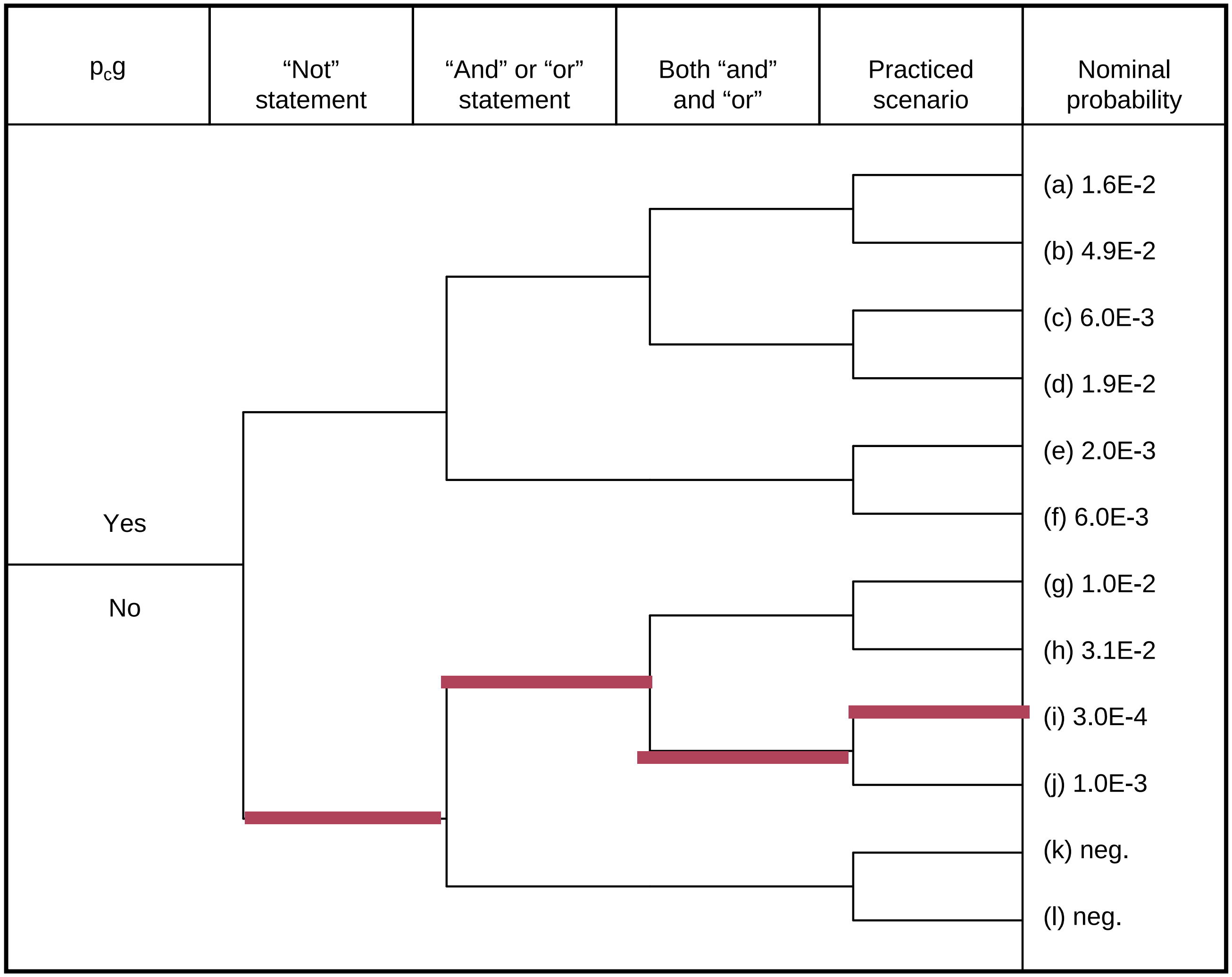
CBDTM decision tree:
pc-e Relevant step in procedure missed



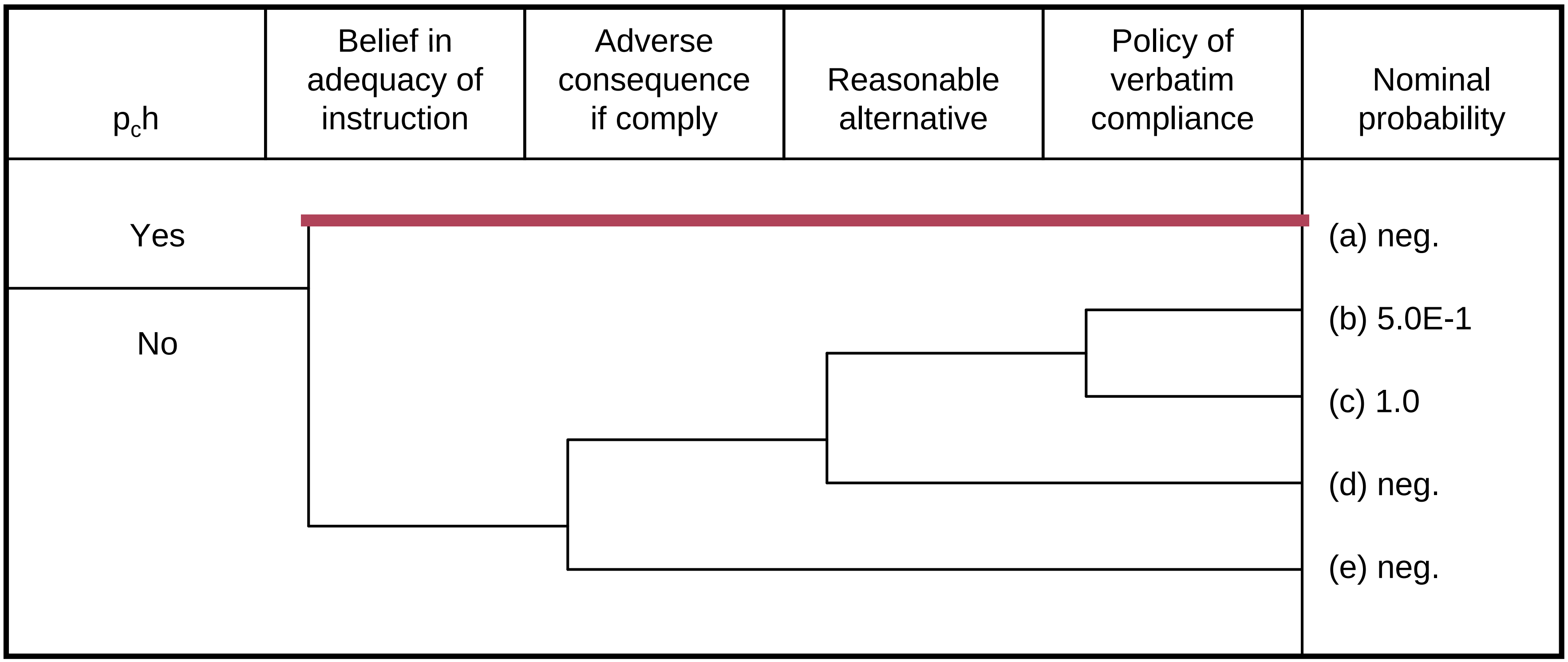
CBDTM decision tree: pc-f Misinterpret instruction



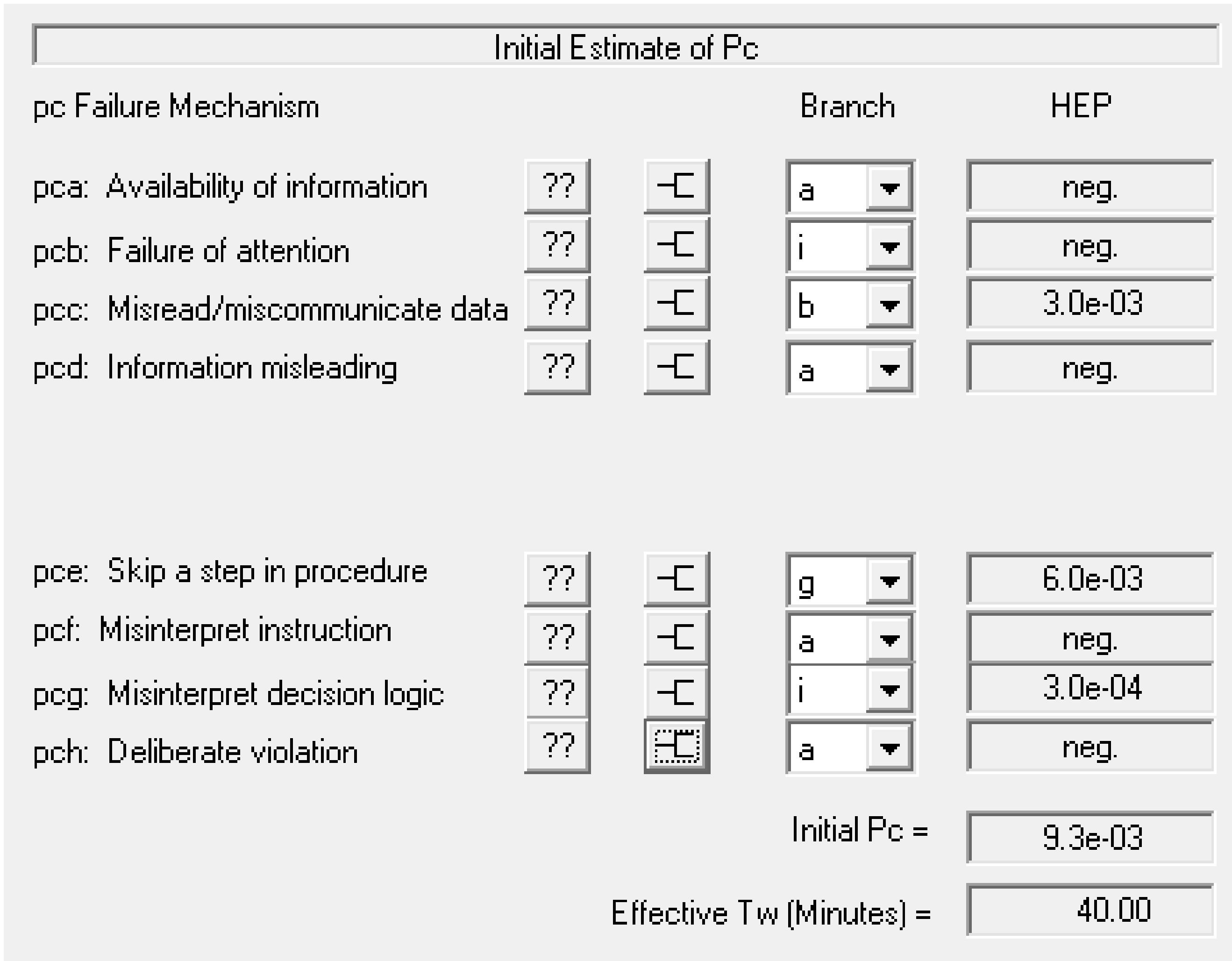
CBDTM decision tree:
pc-g Error in interpreting logic



CBDTM decision tree: pc-h Deliberate violation



CBDTM Summary Unrecovered

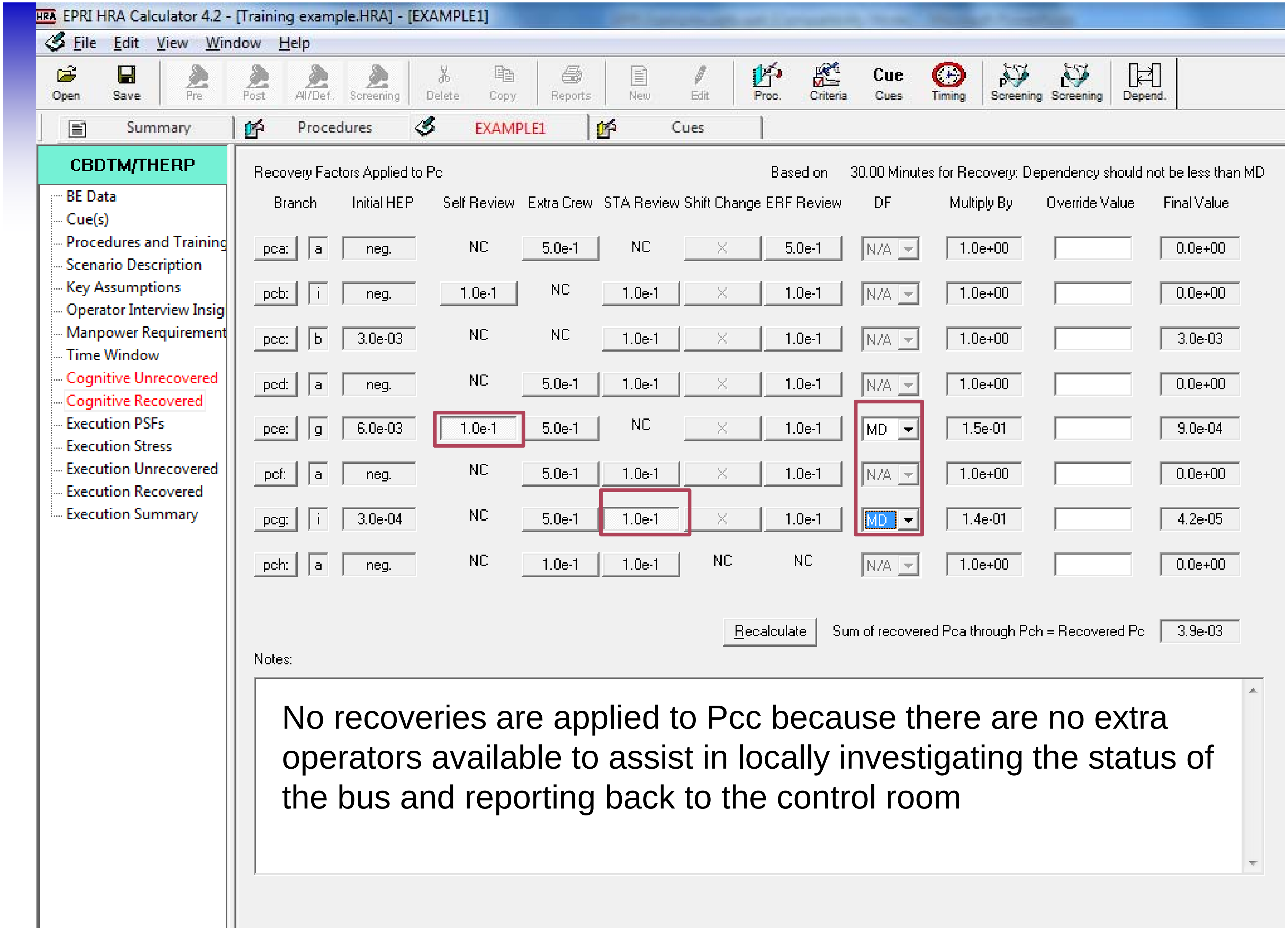


Initial Estimate of Pc

pc Failure Mechanism			Branch	HEP
pca: Availability of information	??		a	neg.
pcb: Failure of attention	??		i	neg.
pcc: Misread/miscommunicate data	??		b	3.0e-03
pcd: Information misleading	??		a	neg.
pce: Skip a step in procedure	??		g	6.0e-03
pcf: Misinterpret instruction	??		a	neg.
pcg: Misinterpret decision logic	??		i	3.0e-04
pch: Deliberate violation	??		a	neg.

Initial Pc = 9.3e-03

Effective Tw (Minutes) = 40.00



Branch		Initial HEP	Self Review	Extra Crew	STA Review	Shift Change	ERF Review	DF	Multiply By	Override Value	Final Value
pca:	a	neg.	NC	5.0e-1	NC	X	5.0e-1	N/A	1.0e+00		0.0e+00
pcb:	i	neg.	1.0e-1	NC	1.0e-1	X	1.0e-1	N/A	1.0e+00		0.0e+00
pcc:	b	3.0e-03	NC	NC	1.0e-1	X	1.0e-1	N/A	1.0e+00		3.0e-03
pcd:	a	neg.	NC	5.0e-1	1.0e-1	X	1.0e-1	N/A	1.0e+00		0.0e+00
pce:	g	6.0e-03	1.0e-1	5.0e-1	NC	X	1.0e-1	MD	1.5e-01		9.0e-04
pcf:	a	neg.	NC	5.0e-1	1.0e-1	X	1.0e-1	N/A	1.0e+00		0.0e+00
pcg:	i	3.0e-04	NC	5.0e-1	1.0e-1	X	1.0e-1	MD	1.4e-01		4.2e-05
pch:	a	neg.	NC	1.0e-1	1.0e-1	NC	NC	N/A	1.0e+00		0.0e+00

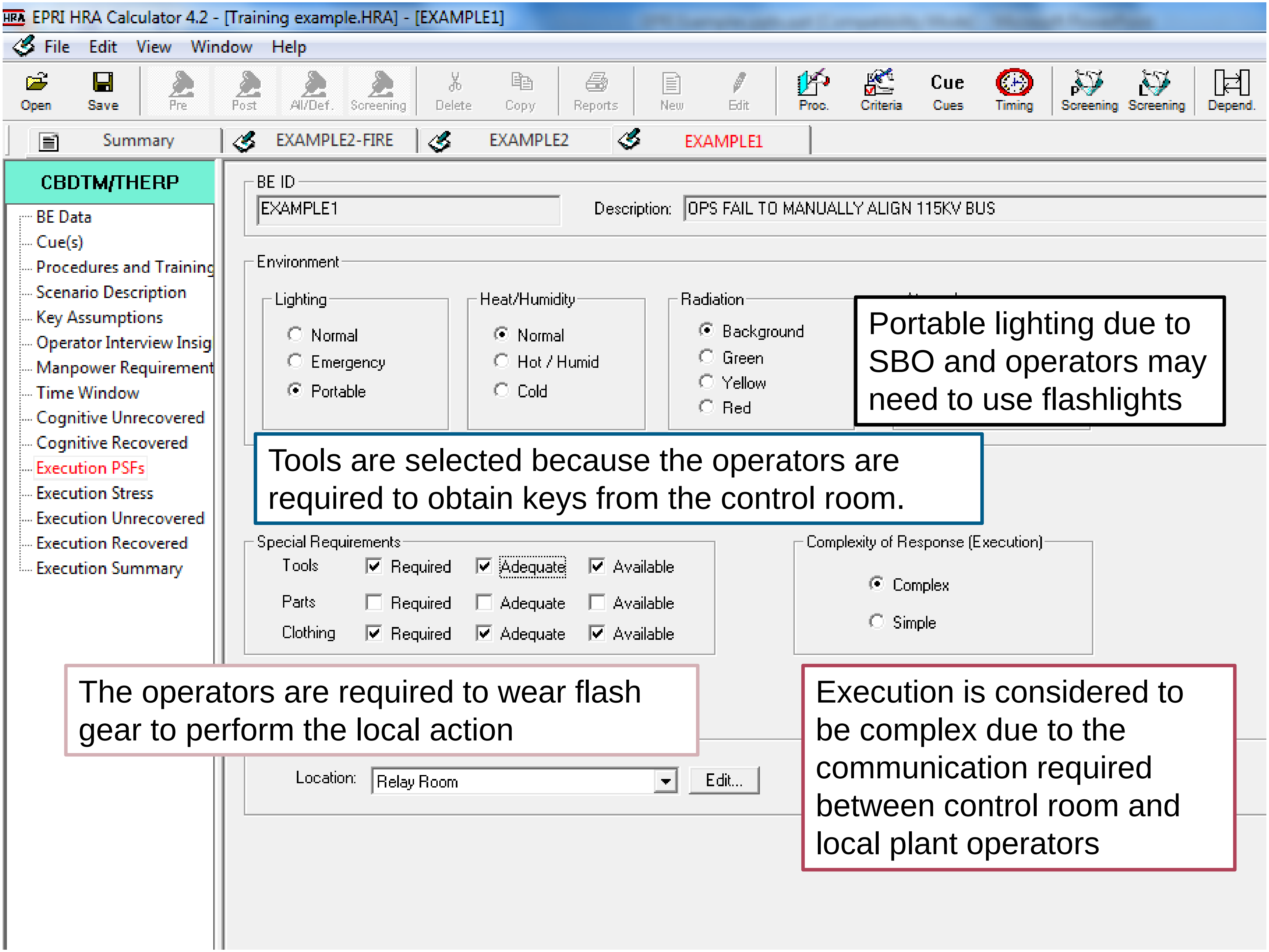
Recalculate — Sum of recovered Pca through Pch = Recovered Pc: 3.9e-03

Notes:

No recoveries are applied to Pcc because there are no extra operators available to assist in locally investigating the status of the bus and reporting back to the control room

Execution PSFs

- **Environment:**
  - **Availability and Accessibility:** Given location of fire and layout of plant, the relay room is accessible and there is no degraded environment (e.g., no smoke) in the relay room or en route to the relay room.
  - **Visibility:** Given a SBO event, lighting will be significantly reduced (i.e., flashlights and/or emergency lighting).
  - **Communications:** Under ideal conditions the Local Plant Operator could use the phone to call the control room. However, for the fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable.
  - **Heat/Humidity**: Normal – fire effects do not reach this area, however, after some time (>action window) there could be a rise in temperature due to SBO.
- **Special Requirements**:
  - Operators are required to wear flash gear to locally remove power from the Train A ESF Loading Sequencer.
  - Operators will need key to access relay rooms due to loss of power all doors will be locked.



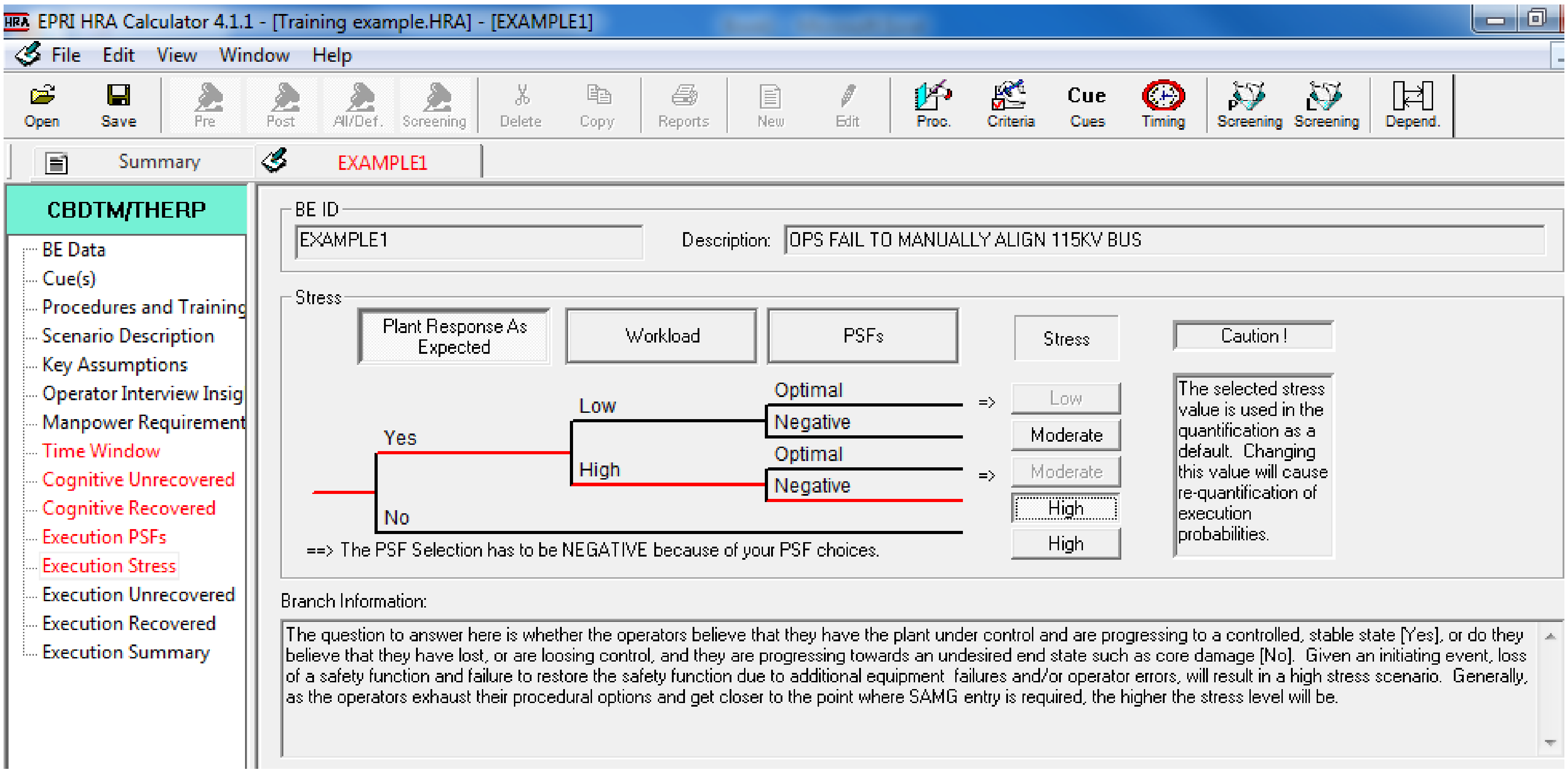
Portable lighting due to SBO and operators may need to use flashlights

Tools are selected because the operators are required to obtain keys from the control room.

