



# Dependency Analysis Using the Integrated Human Event Analysis System (IDHEAS) HRA Methodology

Michelle Kichline  
Senior Reliability and Risk Analyst  
U.S. Nuclear Regulatory Commission



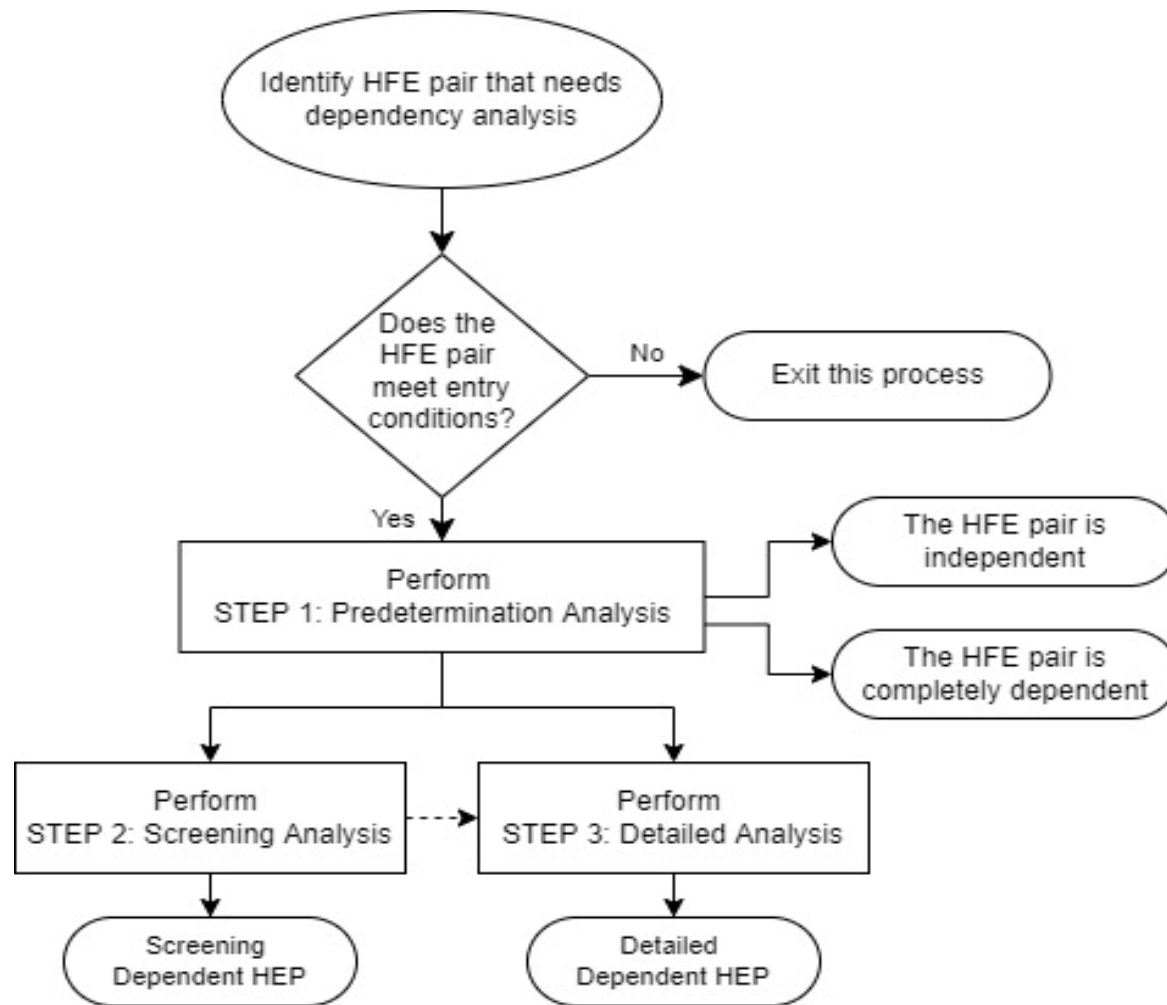
# Background

- The NRC developed the IDHEAS General Methodology (IDHEAS-G) [1] as a general framework that can be used to create application-specific HRA methods.
- IDHEAS-G includes a new dependency framework that analyzes the dependency between two HFEs by identifying and evaluating how failure of the first human action effects the context of subsequent human actions.
- IDHEAS for Event and Condition Assessment (IDHEAS-ECA) [2] was created for quantifying the HEPs for nuclear power plant PRAs.
- IDHEAS Dependency Model (IDHEAS-DEP) [3] was developed using the new dependency framework in IDHEAS-G and the quantification methodology in IDHEAS-ECA.

