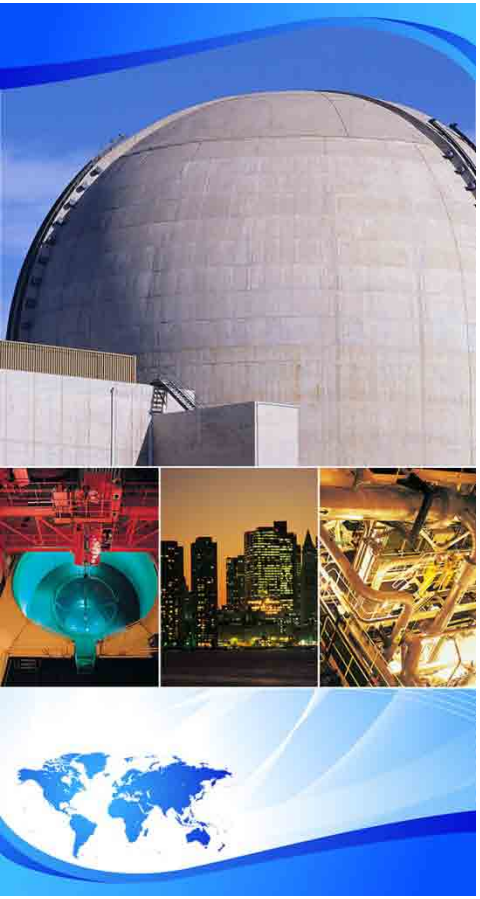


EPRI/NRC-RES FIRE PRA METHODOLOGY
Task 12 – Fire HRA

EPRI Approach to Detailed Fire HRA Quantification

Joint RES/EPRI Fire PRA Workshop 2012

Bethesda, MD

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 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).**

4: Be able to identify **context and performance shaping factors** used in the analysis of 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 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 fire PRA quantification
- HEP development provides qualitative insights on results drivers

Typically done to PRA Standard Capability Category II

- For the risk-significant scenarios

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 fire HRA 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 – 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 Fire PRA Tasks*

- Detailed fire HRA supports fire PRA 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 fire PRA 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)

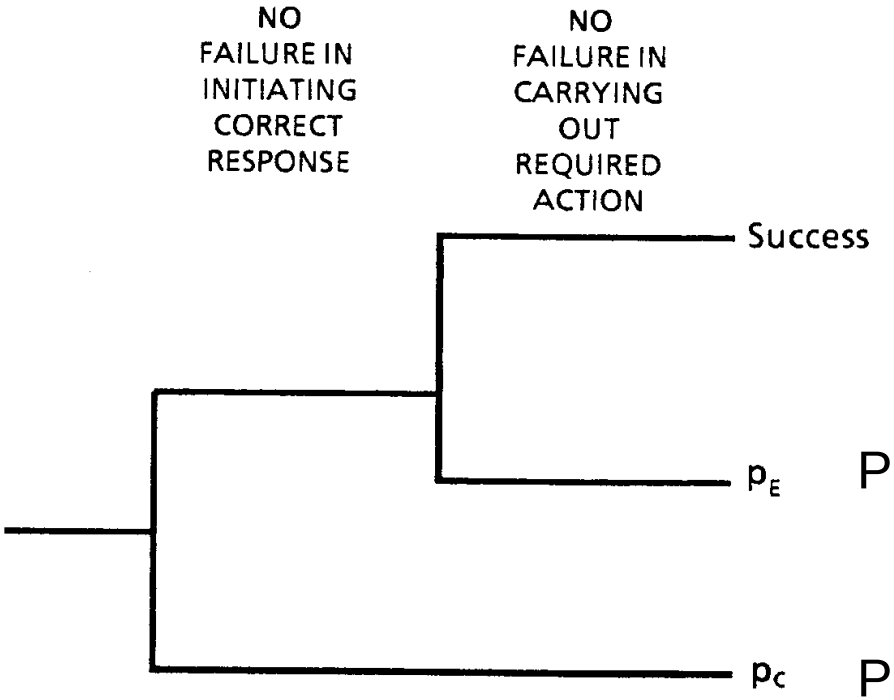
HLR-HRA-C (from the Fire HRA element)

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
    - Alternate method for cognitive
  - 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



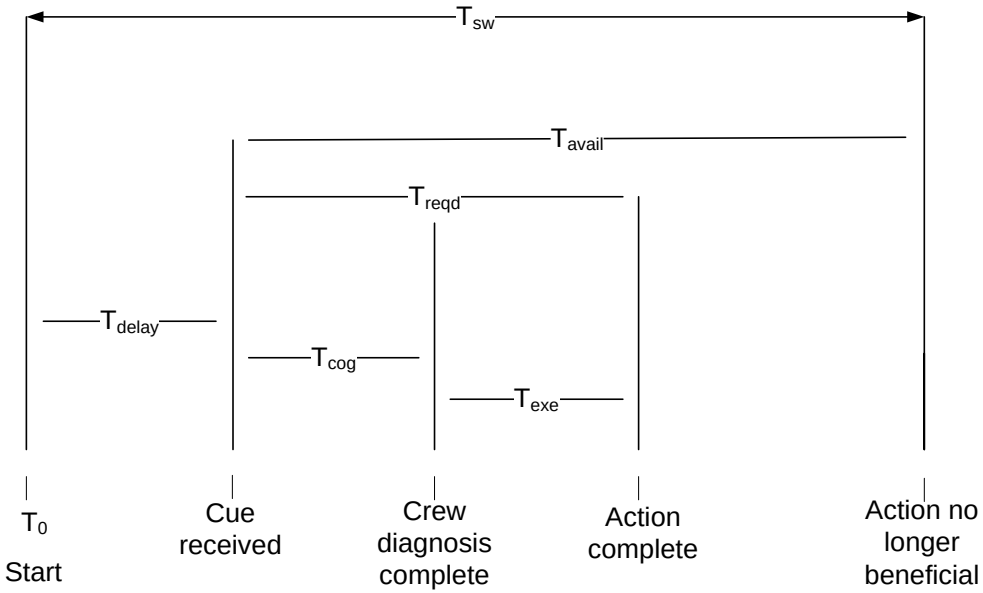
Pe = Execution is quantified using THERP

Pc = Cognitive is quantified using

CBDTM (default)

HCR/ORE (time critical HFEs)

EPRI Timeline for a Post-Initiator HFE



$\mathbf{T_0}$ = Start Time usually the initiating event

$\mathbf{T_{sw}}$ = System time window

$\mathbf{T_{delay}}$ = Time from start until cue

$\mathbf{T_{exe}}$ = Execution time (includes transit, tools, PPE & component manipulation)

$\mathbf{T_{cog}}$ = Cognition time (consists of detection, diagnosis, & decision-making)

$\mathbf{T_{avail}}$ = Time available = ($\mathbf{T_{sw}} - \mathbf{T_{delay}}$)

$\mathbf{T_{reqd}}$ = Time required for response = ($\mathbf{T_{cog}} + \mathbf{T_{exe}}$)

