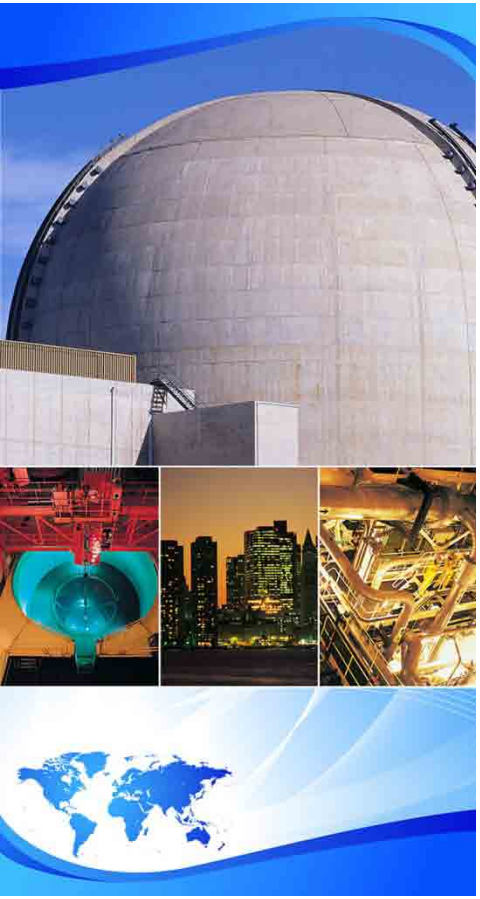

EPRI/NRC-RES FIRE PRA METHODOLOGY: Task 12 – Fire HRA

Recovery, Dependency, and Uncertainty Analysis

Joint NRC-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)

Outline of the Presentation

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)
   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 several types of recovery actions of concern for fire HRAs. Three of 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 Approach – addresses via Cognitive Recovery and Execution Recovery, with 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 of cutsets

- 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 2, HR-H; Part 4, HRA-D1 and –D2

Recovery of cutsets (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 versus repair (from 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 & returning a failed SSC to operability.
  - HRA techniques cannot be used since the method of repair is not known without knowing the specific causes.
  - Fire-induced failures are often not repairable in the mission time.

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)
    - NUREG-1921, Sections 3.5 and 4.3

Recovery Analysis
Fire HRA (continued)

- **Qualitative Analy**sis
  - 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 fire PRA Model
  - Model-specific (e.g., 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 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
  - require significant activity and/or communication among individuals while wearing SCBA (unless SCBA contains internal communication devices)
- NUREG/CR-6850 [EPRI 1011989] considerations apply to screening quantification
- Detailed quantification methods provide for re-consideration, such as actions with SCBA

Recovery actions

Relaxation from original NUREG/CR-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 to see if it can be considered for fire HRA
- Non-proceduralized HFEs can 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	Time Required (diagnosis + execution)	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 fails to 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."

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

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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