# Development of IDHEAS-DEP

- NRC created a working group (WG) with members from RES, NRR, Region 2, and EPRI.
- RES developed a set of dependency relationships and factors and presented them to the WG.
- 6 WG members analyzed an HFE pair for dependency using IDHEAS-ECA and presented their results to the WG.
- The WG discussed each example and how the dependency impacts could be evaluated using IDHEAS-ECA.
- The WG reviewed the dependency factors created by the project team and the draft guidance document.

# Process Overview



# IDHEAS Dependency Types

- **Consequential** – Occurrence of the preceding HFE (HFE1) changes the context for performing the subsequent HFE (HFE2) from the context that was assumed when the HFE was analyzed without dependency.
- **Cognitive** – Dependency in the cognitive information for two consecutive HFEs.
- **Resource-sharing** – The two HFEs share limited resources such as critical tools, staffing, water, or electricity.



# Dependency Relationships

IDHEAS-DEP defines five different dependency relationships:

**R1** – Functions or Systems

**R2** – Time Proximity

**R3** – Personnel

**R4** – Location

**R5** – Procedure



# Entry Conditions

HFE1 and HFE2 are in the same PRA event sequence or minimal cutset



There are no relevant human action success events between HFE1 and HFE2.

*OR*

The initiating event is caused by human actions and is analyzed as the first HFE, such that the subsequent HFEs need to be assessed for dependency.



Proceed to Predetermination (Step 1)

# Predetermination Analysis

Dependency Relationship	Assessment Guidelines	
<b>Complete Dependency</b>	1) HFE1 and HFE2 use the same procedure, <b>AND</b> 2) HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), <b>AND</b> 3) There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2.	<input type="checkbox"/> YES <input type="checkbox"/> NO
<b>R1 – Functions or Systems</b>	1) HFE1 and HFE2 have the same functions or systems, <b>OR</b> 2) HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed.	<input type="checkbox"/> YES <input type="checkbox"/> NO
<b>R2 – Time Proximity</b>	1) HFE1 and HFE2 are performed close in time, <b>OR</b> 2) The cues for HFE1 and HFE2 are presented close in time.	<input type="checkbox"/> YES <input type="checkbox"/> NO
<b>R3 – Personnel</b>	1) HFE1 and HFE2 are performed by the same personnel.	<input type="checkbox"/> YES <input type="checkbox"/> NO
<b>R4 – Location</b>	1) HFE1 and HFE2 are performed at the same location, <b>OR</b> 2) The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation).	<input type="checkbox"/> YES <input type="checkbox"/> NO
<b>R5 – Procedure</b>	1) HFE1 and HFE2 use the same procedure.	<input type="checkbox"/> YES <input type="checkbox"/> NO



# Basis for Screening Process

- Dependency relationships between HFEs can result in one or more dependency factors.
- Each dependency factor potentially impacts some PIFs associated with HFE2.
  - The impact of each dependency factor on HFE2 is based on how occurrence of HFE1 changes the context for HFE2.
  - If occurrence of HFE1 would not result in any changes to the context associated with HFE2, the dependency factor may be discounted.
  - Each undiscounted dependency factor potentially results in new PIFs, new PIF attributes, or worsening of the PIF attributes that were originally assessed in the individual HEP of HFE2.
- Some PIF attributes impact HEPs more significantly than others. The screening process focuses on evaluation of the more significant PIF attributes.
- The screening process groups the impact of the most likely affected PIF attributes for each dependency factor into “Low,” “Medium,” and “High” impact categories.
- The dependency impact values ( $P_d$ ) are based on IDHEAS-ECA.