The operators are required to wear flash gear to perform the local action

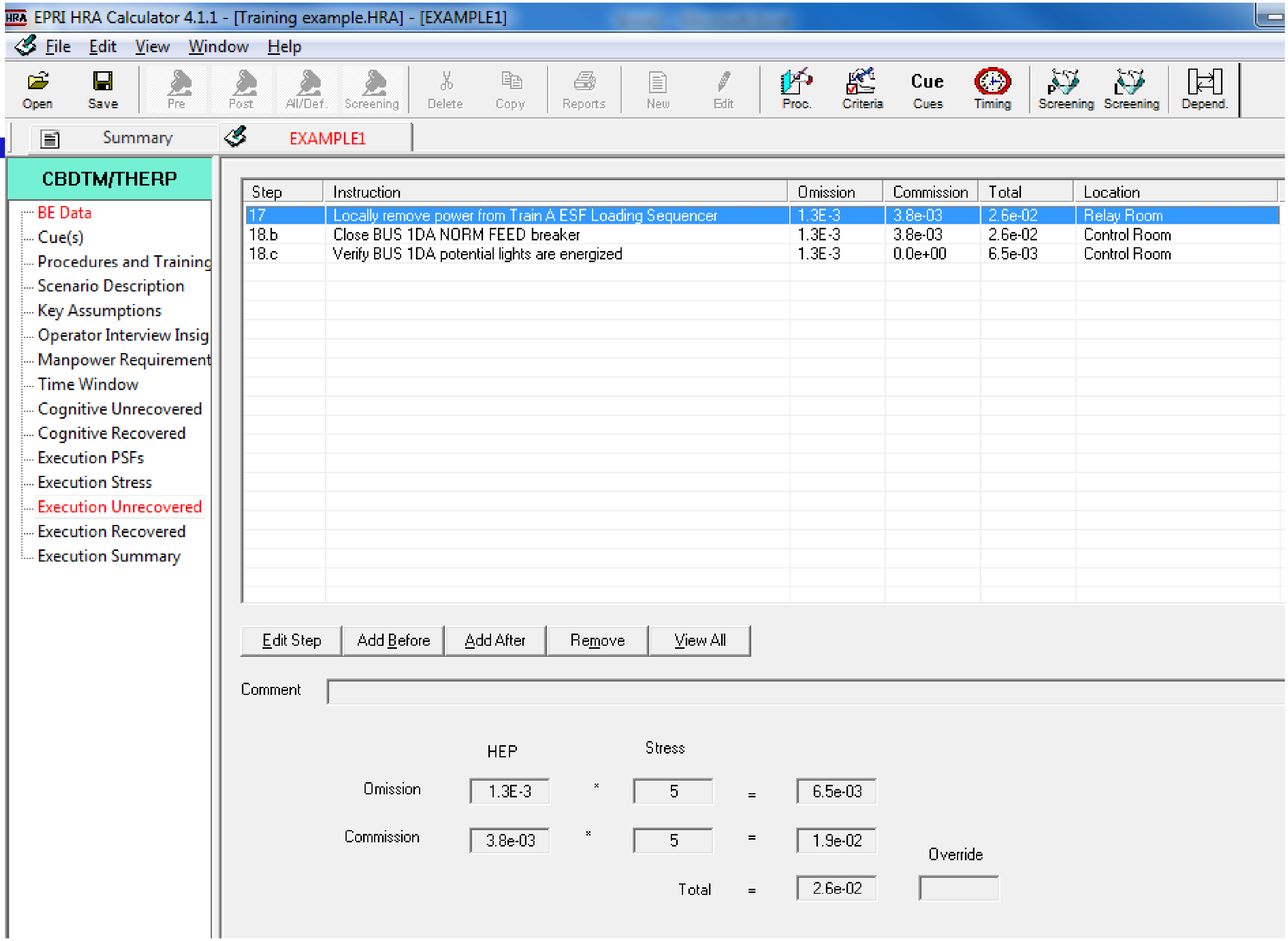
Execution is considered to be complex due to the communication required between control room and local plant operators

EPRI Stress Decision Tree



Critical Steps (Execution)

- LOCALLY Reset ESFLS to clear trip signal
  - Plant Operator, stationed at or near the MCR, gets ESFLS panel key from the MCR and proceeds to the Relay Room
  - Dons flash gear
  - Opens left cabinet (~2ft from floor) and locally removes power from the loading sequencer
  - Alert control operator that the trip signal is clear and that break can closed from the control room
- Close Breaker in MCR
  - Ensure BUS 1DA XFER INIT Switch is in OFF
  - Close BUS 1DA ALT FEED Breaker
  - Verify BUS 1DA potential lights are energized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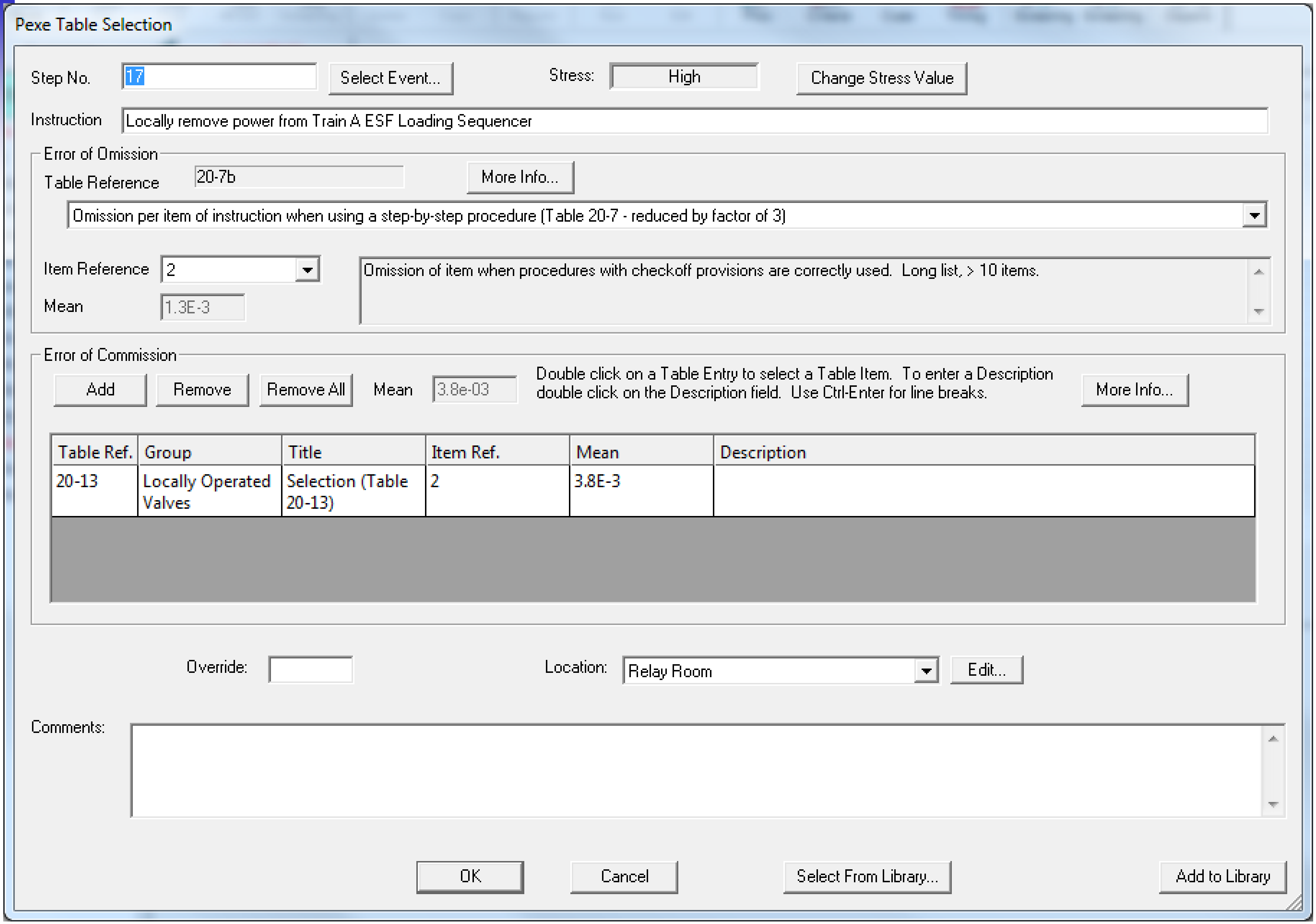
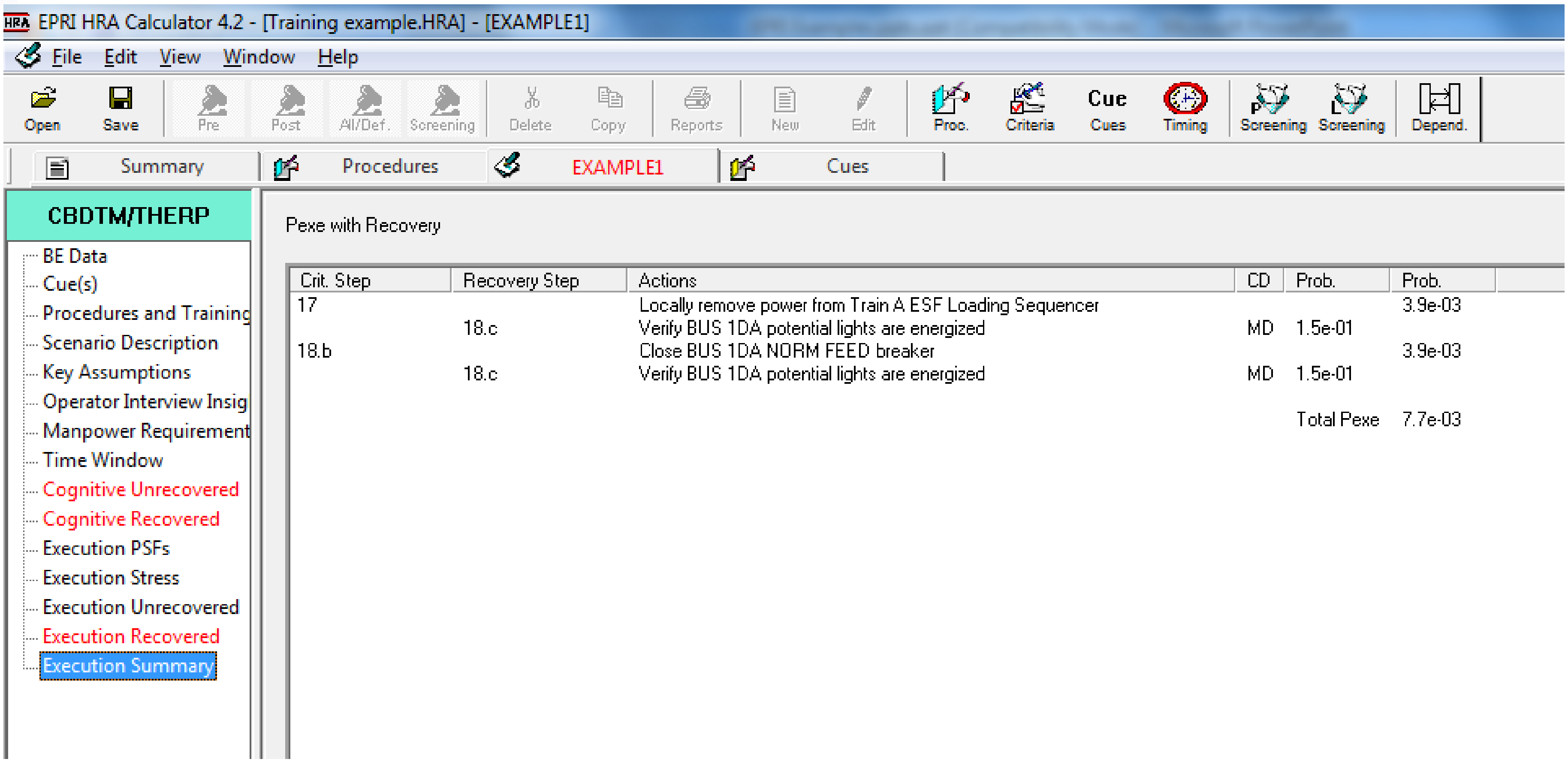
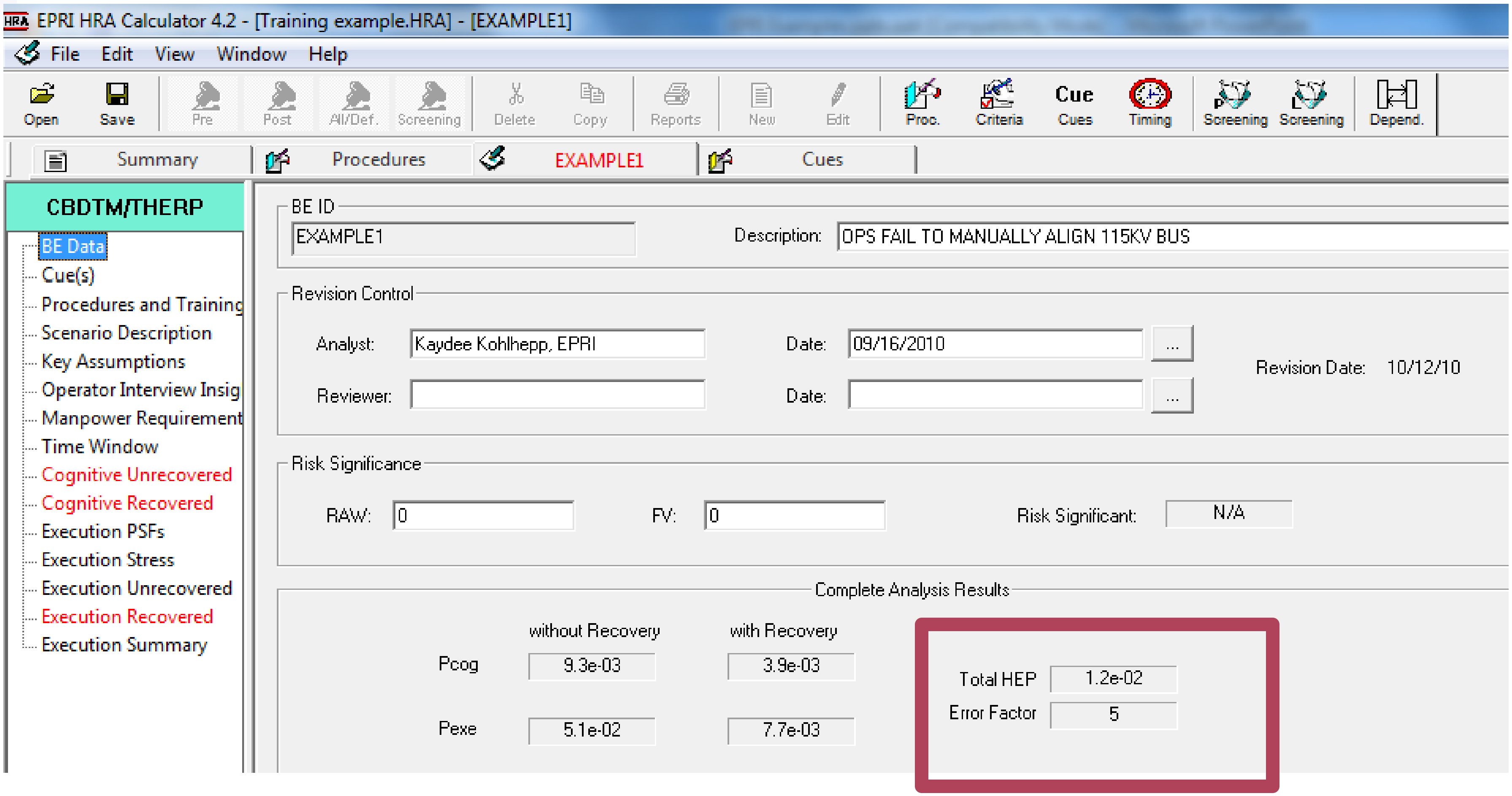
Cognitive Recovered
Execution PSFs
Execution Stress
Execution Unrecovered
Execution Recovered
Execution Summary
Step Instruction Omission Commission Total Location
17 Locally remove power from Train A ESF Loading Sequencer 1.3E-3 3.8e-03 2.6e-02 Relay Room
18.b Close BUS 1DA NORM FEED breaker 1.3E-3 3.8e-03 2.6e-02 Control Room
18.c Verify BUS 1DA potential lights are energized 1.3E-3 0.0e+00 6.5e-03 Control Room
Edit Step
Add Before
Add After
Remove
View All
Comment
HEP
Stress
Omission 1.3E-3 * 5 = 6.5e-03
Commission 3.8e-03 * 5 = 1.9e-02
Override
Total = 2.6e-02


Pexe Table Selection
Step No.
17
Select Event...
Stress:
High
Change Stress Value
Instruction
Locally remove power from Train A ESF Loading Sequencer
Error of Omission
Table Reference
20-7b
More Info...
Omission per item of instruction when using a step-by-step procedure (Table 20-7 - reduced by factor of 3)
Item Reference
2
Mean
1.3E-3
Omission of item when procedures with checkoff provisions are correctly used. Long list, > 10 items.
Error of Commission
Add
Remove
Remove All
Mean
3.8e-03
Double click on a Table Entry to select a Table Item. To enter a Description double click on the Description field. Use Ctrl-Enter for line breaks.
More Info...
Table Ref.
Group
Title
Item Ref.
Mean
Description
20-13
Locally Operated Valves
Selection (Table 20-13)
2
3.8E-3
Override:
Location:
Relay Room
Edit...
Comments:
OK
Cancel
Select From Library...
Add to Library

Execution Summary



Summary Results



Example 2

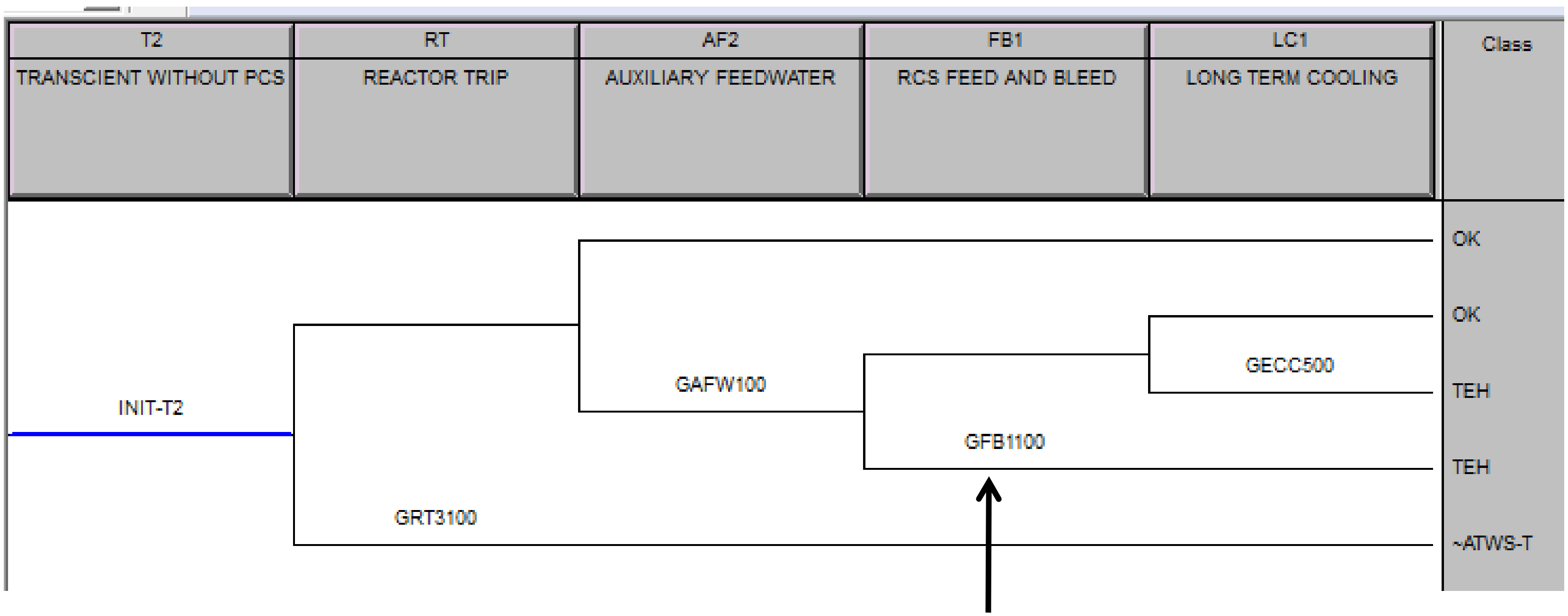
- Operators fail to perform feed and bleed during a fire
- For this example, the HFE has been quantified in detail for internal events

EXAMPLE2	Post					
Annunciator Response/THERP		2.7e-04	1.5e-03	1.7e-03	5
ASEP		7.7e-03	1.5e-03	9.1e-03	5
CBDTM/HCR Combination (Sum)		1.1e-03	1.5e-03	2.6e-03	5
CBDTM/THERP	X	1.1e-03	1.5e-03	2.6e-03	5
HCR/ORE/THERP		2.2e-10	1.5e-03	1.5e-03	5
Screening HEP		-	-	1.0e+00	1

Scenario Description

- **Initial Conditions**:
  - Steady state, full power operation. Night shift with minimal staff onsite.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine hall causes reactor trip.
  IE - TRANS
- **HFE:** Operators fail to perform feed and bleed (fire)
- **Fire Impacts:** The fire fails AFW, MFW and 2/4 SG level indicators in the control room.

Accident Sequence

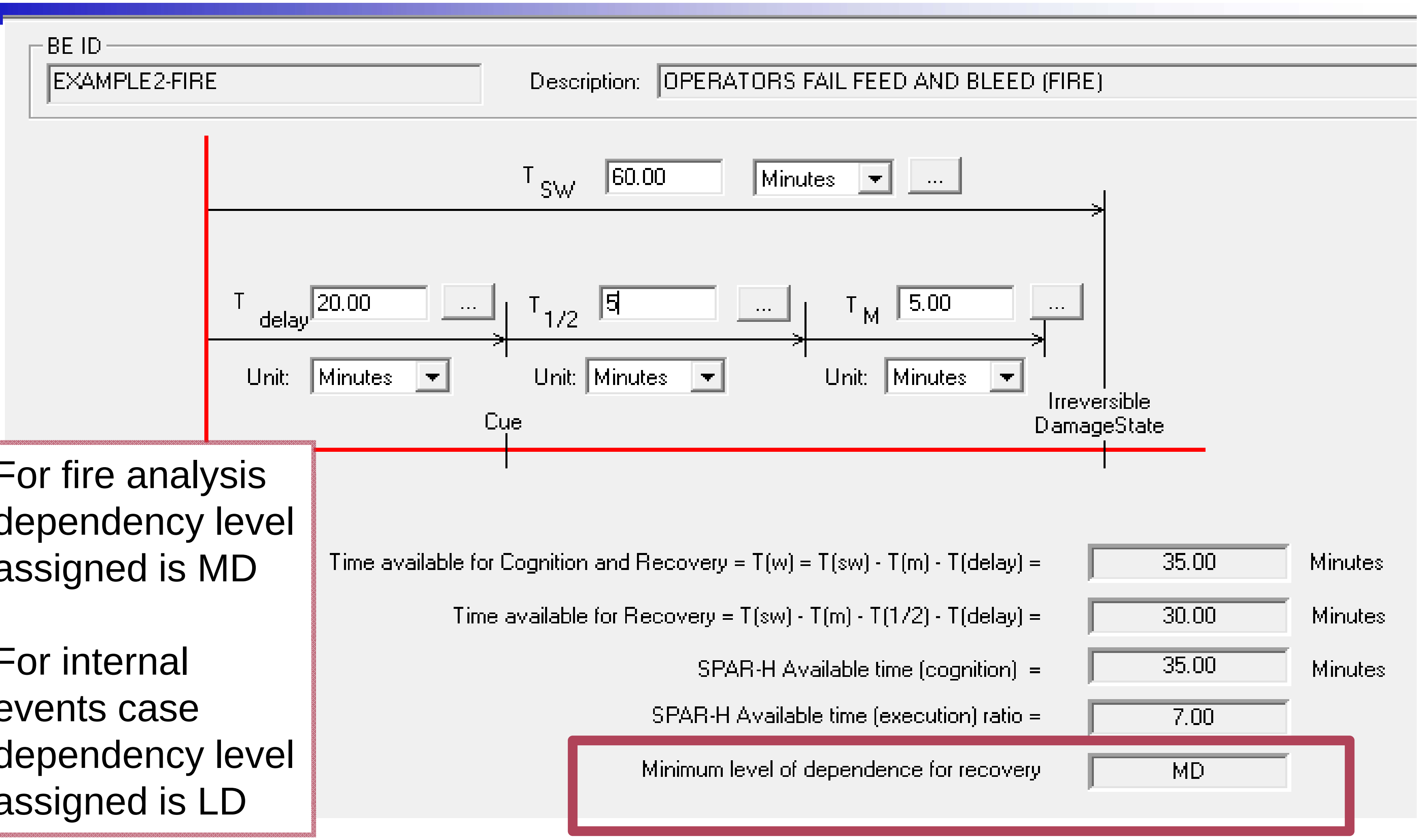


Operator fails to perform feed and bleed

Timeline

- $T = 0$ reactor trip and start of the fire
- T_{sw} = 60 minutes -Time to SG dryout
- T_{delay}= 20 minutes -Time to cue
- T_m = 5 minutes - Time to execute and procedurally verify execution steps. (Based on operator interviews)
- For internal events
  - $T_{1/2}$=1 minutes All cues and indications are accurate
- For fire case with 2/4 SG levels impacted
  - $T_{1/2}$=5 minutes To determine which SG levels indicators are accurate.

Timeline



For fire analysis dependency level assigned is MD

For internal events case dependency level assigned is LD

Procedure FR.H-1

UTILITY X
PWR

NUMBER EOP FR-H.1
REVISION 25
PAGE 12 OF 28

TITLE: Response to Loss of Secondary Heat Sink

UNIT 1

ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED
10. CHECK S/G Levels:	
a. S/G NR Level in at least one S/G - GREATER THAN 15% [25%]	a. IF Feedflow to at least one S/G verified, • WR Level increasing • Core Exit TCs decreasing THEN Maintain flow to restore S/G NR Level to GREATER THAN 15% [25%]. IF Feedflow NOT verified, THEN GO TO Step 11.
11. Check For Loss Of Secondary Heat Sink: WR S/G Level LESS THAN 15% in 2 S/G	Return to Step 1

Procedure FR.H-1

UTILITY X		**NUMBER**	**EOP FR-H.1**
PWR		**REVISION**	**25**
		PAGE	**13 OF 28**
TITLE:	**Response to Loss of Secondary Heat Sink**	**UNIT**	**1**

ACTION / EXPECTED RESPONSE	**RESPONSE NOT OBTAINED**

****

CAUTION: Steps 12 through 18 must be performed without delay in order to establish RCS heat removal by RCS bleed and feed.

****

ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED
12. ACTUATE SI	
13. VERIFY RCS Feed Paths:	Manually start ECCS Pps and align ECCS Injection Valves to establish RCS feed path.
a. Check ECCS Pp status: • ECCS CCP - AT LEAST ONE RUNNING OR • SI Pps - AT LEAST ONE	IF An RCS feed path CANNOT be established, THEN Activate the monitor lights for monitor light Box C by turning the Monitor Test Light Switch to ON.
b. Verify ECCS valve alignment - PROPER EMERGENCY ALIGNMENT	Use White Status light to verify ECCS valve alignment.