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

$\mathbf{T_{exe}}$ = Execution time (expansion of EPRI $\mathbf{T_m}$ component manipulation for fire)

$\mathbf{T_{cog}}$ = Cognition time (when HCR/ORE is used = $\mathbf{T_{1/2}}$)

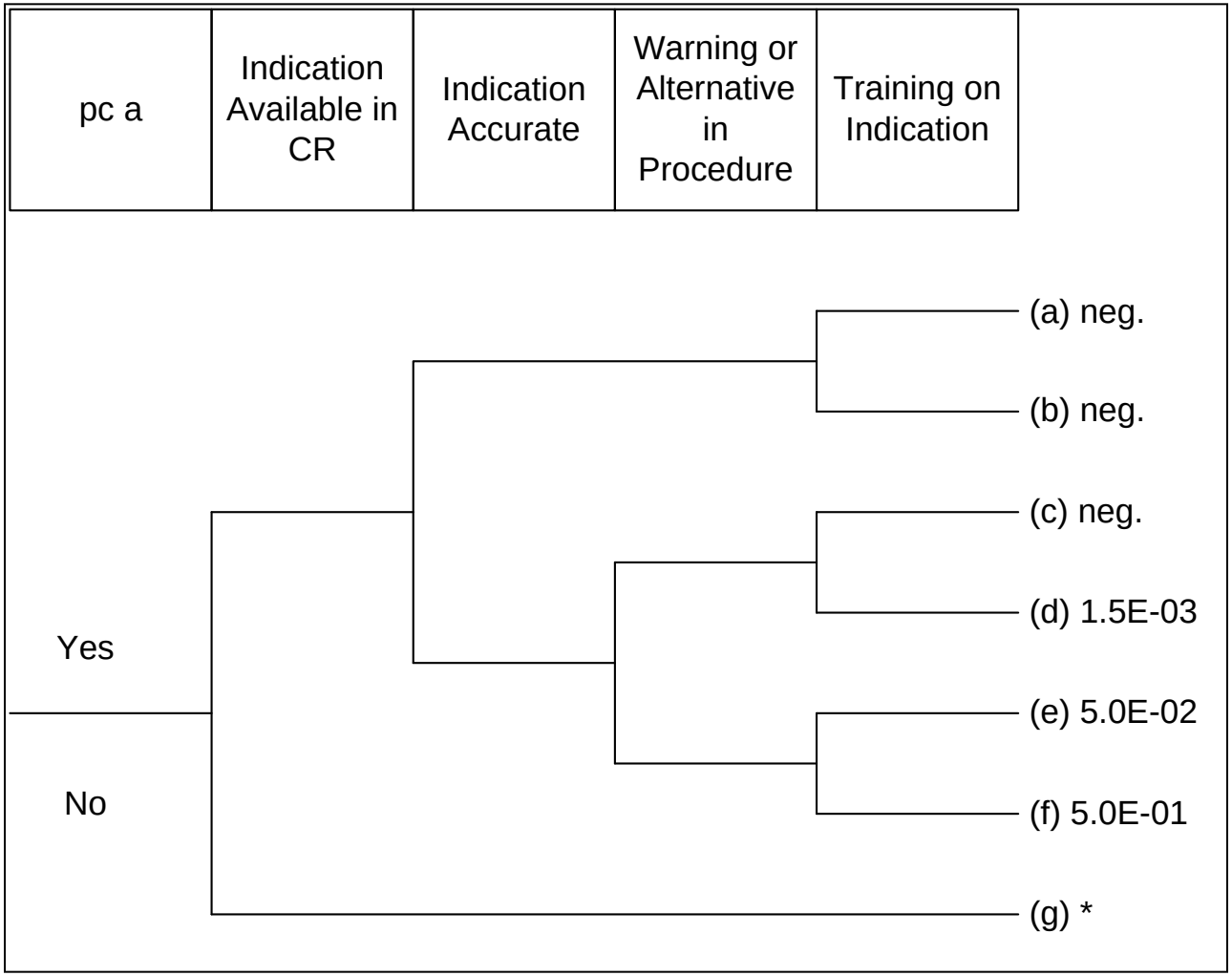
CBDTM Overview – Cognitive Method

- 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

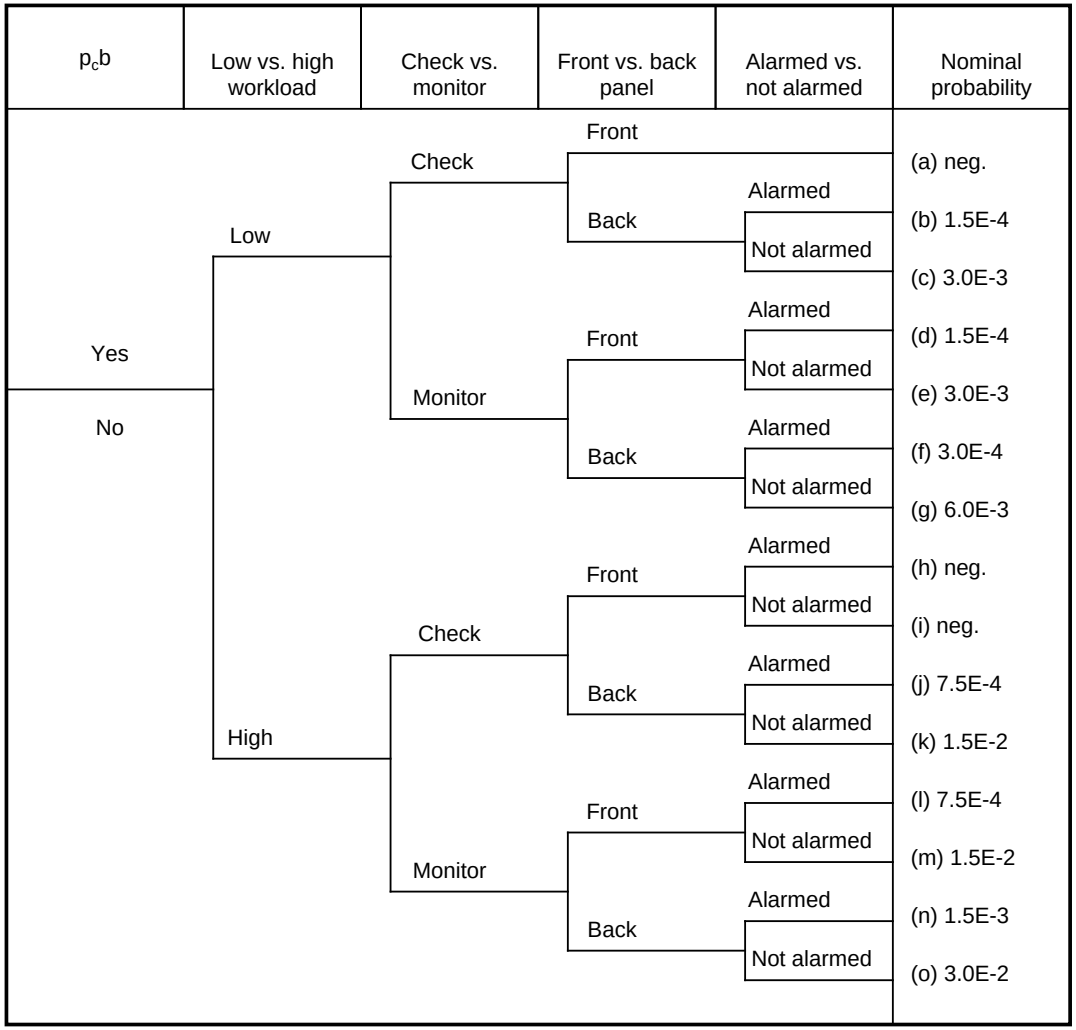
CBDT - Summary of Failure Mechanisms

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)