# Screening Analysis

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
<p><b>R1.1</b> Same functions or systems leads to cognitive dependency</p> <p>A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained; thus, the scenario associated with HFE2 becomes less familiar. (Note: Occurrence of HFE1 alters the scenario for HFE2; thus, HFE1 causes some level of unfamiliarity with HFE2)</p> <p>B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.</p>	<ul style="list-style-type: none"> <li>□ A - HFE2 was trained in the scenarios that HFE1 occurs (e.g., Feed &amp; Bleed is the last action after others fail) so there is no unfamiliarity due to HFE1.</li> <li>□ B - HFE2 is well trained on in various scenarios such that personnel are unlikely to develop a wrong mental model due to occurrence of HFE1.</li> <li>□ A/B - There is no cognitive link (similar thought process) between the two HFEs; thus, occurrence of HFE1 has no impact on scenario familiarity or mental model associated with HFE2.</li> <li>□ B - There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.</li> </ul>	<p>This cognitive dependency affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when there is something wrong with the mental model and there is no diverse method available to correct the wrong mental model.</p>
		<p>Low: <math>P_d = 5E-2</math></p> <ul style="list-style-type: none"> <li>□ Parts of scenario become unfamiliar (e.g., different from what was trained on), <i>OR</i></li> <li>□ HFE1 creates a biased mental model or preference for wrong strategies.</li> </ul>
		<p>Medium: <math>P_d = 1E-1</math></p> <ul style="list-style-type: none"> <li>□ Parts of scenario become unfamiliar (e.g., different from what was trained on), <i>AND</i></li> <li>□ HFE1 creates a biased mental model or preference for wrong strategies.</li> </ul>
		<p>High: <math>P_d = 3E-1</math></p> <ul style="list-style-type: none"> <li>□ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (e.g., thought process).</li> </ul>

# Screening Dependency Impact

Calculate the screening dependent HEP of HFE2 by taking the probabilistic sum of the individual HEP of HFE2 ( $P_2$ ) and each of the undiscounted dependency impact values ( $P_d$ ), as follows:

$$\text{Dependent HEP of HFE2} = 1 - (1 - P_2) \prod_{i=1}^m (1 - P_{d_i}) = 1 - (1 - P_2)(1 - P_{d_1}) \dots (1 - P_{d_m})$$

NOTE: When the dependency impact values are small, the screening dependent HEP can be approximated by summing the dependency impact values and the individual HEP of HFE2. This approximation should not be used when any “High” dependency impact values are applicable.