Procedure FR.H-1

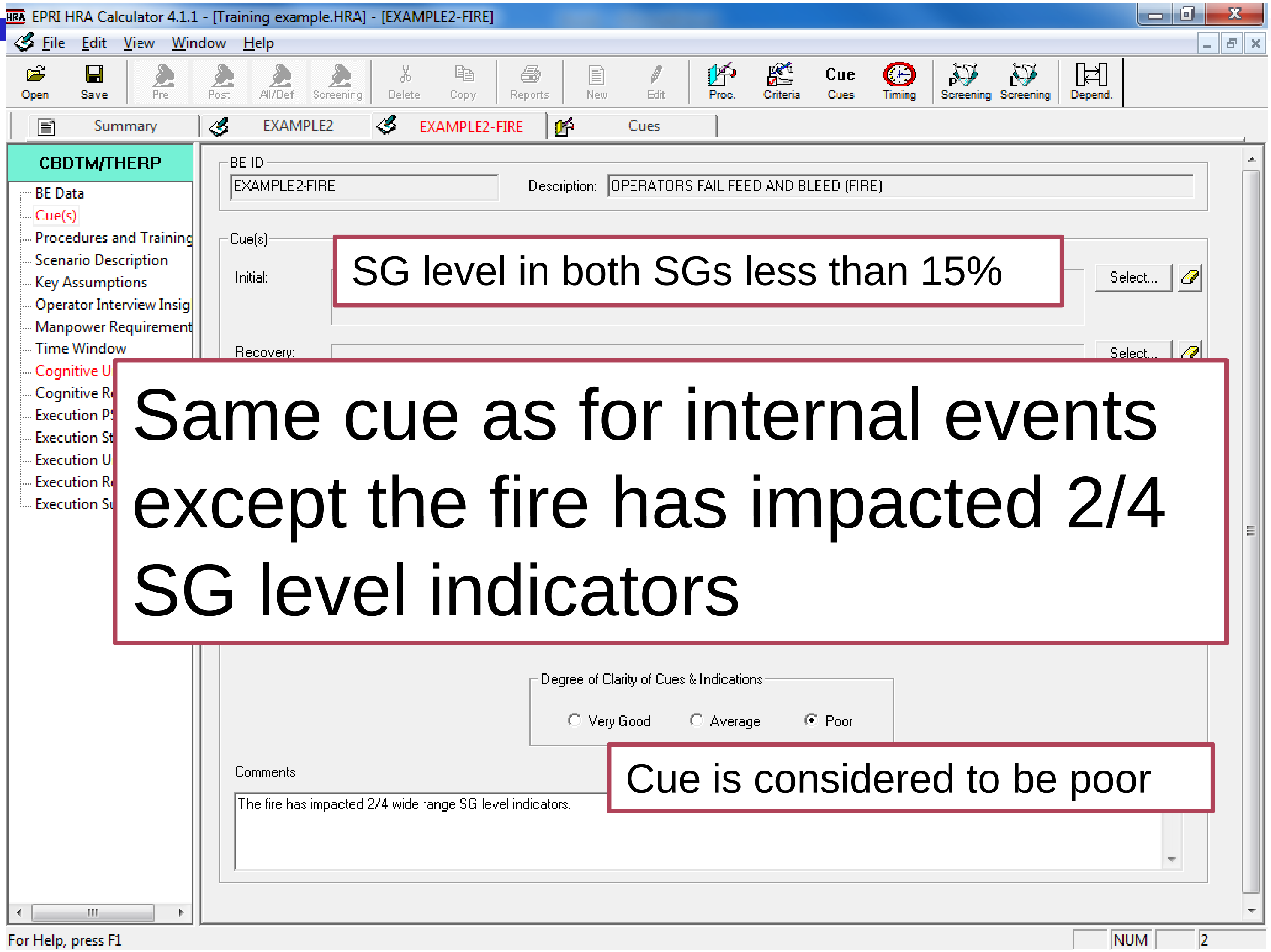
ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED
14. RESET SI	IMPLEMENT OP B-6B, LOCAL SI RESET.
15. RESET Containment Isolation Phase A And Phase B	
16. ESTABLISH Instrument Air To Containment:	
a. Open FCV-584	
b. Check Instrument Air Header Pressure GREATER THAN 90 PSIG, PI-380 (VB4 UNIT 1)	b. IMPLEMENT OP AP-9, LOSS OF INSTRUMENT AIR.
17. ESTABLISH RCS Bleed Path:	
a. Verify PZR PORV Block Vlvs - OPEN • 8000A for PCV-474 • 8000B for PCV-455C • 8000C for PCV-456	a. Restore power to block valves AND OPEN: 8000A: 52-1F-40 AND 52-1F-40R 8000B: 52-1G-46 AND 52-1G-46R 8000C: 52-1H-33 AND 52-1H-33R
b. Open all PZR PORVs	

Fire Procedure

4.0 Fire Area 3-BB (Continued)
Turbine Area, Elev. 115-ft

Affected Equipment	Available Equipment	Required Manual Action
6. MSS		
SG Level Indicators:	SG 1-1: LT-517, LT-519 SG 1-2: LT-527, LT-529	
SG 1-1: LT-516, -518, SG 1-2: LT-526, -528,		
SG Pressure Indicators:	SG 1-1: All Available	
SG 1-1: PT-514, PT-515, PT-516	SG 1-2: PT-524, PT-525	
SG 1-2: PT-526		
ADV: PCV-19, PCV-20,		Manually open valves after isolating supply air (normal, backup and nitrogen supply): PCV-19: AIR-I-1-4541 PCV-20: AIR-I-1-4350

Cues and Indications

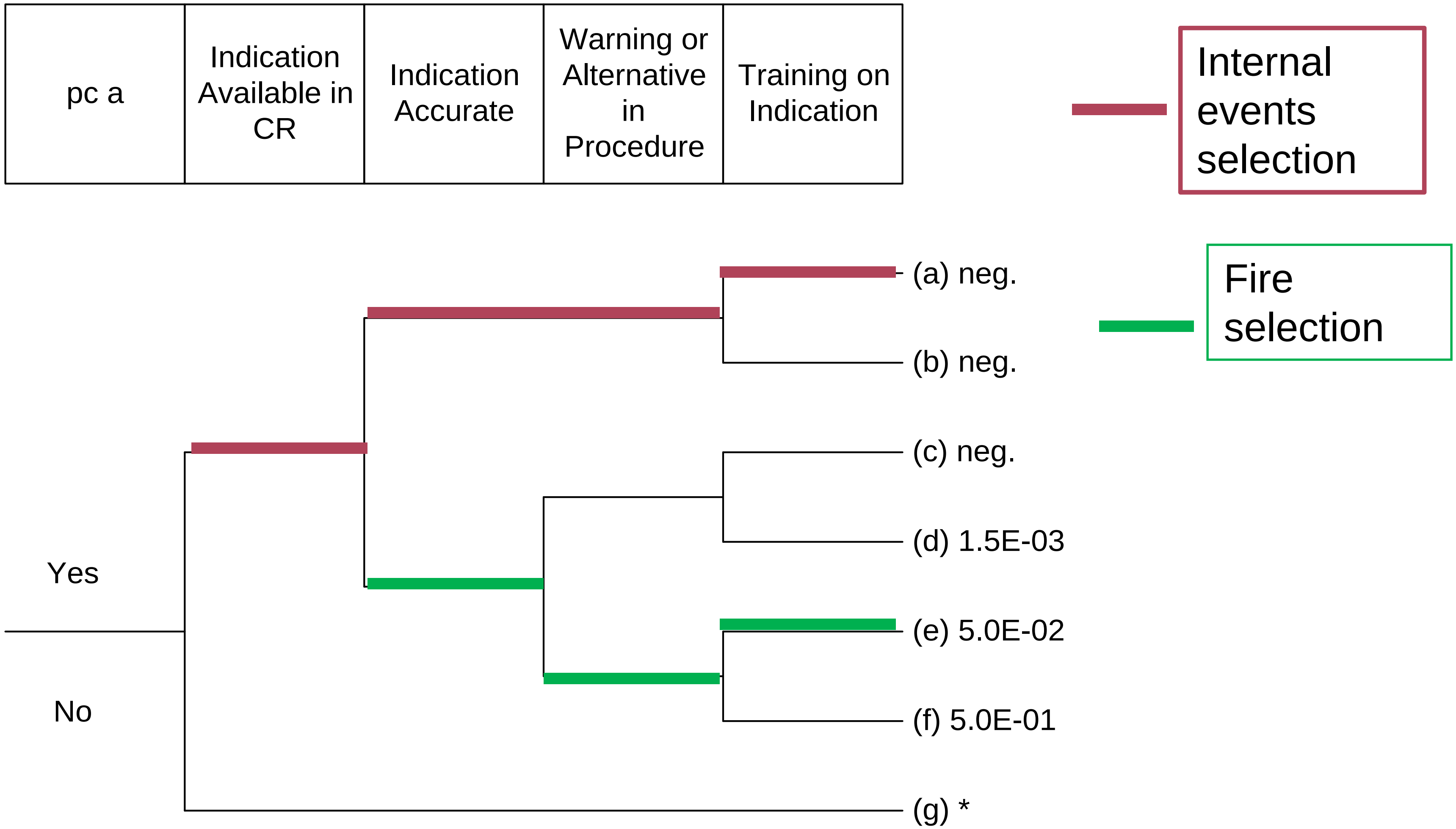


SG level in both SGs less than 15%

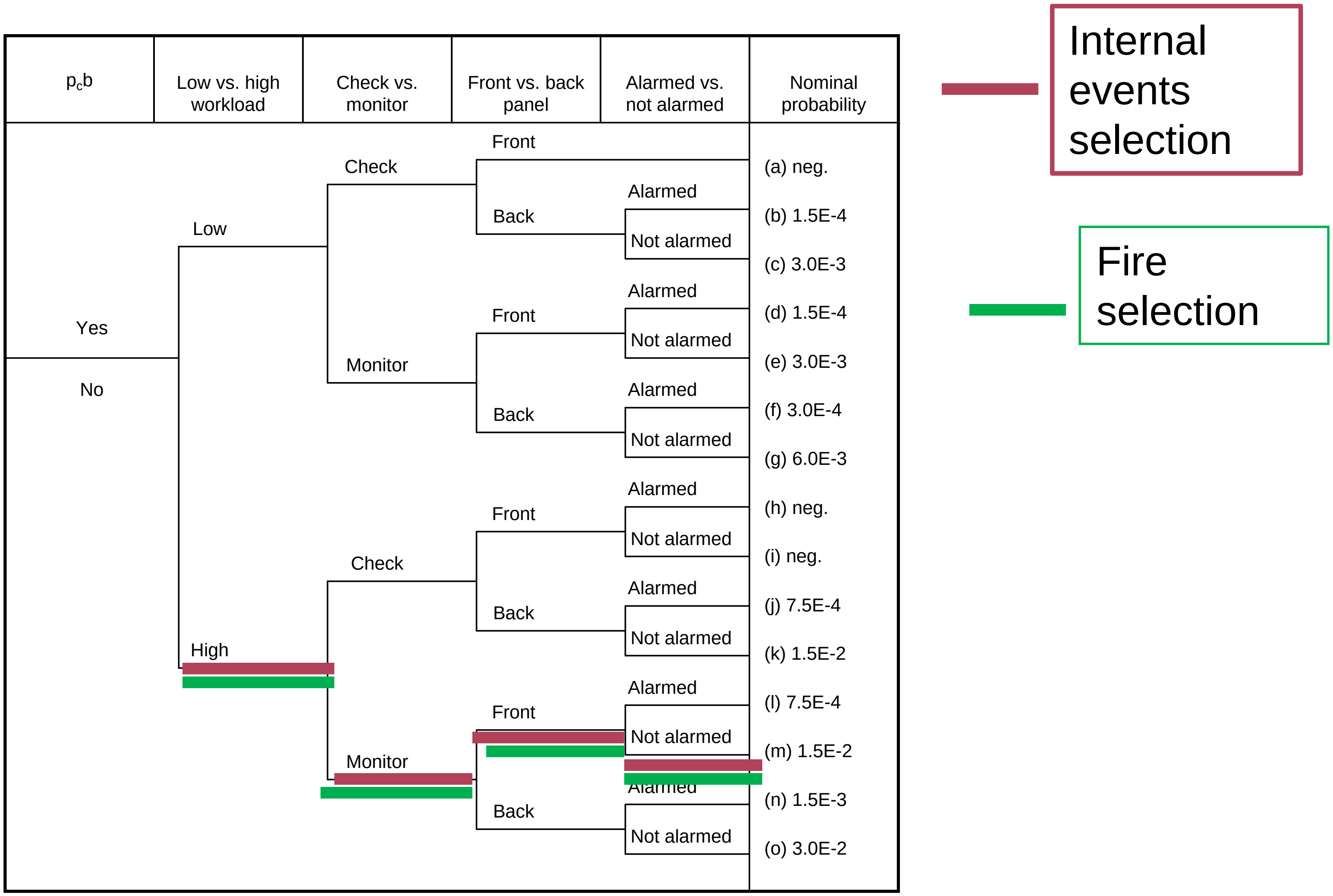
Same cue as for internal events except the fire has impacted 2/4 SG level indicators

Cue is considered to be poor

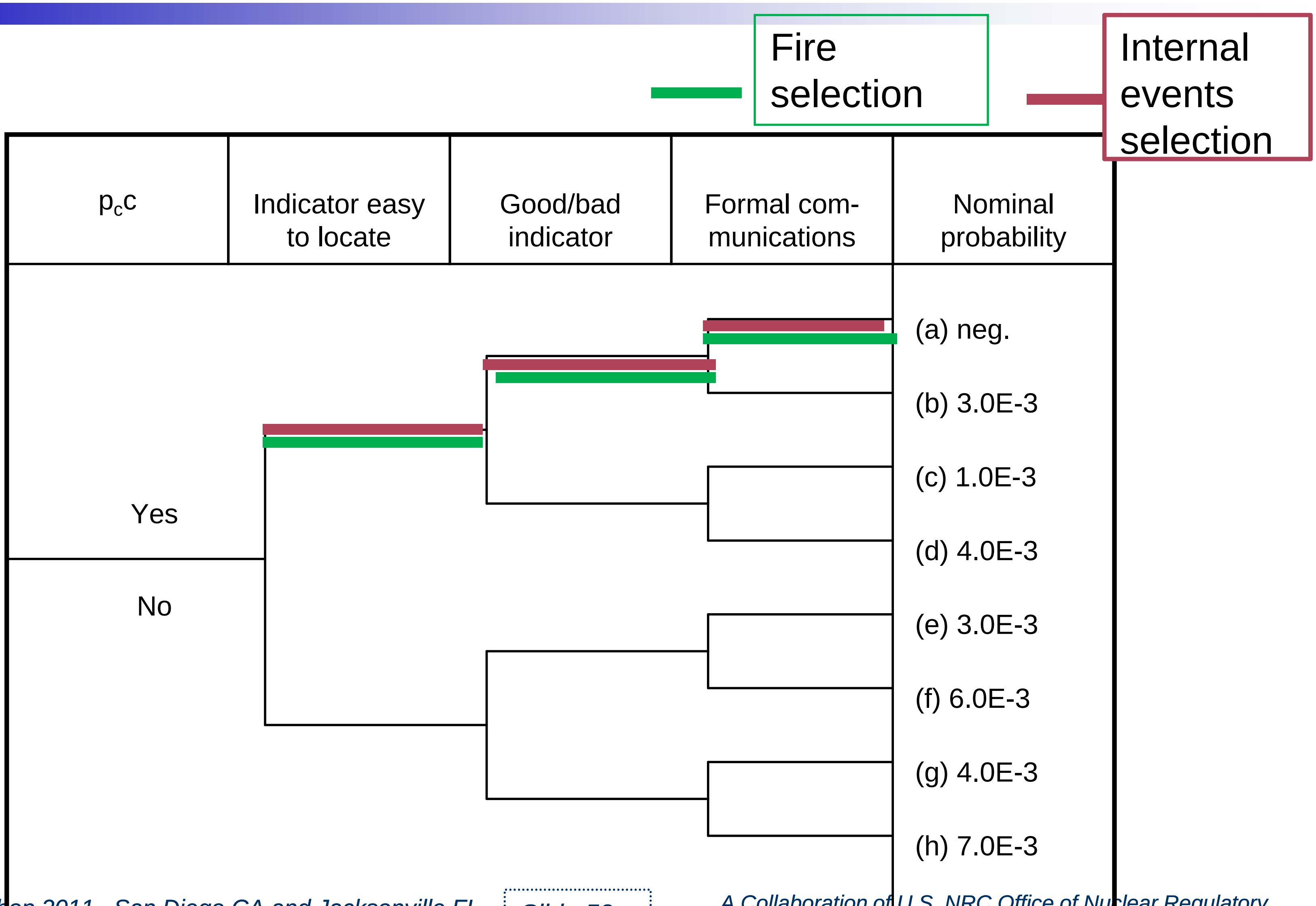
CBDTM decision tree:
pc-a Data not available



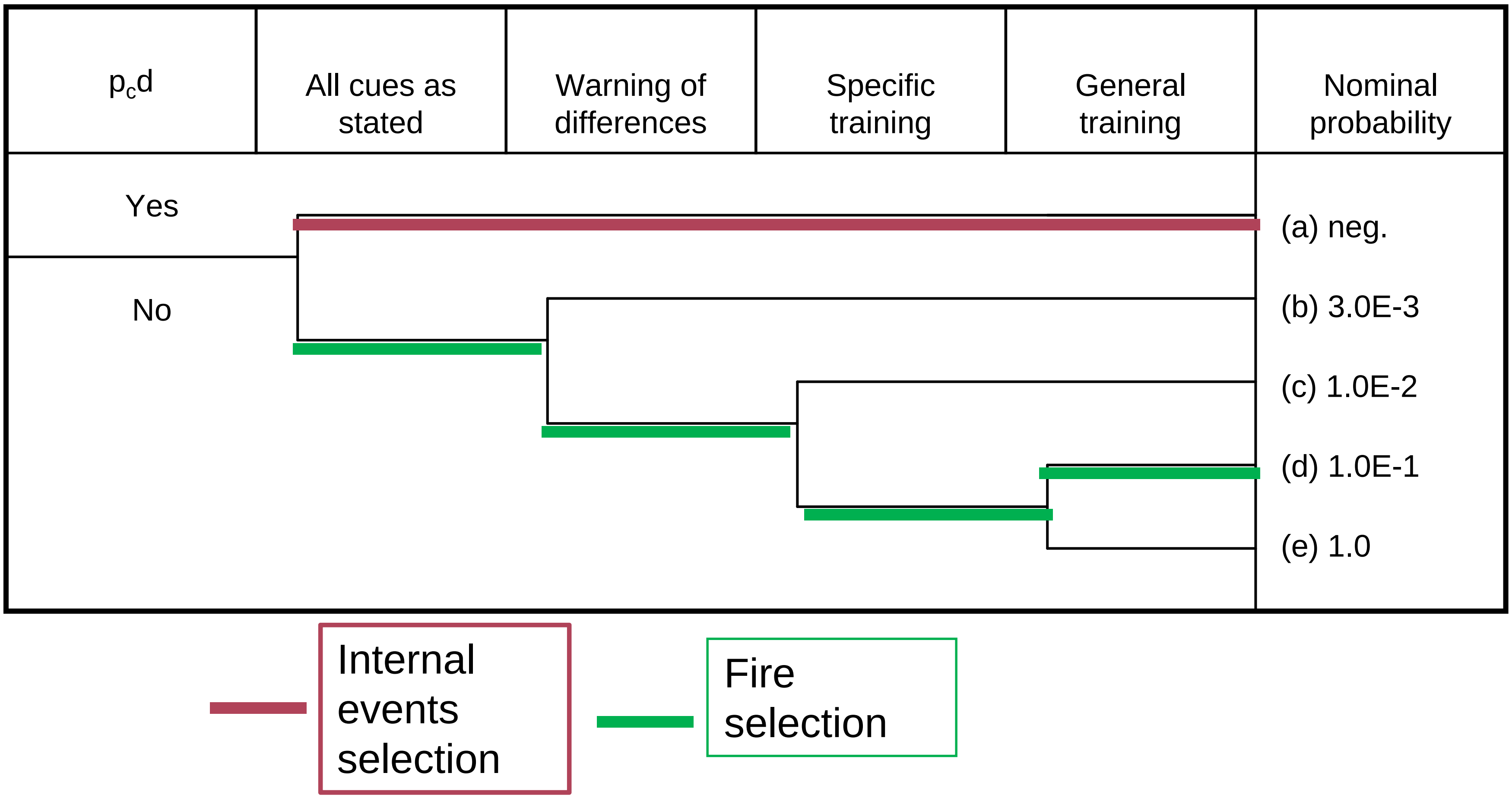
CBDTM decision tree: pc-b Data not attended to



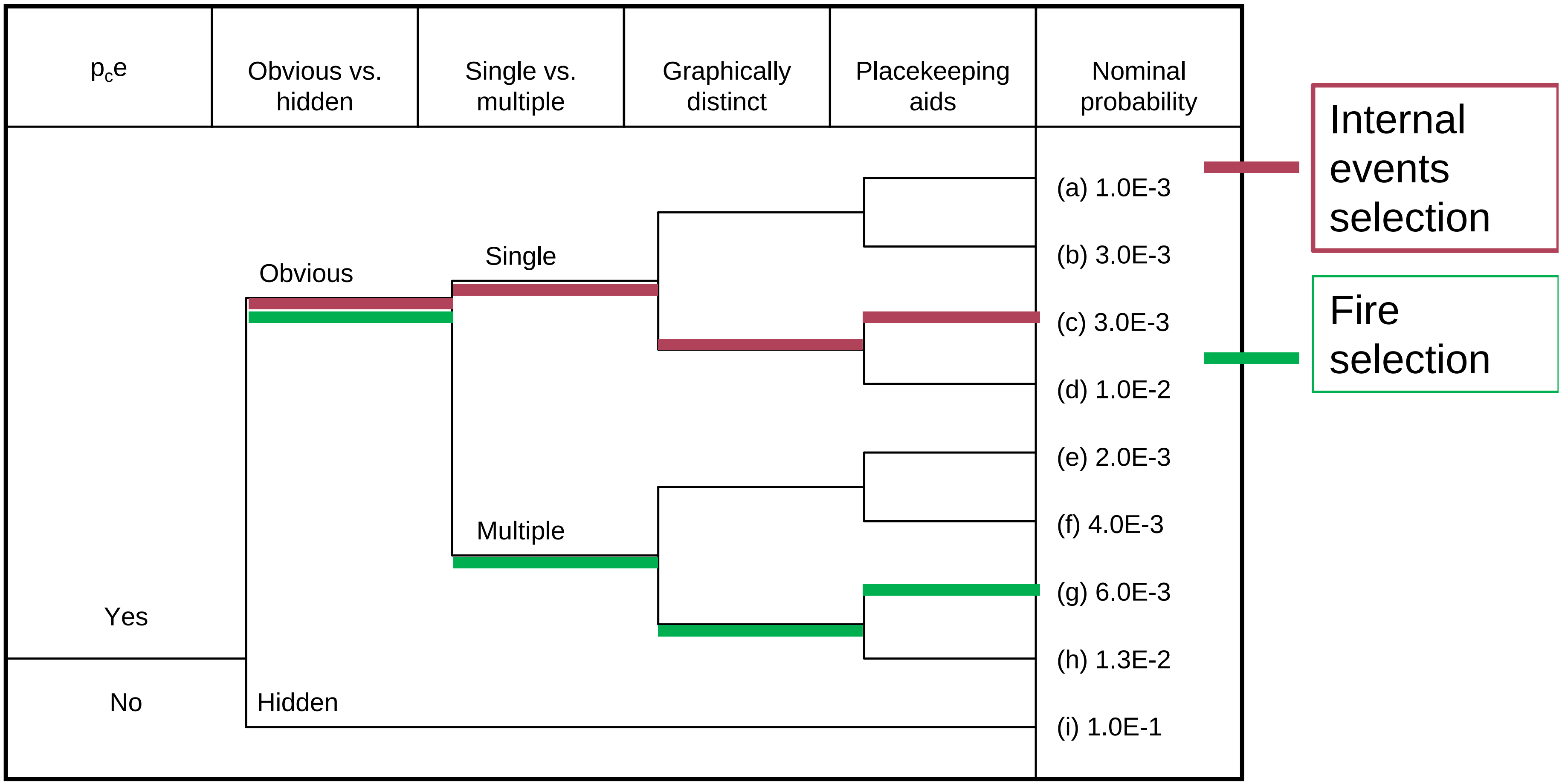
CBDTM decision tree:
pc-c Data misread or miscommunicated



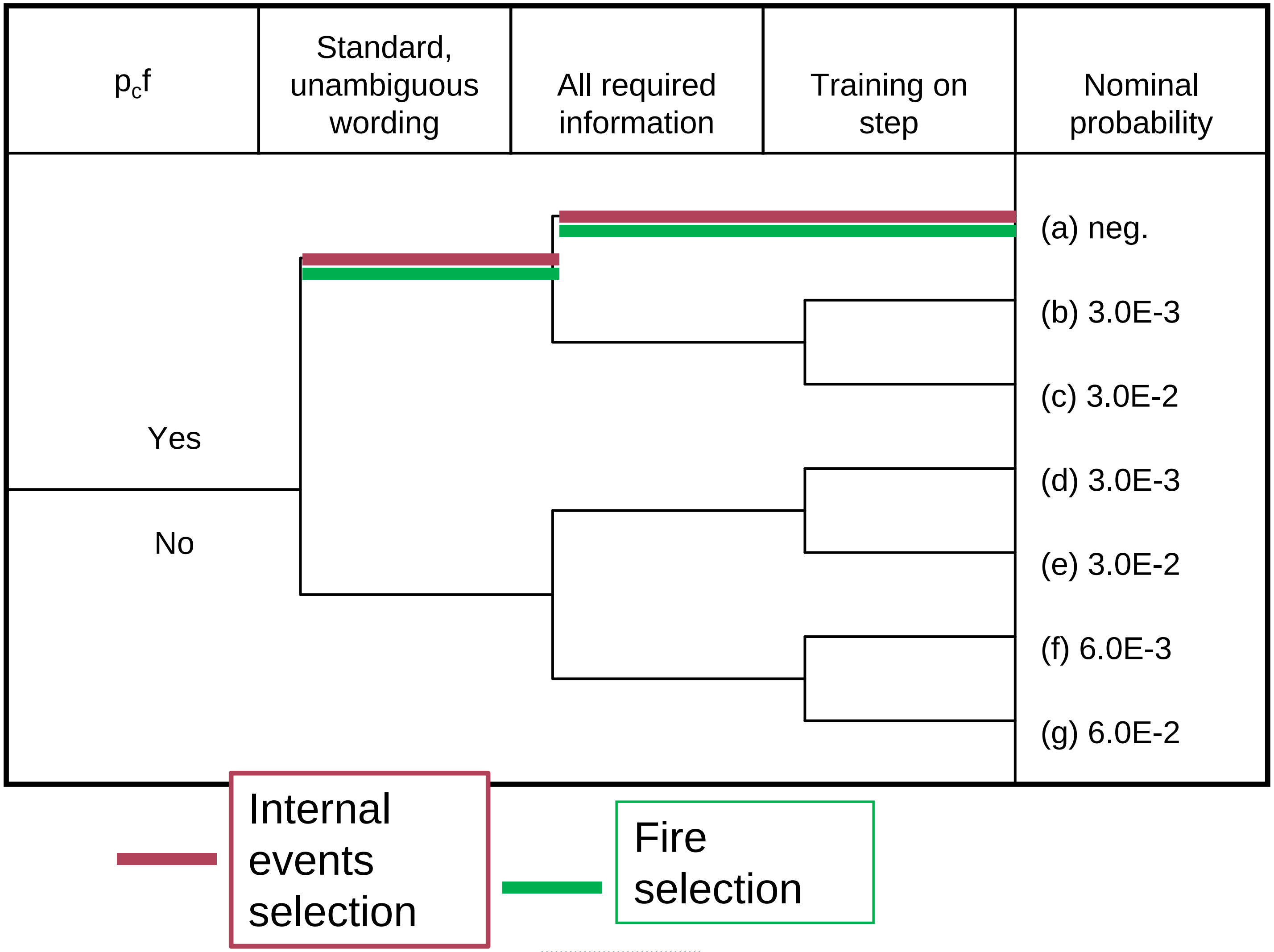
CBDTM decision tree: pc-d Information misleading



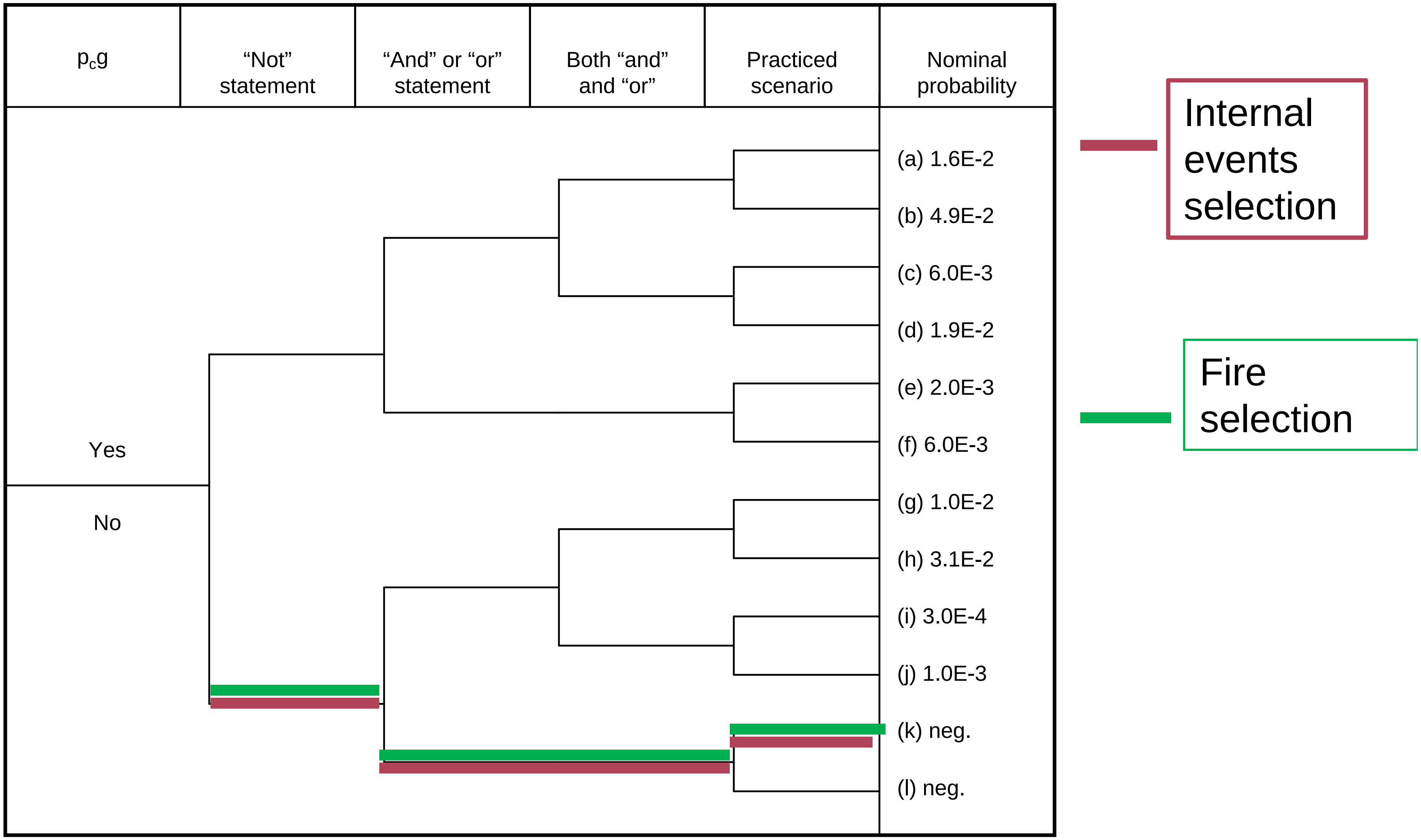
CBDTM decision tree:
pc-e Relevant step in procedure missed