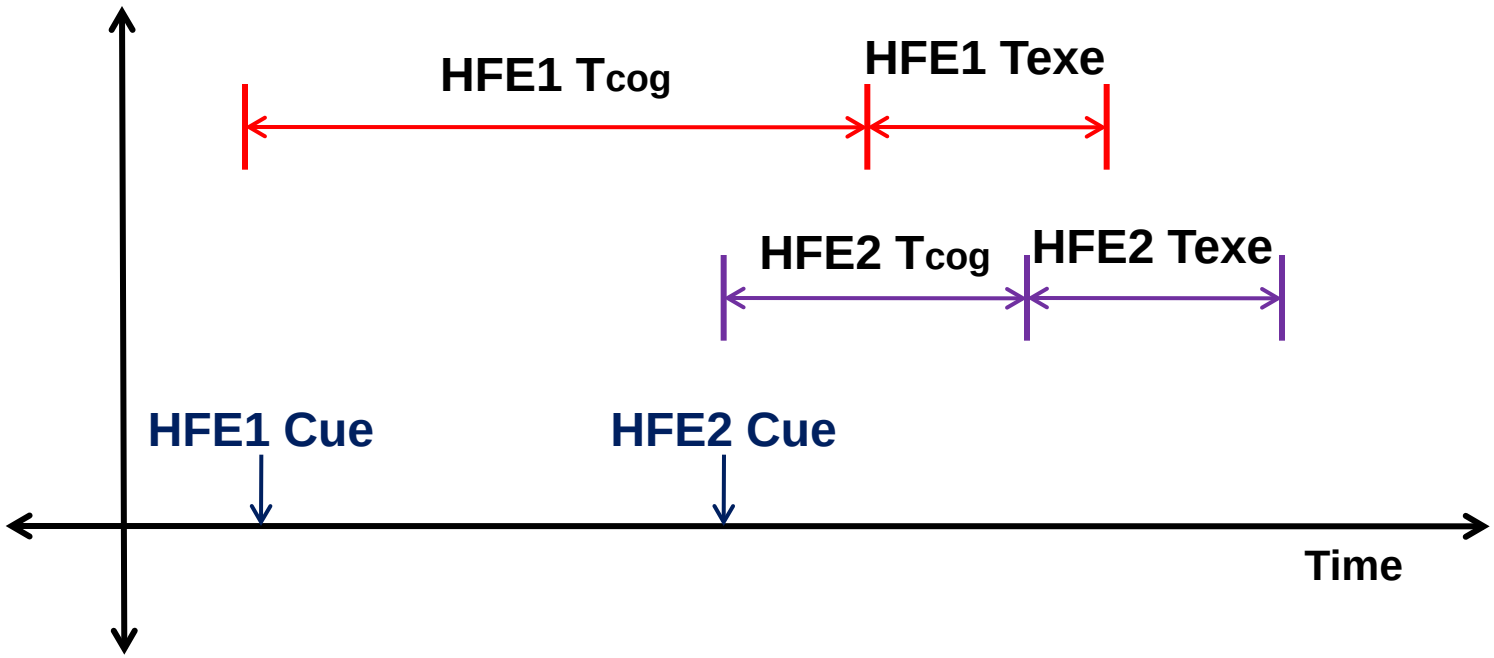
Dependency Analysis
Definitions

- 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

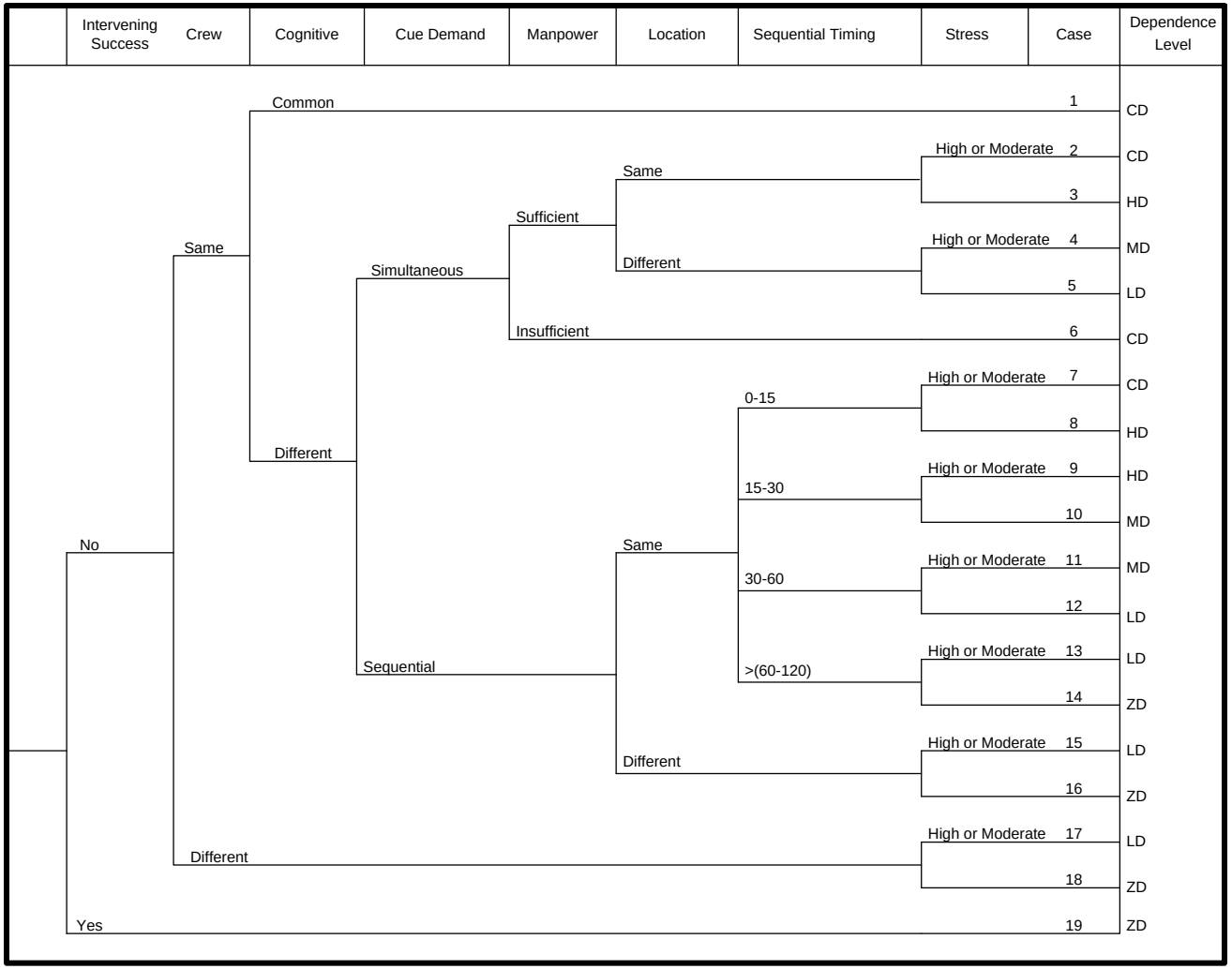
THERP Dependency Formulas

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,proce-dures)
  - Simultaneity
  - Resources
  - Location
  - Timing
  - Stress



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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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 fire HRA 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 fire HRA 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

Potential Sources of HRA Modeling Uncertainty

Category	Potential Sources of HRA Modeling Uncertainty
Timing	Timing data inputs (T_{sw}, T_{delay}, T_{cog}, and T_{exe}) where T_{delay} can be impacted by uncertainty in the fire modeling such as the time to damage based on the selected heat release rates.
	Impact of timing variability on short or constrained timeframe events.
	Ex-control room action travel path changes as a result of fire location.
	Ability to obtain more than one operator's input to timing estimates.
	What to do with varying or conflicting operator input.
	Accuracy of operator timing estimates.
Dependency	Factors that would suggest an increased dependency level such as a common cognitive impact (both HFEs operating from the same cue).
Spurious and multiple spurious	Impact on cues such that the indications may not be accurate.
	Compelling indications or cues that may distract the operator from the modeled task.
	Geometry such that there is the potential for several spurious alarms or indications.
Stress	Is fire stress high?
Workload	Is fire event workload high?
Communications	Fire impacts to normal communications systems and process.
	Backup to radios available?
Training	Frequent and specific enough to be known when needed?
Procedures	Impact of single versus multiple procedures.
	Plant-specific emergency procedures not in standard format.
Crew dependency	Personnel availability and attentiveness during fire.

Uncertainty Analysis

HRA 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 in Detailed HRA

EPRI HRA Approach

- EPRI HRA 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 Approach – Parametric data uncertainty for detailed analyses

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
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