# Potential Dependency Impacts

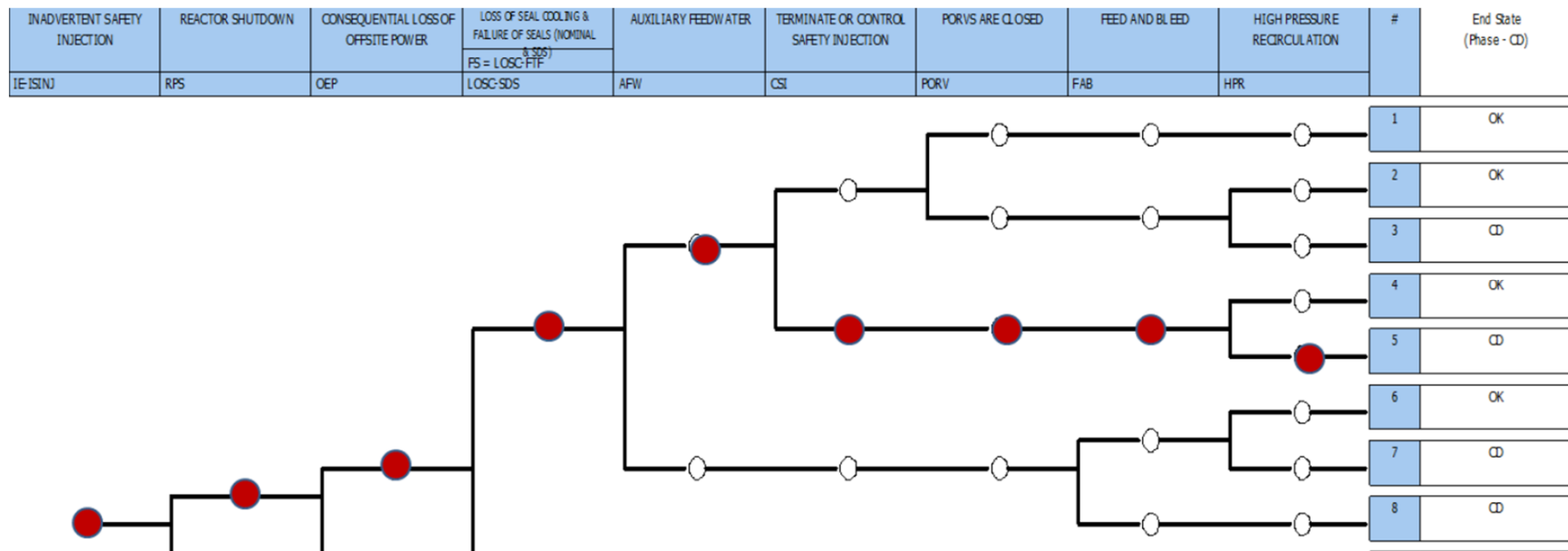
HFE Relationship	Potential Dependency Factors	Dependency Impact			
		No Impact	Low	Medium	High
R1 — Functions or systems	R1.1 Same functions or systems leads to cognitive dependency	0.0	5E-2	1E-1	3E-1
	R1.2 Same functions or systems leads to consequential dependency	0.0	1E-2	5E-2	2E-1
	R1.3 Same functions or systems leads to resource-sharing dependency	0.0	2E-3	1E-2	5E-2
R2 — Time proximity	R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency	Varies depending on the ratio of time available to time required ( $T_a/T_r$ ) for performing HFE2			
		> 4 0.0	$\geq 3$ and $\leq 4$ 1E-3	$\geq 2$ and $< 3$ 1E-2	$\geq 1$ and $< 2$ 1E-1
	R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency	0.0	5E-3	5E-2	1E-1
R3 — Personnel	R3.1 Same personnel leads to cognitive dependency	0.0	5E-2	1E-1	3E-1
	R3.2 Same personnel leads to consequential dependency	0.0	2E-3	1E-2	3E-2
	R3.3 Same personnel leads to resource-sharing dependency	0.0	2E-3	1E-2	5E-2
R4 — Location	R4.1 Same location leads to consequential dependency	0.0	2E-3	5E-3	2E-2
	R4.2 Same location and time leads to consequential dependency	0.0	2E-3	5E-3	7E-3
R5 — Procedure	R5.1 Same procedure leads to cognitive dependency	0.0	5E-3	5E-2	3.5E-1

# Detailed Analysis

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
<p>R1.1 Same functions or systems leads to cognitive dependency</p> <p>A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained; thus, the scenario associated with HFE2 becomes less familiar. (Note: Occurrence of HFE1 alters the scenario for HFE2; thus, HFE1 causes some level of unfamiliarity with HFE2)</p> <p>B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.</p>	<ul style="list-style-type: none"> <li>□ A - HFE2 was trained in the scenarios that HFE1 occurs (e.g., Feed &amp; Bleed is the last action after others fail) so there is no unfamiliarity due to HFE1.</li> <li>□ B - HFE2 is well trained on in various scenarios such that personnel are unlikely to develop a wrong mental model due to occurrence of HFE1.</li> <li>□ A/B - There is no cognitive link (similar thought process) between the two HFEs; thus, occurrence of HFE1 has no impact on scenario familiarity or mental model associated with HFE2.</li> <li>□ B - There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.</li> </ul>	<p><u>Potentially affected CFMs:</u> All CFMs</p> <p><u>Potentially impacted PIFs:</u> SF - Scenario Familiarity</p> <p><u>PIF attributes that are most likely impacted by the dependency factor:</u></p> <ul style="list-style-type: none"> <li>□ SF1 - Unpredictable dynamics in known scenarios</li> <li>□ SF2 - Unfamiliar elements in the scenario</li> <li>□ SF3 - Scenarios trained on but infrequently performed</li> <li>□ SF4 - Bias or preference for wrong strategies exists, mismatched mental models</li> </ul>