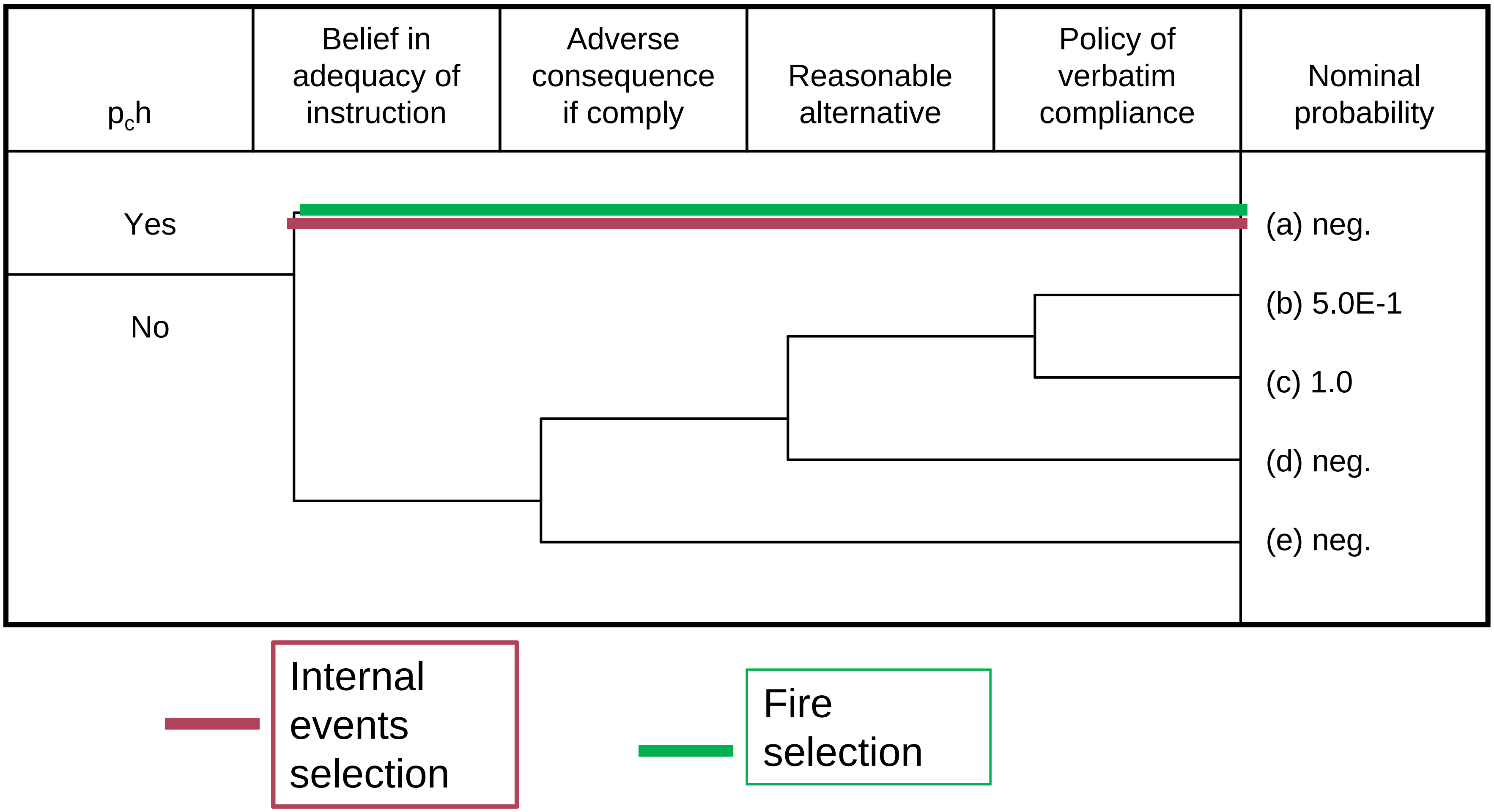
CBDTM decision tree:
pc-f Misinterpret instruction

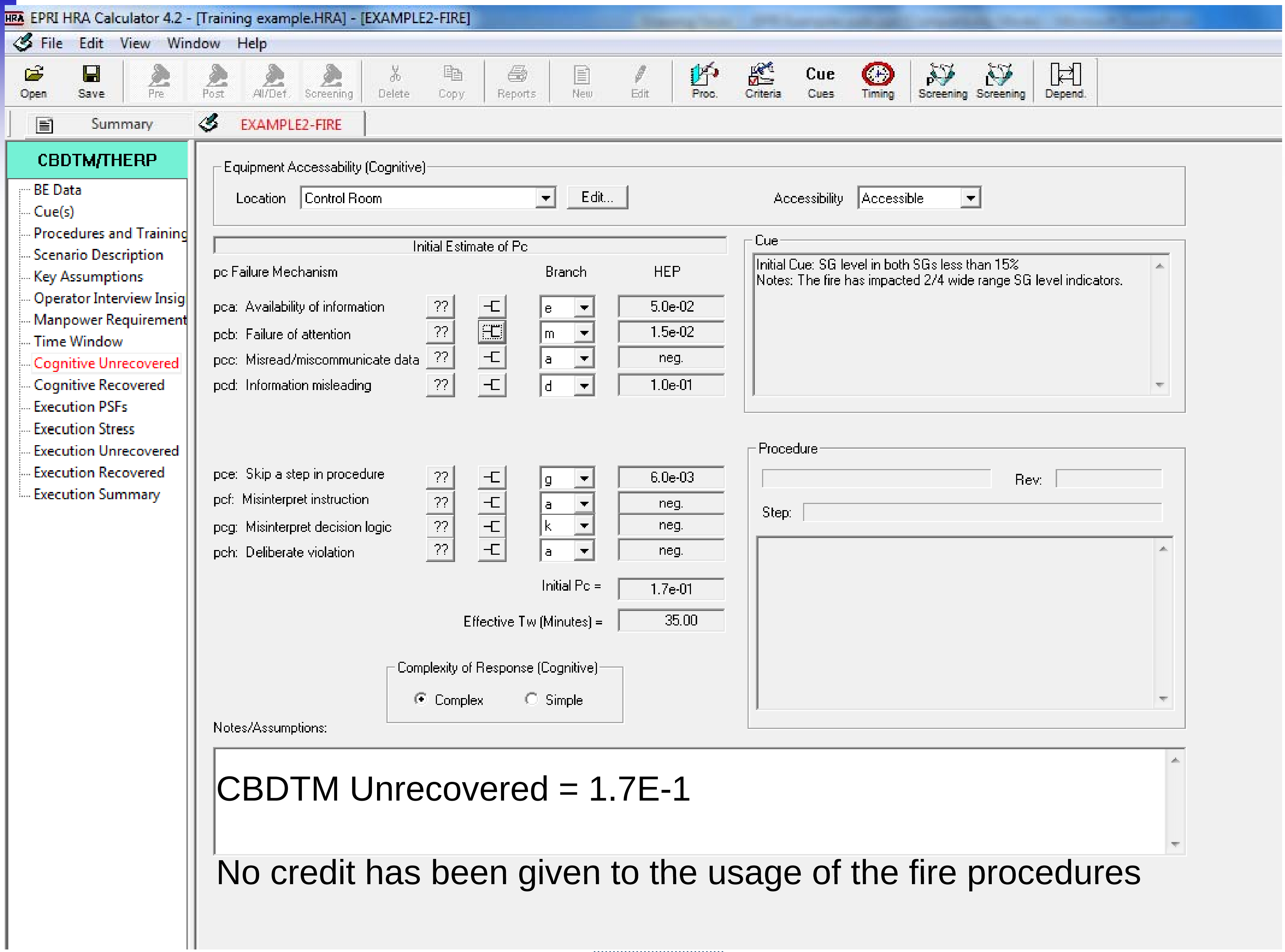


CBDTM decision tree:
pc-g Error in interpreting logic



CBDTM decision tree:
pc-h Deliberate violation



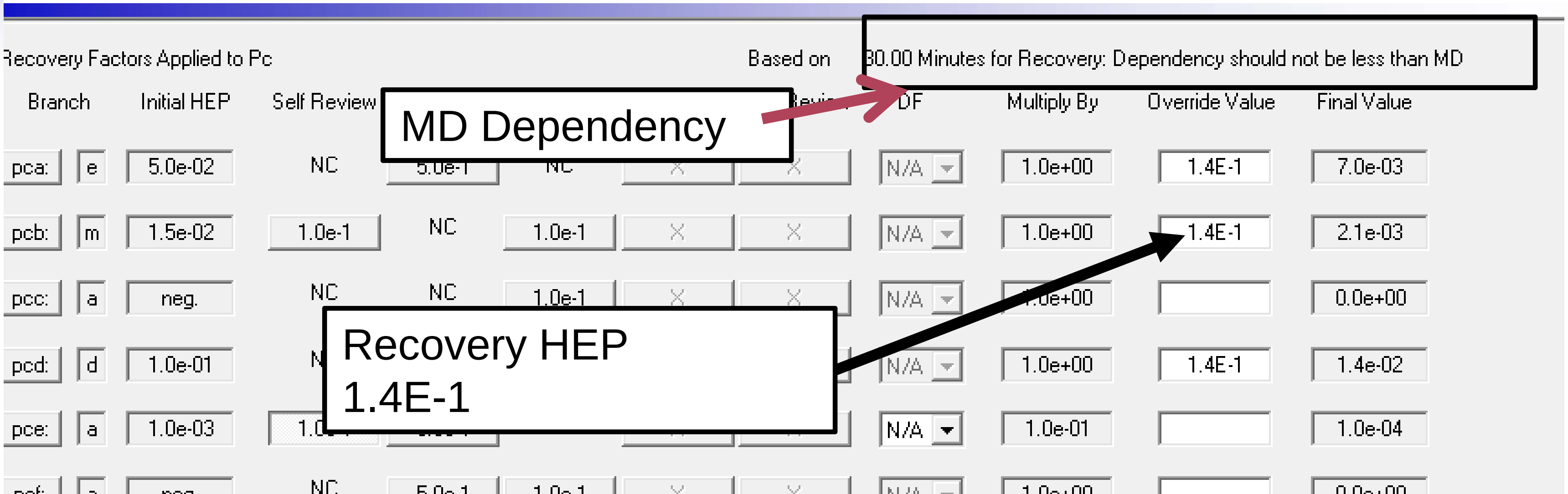


No credit has been given to the usage of the fire procedures

Calculation of Recovery Factor

- Using CBDTM an HEP for operators fail to enter Fire Procedure and diagnose failed indications can be calculated.
- Cue – Fire alarm in the control room. The fire alarm will direct the operators fire procedure and correct attachment
- Timeline – This action occurs concurrently with other FRH-1 actions.
  - T_{sw}= 55 minutes –Longest time in which operators can delay entering FRH-1 and still successfully perform feed and bleed (60 minutes-5 minutes)
  - T_{delay}= 5 minutes - Time to enter fire procedures
  - $T_{1/2}$ = 5 minutes - Time to determine which indications are correct.
  - T_m = 5 minutes - Tm is the time to implement feed and bleed. This time needs to be included to determine the correct time available for recovery.

Calculation of Recovery Factor



Recovery HEP is calculated to be 6E-3 and does not include dependencies.

Based on timing a Moderate dependency is assigned.
Recovery HEP with dependency is (1+ 6 X6E-3) / 7 =1.4E-1

P_{cog} with recoveries is 2.3E-2

Execution

- Same execution steps as for Internal Events

Step	Instruction	Omission	Commission	Total	Location
1	Actuate SI	1.3E-3	1.3e-03	1.3e-02	Control Room
2	Verify Adequate RCS Feed Path	1.3E-3	0.0e+00	6.5e-03	Control Room
3	Open 2 PORVS	1.3E-3	1.3e-03	1.3e-02	Control Room
4	Verify Adequate RCS Bleed Path	1.3E-3	0.0e+00	6.5e-03	Control Room

Execution Recovery

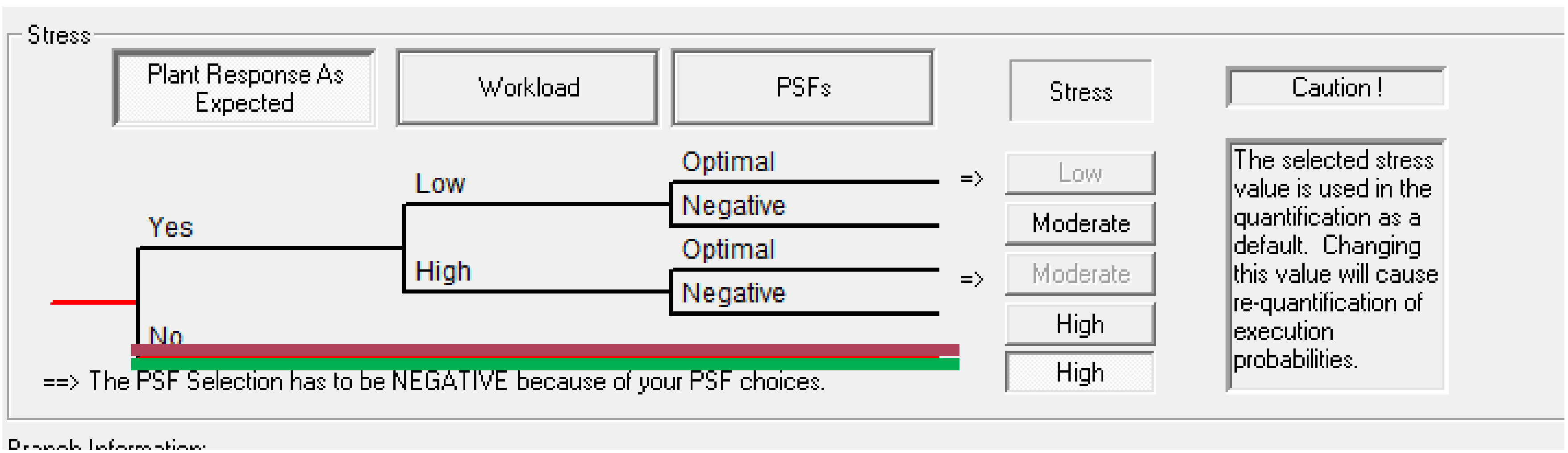
Pexe with Recovery

Crit. Step	Recovery Step	Actions	CD	Prob.	Prob.
1		Actuate SI			1.9e-03
	2	Verify Adequate RCS Feed Path	MD	1.5e-01	
3		Open 2 PORVS			1.9e-03
	4	Verify Adequate RCS Bleed Path	MD	1.5e-01	
				Total Pexe	3.9e-03

Moderate dependency is assigned for recovery

Execution PSFs

- Fire is outside the control room and has no impact on the control room.
- Stress is the same as for internal events



Internal events selection

Fire selection

HEP Summary

Operator fails to perform feed and bleed during fire with 2/4 SG levels impacted

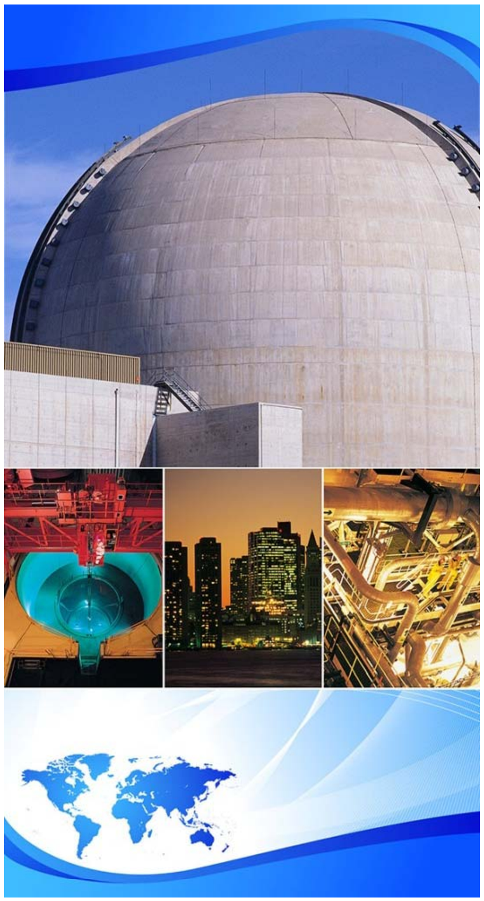
Complete Analysis Results

	without Recovery	with Recovery		
Pcog	1.7e-01	2.4e-02	Total HEP	2.8e-02
Pexe	2.6e-02	3.9e-03	Error Factor	5

Operator fails to perform feed and bleed (internal events)

Complete Analysis Results

	without Recovery	with Recovery		
Pcog	1.8e-02	1.1e-03	Total HEP	2.6e-03
Pexe	2.6e-02	1.5e-03	Error Factor	5



EPRI/NRC-RES FIRE PRA METHODOLOGY

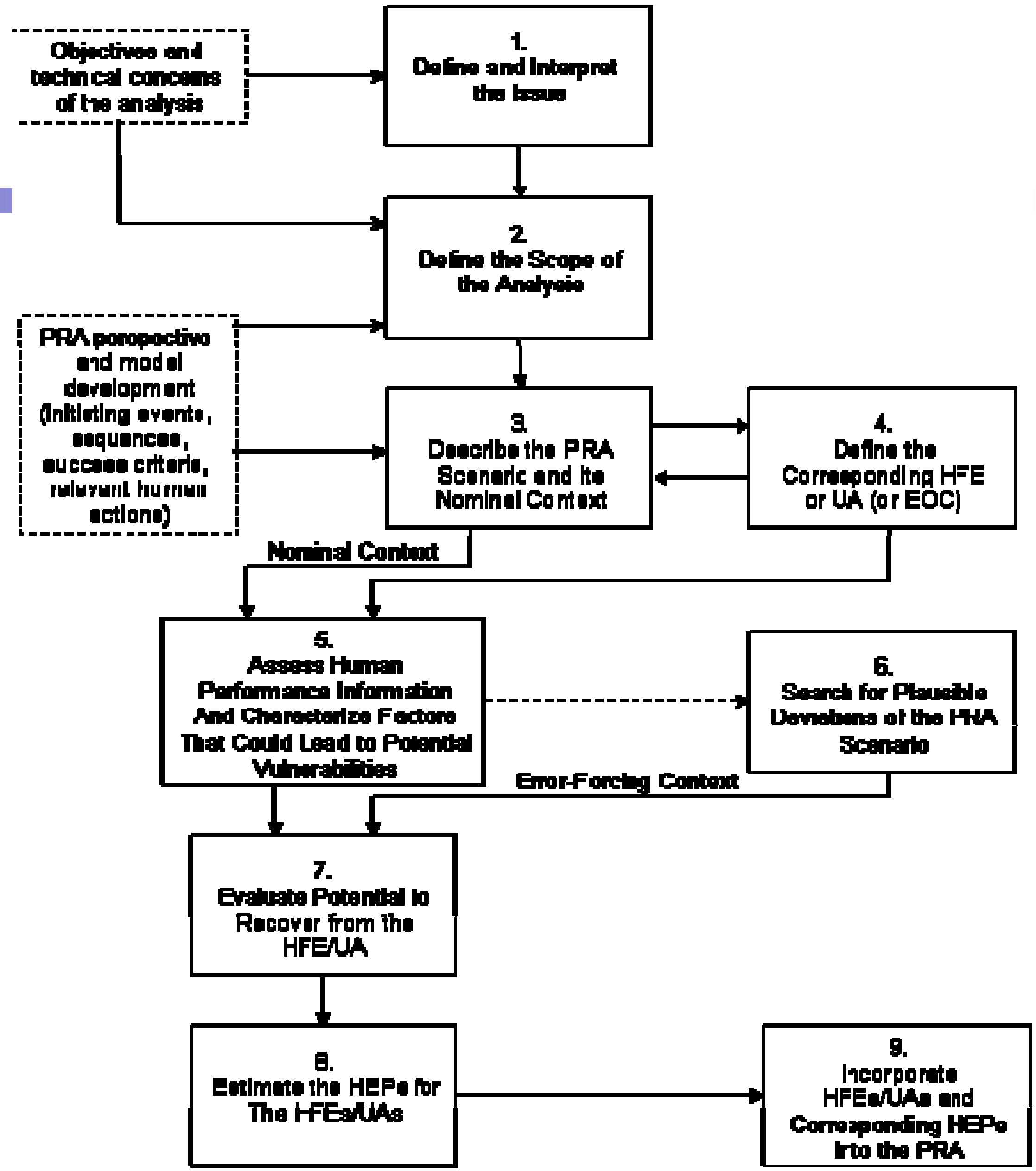
Task 12 – Post-Fire HRA

ATHEANA Example
Detailed Fire HEP Quantification

Mary Presley (ARES Corporation)
Joint RES/EPRI Fire PRA Workshop 2011
San Diego CA and Jacksonville FL

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

Steps in the ATHEANA Process



Steps 1&2: Objectives of the Analysis

- Step 1: Define and Interpret the Issue

    Need to identify, model and quantify relevant HFEs for Fire PRA sequences

  Defined by scope of fire PRA.

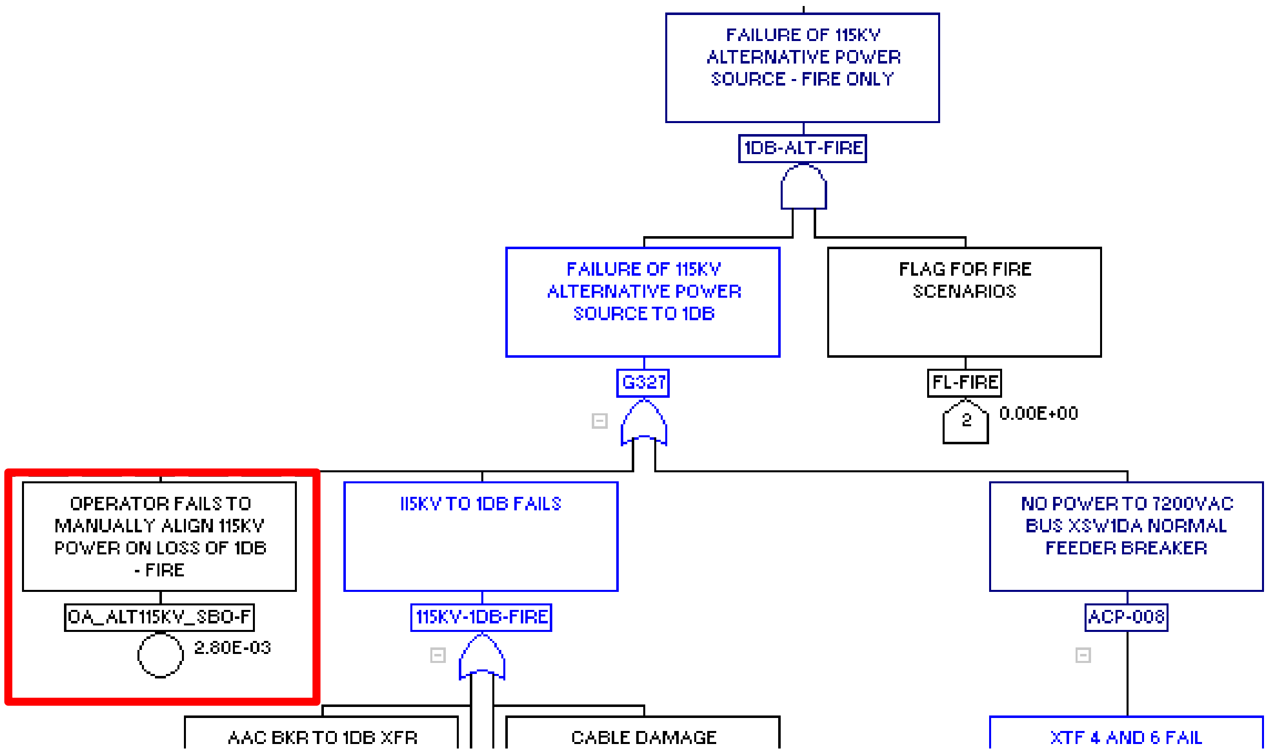
- Step 2: Define the Scope of the Analysis

    Address human actions needed to prevent core damage in fire induced initiating events and subsequent accident sequences under full-power

  Defined by scope of fire PRA.

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Initial Conditions**: Single unit two loop PWR with two trains of electrical power. Steady state, full power operation.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine room causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power following loss of both buses and EDGs fail to start.



Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Accident sequence**:
  - Reactor trip successful.
  - Turbine trip successful.
  - AFW failed due to the fire.
  - Pressurizer PORV spuriously opens due to the fire.
  - The Main Generator breaker opens and the BOP busses are powered through XTF0001 (reverse) and XTF0002.
  - EDG B will start and the ESF Loading Sequencer will load the bus.
  - Given the EDGs do not start (or start and trip) or if the EDG output breaker would not close, the ESF Loading Sequencer would still be sending a signal to trip the normal and alternate feeder breakers (for EDG protection) to the bus. To close the alternate feeder breaker (or reclose the normal feeder breaker), power must be removed from the ESFLS to remove the trip open signal.
  - XSW1DA or 1DB must then be energized from the alternate power source.
  - DC power available until batteries deplete (~4hrs)
- **Consequence of failure of this action:** Core damage due to stuck open Pressurizer PORV

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Procedures**:
  - Upon Reactor Trip, enter EOP-0
    - Step 3 of EOP-0 verifies that buses are energized. Buses are de-energized; this will take the operator to ECA 0.0 [Station Blackout Procedure]
    - Step 10 of ECA 0.0 checks that buses 1DB and 1 DA are energized. Both buses are de-energized; this will take the operator to AOP 304 due to loss of bus with no EDG.
    - Steps 17 and 18 of AOP 304 are the relevant response actions for this HFE:

ACTION/EXPECTED RESPONSE	ALTERNATIVE ACTION
17 **Locally remove power from the Train A ESF Loading Sequencer (XPN-6020 CB-436).** ☐	
18 **Energize XSW1DA from the normal power source:** a. Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b. Close BUS 1DA NORM FEED Breaker. ☐ c. Verify BUS 1DA potential lights are energized. ☐	18 <u>IF</u> XSW1DA normal power source is <u>NOT</u> available, <u>THEN</u> energize XSW1DA from the alternate power source: a) Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b) Close BUS 1DA ALT FEED Breaker. ☐ c) Verify BUS 1DA potential lights are energized. ☐

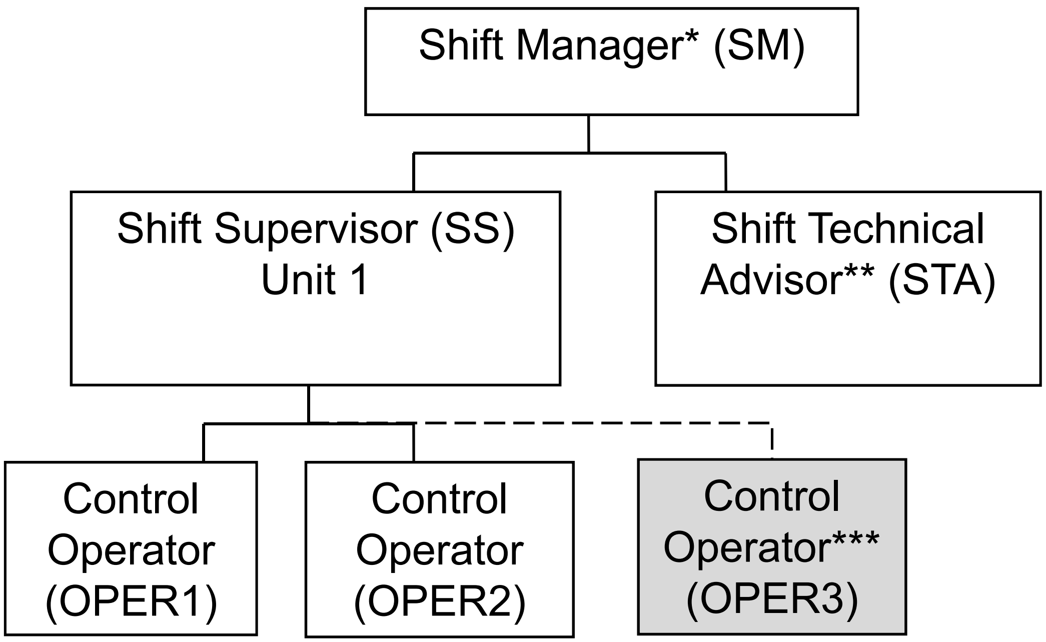
Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Operator action success criteria**: Reset ESFLS to clear trip signal and align alternate power source to XSW1DA.
- **Required Operator Actions:**
  1. Shift Supervisor directs the Control Room Operator to power 1DA
  2. Reset ESFLS to clear trip signal (local action, skill-of-craft)
     a) Local Plant Operator, stationed at or near the MCR, gets ESFLS panel key from the MCR and proceeds to the Relay Room
     b) Dons flash gear
     c) Opens left cabinet (~2ft from floor) and locally removes power from the loading sequencer
     d) Alerts Control Room Operator that the trip signal is clear
  3. Close Breaker in MCR
     a) Control Room Operator will ensure BUS 1DA XFER INIT Switch is in OFF
     b) Close BUS 1DA ALT FEED Breaker
     c) Verify BUS 1DA potential lights are energized

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Staffing: Minimum staffing of the plant is as follows:

Inside Control Room:



*Dealing with high-level management issues (e.g., communicating with NRC)

**Normally outside CR. Will be in CR within 10 minutes of reactor trip.

***Daytime only

Outside Control Room:

Local Plant Operator	Crew #
Auxiliary Operators	3
Turbine Hall Operator	2
Aux bldg/WaterTreatment	2

Crew composition and titles are plant specific

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Interaction with Fire Procedures:**

Time	Event	Comment
T=0min	Fire and Reactor Trip	
T=0min	Control Room dispatches fire brigade to fight the fire; immediate memorized actions (steps 1-3 EOP 0) performed	Fire brigade comprised of 3 Local Plant Operators
T=3min	EOP 3, step 3 indicates SBO. Procedure transition brief held by SS to alert all control room staff that they have an SBO and fire. They will be entering ECA 0.0	OPER1 designated to perform ECA 0.0; OPER2 designated to start reviews of FP
T=5min	OPER1 begins ECA 0.0	
T=7min	Step 4 ECA 0.0 dispatch Local Plant Operator to investigate failure of AFW	Assume this Local Plant Operator will be tied up restoring AFW and not available to assist in additional actions
T=10min	STA arrives	Begins monitoring critical safety functions
T=15min	OPER1 reaches step 10 ECA 0.0, notifies SS that they need to transition to AOP 304	By this time OPER2 has finished reading through FP
T=15min	SS briefs control room staff on the AOP coordination with the FPs	7 contingent time critical action (need in the first hr) in FP; 2 necessary. Confirmed: FP actions will not interfere with AOP actions; sufficient personnel available to do both in parallel. Late actions (>4hr) are postponed until SBO is recovered.
T=20min	OPER1 begins AOP 304; OPER2 begins directing FP actions	OPER2 dispatches 1 Local Plant Operator to perform FP actions
T=35min	OPER1 arrives at step 17 of AOP 304 (locally remove power from ESFLS)	Cue for action

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Staffing Adequacy:

- Analysts walked through the scenario, including the parallel use of the fire procedure and confirmed staffing is adequate to perform this function (see table below).
  - o Assessment based on minimum staffing situation (i.e., night time). Daytime shifts would have, at the minimum, an additional Control Room Operator.