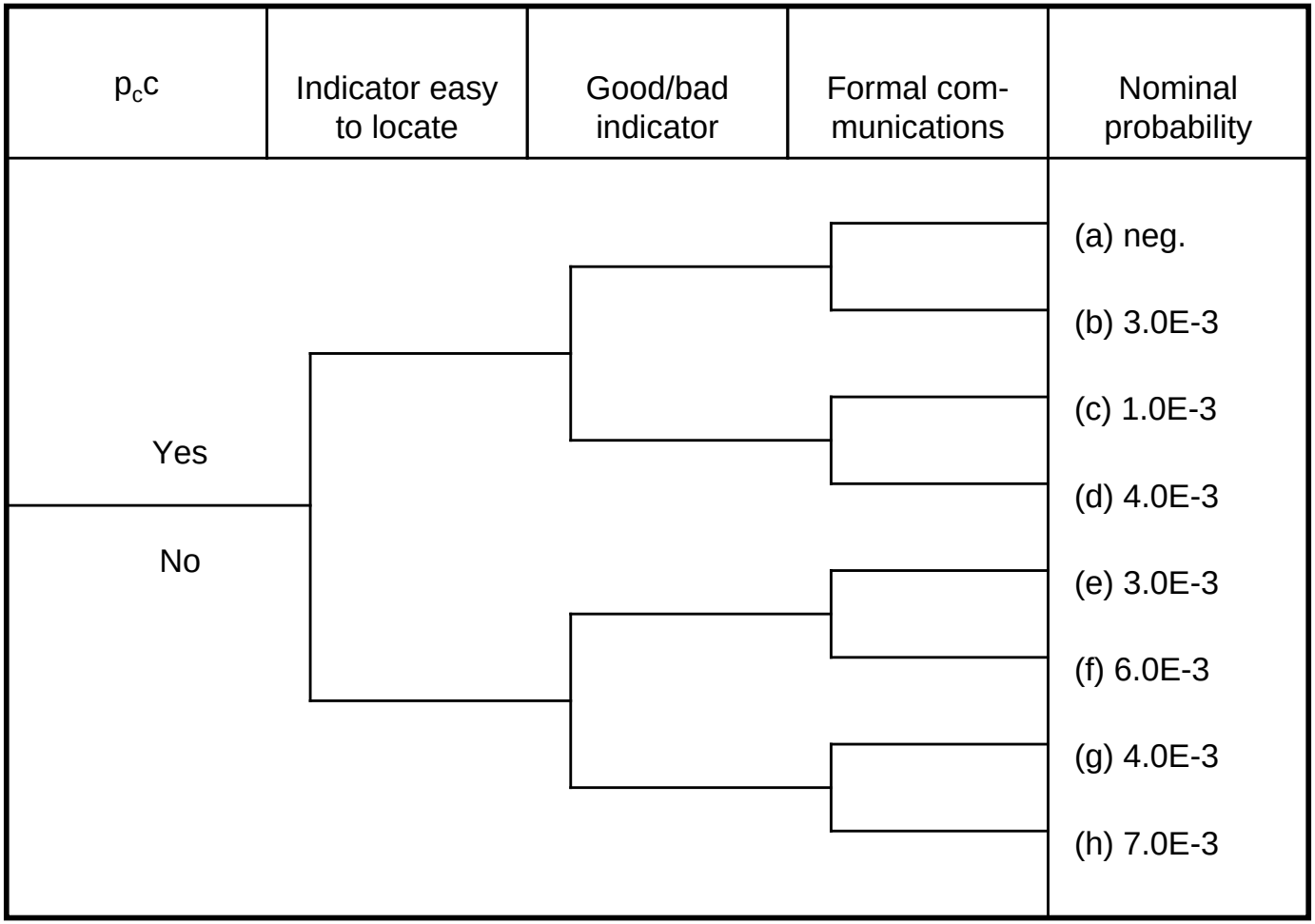
CBDTM decision tree: pc-a Data not available



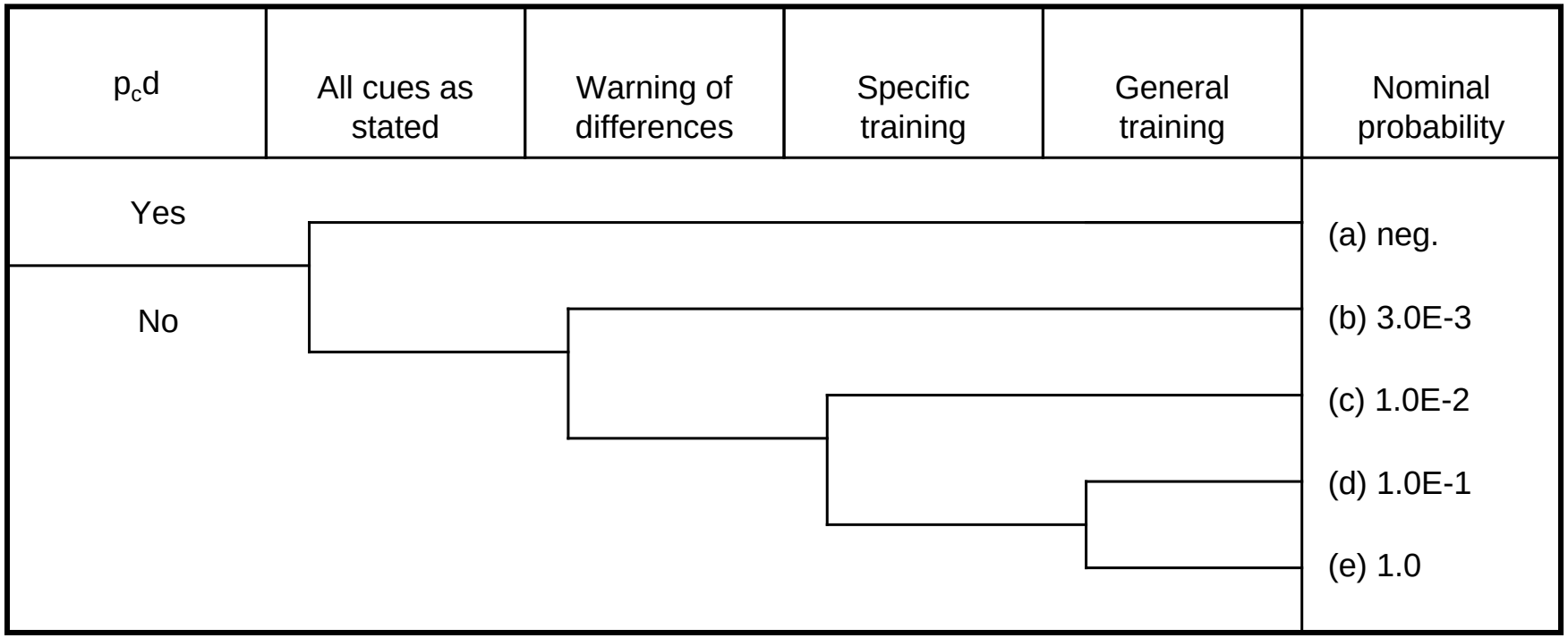
CBDTM decision tree: pc-b Data not attended to