# Simplified Example

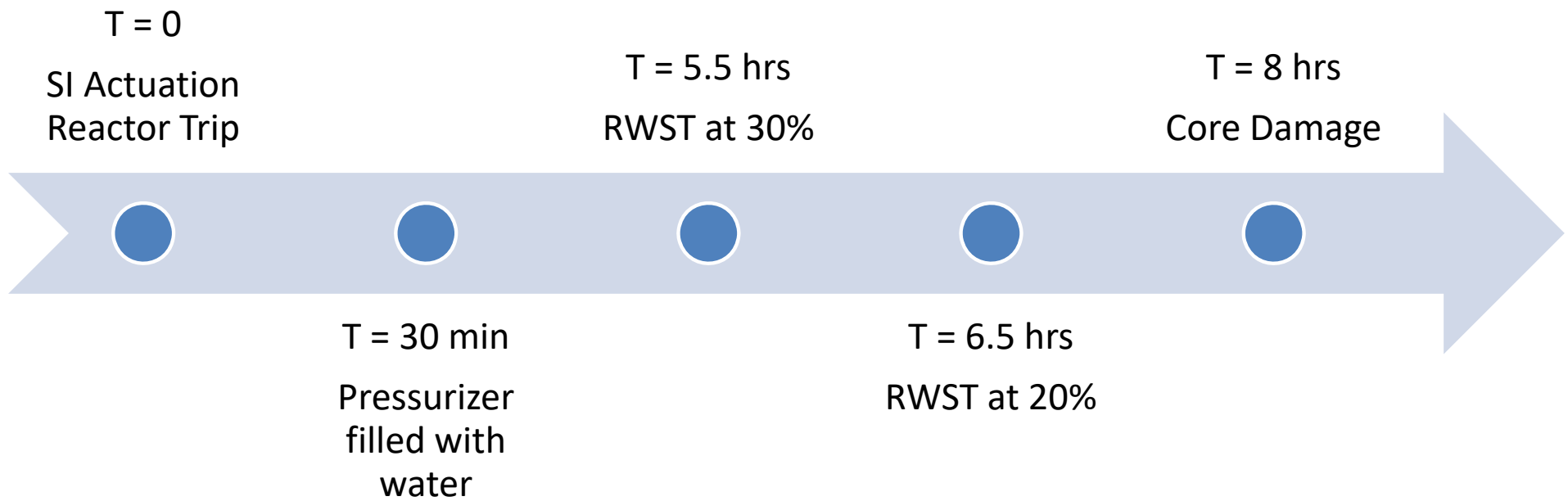
- Inadvertent safety injection (SI) actuation due to a stuck open pressurizer spray valve at power.
- SI triggers a reactor trip. All automatic actions occur as expected.



# Human Failure Events

- HFE 1: Terminate SI
  - Performed using procedure ES-1.1 and takes 15 min to complete.
  - E-0 is entered due to the reactor trip. E-0 directs entering ES-1.1 to terminate SI flow if RCS pressure is stable or rising and other parameters are within criteria.
- HFE 2: Start high pressure recirculation (HPR)
  - Performed using procedure ES-1.3 and takes 12 min to complete.
  - E-0 directs entering ES-1.3 when RWST level reaches 30%. ES-1.3 directs operators to start HPR once RWST level drops to 20%.

# Timeline



- 5.5 hours available to terminate SI.
- 1.5 hours to start high pressure recirculation.