Crew Member	Total Available Before Fire	# assisting with fire*	# Available for EOP actions	Required for Bus Alignment
Shift Manager	1	1	0	0
Shift Supervisor	1	Directing both procedures		0
STA	1	0	1	0
Control Room Operators	2	1	1	1
Plant operators	7	4	3	1

*This includes members of fire brigade and staff occupied with FPs or otherwise occupied due to the fire

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Timing analysis:

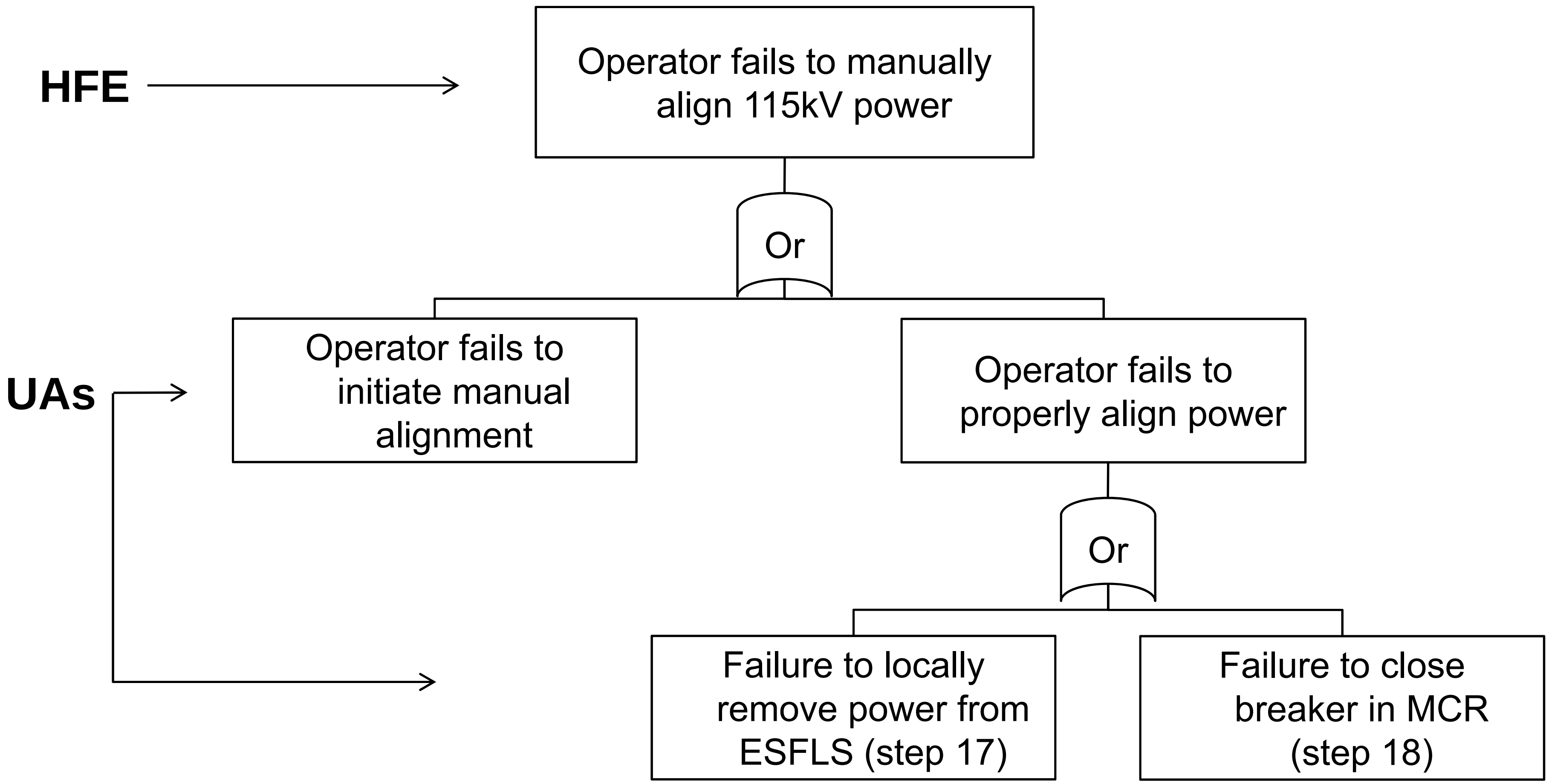
- Fire ongoing throughout the scenario
  - o Detailed fire modeling shows fire will last approximately one hour
- 90 minutes for the total window (from initiator to core damage) based on a thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open.
- T_delay = 35 min from reactor trip to receiving cue for action (step 17 in AOP 304)
  - o Based on Simulator observation for a similar scenario for SBO it took operators 10 minutes to get through ECA 0.0 step 10
    - ▪ Simulation based on non-fire SBO, so add an 5 additional minutes to account for the initial coordination
  - o Based on operator interviews, estimated additional 20 minutes to reach step 17 of AOP 304
    - ▪ Majority of the steps in AOP 304 are checking indicators, so < 1min per step on average
    - ▪ Includes time to locally check out the buses for damage and report back (walk back to MCR because communications are not available due to fire)
    - ▪ Includes 5 minutes to account for AOP/FP meeting to coordinate

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Timing analysis (con't):

- T_action = 22 min for diagnosis and execution
  - o Diagnosis and SS approval ~2 minutes
  - o The action to locally remove power from the Train B ESF Loading Sequencer is trained on using Job Performance Measure (JPM) 12654 – Align ALT Feed Breaker. This JPM has a time requirement to be able to complete the local portion of the actions within 15 minutes, and this has been verified by observations of the JPM. The timing starts once the operator is given the instructions to perform this action and ends once the MCR action had been complete (end of step 18).
    - ▪ As part of this JPM the operators train on putting on flash gear which is required to locally remove power from the Train B ESF Loading Sequencer. The flash gear is stored in a cabinet at the entrance to the relay room.
  - o After the operators complete the local action they will need to return to the control room to tell the control room operators they were successful. This additional travel time is expected to take 5 minutes.
    - ▪ Under ideal conditions the Local Plant Operator could use the phone to call the control room. However, for fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable. Radio unavailable during SBO.

Step 4: Define HFE and Unsafe Actions



Step 4: Define HFE and Unsafe Actions

- **HFE**:
  - Operator fails to manually align 115kV power (alternate power source) given an SBO.
  - HFE defined as part of previous steps of Fire HRA process (Identification and Definition) but unsafe actions must be defined here if applicable.
- **Cues**:
  - Multiple Indications of Loss of Buses1DA and 1DB with EDG not Available. SS makes call to power 1DA after buses have been inspected.
  - AOP-304, Step 17: Locally remove from the Train A ESFLS (Local, Skill-of-Craft action).
  - AOP-304, Step 18: Energize XSW1DA from the normal power source (MCR, proceduralized action):
    - Ensure BUS 1DA XFER INIT Switch is in OFF
    - Close BUS 1DA ALT FEED Breaker
    - Verify BUS 1DA potential lights are energized

Step 4: Define HFE and Unsafe Actions

- Unsafe Actions:
  - o Control room crew actions:
    1. Fails to initiate manual alignment (EOO)
    2. Fails to close breaker in MCR (to properly align alternate power) (EOC)
       a) Fails to recover from EOC (long time window, immediate feedback)
  - o Local operator actions:
    3. Fails to locally remove power Train A ESFLS (only credible failure mode is EOC)
       a) Fails to recover from EOC (with no local feedback available)

Potential Failure Modes and Recovery

- **Unsafe actions:**
  1. Control room crew fails to initiate manual alignment (EOO):

     Given the nature of the action and the training, it is unlikely that the crew will skip either step 17 or step 18, but it is possible that sufficient distractions (and other factors elongating the timeline) exist that the crew could **fail to complete the action in time**

  2. Control room crew fails to close breaker in MCR (to properly align alternate power) (EOC)

     These unsafe actions is not considered further because there is a very high potential for recovery, e.g.,

     –Good cues for recovery

     –Long Time Frame (35 minute time available for recovery)

     –Fire extinguished by this point in time

Potential Failure Modes and Recovery (cont.)

- Unsafe actions (continued):
  3. Local operator fails to locally remove power Train A ESFLS (only credible failure mode is EOC), **AND**

  3a. Local operator fails to recover from EOC (with no local feedback available)

  EOC:

  – Well proceduralized/skill-of-craft step with good training
  – EOC failure modes may include: Open wrong switch (fail local action)
  – Diagnosis is largely performed by CR operators; plant operators must simply execute the required actions and report back to CR (for purposes of coordination)

  Recovery of EOC: In this case, there is no feedback available to the local operator that the wrong action was performed. Clear indications in the MCR that the ESFLS signal has not been cleared; the local operator will not get this feedback until he returns to the MCR to report back. After being notified that the wrong action has been performed, the local operator must return to the location of the ESFLS switch.

Steps 5-8: Understanding the Context (Iterative Process)

Step 5: Identify Potential Vulnerabilities

Step 6: Search for Plausible Scenario Variations

Step 7: Evaluate Potential to Recover

Step 8a: Create Operational Story/Stories

Step 8b: Numerical Assessment

Group Exercise

- **Break into groups and identify factor that could:**
  - Create potential vulnerabilities in the crew's ability to respond to the scenario(s) of interest and increase the likelihood of the HFEs or UAs
  - Failure modes (i.e., how can the scenario go wrong?)
  - Lead to variability in crew response

- **You may want to consider the following**
  - Division of Labor/Workload
  - Procedures
  - Training
  - Complexity
  - Environment
  - Special Requirements (e.g., keys)
  - Stress due to Fire
  - Communication
  - Crew Coordination
  - Variations in Timing
  - Variation in Crew Characteristics

Group Exercise (2)

- Which factors are drivers? [Error Forcing Contexts]
  - Note: Normally this would be done with the input of those knowledgeable of the plant and crews (e.g., operators, trainers) and any assumptions would be verified against the plant's operations

Potential Vulnerabilities

- **Training**: Operators trained on procedures, including applicable alternative actions. Non-fire SBO scenarios are common in training and “Align ALT Feed Breaker” is a Job Performance Measure which is trained on bi-annually. Annual training on Fire Procedures. *Trained as crew on SBO, not single operator. Fire Procedure training may not include doing the procedures in parallel.*
- **Parallel Procedures**: The fire is ongoing during this scenario, so a portion of the staff will be unavailable to help with the EOPs as they will be in the fire procedures. Through operator talk-throughs verified that adequate personnel are available for the necessary actions in this scenario. While operators will be going through two procedures in parallel (FP and EOP), the relevant steps of the FP have been examined and do not conflict with the EOP actions. While the Control Room Operators will be operating in parallel, the Shift Supervisor’s attention will be split and he is a key decision point at several places in the procedure.
- **Complexity:** Local action to remove power from ESFLS is a simple, skill-of-craft action.
- **Environment:**
  - **Availability and Accessibility:** Given location of fire and layout of plant, the relay room is accessible and there is no degraded environment (e.g., no smoke) in the relay room or en route to the relay room.
  - **Visibility:** Given a SBO event, lighting will be significantly reduced (i.e., flashlights and/or emergency lighting). Training is performed in these conditions.
  - **Heat/Humidity**: Normal – fire effects do not reach this area, however, after some time (>action window) there could be a rise in temperature due to SBO.

Potential Vulnerabilities

- **Stress due to Fire:** Some stress due to on-going fire and related distractions.

- **Communications:** Communication lines impacted by SBO (no radios) and landlines potentially impacted by fire (no cable tracing). Timeline adjusted appropriately.
  - Previous steps in the ECA/AOP (e.g., local actions such as step 13) might cause delays due to extra time required for communication, delaying the cue (step 17).
  - Generally, Local Plant Operators have to travel back to MCR to report

- **Efficiency of crew coordination:**
  - Crew variations that could result in variability in the time to perform actions and effectiveness of communication back to control room.
  - Too much focus on fire.
  - “Weaker” crews.

- **Special Requirements:**
  - Operators will need key to access relay room; all doors locked on loss of power.
  - Change in security configuration due to SBO may require operators to take a different pathway or some doors which would otherwise be open may now be closed and locked. Not all operators have all keys.

Step 8: Quantification (6 Steps Overview)

1: Discuss HFE and possible influences / contexts using a factor "checklist" as an aid

2: Identify "driving" influencing factors and thus most important contexts to consider (e.g., operational story)

3: Compare these contexts to other familiar contexts and each expert independently provide the initial probability distribution for the HEP based on a common calibration scale.

4: Each expert discuss and justify their HEP

5: Openly discuss opinions and refine the HFE, associated contexts, and/or HEPs (if needed) – each expert independently provides HEP (may be the same as the initial judgment or may be modified)

6: Arrive at a consensus HEP for use in the PRA

Step 8: Quantification (Operational Story)

- Not limited to one operational story, particularly if the analysts have identified multiple credible contexts [EFCs] that need to be examined separately.
- A full operational scenario description, or "operational story," including accident progression and as many "bells and whistles" as are reasonable, such that operator trainers can "put themselves into" scenario.
  - In quantification, you will be asking them, "what would your crews do in this situation?"
- The resulting operational scenario description may include:
  - Additional plant conditions that will need to be quantified as part of the HFE (unless accident sequence analyst wants to revise event trees or fault trees).
  - Distinctions on timing of plant behavior (that might need to be addressed as part of the HFE, unless logic is revised).
  - Instrument or indication issues (including failures) that will need to be reflected (for fire, might be explicitly part of PRA model, or may not).
  - Different possible procedure paths or response strategies that operators might rationally take.
  - Reasons why operators might take different procedure paths.
  - Credible **recovery actions**.

Step 8: Quantification (Operational Story, UA1) Operator Fails to Initiate Manual Alignment

Possible factors/sub-scenario to explore with experts in:

- Staffing variations: can be two sub-cases if large impact on crew performance
  - Night time, minimal staffing (2 Control Room Operators)
  - Day time, normal staffing (3 Control Room Operators)
- Crew variations, such as these two extremes in possible timing outcomes:
  - Methodical crew that is good at taking time to work through the procedures and talk through potential conflicts. The crew works well as a team and rely on each other a lot. Training is done as a team on both the non-fire SBO procedures and the fire procedure, so the Control Room Operators are a bit slower in working through their respective procedures when they are done in parallel, depending heavily on the Shift Supervisor for coordination, OR
  - Aggressive crew, good at planning ahead, working fairly autonomously but coordinating when needed. Efficient at parallel procedures.
- Weak team members, i.e., OPER1 is struggling to keep pace with the rest of the team. There may or may not be an OPER3 that is available to look at boards and help with EOPs and/or FPs.

Step 8: Quantification (Operational Story, UA1) Operator Fails to Initiate Manual Alignment

Possible factors/sub-scenario to explore with experts:

- Variations in SS experience, command & control style, & so forth, e.g.,
  - SS's first actual fire and, because it is a fairly big fire, he gets very focused on fire and becomes less cognizant of timeline or becomes a bottle neck for key decisions.
  - SS calm under stress and has no problem coordinating the two procedures. Team is working at a fairly fast pace and multi-tasking well (e.g., dealing with distractions), but working at the top of their capacity.
- Timing Variations:
  - Delays in previous steps due to combination of radio unavailability and operators having to "hunt down" appropriate keys due to change in security configuration for SBO.
- Other:
  - Fairly significant fire (lasts 60 min), so there are many distractions (e.g., failed indicators and/or spurious indicators not directly relevant to this HFE, but may take time/attention away from operators)
  - End of shift fatigue
- **Overall, explore what factors (e.g., "slow crew" and other delays), result in crew missing timeframe to take action.**

Step 8: Quantification (Operational Story, UA3/3a) Fail Local Action

Possible factors/sub-scenario to explore with experts:

Unsafe action #3 (EOC):

- Training of non-fire SBO only; JPM timing based on average crew time, but accounts for many Local Plant Operators to be available to help with the procedure. With only two Local Plant Operators available for the EOP/AOP, the operator in question may be fatigued from rushing around and performing the higher workload.
- Timing Variations:
  – Delays in previous steps due to combination of radio unavailability and operators having to “hunt down” appropriate keys due to change in security configuration for SBO.
- Given fast pace and general stress, the Local Plant Operator may feel rushed and open the wrong switch

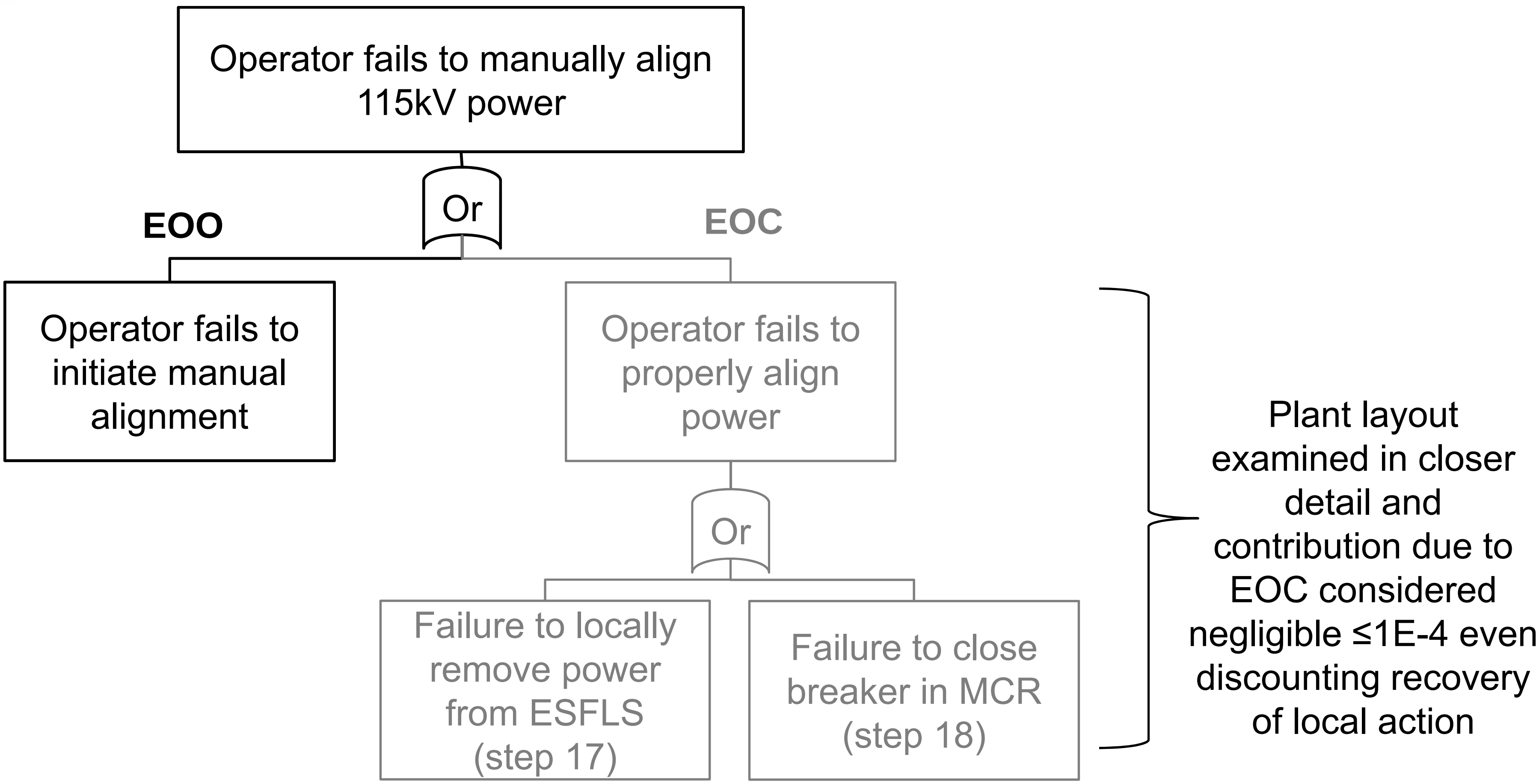
Step 8: Quantification (Operational Story, UA3/3a) Fail Local Action

Possible factors/sub-scenario to explore with experts:

Unsafe action #3a (Failure to recover EOC):

- Staffing:
  - Variations in staffing not applicable to this failure mode (i.e., 2 or 3 CROs)
  - 2 Local Plant Operators available for assistance with this action
- Recovery includes:
  - Diagnosis of problem (good cues); 5-10 minutes
    - Clear indications in the MCR that the ESFLS signal has not been cleared.
  - Action time (including travel time)
    - 20-25 minutes because, while OPER1 knows right away that the ESFLS switch has not been cleared, he has to wait until the Local Plant Operator gets back to re-dispatch him to perform the local action. Need to account for travel time and time to perform the local <u>and</u> MCR actions.
- Fire is extinguished at this point.
- Adequate time for recovery
  - 25-35 minutes required compared to the nominal 55 minutes available.

Logic of Failure Modes



Quantifying Unsafe Action #1 (EOO)

- Driving factors:
  - Slow crew
  - Excessive travel time for local actions extends timeline
  - Mismatch between training (heavy interaction as crew) and reality (relatively autonomous, especially with minimum staffing)
  - Distractions and stress due to fire
  - SS is a funnel point for decisions
- Staffing identified as a driver, so can split this scenario into 2 contexts:
  - 2 Control Room Operators available (Minimal Staffing): 33%
  - 3 Control Room Operators available (Normal Staffing): 67%
- Given "slow and careful" crew, they are unlikely to make a mistake in the action, but may come close to missing the action time window (see next slide).
- "Nominal" case accounted for by shape of the distributions
  - If heavily weighted to left, positive or nominal factors more likely; having the right combination of "driving" factors is less likely

Timing Variations

- Timing is a driving factor in the Operational Story
  - Would ask "experts" to develop a more detailed analysis of potential variations in timing (e.g., more explanations, more developed description of possible scenario variations, detailed histogram of probability of timing for both arrival at Step 17 and performance of required actions)
  - Might separate HFE into two or more separate HFEs to address different timing for different scenarios
- Variations in timing due to factors discussed earlier:
  - Could there be variations in the scenario (e.g., additional minor distractions in working through procedure?
    - "Experts" estimate minor variations: **10-15 additional minutes** to get to critical procedure step
  - Could there be variations in the time to perform (especially with different crews, availability of equipment, communication)?
    - "Experts" estimate minor variations: **5-10 additional minutes** to perform critical procedure steps
- Overall, could reduce time for recovery to as little as **8 minutes**. This, however, does not jeopardize the timeline for the actions themselves.

Step 8: Quantification (Numerical Assessment)

- Combining Multiple Contexts

$$P(HFE|S) = \sum_{j} \sum_{i(j)} P(EFC_i \,|\, S) * P(UA_j \,|\, EFC_i, S)$$

- Only one dominant UA, so this formula simplifies to:

$$P(HFE|S) = \sum_{i} P(UA| EFC_i, S)$$

- Two distributions need to be estimated
  - o Minimal Staffing
  - o Normal Staffing

- Only one distribution will be estimated here for illustration

Step 8: Quantification (Calibrate Experts)

Circumstance	Probability	Meaning
Operator(s) is “Certain” to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
Operator(s) is “Likely” to fail	~0.5	5 out of 10 operators would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
Operator(s) would “Infrequently” fail	~0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crew/operators were to experience this scenario.
Operator(s) is “Unlikely” to fail	~0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
Operator(s) is “Extremely Unlikely” to fail	~0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

Note: These values are meant as calibration points, not discrete values. The 1E-03 values is not meant to be a lower bound.

Step 8: Quantification (Numerical Assessment)

- Very structured, facilitator led, expert opinion elicitation process
  - o leads to consensus distributions of operator failure probabilities
- Considerations in elicitation process (covered in NUREG-1880):
  - o Forming the team of experts (include experts familiar with important relevant factors during fire conditions, operator trainers, etc.)
  - o Controlling for biases when performing elicitations
  - o Addressing uncertainty
- Distribution characteristics:
  - o the 99th percentile is the HEP for the worst coincident (but not too unlikely) set of negative influences representing a very strong EFC
  - o the 1st percentile is the HEP for the best coincident set of positive influences representing a weak EFC (actually a very positive context
  - o dependency considerations embedded
  - o uncertainty distribution explicitly considered
- **For this illustrative example an HRA SME was used to derive the HEP; this would not normally be sufficient for an actual quantification.**

Step 8: Quantification

- A tip for expert elicitation facilitators:
  - In order to get “experts” to better access their knowledge (i.e., not just remember recent history), you can use examples from real events (i.e., “stories”) to illustrate how operators can do “surprising” things (but for good reasons.
    - You know that you’ve succeeded in getting access to this deeper knowledge when the “experts” start exchanging stories (e.g., “do you remember when ‘Charlie’ ….?” “I can remember a time or two kind of like that….”)

Step 8: Quantification (Bases for Consensus Distribution)

	Percentiles						
Analyst	1st	10th	25th	50th	75th	90th	99th
Larry	0.00001	0.0001	0.0007	0.001	0.005	0.007	0.01
Moe	0.0001	0.0003	0.001	0.005	0.007	0.03	0.07
Curly	0.00001	0.00005	0.0007	0.003	0.005	0.01	0.05
Consensus	**1E-04**	**1E-04**	**1E-03**	**3E-03**	**5E-03**	**1E-02**	**5E-02**

- **Bases for Consensus Distribution:**
  - Under normal circumstances, the action is “Extremely Unlikely” to fail, but the shortened time frame due to no radio communication in combination with potential coordination complications from the fire may produce some difficulties for the crews.
    - Holistically, on average the action was determined to be “Extremely Unlikely” because actions are well trained, proceduralized/skill-of-craft, long timeline, a high potential for recovery and cues are clear so little potential for confusion or mis-direction.
    - Probability capped at 1E-04
    - Worst case falls between “Unlikely” to fail and “Infrequently” fails because even in the worst case they still have buffer time.
    - Tails: effectiveness of crew collaboration, specifics of timing

Step 9: Incorporating HEP into PRA

- When quantifying a scenario with multiple contexts, need to combine weighted distributions. Discrete distributions can be combined using a convolution:

$$(f * g)[n] = \sum_{m=0}^{t} f[n-m]\, g[m]$$

  – Recommend using a statistical software package (e.g., Crystal Ball)

- Depending on the PRA needs, you may:
  – Provide the entire consensus histogram as your answer.
  – Need to develop a mean value for the distribution using a software tool (e.g., Crystal Ball).