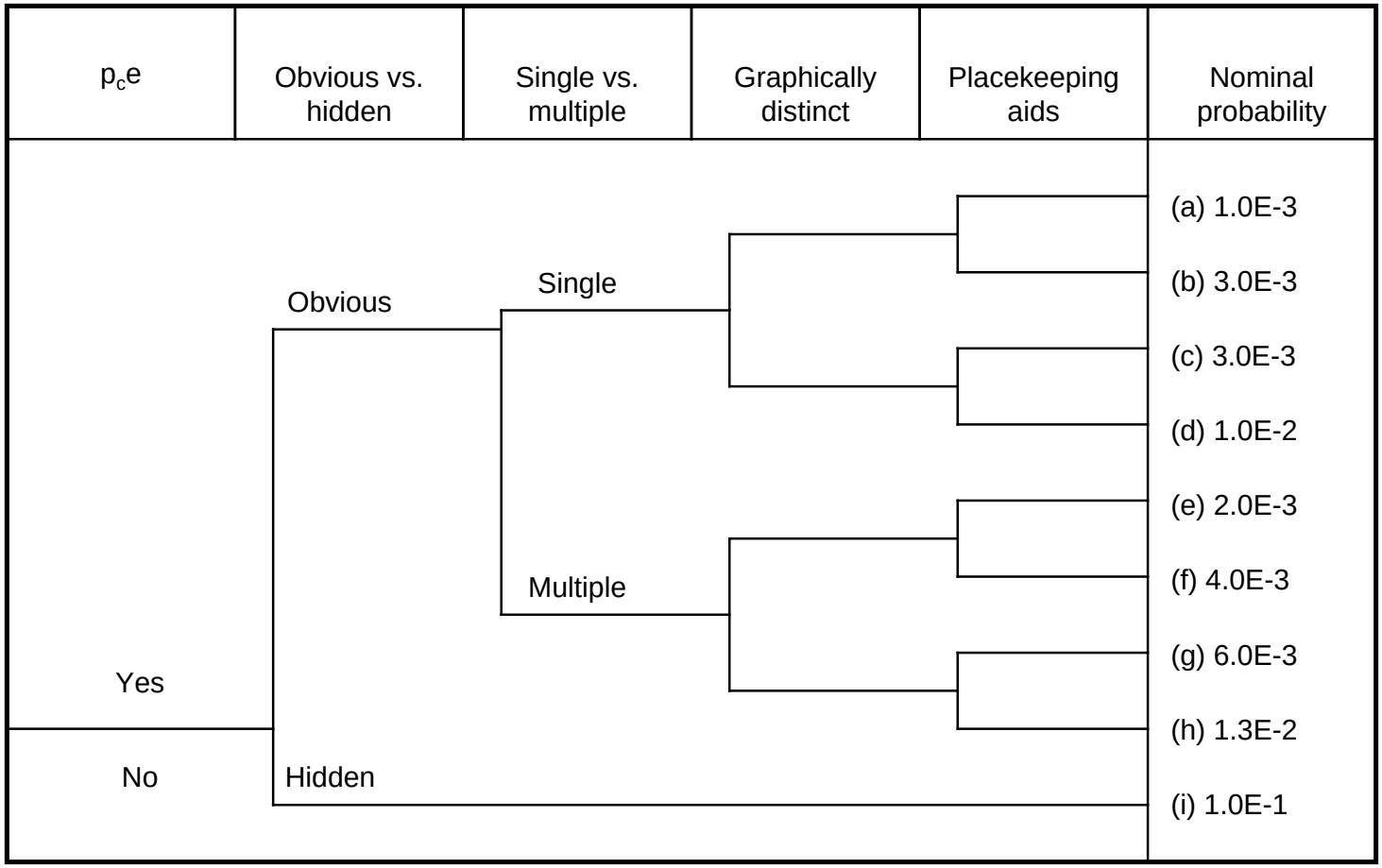
CBDTM decision tree:
pc-c Data misread or miscommunicated



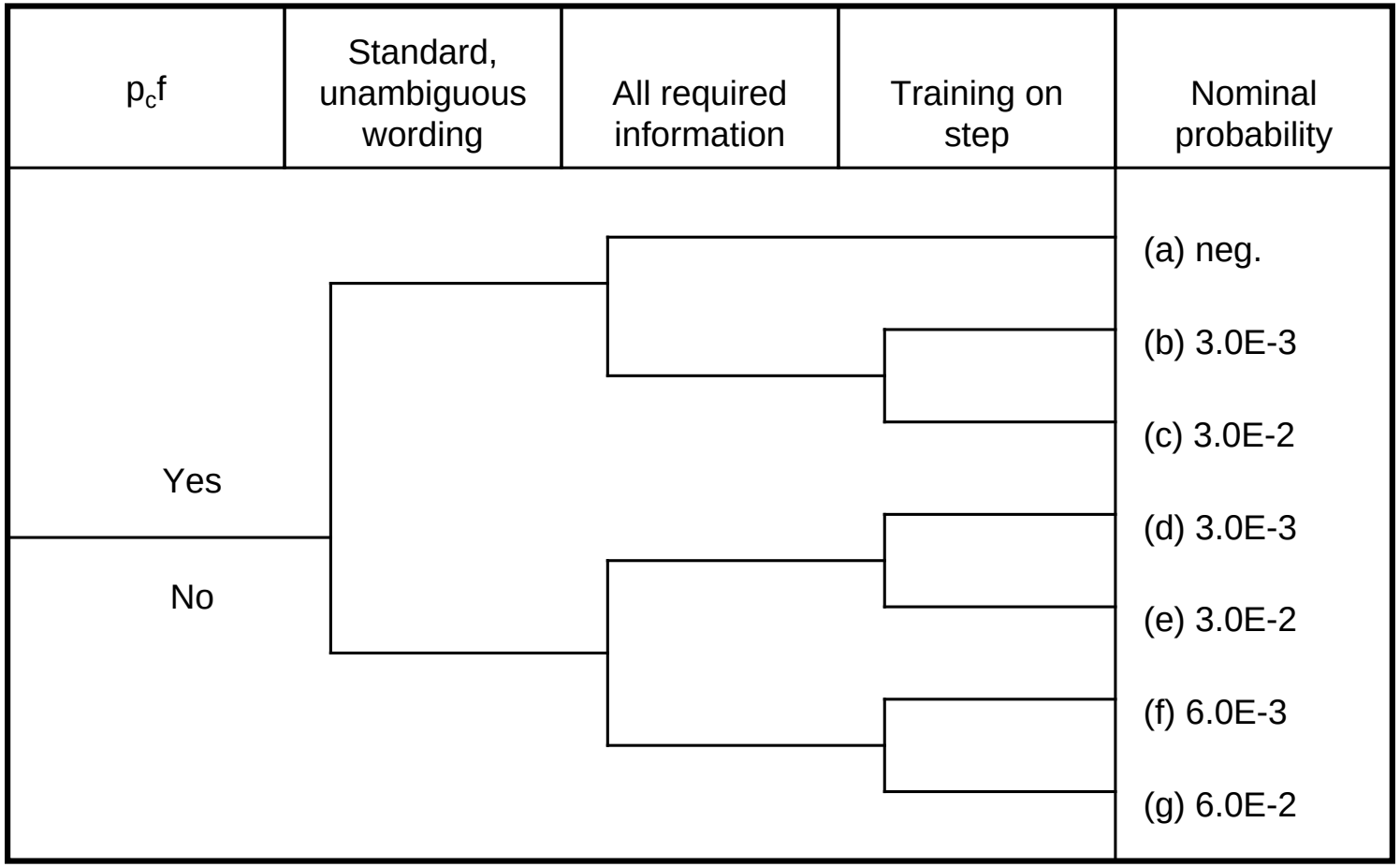
CBDTM decision tree: pc-d Information misleading