# Step 1: Predetermination Analysis

Relationship	Assessment Guidelines	
Complete Dependency	<input checked="" type="checkbox"/> HFE1 and HFE2 use the same procedure, <b>AND</b> <input type="checkbox"/> HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), <b>AND</b> <input type="checkbox"/> There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2.  <b>Justification:</b> (1) HFE1 uses procedures E-0 and ES-1.1. HFE2 uses procedures E-0 and ES-1.3, or E-1 and ES-1.3. E-0 is the shared procedure. (2) The cues of HFE1 and HFE2 are different. The common procedure is not a likely cause of dependency.	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO
R1— Functions or Systems	<input checked="" type="checkbox"/> HFE1 and HFE2 have the same functions or systems, <b>OR</b> <input checked="" type="checkbox"/> HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed.  <b>Justification:</b> HFE1 and HFE2 use the same system (ECCS) for different functions. HFE1's function is to control RCS inventory. HFE2 provides core cooling.	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
R2— Time Proximity	<input type="checkbox"/> HFE1 and HFE2 are performed close in time, <b>OR</b> <input type="checkbox"/> The cues for HFE1 and HFE2 are presented close in time.	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO
R3— Personnel	<input checked="" type="checkbox"/> HFE1 and HFE2 are performed by the same personnel.  <b>Justification:</b> HFE1 and HFE2 are assumed to be performed by the same crew.	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
R4— Location	<input checked="" type="checkbox"/> HFE1 and HFE2 are performed at the same location, <b>OR</b> <input type="checkbox"/> The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation).  <b>Justification:</b> HFE1 and HFE2 are performed in the main control room. No environmental factors are expected to affect the reliability of HFE1 and HFE2.	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
R5— Procedure	<input checked="" type="checkbox"/> HFE1 and HFE2 use the same procedure.  <b>Justification:</b> HFE1 and HFE2 could share the same procedure (E-0).	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO

## Step 2: Screening Analysis – Same Personnel

- Individual HEP =  $3.5E-3$
- $P_d(R3.2) = 2E-3$
- Screening dependent HEP =  $5.5E-3$

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
<b>R3.2</b> Use of the same personnel leads to consequential dependency  A. Mental fatigue, time pressure, or stress level increase due to the same personnel performing HFE1 and HFE2 (e.g., HFE1 could cause high stress or mental fatigue because several layers of defense in depth have failed, such as in situations beyond the EOPs).  B. Personnel need to perform HFE1 and HFE2 at the same time (i.e., personnel must switch between tasks).	<input type="checkbox"/> A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue.  <b>Justification:</b> Simulator training never requires the crew to wait for more than 5 hours before performing cold-leg recirculation (HFE2). The mental fatigue is different in training than in actual events.  <input checked="" type="checkbox"/> B—HFE1 and HFE2 are not performed at the same time  <input type="checkbox"/> B—Additional personnel are available to perform HFE2.	This consequential dependency potentially affects the PIFs for mental fatigue, stress, time pressure, and staffing. Mental fatigue may occur due to working on cognitively demanding tasks in HFE1 and HFE2. Staffing may be impacted due to lack of personnel to perform both actions or when both actions are performed in parallel.  Low: $P_d = 2E-3$ <input checked="" type="checkbox"/> Mental fatigue increases due to sustained highly demanding cognitive activities, <b>OR</b> <input type="checkbox"/> Time pressure increases due to perceived time urgency and task load.  Medium: $P_d = 1E-2$ <input type="checkbox"/> Same personnel perform HFE1 and HFE2 in parallel, <b>AND</b> <input type="checkbox"/> HFE2 does not require complicated diagnosis.  High: $P_d = 3E-2$ <input type="checkbox"/> Same personnel perform HFE1 and HFE2 in parallel, <b>AND</b> <input type="checkbox"/> HFE2 requires complicated diagnosis.