- NUREG-1880 provides some guidance and cautions on the development of mean values.

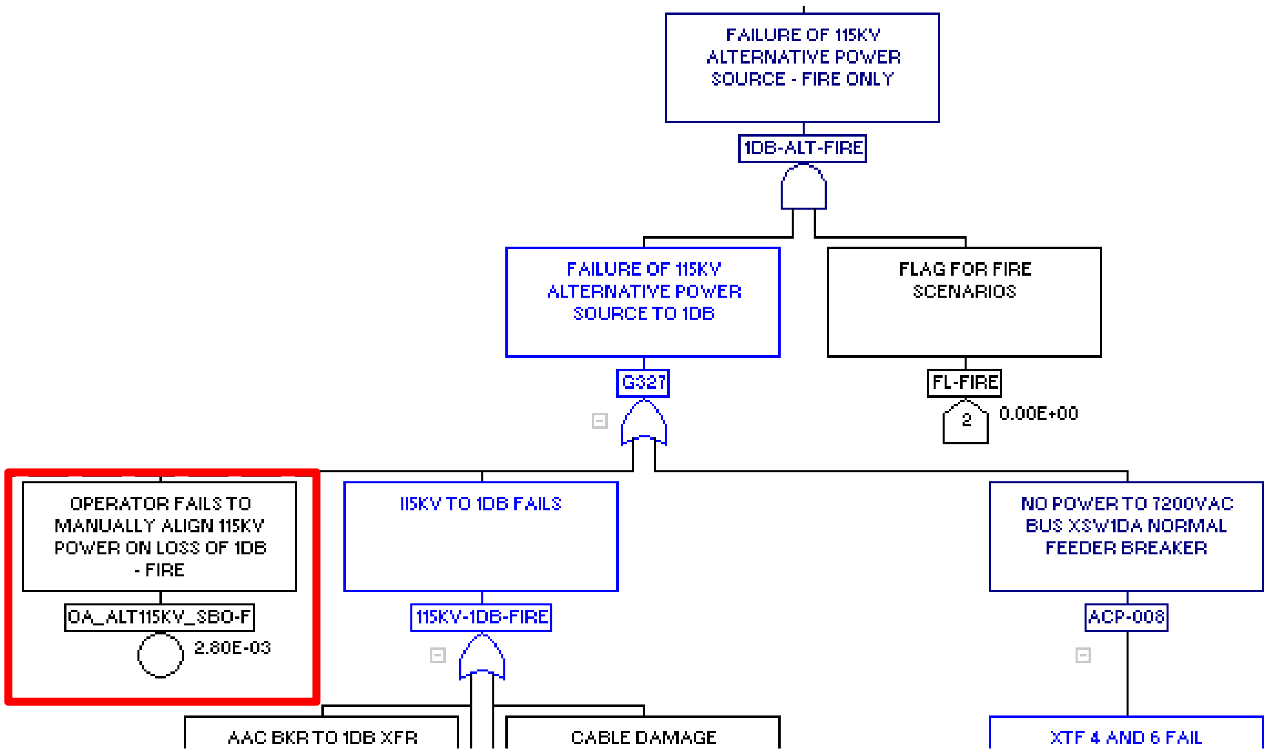
What if…

- What if communication was not impacted, how would the analysis change?
- What if there were not clearly enough people to complete the actions, how would the analysis change?
- What if the operators had to take a detour that comes close to the fire?

SCOPING ANALYSIS OF FIRE SBO

Review of HFE

- **Initial Conditions**: Single unit two loop PWR with two trains of electrical power. Steady state, full power operation. Night shift with minimal staff onsite.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine room causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power on loss of both buses and EDGs fail to start.



Minimum Criteria

1. Procedures
   – Plant procedures covering each operator action being modeled
   – Support both diagnosis & execution of the action

   Local action (step 17) is skill-of-craft; MCR action (step 18) well proceduralized.

2. Training – on the procedures and the actions

   Regular training on non-fire SBO, including alternative actions. Training on FPs.

3. Availability and Accessibility of Equipment
   – Key to ESFLS Panel needed, but available in MCR

   Key to ESFLS Panel needed, but available in MCR.
   Flash gear needed, but available locally.

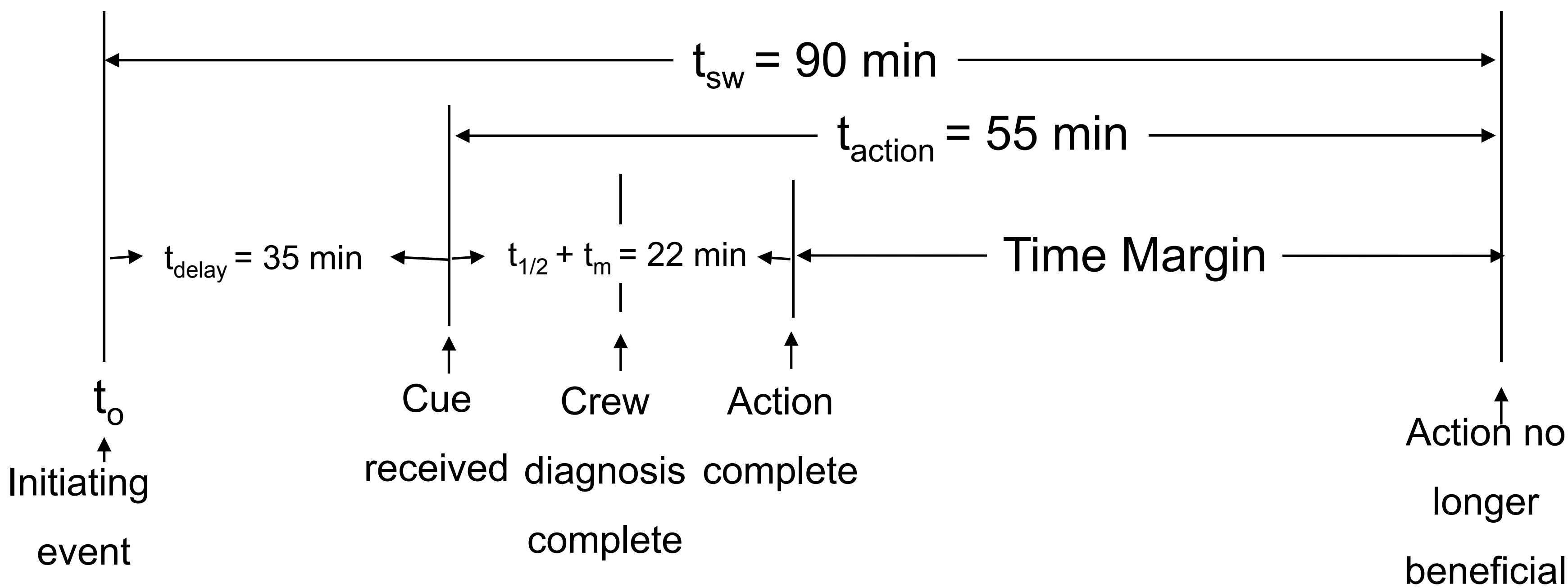
Feasibility

- **Timing analysis**:
  - Tsw: Assume 90 minutes for the total window (IE to core damage) based on a thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open.
  - T_delay = 35 min from reactor trip to receiving cue for action (step 17 AOP 304)
  - $T_{1/2}$ + Tm = 22 min for diagnosis and execution

- **Feasible?** Yes time available (90 minutes) is greater than time for action (55 minutes).

Time Margin

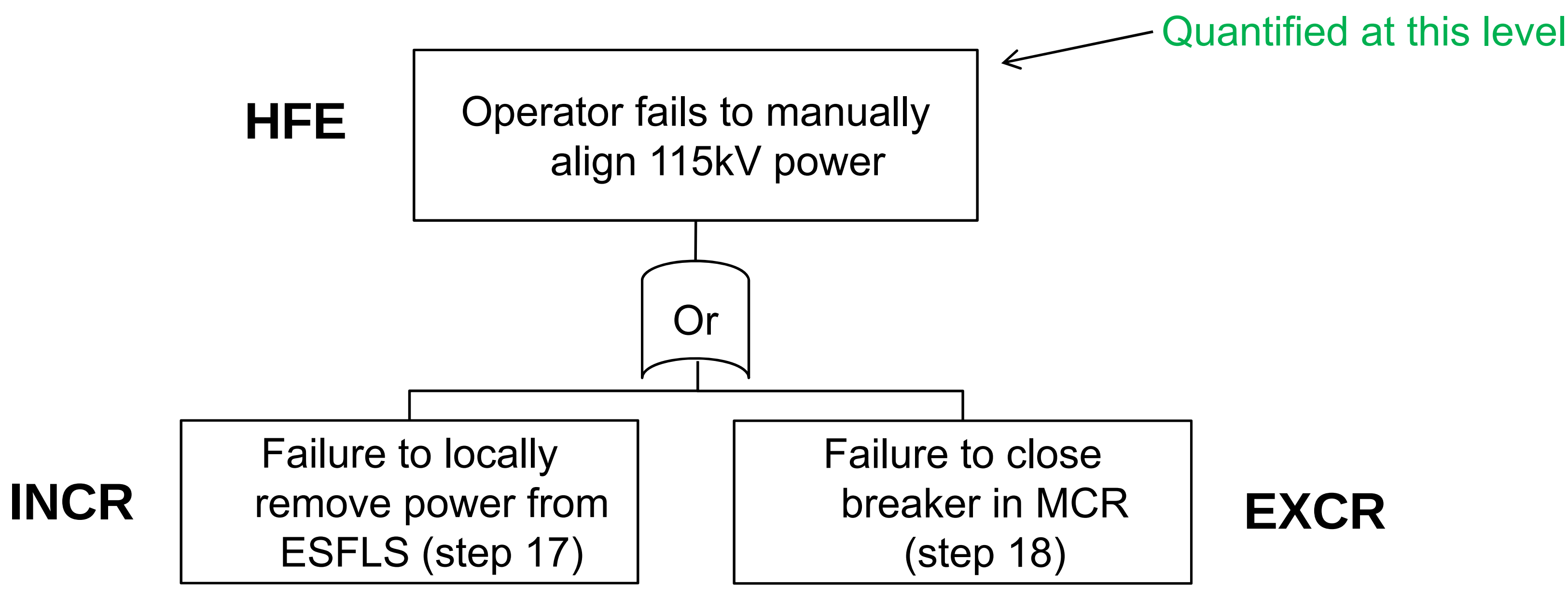
$$\text{Time\_Margin} = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\% = \frac{55 - 22}{22} * 100\% = 150\%$$



Assessing Key Conditions & PSFs within the Scoping Flowcharts

- How well the procedures match the scenario
- Response execution complexity
- Timing of cues for the action relative to expected fire suppression time
- Action time window
  - Short time window = 30 minutes or less
  - Long time window = greater than 30 minutes
- Level of smoke and other hazardous elements in the action areas
  - Need for special equipment (e.g., SCBA)
  - Impairment of vision or prevention of the execution of the action
- Accessibility

HFE Breakdown



While the HFE can be broken down into multiple steps (INCR and EXCR), because this is defined as one HFE (based on the fact it is one diagnostic step), we will quantify this HFE using the EXCR tree because it is more conservative.

Search Scheme

Scoping Analysis:

•**Define HFE:** Failure to locally remove power from ESFLS (step 17). This includes both the diagnosis and the execution.

•**Does it meet the minimum criteria**? Yes

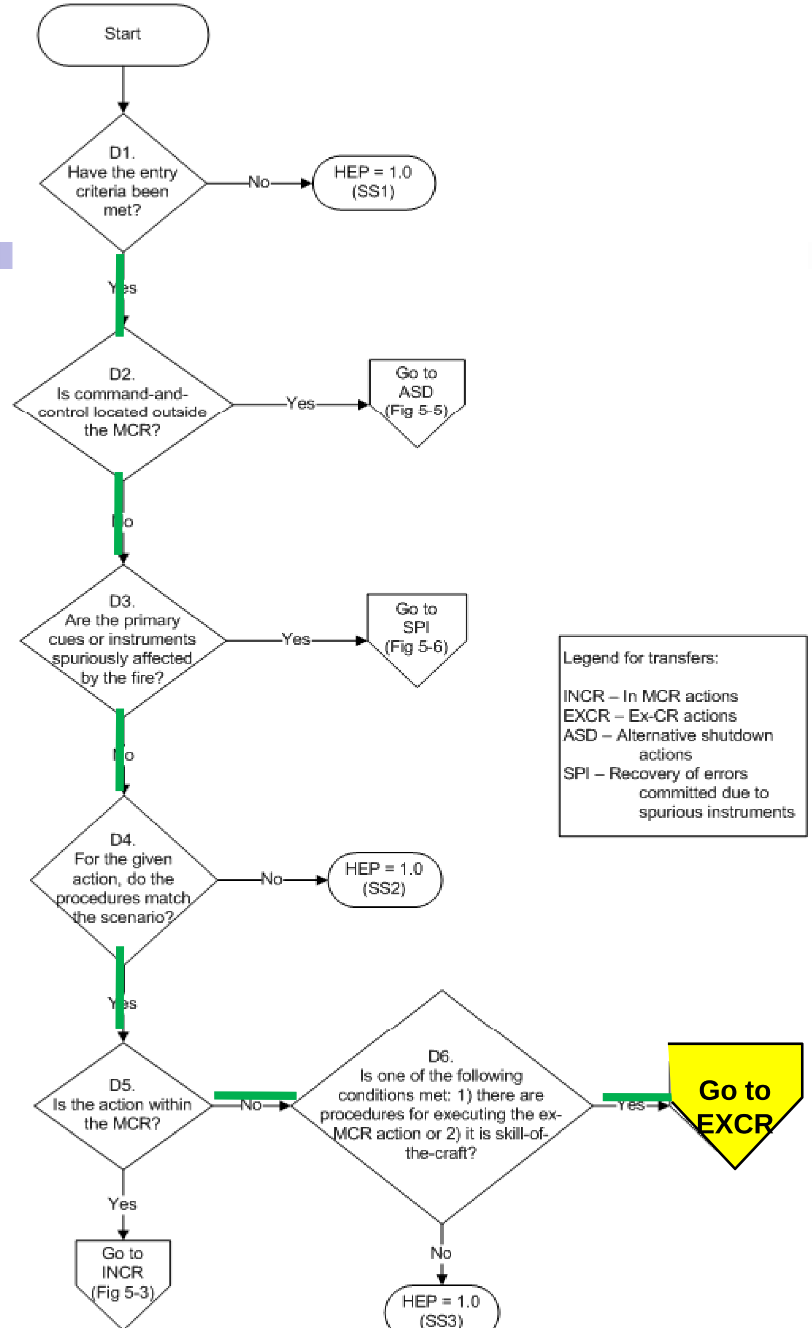
1)Procedures are available
2)Training is performed on the procedure
3)The key to the Relay Room is determined to be accessible

•**Is the action Feasible?** Yes

1)Demonstrated sufficient time to perform action

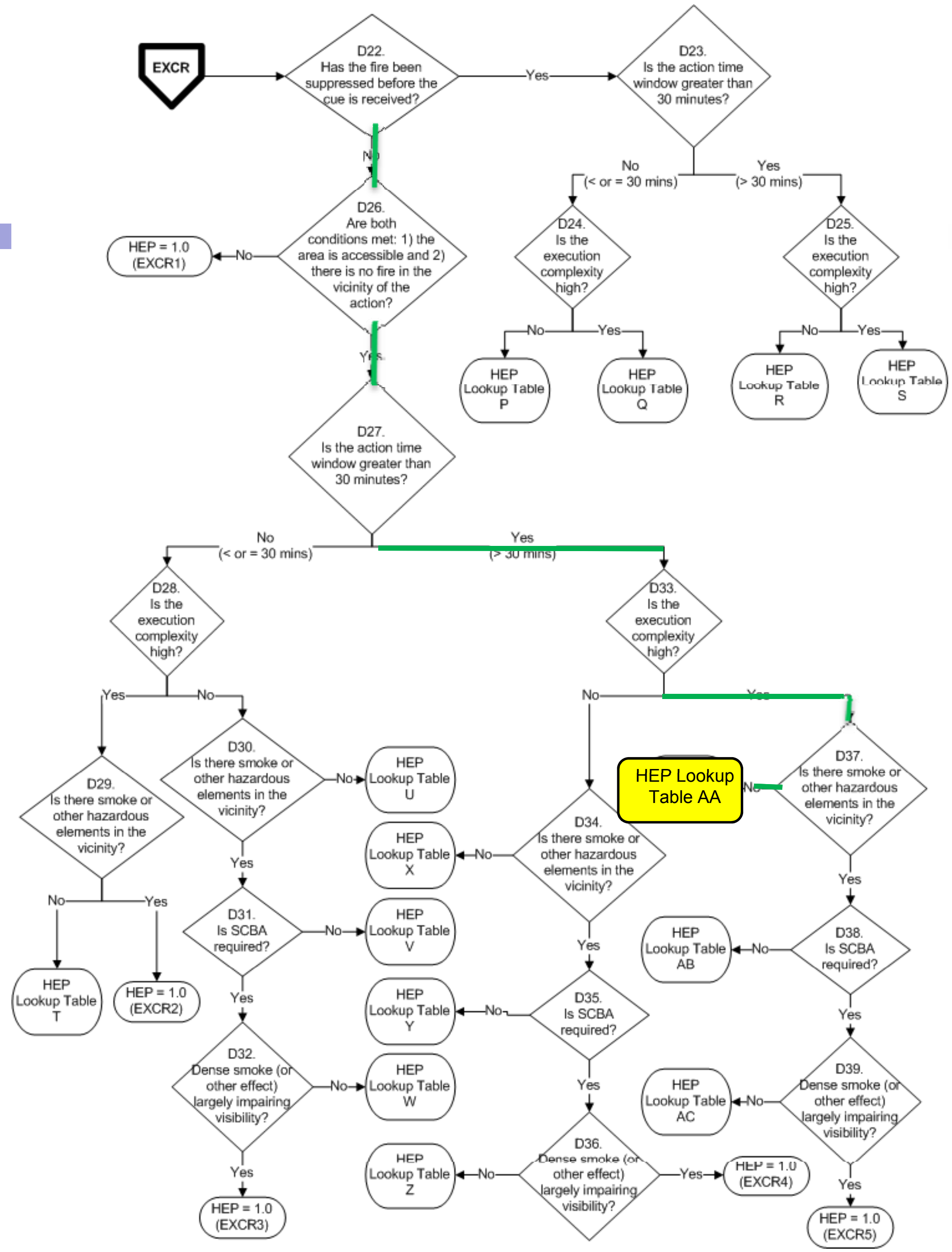
•**Selection Scheme**:

1)D1: Entry criteria are met
2)D2: command and control in MCR
3)D3: primary cues/instrument not spuriously affected by fire
4)D4: procedures match the scenario
5)D5: some actions within MCR, but key actions outside MCR, so use EXCR tree
6)D6: procedures available/skill-of-craft
7)GO TO EXCR TREE



HFE

- Local Action
  - D22: Fire is ongoing
  - D26: Area accessible and no fire in vicinity.
  - D27: Time window is greater than 30 min (90 – 35 = 55min).
  - D33: High complexity in execution due to multiple step/locations
  - D37: No smoke.
  - Time Margin >100%
  - **Look up Table AA value = EXCR36 = 0.1.**



Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

SCOPING EXAMPLE

General Assumptions for Examples

- Actions have applicable plant emergency procedures and fire procedures
- Fire does not impact control room environment
- There is a full area burn out
- At least one train of heat removal is available as demonstrated by Appendix R
- Adequate inventory in fire protection system (FPS)

Example 1A: Operator fails to align FPS water to AFW pumps

- The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
- With low low level in the tank, the operator would align the FPS (fire protection system) to the pumps.
- Consider the tank low low level (10%) would be reached in 10 hours. At this level the operator will receive an alarm (sound and light)
- The operator has to open manual valves. (At least one valve)
- At 10% low low level the local operator must align the FPS.
- Operator has 1 hour before loss of cooling from low low level cue

Example 1A:
Operator fails to align FPS water to AFW pumps

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis time = 2 minutes
  - Execution time = 10 minutes

Example 1A: Minimum Criteria

1. Procedures
   – Plant procedures covering each operator action being modeled
   – Support both diagnosis & execution of the action

2. Training – on the procedures and the actions

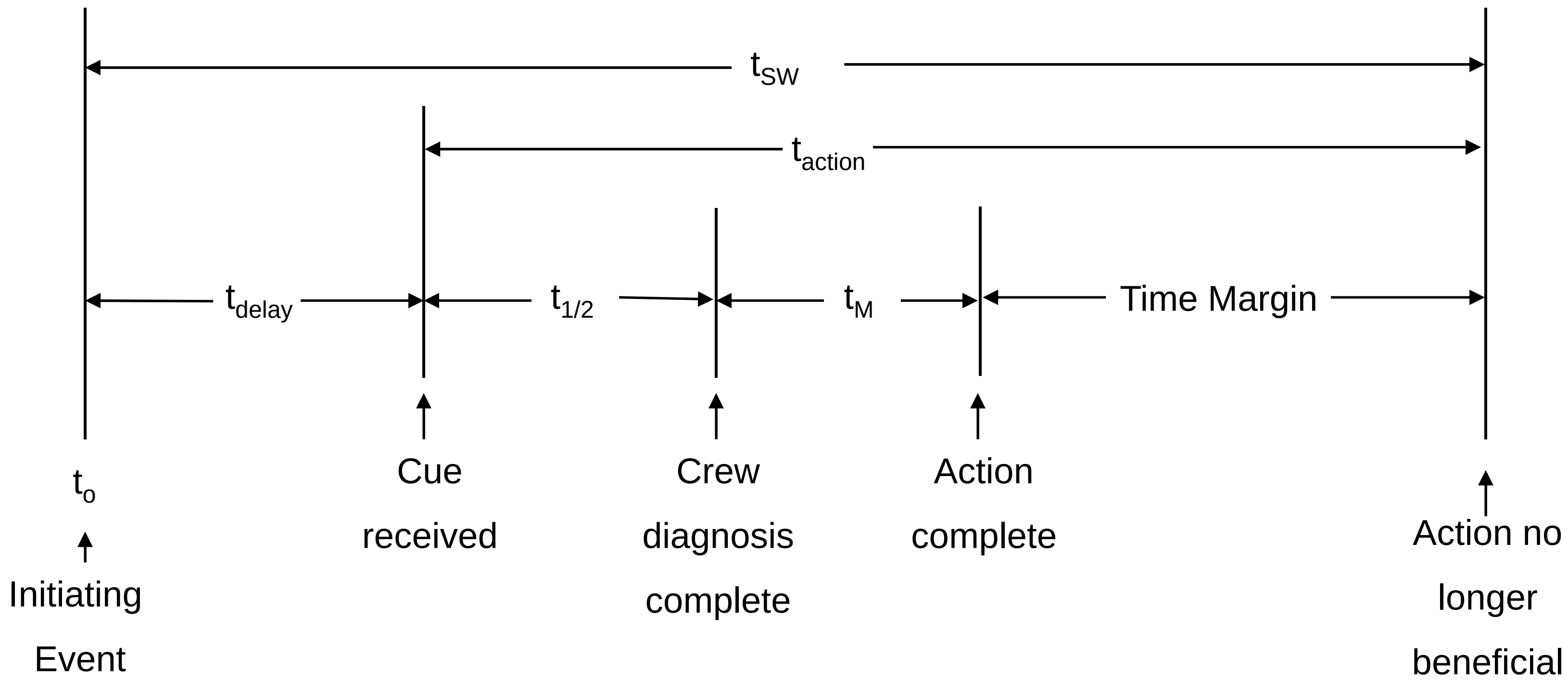
3. Availability and Accessibility of Equipment

Example 1A: Feasibility

- Timing Analysis:
  - Time available (60 mins) > Time required (12 mins)
- Cues available to aid diagnosis
  - Cable tracing was done on AFWST alarms
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 1A: Time Margin

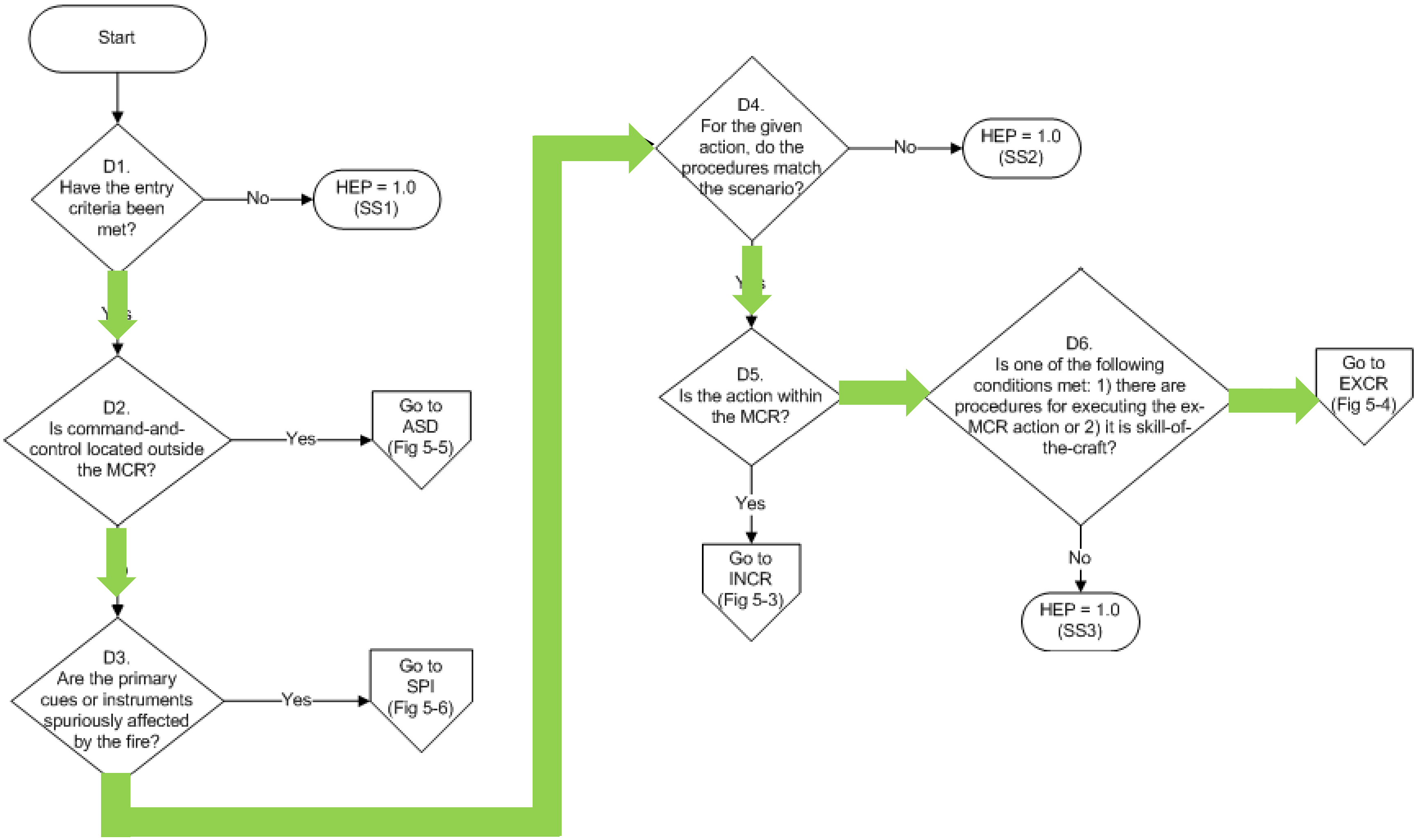
$$\text{Time Margin} = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\% = \frac{60 - (2+10)}{(2+10)} * 100\% = 400\%$$