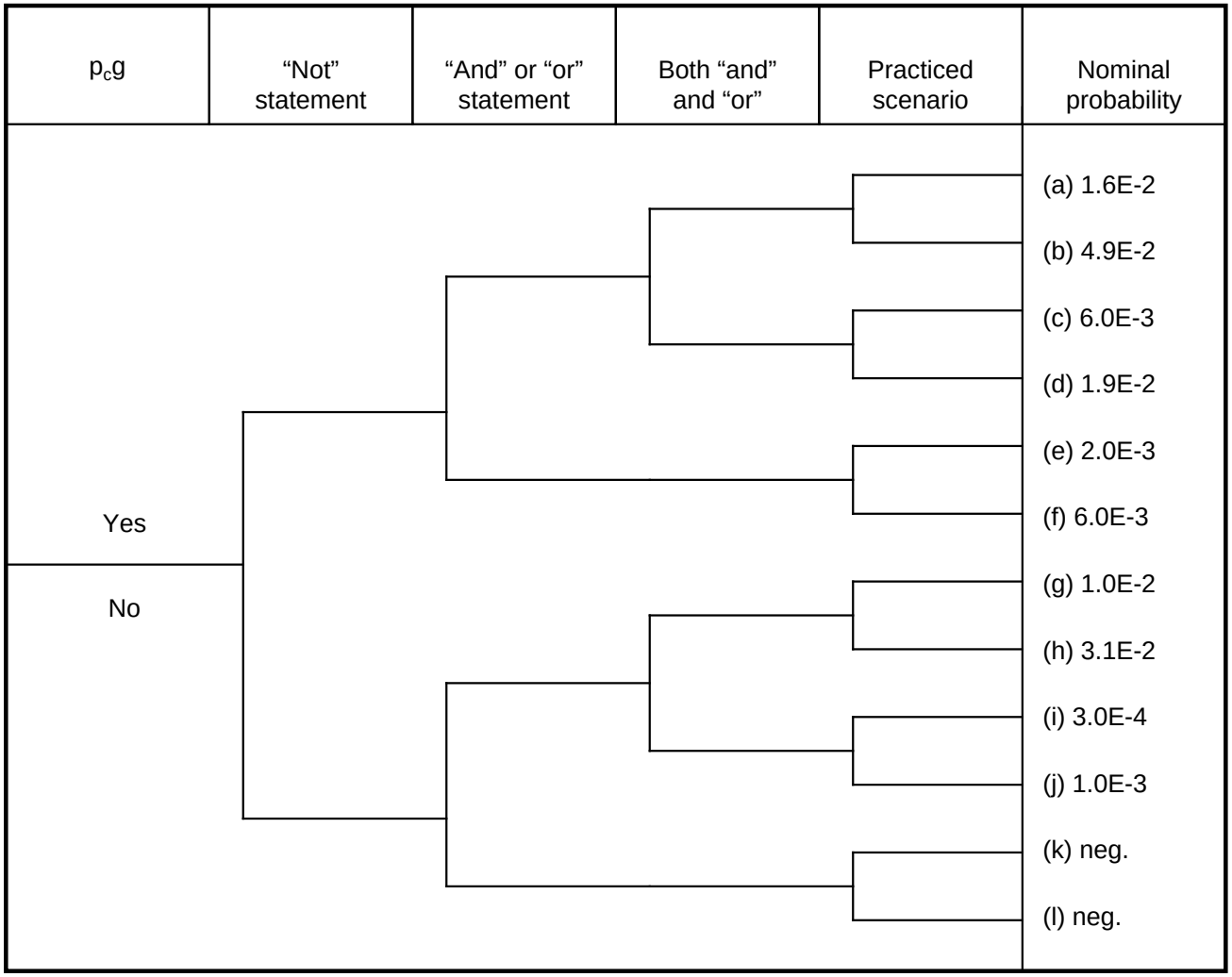
CBDTM decision tree:
pc-e Relevant step in procedure missed