Potential Dependency Factors	Dependency Impact
<p><b>R3.2</b> Use of the same personnel leads to consequential dependency</p> <p>A. Mental fatigue, time pressure, or stress level increase due to the same personnel performing HFE1 and HFE2 (e.g., HFE1 could cause high stress or mental fatigue because several layers of defense in depth have failed, such as in situations beyond the EOPs).</p> <p>B. Personnel need to perform HFE1 and HFE2 at the same time (i.e., personnel must switch between tasks).</p>	<p><u>Potentially affected CFMs:</u> All CFMs</p> <p><u>Potentially impacted PIFs:</u> MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions</p> <p><u>PIF attributes that are most likely impacted by the dependency factor:</u></p> <p><input type="checkbox"/> MF1—Sustained (&gt; 30 minutes), highly demanding cognitive activities requiring continuous attention (e.g., procedure-situation mismatches demand constant problem-solving and decisionmaking; information changes over time and requires sustained attention to monitor or frequent checking)</p> <p><input type="checkbox"/> MF2—Time pressure due to perceived time urgency</p> <p><input type="checkbox"/> MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff)</p> <p><input checked="" type="checkbox"/> MF5—Long working hours (&gt; 4 hours) with highly cognitively demanding tasks</p> <p><b>Note:</b> The analyst added MF5 to the list.</p> <p><input type="checkbox"/> MT3—Concurrent visual detection and other tasks</p> <p><input type="checkbox"/> MT4—Concurrent auditory detection and other tasks</p> <p><input type="checkbox"/> MT5—Concurrent diagnosis and other tasks</p> <p><input type="checkbox"/> MT8—Concurrently executing action sequence and performing another attention/working memory task</p> <p><input type="checkbox"/> MT9—Concurrently executing intermingled or interdependent action plans</p>

## Step 3: Detailed Analysis – Same Personnel

- Individual HEP =  $3.5E-3$
- The dependency impact was accounted for in the original analysis of the individual HEP.
- HEP with dependency =  $3.5E-3$
- HEP without dependency applied =  $2.6E-3$
- $P_d(R3.2) = 9E-4$

## Example Results

- Original individual HEP =  $3.5\text{E-}3$
- Screening dependent HEP =  $5.5\text{E-}3$ 
  - Screening consequential dependency impact due to use of same personnel:  $P_d(\text{R3.2}) = 2\text{E-}3$
- Detailed dependent HEP =  $3.5\text{E-}3$ 
  - Detailed consequential dependency impact due to use of same personnel:  $P_d(\text{R3.2}) = 9\text{E-}4$
  - Individual HEP without dependency impact =  $2.6\text{E-}3$

# Conclusion

- IDHEAS-DEP leverages the IDHEAS-ECA quantification method to develop screening dependency values that can be applied to HEPs for HFEs modeled using any HRA method.
- Both the screening analysis and detailed analysis provide a dependent HEP for HFE2 and identify the dependency relationships, dependency factors, and PIFs impacted by the occurrence of HFE1
- In general, the dependent HEPs calculated using IDHEAS-DEP are lower than those calculated using THERP.
- In some cases, the independent HEP may already account for the dependency impacts (such as for feed and bleed or initiating high pressure recirculation).

# Questions?



# Acronyms

- CFM – Cognitive Failure Mode
- EPRI – Electric Power Research Institute
- HEP – Human Error Probability
- HFE – Human Failure Event
- HRA – Human Reliability Analysis
- HPR – High Pressure Recirculation
- IDHEAS – Integrated Human Event Analysis System
- IDHEAS-DEP – IDHEAS Dependency Analysis
- IDHEAS-ECA – IDHEAS for Event and Condition Assessment
- IDHEAS-G – IDHEAS General Methodology
- NRC – Nuclear Regulatory Commission
- NRR – Office of Nuclear Reactor Regulation
- PIF – Performance Influencing Factor
- PRA – Probabilistic Risk Analysis
- RCS – Reactor Coolant System
- RES – Office of Nuclear Regulatory Research
- SI – Safety Injection
- WG – Working Group

# References

1. U.S. Nuclear Regulatory Commission, NUREG-2198, “The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G),” May 2021, ADAMS Accession No. ML21127A272.
2. U.S. Nuclear Regulatory Commission, NUREG-2256, “Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA),” October 2022, ADAMS Accession No. ML22300A117.
3. U.S. Nuclear Regulatory Commission, Research Information Letter 2021-14, “Integrated Human Event Analysis System Dependency Analysis Guidance (IDHEAS-DEP),” November 2021, ADAMS Accession No. ML21316A107. (Will be NUREG-2258)