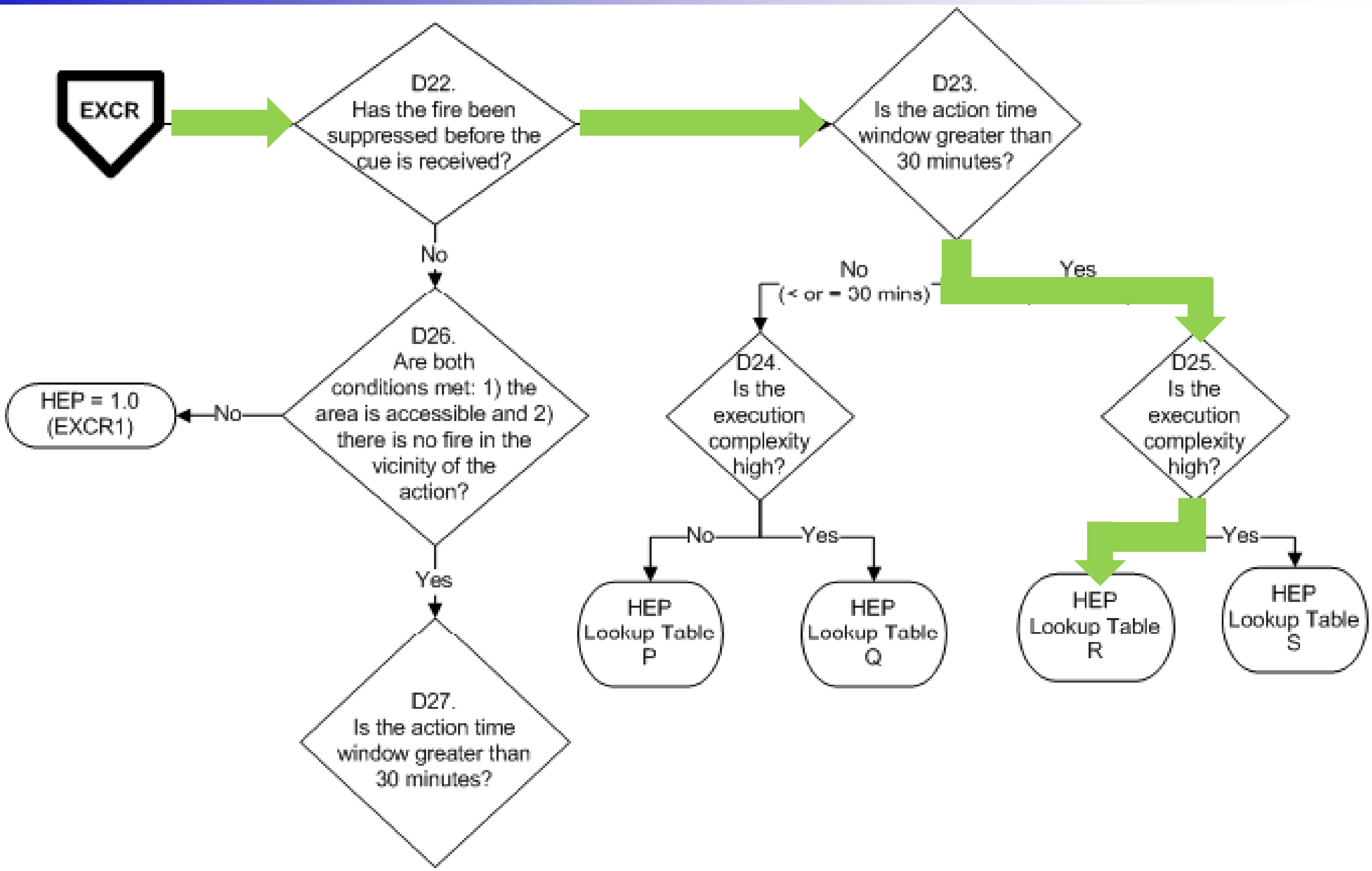
Example 1A: Assessing Key Conditions & PSFs

Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	Yes
What's the action time window?	60 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

Example 1A: Search Scheme



Example 1A: EXCR



Example 1A:
EXCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
R	> 100%	0.002	EXCR12
	50 – 99%	0.01	EXCR13
	< 50%	1.0	EXCR14

Example 1B:
Operator fails to align FPS water to AFW pumps with failed alarm

- Same basic scenario as Example 1A
  - The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
  - When low low level in the tank is reached, the operator needs to align the FPS (fire protection system) to the pumps.
- Cable tracing has not been done, therefore assume fire fails the AFWST alarm at the 10% level
  - Assumed that the action would not occur (error of omission) and the spurious indication flowchart must be used!
- Fire procedures direct operator to check tank level locally and consider refilling if needed
  - Diagnosis time is increased

Example 1B: Operator fails to align FPS water to AFW pumps with failed alarm

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis time = 15 minutes
  - Execution time = 10 minutes

Example 1B: Minimum Criteria

1. Procedures
   – Fire procedures covering each operator action being modeled
   – Support both diagnosis & execution of the action

2. Training – on the procedures and the actions

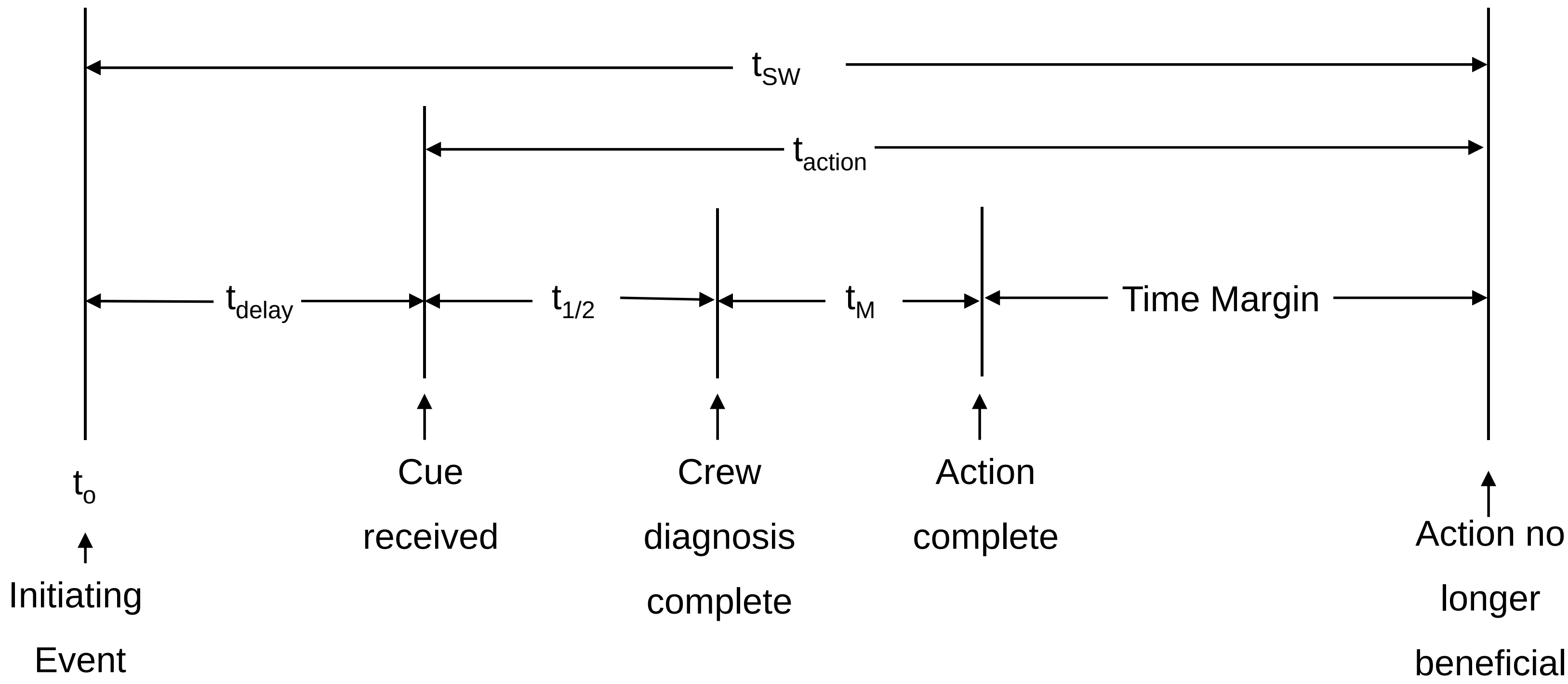
3. Availability and Accessibility of Equipment

Example 1B: Feasibility

- Timing Analysis:
  - Time available (60 mins) > Time required (25 mins)
- Cues available to aid recovery
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 1B: Time Margin

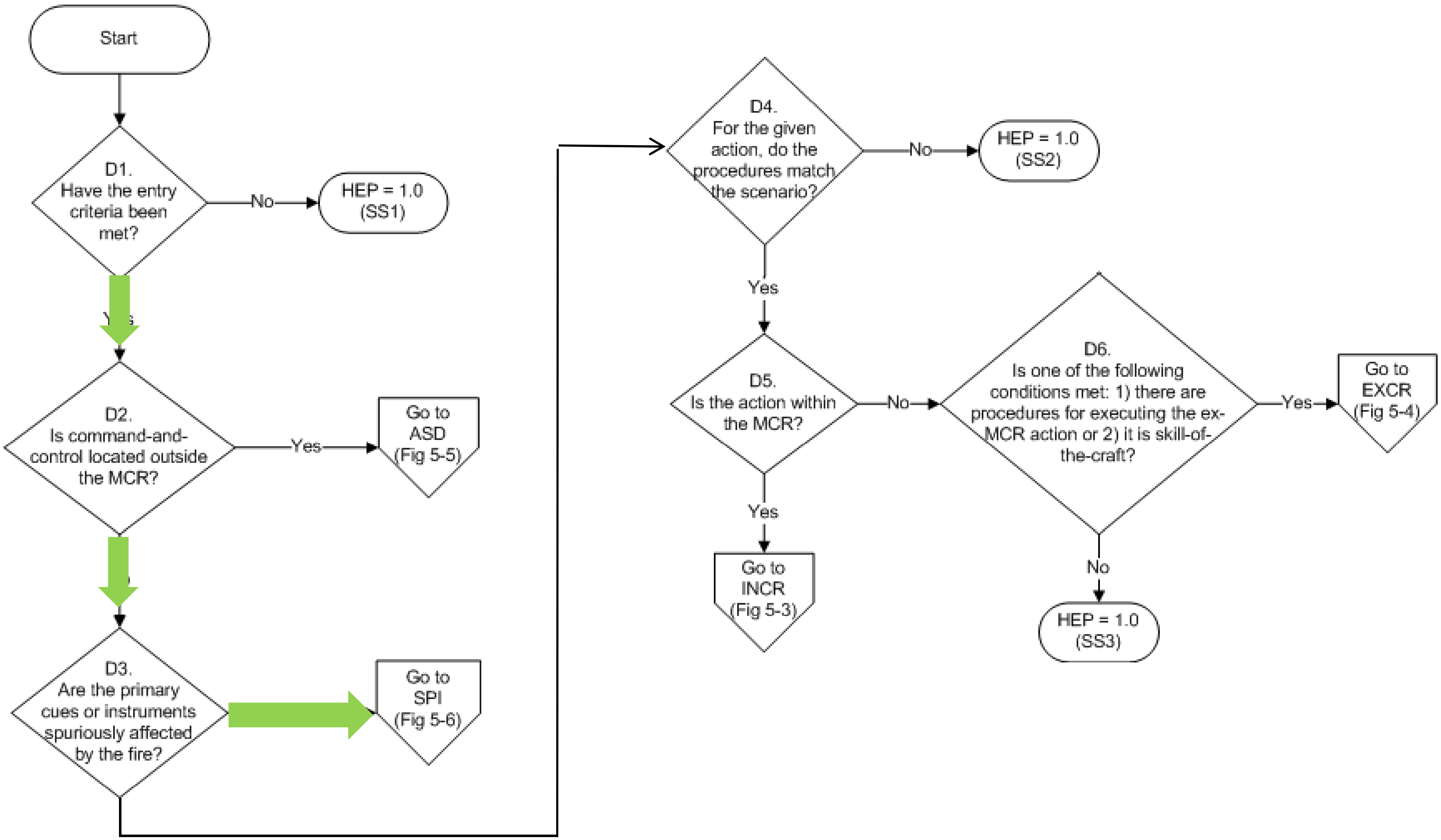
$$\text{Time Margin} = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\% = \frac{60 - (15 + 10)}{(15 + 10)} * 100\% = 140\%$$



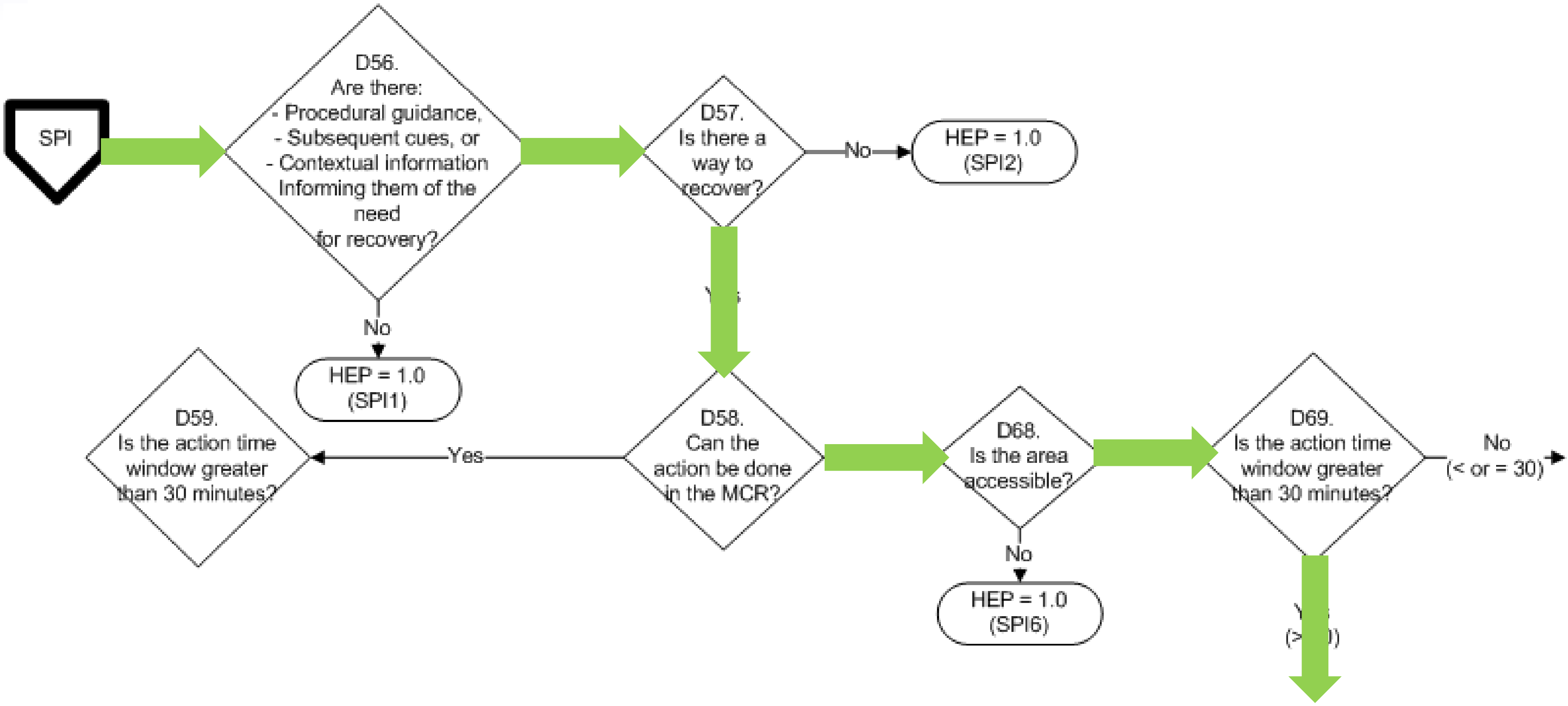
Example 1B:
Assessing Key Conditions & PSFs

Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	Yes
What's the action time window?	60 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

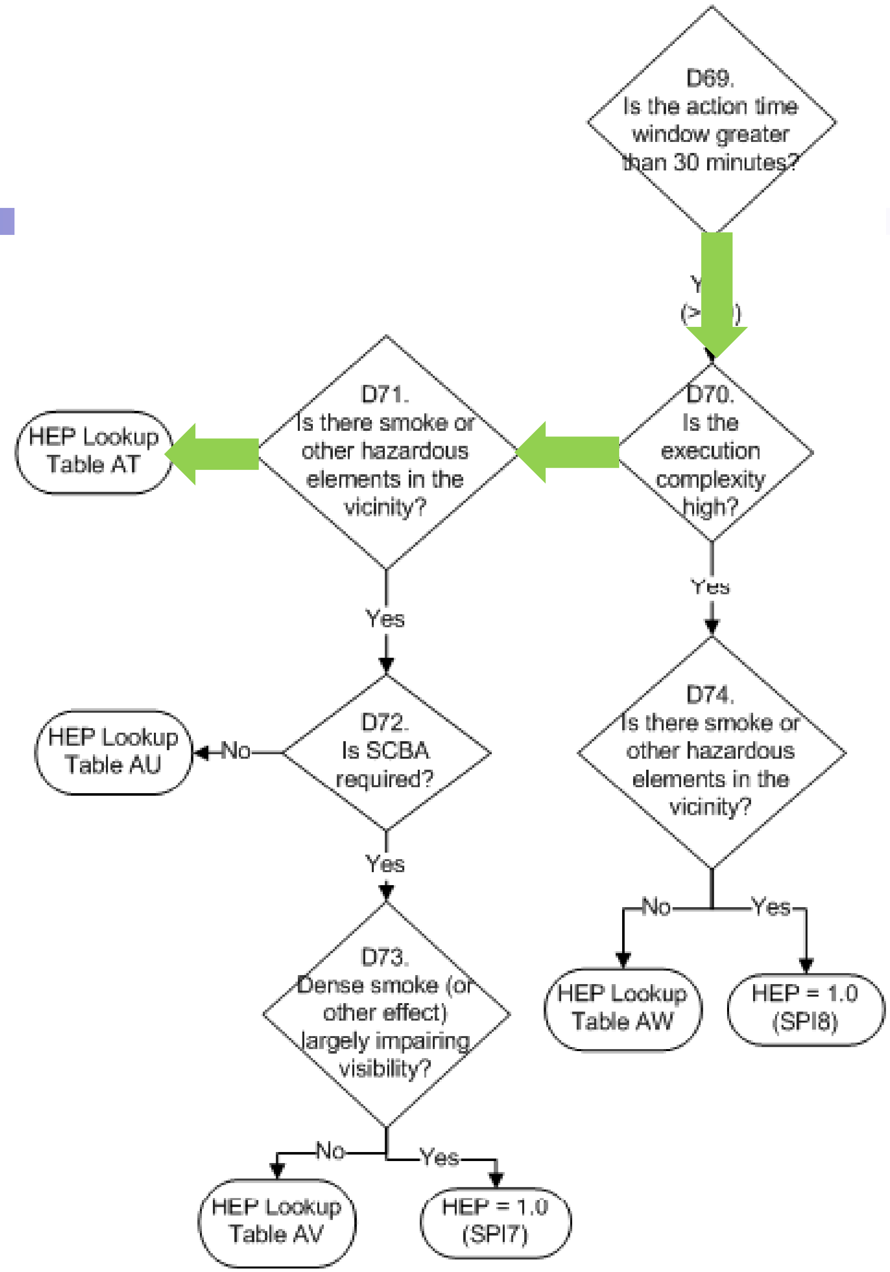
Example 1B: Search Scheme



Example 1B: SPI



Example 1B: SPI



Example 1B: SPI Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
AT	> 100%	0.1	SPI27
	50 – 99%	0.5	SPI28
	< 50%	1.0	SPI29

Example 2A:
Operator fails to initiate bleed & feed

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case all indications of level are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Example 2A:
Operator fails to initiate bleed & feed

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time remaining after cue = 25 minutes
- Time for carrying out action:
  - Diagnosis time = 3 minutes
  - Execution time = 8 minutes

Example 2A: Minimum Criteria

1. Procedures
   - Plant procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action

2. Training – on the procedures and the actions

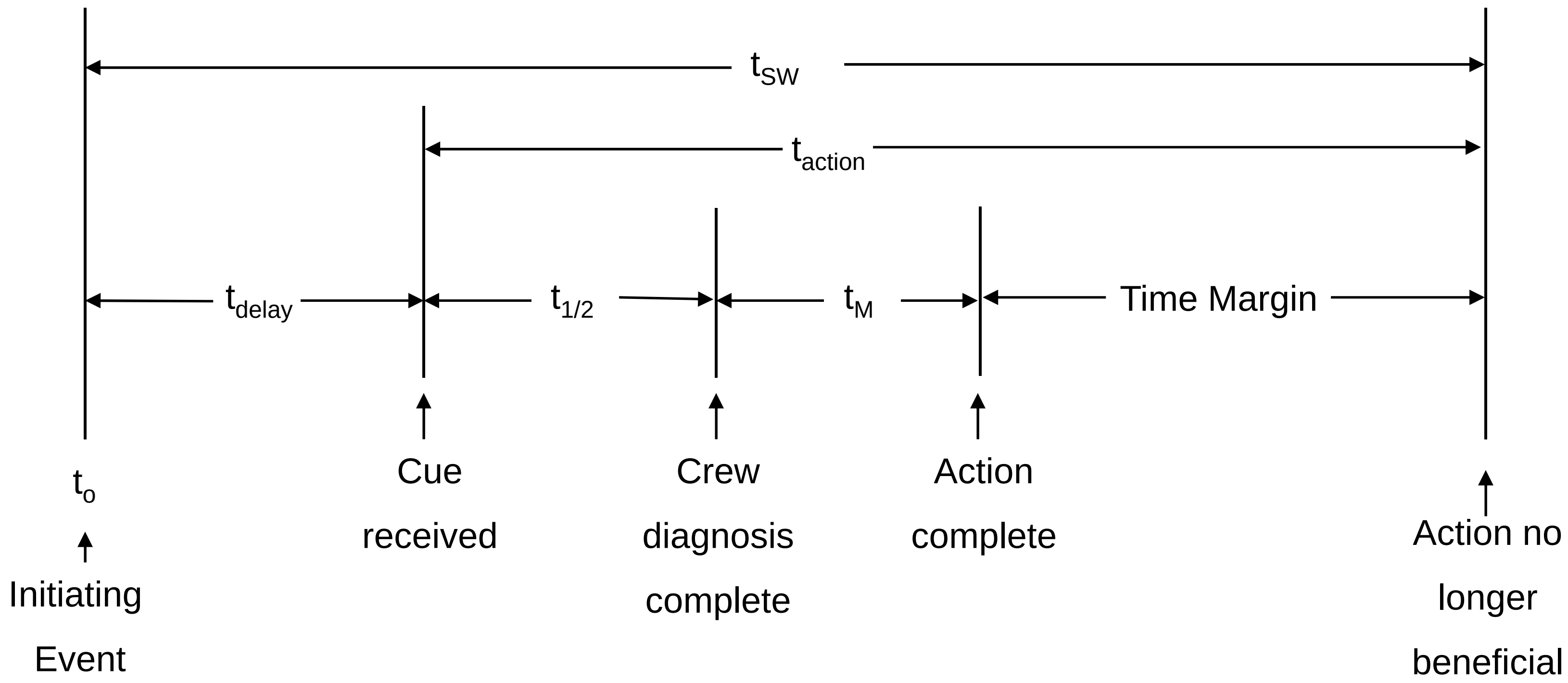
3. Availability and Accessibility of Equipment

Example 2A: Feasibility

- Timing Analysis:
  - Time available (25 mins) > Time required (11 mins)
- Cues available to aid diagnosis
  - All indications of SG level are accurate
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 2A: Time Margin

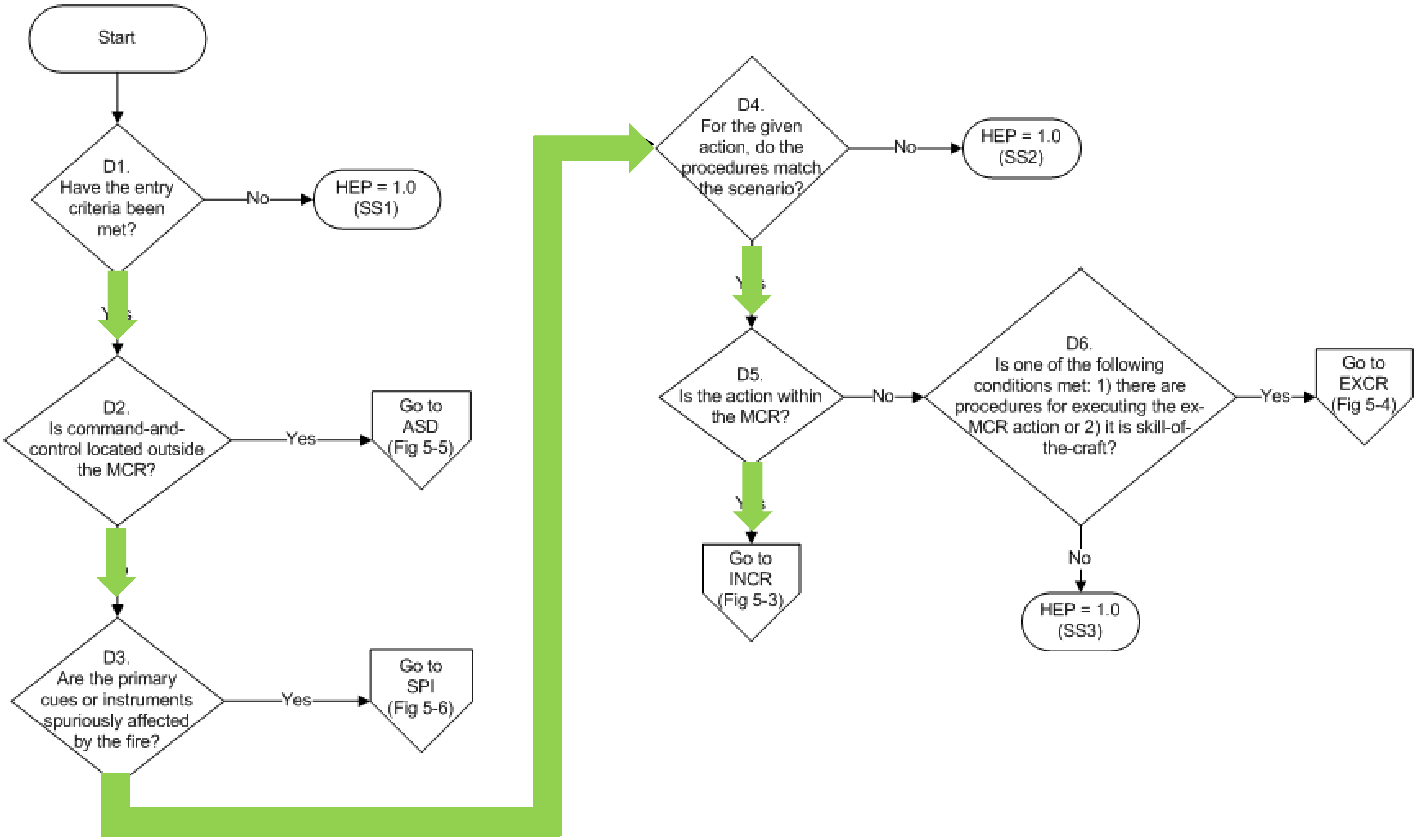
$$\text{Time Margin} = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\% = \frac{25 - (3+8)}{(3+8)} * 100\% = 127\%$$