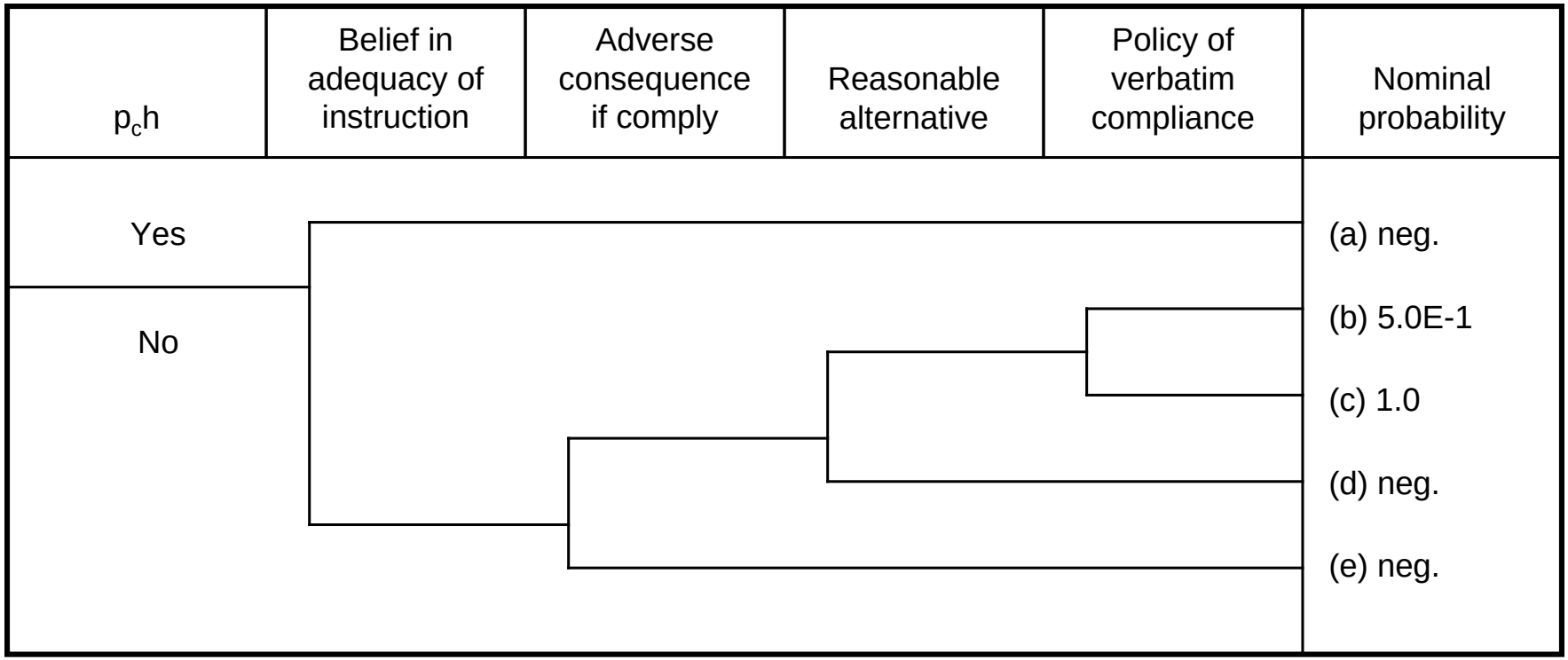
CBDTM decision tree: pc-f Misinterpret instruction



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

Cautions:

- **Method allows multiple recoveries, so analysts need to consider:**
  - Dependencies, if multiple recoveries credited
  - Defensibility, given response to fire (e.g., may be staff limited)
  - For example, may want to limit recovery credit during screening quantification

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. Extrapolations are 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

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

P_C = Probability of cognitive non-response

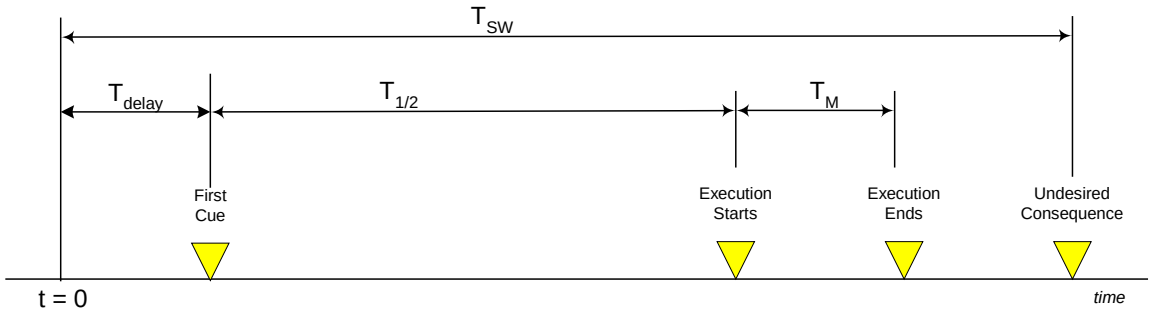
- σ = Logarithmic standard deviation (Determined based on cue response structure – next slide)
- Φ = Standard normal cumulative distribution
- $T_W = T_{SW} - T_{delay} - T_M$
  = time window available for cognitive response
- $T_{1/2}$ = Crew median response time
  - Replaces T_{cog} in the general timeline
- T_M = Manipulation time = T_{exe} in the general timeline

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	*	*

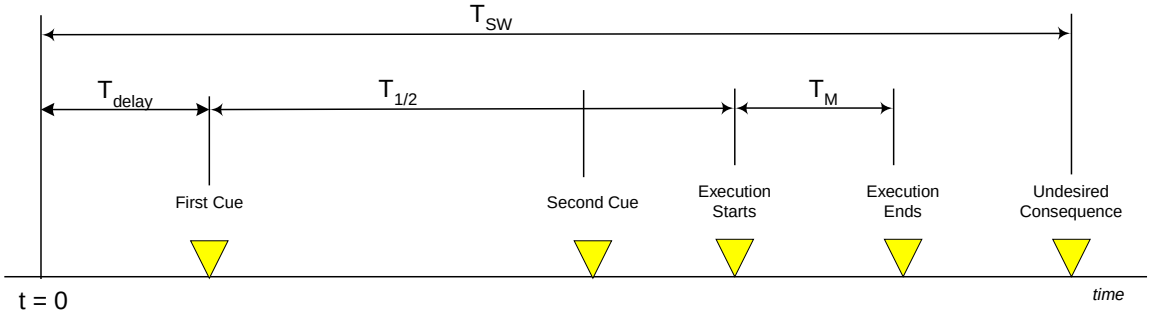
Categorization of Type CP Actions

CP1



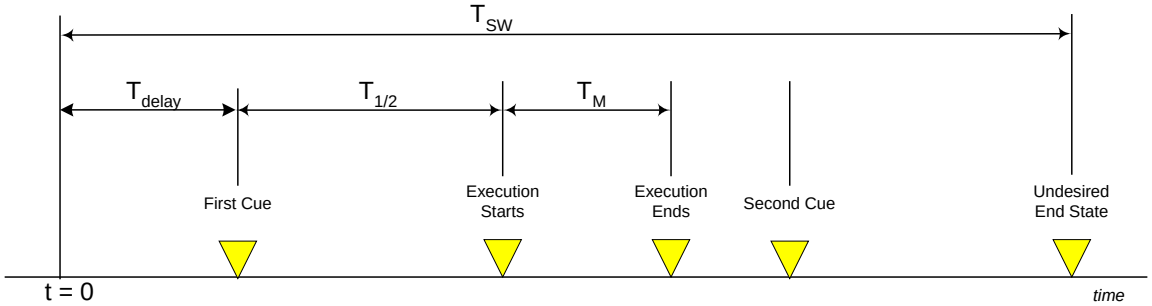
IF

CP2



WHEN

CP3

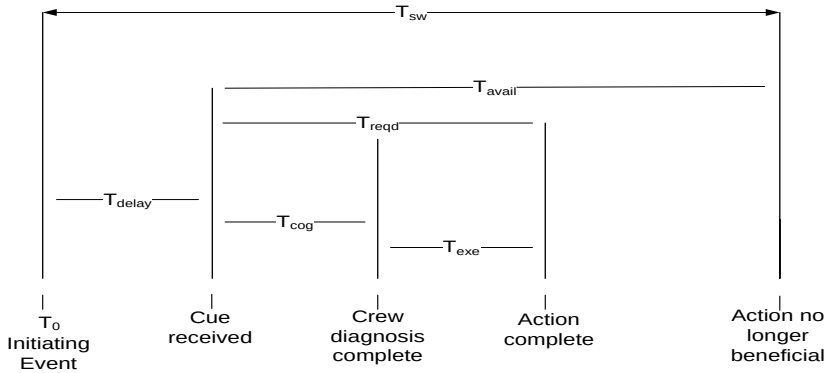


BEFORE

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_{cog} = If the fire impacts some but not all of the **instrumentation** T_{cog} 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_{exe} = 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.

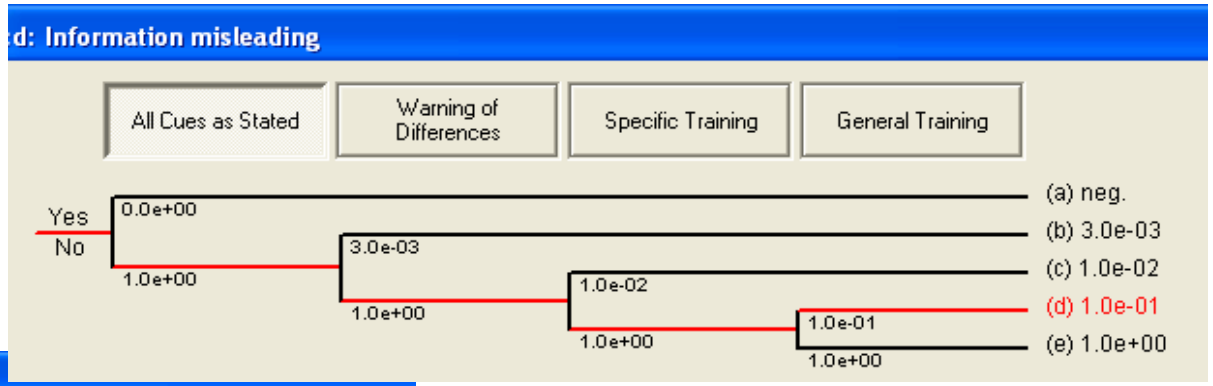
Fire Impacts on Timing (cont'd)

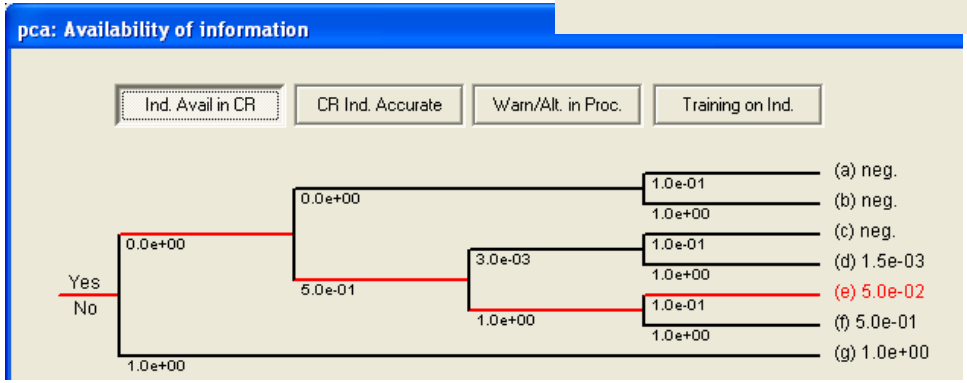
- If time available for recovery is reduced due to fire impacts on timing, then the recoveries previously credited in the internal events PRA within the CBDTM are to be revisited

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

Fire Impacts on Instrumentation

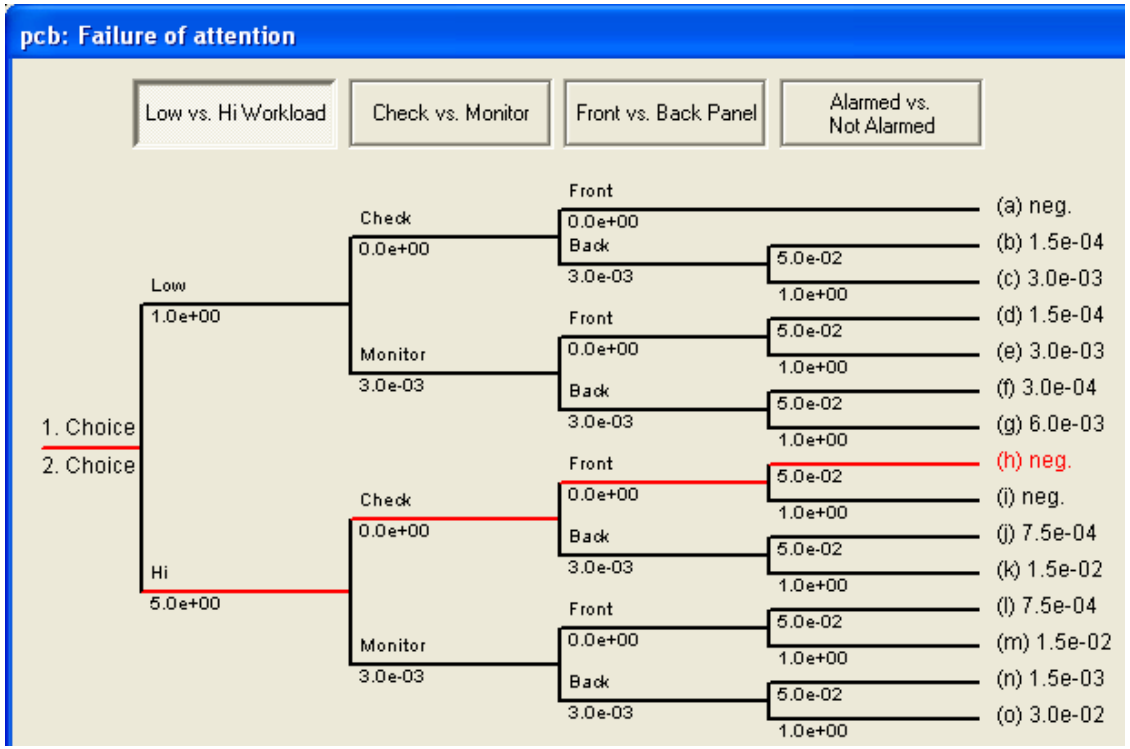
- If all **instrumentation is impacted** and there are no cues for diagnosis then HEP =1.0
- **Partial instrumentation** impacted is modeled in decision tree **Pc-a & Pc-d** (HEP range 1E-2 to 1.0)
- If the fire causes **no impact on instrumentation** then Pc-a and Pc-d typically evaluate to "Negligible"