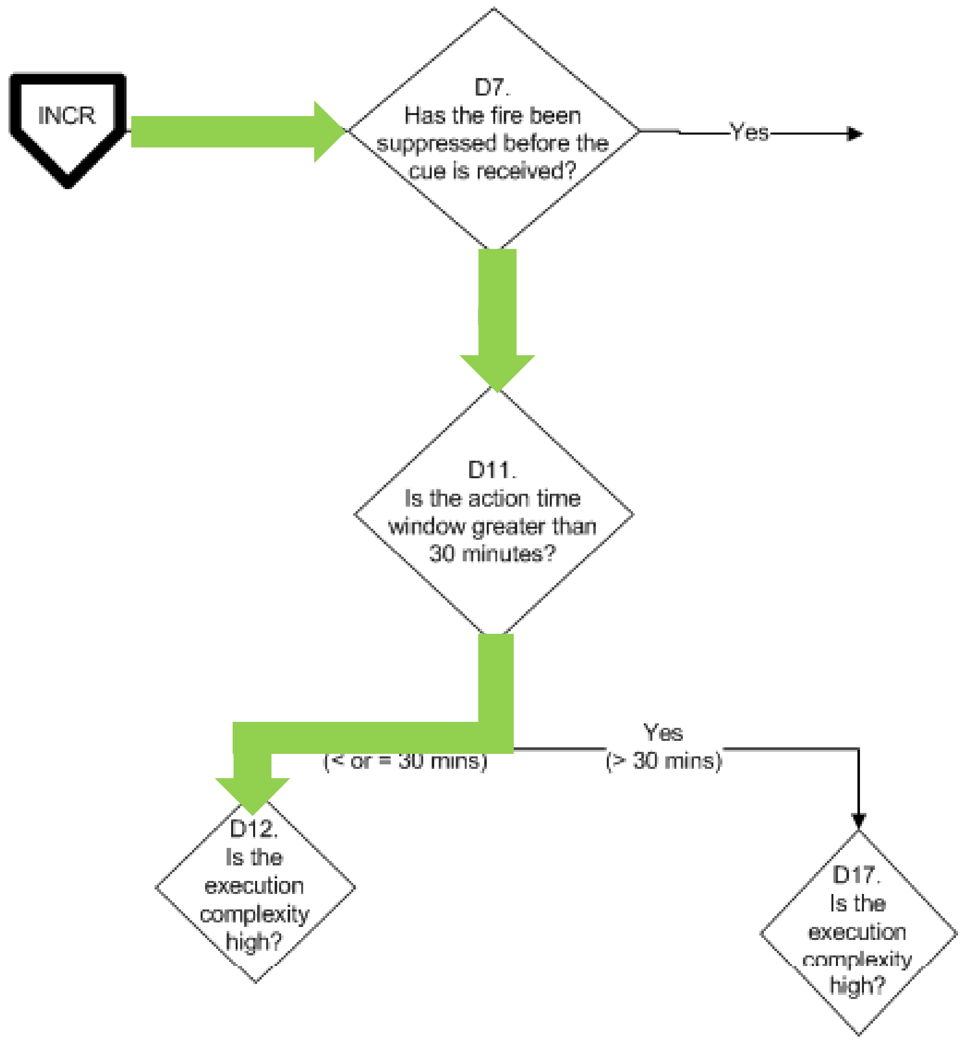
Example 2A: Assessing Key Conditions & PSFs

Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	No
What's the action time window?	25 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

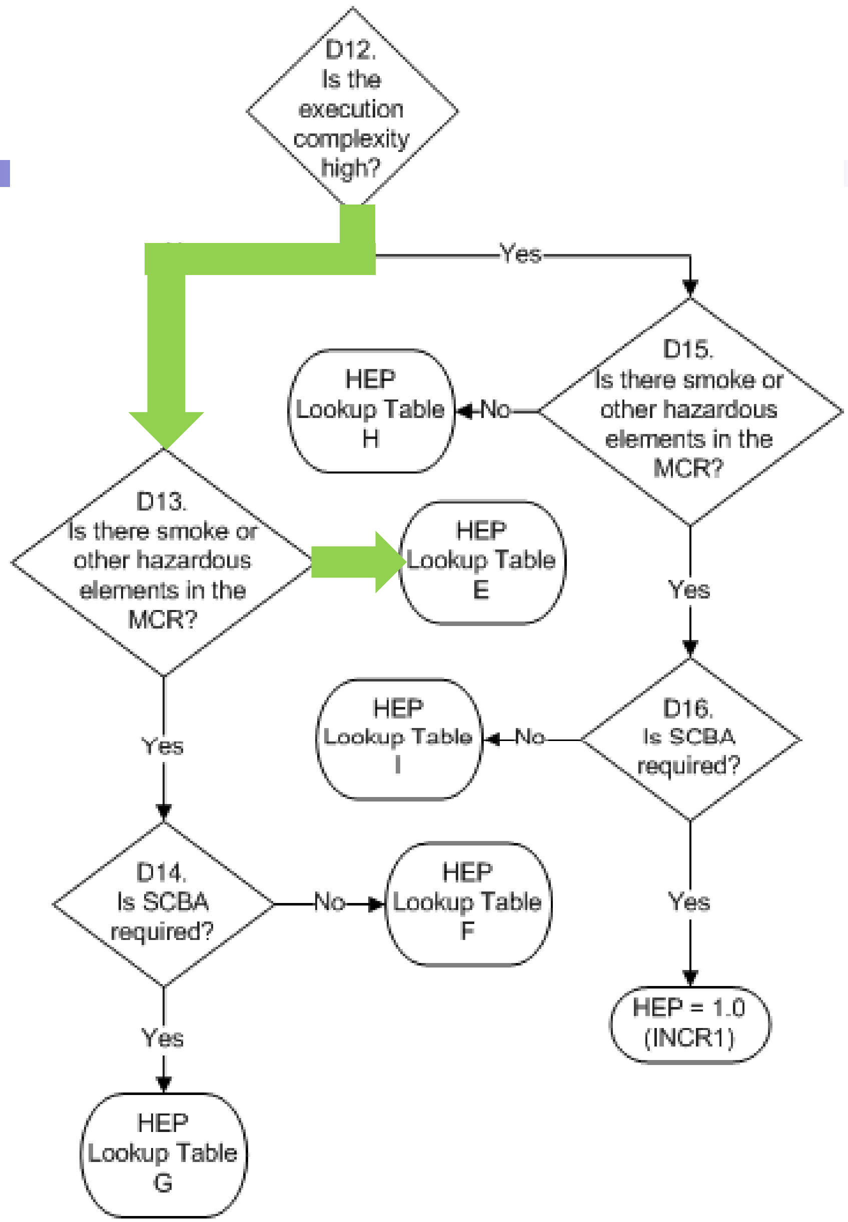
Example 2A: Search Scheme



Example 2A: INCR (part 1)



Example 2A: INCR (part 2)



Example 2A:
INCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
E	> 100%	0.05	INCR14
	50 – 99%	0.25	INCR15
	< 50%	1.0	INCR16

Example 2B: Operator fails to initiate bleed & feed and use of fire procedures

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case half of the indicators of SG level are failed and fire procedures must be used to identify which indicators are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Example 2B:
Operator fails to initiate bleed & feed and use of fire procedures

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time remaining after cue = 25 minutes
- Time for carrying out action:
  - Diagnosis time = 8 minutes
  - Execution time = 8 minutes

Example 2B: Minimum Criteria

1. Procedures
   – Fire procedures covering each operator action being modeled
   – Support both diagnosis & execution of the action

2. Training – on the procedures and the actions

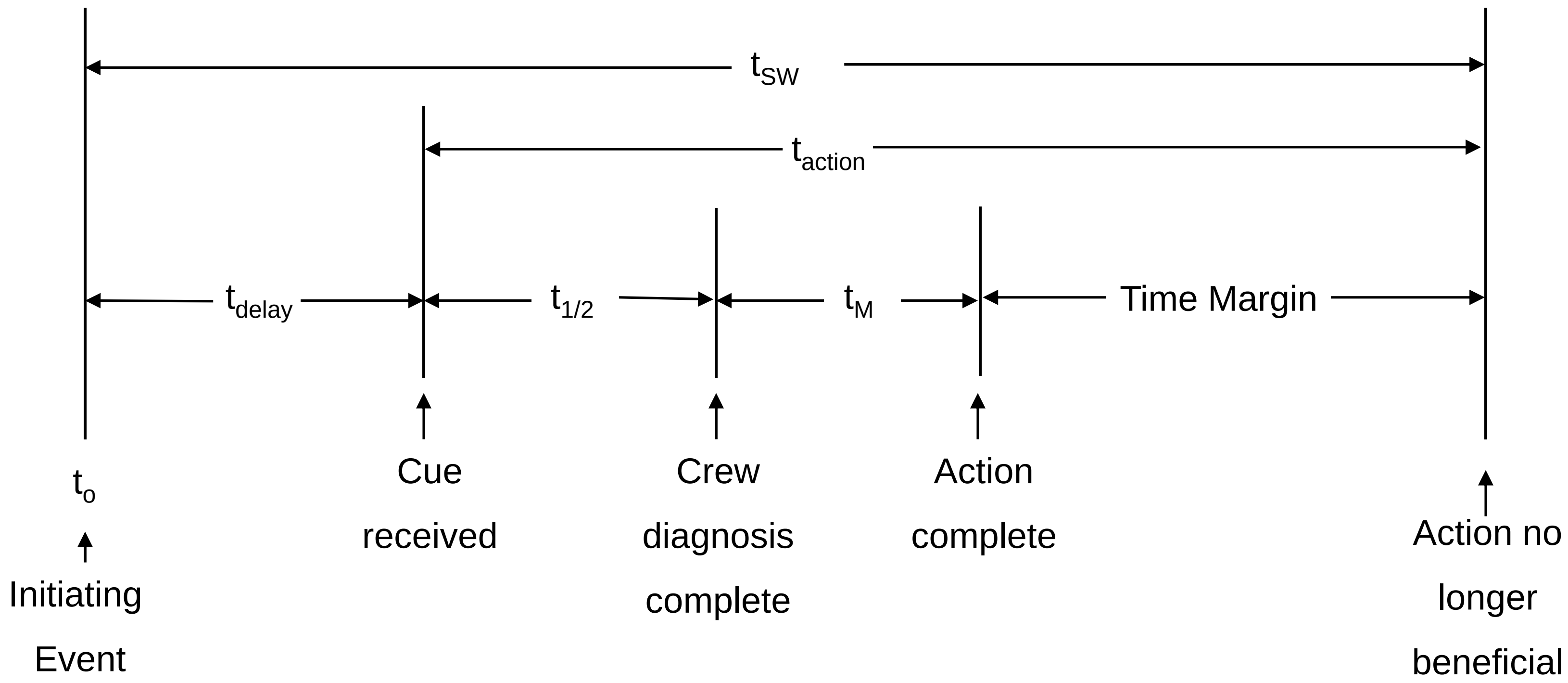
3. Availability and Accessibility of Equipment

Example 2B: Feasibility

- Timing Analysis:
  - Time available (25 mins) > Time required (16 mins)
- Cues available to aid diagnosis
  - Some indications of SG level are accurate
  - Fire procedures used to determine which indicators to trust
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 2B: Time Margin

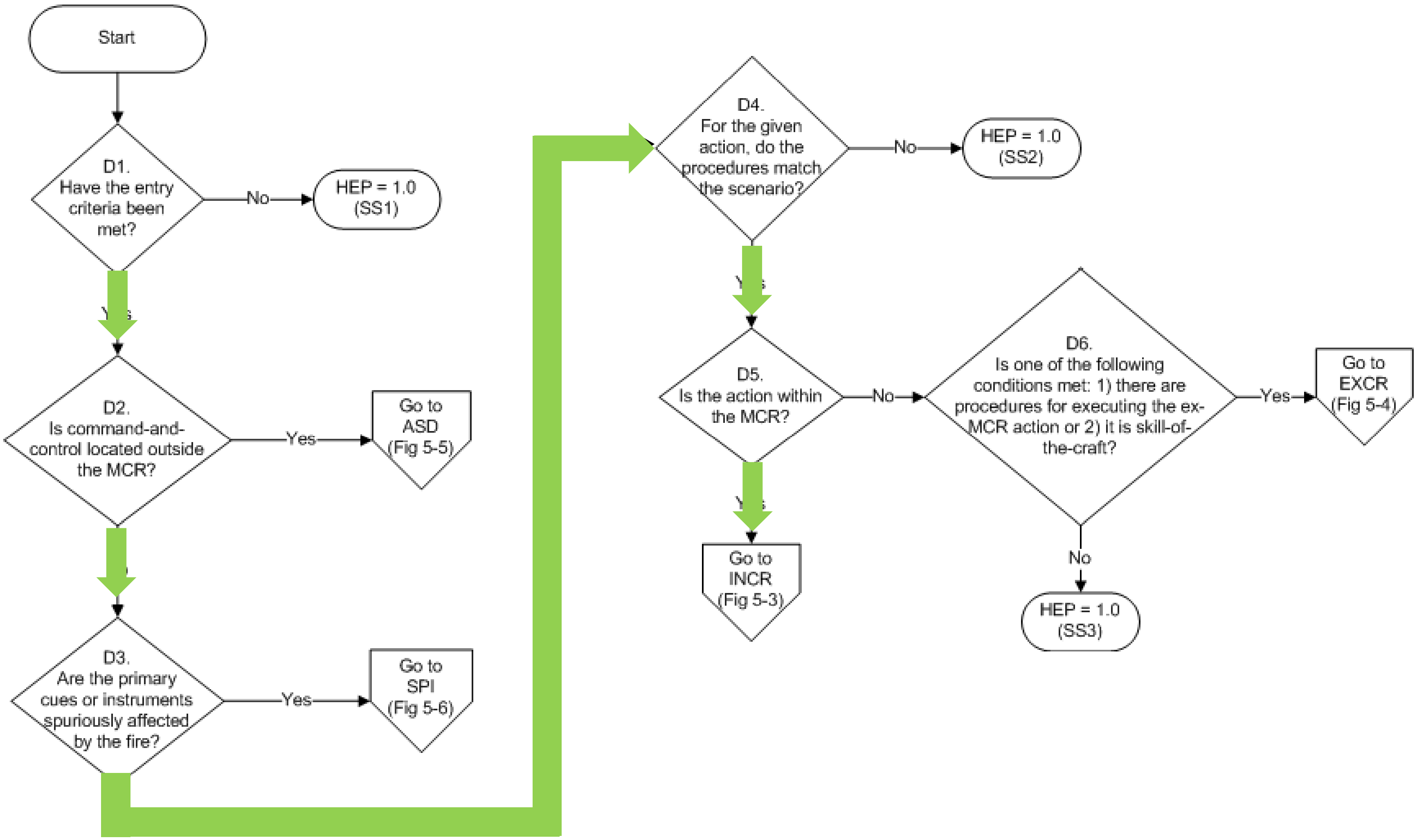
$$\text{Time Margin} = \frac{t_{action} - (t_{1/2} + t_m)}{(t_{1/2} + t_m)} * 100\% = \frac{25 - (8+8)}{(8+8)} * 100\% = 56\%$$



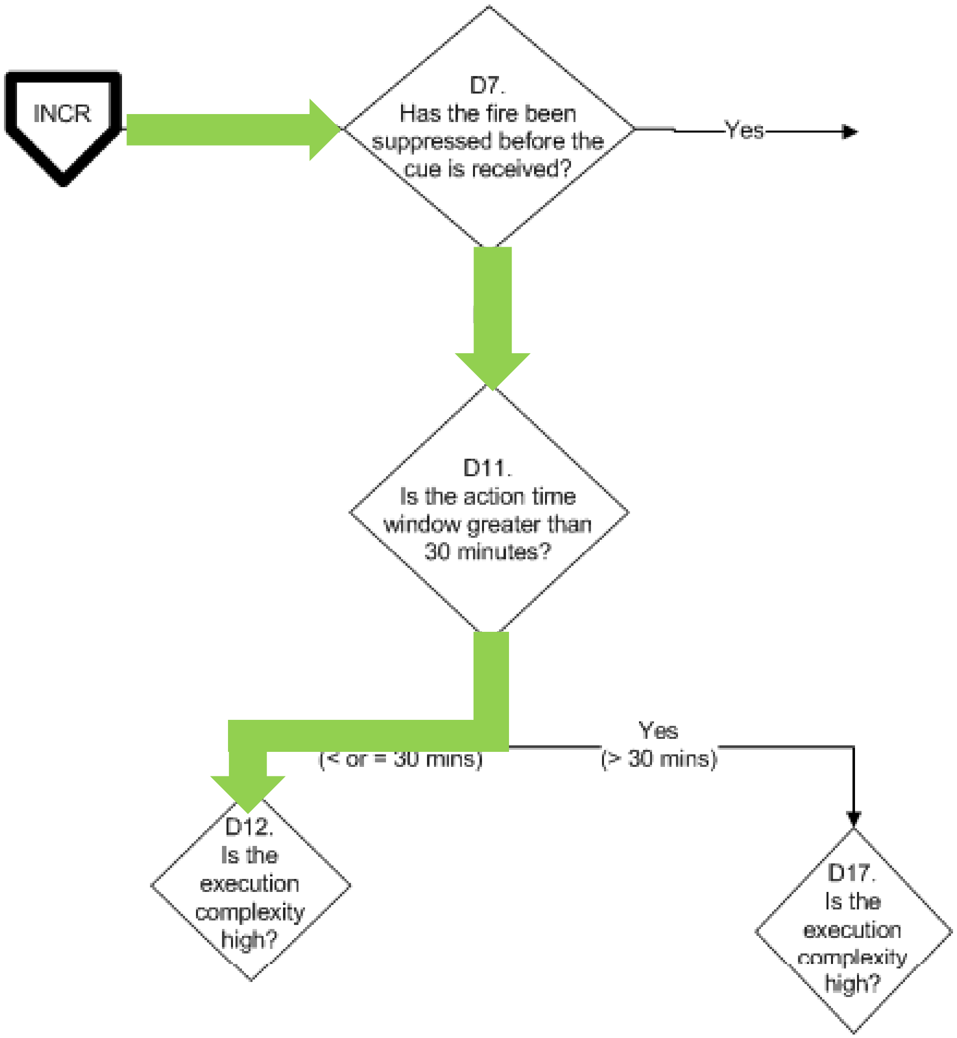
Example 2B: Assessing Key Conditions & PSFs

Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	No
What's the action time window?	25 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

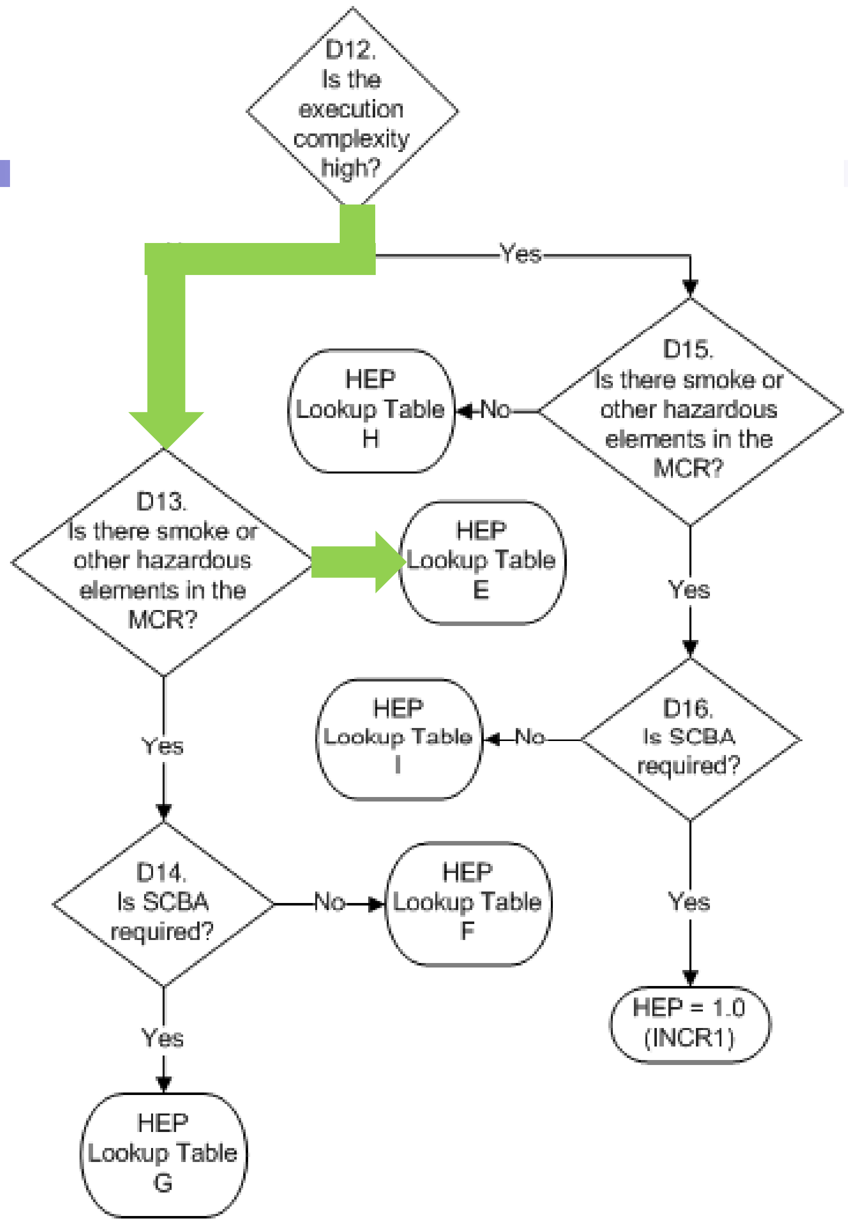
Example 2B: Search Scheme



Example 2B:
INCR (part 1)



Example 2B: INCR (part 2)



Example 2B: INCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
E	$\geq$ 100%	0.05	INCR14
	50 – 99%	0.25	INCR15
	< 50%	1.0	INCR16

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
    a) **Screening**
    b) Scoping
    c) EPRI approach (detailed)
    d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

SCREENING EXAMPLES

General Assumptions for Screening Examples

- Actions have applicable plant emergency procedures and fire procedures
- Fire does not impact control room environment
- Limited information is available on fire locations and equipment impacts since fire modeling and circuit analysis are usually still in early stages
- Fire PRA model needs preliminary fire HEPs to test model logic and ensure that HFEs are not lost in the noise
- Fire effects minimized after one hour

Quantitative Screening Approach Summary

<table>
<tr><th rowspan="2">Screening Criteria</th><th colspan="2">Short Term Human Actions</th><th colspan="2">Long Term Human Actions</th></tr>
<tr><th>Definition</th><th>Value</th><th>Definition</th><th>Value</th></tr>
<tr><td>Set 1 – like Internal Events HFE, but with some fire effects</td><td rowspan="3">Required within first hour of trip/fire</td><td>10x IE HEP</td><td rowspan="3">Performed ~one hour after fire/trip

(fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)</td><td>same as IE HEP</td></tr>
<tr><td>Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division</td><td>0.1, or 10x IE HEP, whichever is greater</td><td>0.1, or 10x IE HEP, whichever is smaller</td></tr>
<tr><td>Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions</td><td>1</td><td>0.1, or 10x IE HEP, whichever is smaller</td></tr>
<tr><td>Set 4 – Alternate Shutdown (including MCR abandonment)</td><td colspan="4">1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown</td></tr>
</table>

Example 1:
Operator fails to switch turbine building SW header

- While in an at power condition with normal alignment of Service Water, a low Service Water pressure condition develops. At the same time fire causes a reactor trip
- Annunciators activate and Service Water pressure indicates less than 72 psig
- Operator fails to respond per appropriate ARP and swap the turbine building SW header selector switch to the opposite header

Example 1:
Operator fails to switch turbine building SW header

- MCR action
- Short term action (14 minutes) according to Internal Events HRA
- Time for carrying out action:
  - Diagnosis time = 4 minutes
  - Execution time = 1 minute
- Internal Events HEP using HCR/ORE/THERP in EPRI HRA Calculator = 1.7E-03
- Similar to Internal Events situation, but some potential fire effects

Example 1:
Screening Selection Criteria

1. Operator Action timeframe
   - Short (<1 hour)
   - Long (> 1 hour)

2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - No

3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - Yes
   - No

Example 1: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	**10x IE HEP** 1.7E-03 * 10 = 1.7E-2	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as IE HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x IE HEP, whichever is greater		0.1, or 10x IE HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x IE HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 2: Operator fails to align FPS water to AFW pumps

- The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
- With low low level in the tank, the operator would align the FPS (fire protection system) to the pumps.
- Consider the tank low low level (10%) would be reached in 10 hours. At this level the operator will receive an alarm (sound and light)
- The operator has to open manual valves. (At least one valve)
- At 10% low low level the local operator must align the FPS.
- Operator has 1 hour before loss of cooling from low low level cue

Example 2:
Operator fails to align FPS water to AFW pumps

- Local action
- Cable tracing for AFWST level transmitters <u>has</u> been performed and the cues are not impacted by fire
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis time = 2 minutes
  - Execution time = 10 minutes

Example 2: Screening Selection Criteria

1. Operator Action timeframe
   – Short (<1 hour)
   – Long (> 1 hour)

2. Spurious Instrumentation/Equipment effects in one safety-related train
   – Yes
   – No

3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   – Yes
   – No

Example 2: Quantitative Screening Summary

<table>
<tr><th rowspan="2">Screening Criteria</th><th colspan="2">Short Term Human Actions</th><th colspan="2">Long Term Human Actions</th></tr>
<tr><th>Definition</th><th>Value</th><th>Definition</th><th>Value</th></tr>
<tr><td>Set 1 – like Internal Events HFE, but with some fire effects</td><td rowspan="3">Required within first hour of trip/fire</td><td>10x IE HEP</td><td rowspan="3">Performed ~one hour after fire/trip

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<tr><td>Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions</td><td>1</td><td>0.1, or 10x IE HEP, whichever is smaller</td></tr>
<tr><td>Set 4 – Alternate Shutdown (including MCR abandonment)</td><td colspan="4">1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown</td></tr>
</table>

Example 3: Operator fails to align FPS water to AFW pumps with failed alarm

- Same basic scenario as Example 2
  - The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank (AFWST).
  - When low low level in the tank is reached, the operator needs to align the FPS (fire protection system) to the pumps.
- Cable tracing has not been done therefore assume that fire fails the AFWST alarm at the 10% level
  - spurious indication assumed
- Fire procedures direct operator to check tank level locally and consider refilling if needed
  - Diagnosis time is increased

Example 3:
Operator fails to align FPS water to AFW pumps with failed alarm

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  – Diagnosis time = 15 minutes
  – Execution time = 10 minutes

Example 3: Screening Selection Criteria

1. Operator Action timeframe
   - Short (<1 hour)
   - Long (> 1 hour)

2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - No

3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - Yes
   - No

Example 3: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x IE HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as IE HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x IE HEP, whichever is greater		0.1, or 10x IE HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x IE HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 4: Operator fails to initiate bleed & feed and use of fire procedures

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case half of the indicators of SG level are failed and fire procedures must be used to identify which indicators are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Example 4:
Operator fails to initiate bleed & feed and use of fire procedures

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time from cue = 25 minutes
- Time for carrying out action:
  - Diagnosis time = 8 minutes [additional time than standard bleed & feed due to using multiple procedures]
  - Execution time = 8 minutes

Example 4: Screening Selection Criteria

1. Operator Action timeframe
   – Short (<1 hour)
   – Long (> 1 hour)

2. Spurious Instrumentation/Equipment effects in one safety-related train
   – Yes
   – No   Potentially multiple effects

3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   – Yes   Simultaneous use of multiple procedures
   – No

Example 4: Quantitative Screening Summary

<table>
<tr><th rowspan="2">Screening Criteria</th><th colspan="2">Short Term Human Actions</th><th colspan="2">Long Term Human Actions</th></tr>
<tr><th>Definition</th><th>Value</th><th>Definition</th><th>Value</th></tr>
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<tr><td>Set 4 – Alternate Shutdown (including MCR abandonment)</td><td colspan="4">1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown</td></tr>
</table>

Example 5:
Operator fails to establish containment spray sump recirculation when RWST depleted

- Operator action to align containment spray (CS) to sump recirc when the RWST is depleted
- The operators cue on RWST level <37%, per the foldout page in Procedure E-1 Transition to ES-1.3, Transfer to Containment Sump Recirculation.
- The following assumptions are made:
  - All equipment operates as designed
  - Conditions requiring CS exist

Example 5:
Operator fails to establish containment spray sump recirculation when RWST depleted

- MCR action
- Since CS is needed, fire is presumed to be severe in its consequences
- RWST level indicators have cable tracing and the cues are not impacted by fire
- Total system time window = for the 37% RWST level to have been reached, more than 60 min are assumed to have passed since the reactor trip
- Internal Events HEP using CBDTM/THERP in EPRI HRA Calculator = 3.6E-03

Example 5: Screening Selection Criteria

1. Operator Action timeframe
   – Short (<1 hour)
   – Long (> 1 hour)

2. Spurious Instrumentation/Equipment effects in one safety-related train
   – Yes
   – No   Uncertain what multiple effects might occur

3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   – Yes
   – No

Example 5: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x IE HEP	**Performed ~one hour after fire/trip** (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as IE HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x IE HEP, whichever is greater		0.1, or 10x IE HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x IE HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probabi representing failure to reach safe shutdov			

3.6E-03 * 10 = 3.6E-2

Example 6:
Operator fails to maintain control from alternate shutdown location

- Multiple MCR and local actions
- Procedures exist but actions require significant coordination and communication among operators
- In such cases, presume detailed analysis will be required if risk-significant in Fire PRA model

Example 6: Quantitative Screening Summary

<table>
<tr><th rowspan="2">Screening Criteria</th><th colspan="2">Short Term Human Actions</th><th colspan="2">Long Term Human Actions</th></tr>
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(fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)</td><td>same as IE HEP</td></tr>
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<tr><td>Set 4 – Alternate Shutdown (including MCR abandonment)</td><td colspan="4">1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown</td></tr>
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