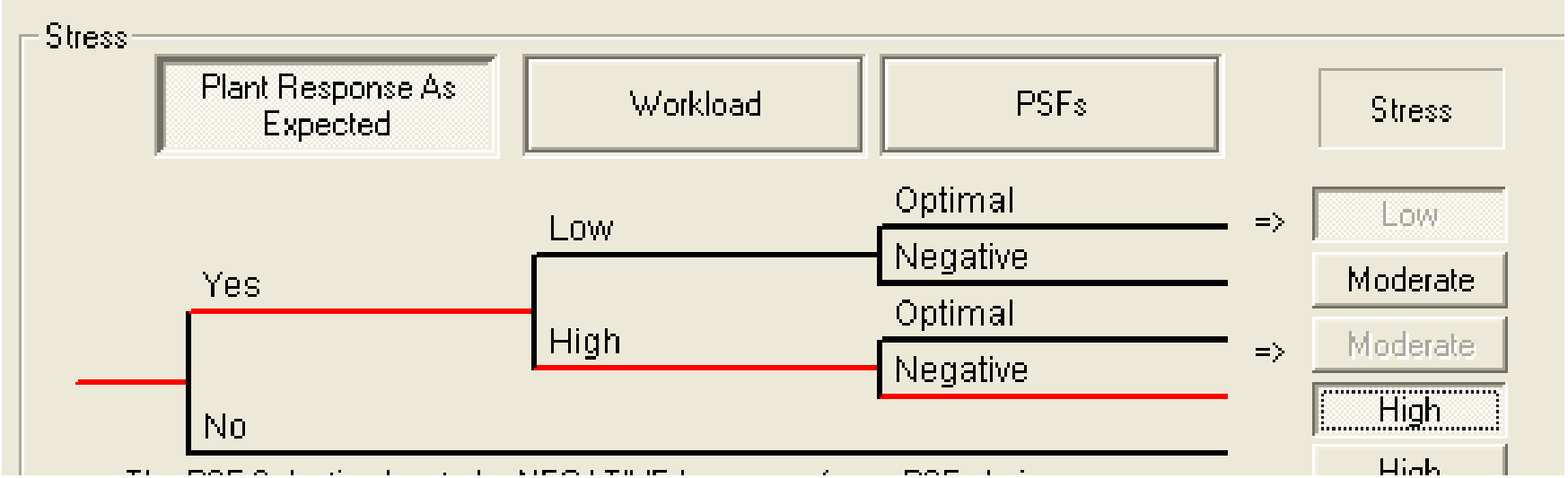
CBDT Example - Fire Impacts on Workload (Pc)

- 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



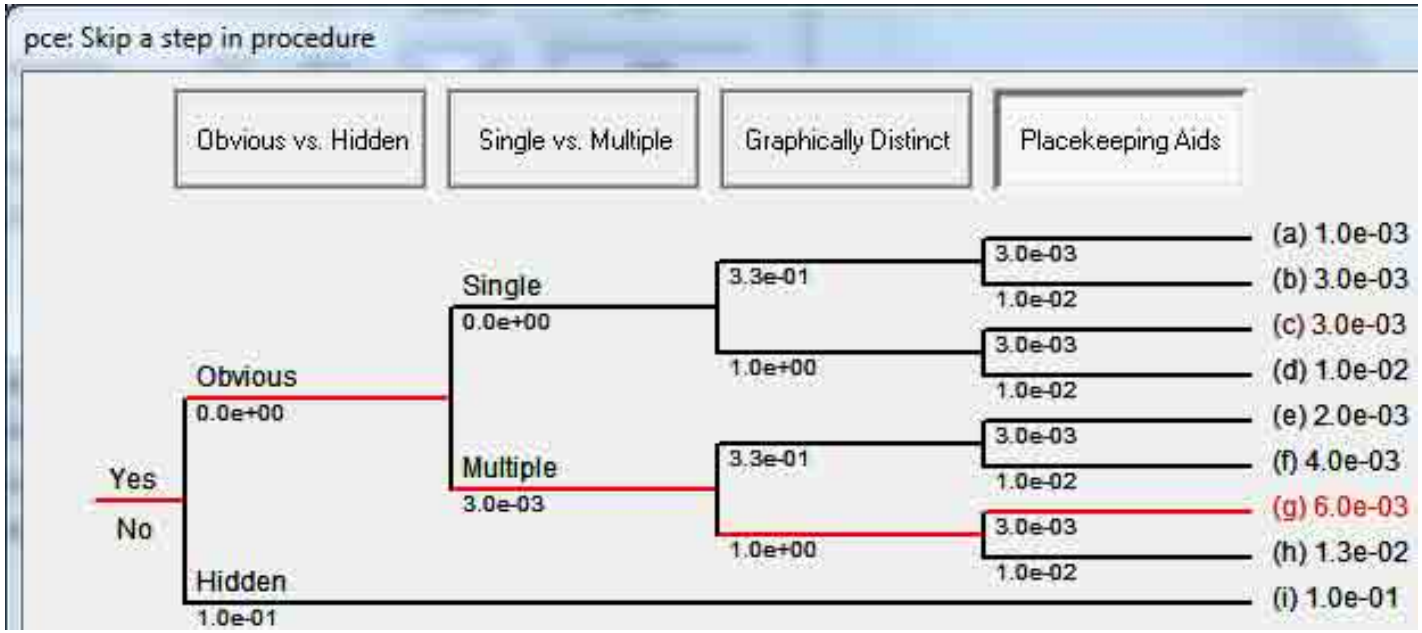
CBDT Example - Fire Impacts on Workload (Pe)

- 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 (THERP)

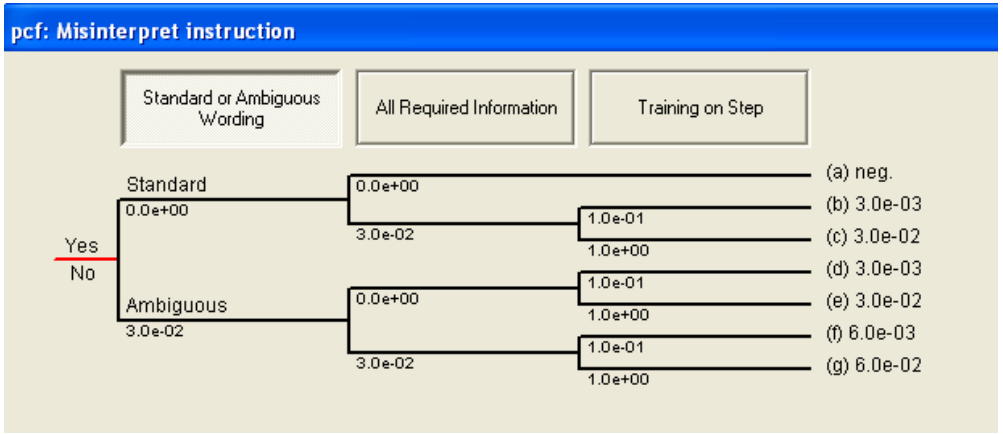
- Stress is often increased from internal events case
  - Except for control room actions when operator actions occurring more than 70 minutes after the fire started, because
    1. 99% of fires are extinguished within 70 minutes per NUREG/CR-6850 Supplement 1 (EPRI 1011259, Sept 2010)
    2. On average, a fire is extinguished in 13 minutes
- For local actions, an additional factor 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 use 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, as initial results show that frequency is low enough to not be a concern

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 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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