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Integrated Human Event Analysis System Dependency Analysis Guidance (IDHEAS-DEP)

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ABSTRACT

Dependency in the context of human reliability analysis (HRA) refers to the impact of success or failure of a human action on performance of subsequent human actions. Existing dependency models assess the level of dependency between two consecutive human failure events (HFEs) based on the coupling factors or commonalities that exist for both HFEs. The U.S. Nuclear Regulatory Commission (NRC) developed a new dependency model that is informed by behavioral and cognitive science and expands on existing dependency models by identifying the specific cognitive failure modes (CFMs), performance influencing factors (PIFs), and PIF attributes that are impacted by dependency. This new dependency model identifies and evaluates how failure of the first human action affects the context of subsequent human actions. The NRC presents the model in NUREG-2198, "The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G)," issued May 2021. The NRC staff developed IDHEAS-G as a new HRA methodology for agency use. IDHEAS-G is a general HRA methodology that can be used to develop application-specific HRA methods. The NRC used the IDHEAS-G framework to develop a new method for performing HRA for nuclear power plant probabilistic risk assessments, which is documented in Research Information Letter 2020-02, "Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)," issued February 2020. This report documents how to perform a dependency analysis using the dependency model that was developed as part of IDHEAS-G to be used with the IDHEAS-ECA HRA method.

The IDHEAS-G dependency model evaluates dependency at the macrocognitive level. The impact of dependency is modeled in a manner consistent with how individual HFEs are modeled. The IDHEAS-G dependency model consists of three parts: (1) identifying how occurrence of an HFE changes the context of subsequent HFEs, (2) determining how the identified dependency affects the context (e.g., critical tasks, CFMs, PIFs) associated with the subsequent HFEs, and (3) calculating the probability of the subsequent HFE based on the changes to the dependency context. The impact of the change in context for the subsequent HFE is modeled using additional PIFs and PIF attributes or by increasing the PIF attribute levels in IDHEAS-ECA.

The dependency analysis process in this guidance document (IDHEAS-DEP) is presented in three steps. Step 1 is the Predetermination Analysis, which identifies the relationships between HFEs that can result in dependency and assesses whether the HFEs are independent or completely dependent. If the HFE pair is not independent nor completely dependent and a dependency relationship exists, then the analyst proceeds to Step 2 or Step 3. Step 2 is the Screening Analysis, which is used to perform a quick, rough dependency analysis that results in a screening dependent human error probability (HEP) value. Step 2 can be used for HFEs that were evaluated using IDHEAS-ECA or other HRA methods and can be skipped if the analyst does not want a screening result. If Step 2 is performed and the analyst wants a more refined dependency result, the analyst performs Step 3. Step 3 is the Detailed Analysis, which calculates dependent HEPs using IDHEAS-ECA and is applicable to HRA applications for which the individual HEPs are calculated using IDHEAS-ECA. Both Step 2 and Step 3 provide dependent HEP values along with an explanation of what dependency factors cause the increase in individual HEPs. To facilitate use of the IDHEAS dependency model, Appendix A provides the IDHEAS dependency analysis worksheet that includes the three steps described above.

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1 INTRODUCTION

1.1 Purpose

NUREG-2198, "The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G)," issued May 2021 (Ref. 1), documents a new human reliability analysis (HRA) methodology that was developed by the U.S. Nuclear Regulatory Commission (NRC) staff in response to Staff Requirements Memorandum (SRM) M061020, dated November 8, 2006 (Ref. 2), which requested that the NRC staff propose a single HRA method or set of methods for agency use. IDHEAS-G is a general HRA methodology that can be used to develop application-specific HRA methods. Research Information Letter (RIL) 2020-02, "Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)," issued February 2020 (Ref. 3), documents a new HRA method for performing HRA for nuclear power plant probabilistic risk assessments (PRAs) that is based on the framework in IDHEAS-G. IDHEAS-G includes a dependency model that is based on the cognitive structure of HRA. This report documents how to perform a dependency analysis using the dependency model that was developed as part of IDHEAS-G to be used with the IDHEAS-ECA HRA method.

This dependency model analyzes the dependency between two human failure events (HFEs) by identifying and evaluating how failure of the first human action effects the context of subsequent human actions. This guidance document was developed primarily for use by the NRC staff in risk-informed applications, such as the Significance Determination Process (SDP) and Accident Sequence Precursor Program, but the guidance can be used in any application for which the HFEs can be modeled using IDHEAS-ECA.

1.2 Scope

In this document, dependency refers to the dependency between two HFEs. The dependency evaluation assesses the impact of occurrence of the first HFE (failure of the first human action) on the probability of the subsequent HFE (failure of the second human action). This process requires that one of the two HFEs being evaluated for dependency occurs before the other HFE. If the HFEs occur at the same time, the analyst must assume a time sequence in which one HFE occurs before the other. If more than two HFEs need to be evaluated for dependency, the analyst must break the HFEs into pairs based on the order in which they occur or their assumed time sequence.

The full dependency analysis process in PRA begins by identifying minimal cutsets associated with an initiating event, determining which pairs of HFEs in a cutset require dependency analysis, and evaluating dependency between HFE pairs. This guidance is intended to be used to evaluate dependency between HFE pairs after the minimal cutsets and HFE pairs requiring analysis have been identified.

This document is intended to be used for HFEs that have been evaluated using IDHEAS-ECA. The guidance includes a Predetermination Analysis, Screening Analysis, and Detailed Analysis. While the Detailed Analysis relies on using IDHEAS-ECA, the Predetermination Analysis and Screening Analysis can be used for HFEs that were evaluated using other HRA methods.

This guidance document only evaluates the potential increase in the probability of an HFE due to its dependency on the preceding HFE. Current HRA practice does not credit the success of a human action with lowering the failure probability of subsequent human actions.

1.3 Related Regulatory Documents

This document is related to the following NRC documents:

- NUREG-2198 presents a general methodology for performing HRA for all nuclear applications based on a cognitive model of human performance, IDHEAS-G. Appendix K to NUREG-2198 describes the IDHEAS dependency model, reviews existing dependency methods, and discusses areas for improvement in HRA dependency.

- RIL 2020-02 (IDHEAS-ECA) provides step-by-step guidance for analyzing human actions performed at nuclear power plants and estimating the human error probabilities (HEPs) associated with those actions for use in PRAs. IDHEAS-ECA is based on the cognitive framework in IDHEAS-G. This guidance document assumes that users are familiar with how to quantify the HEPs using IDHEAS-ECA.

1.4 Terminology

- **HFE1 and HFE2**—HFE1 and HFE2 are in the same PRA event sequence or minimal cutset. Chronologically, HFE1 starts before HFE2, but performance of HFE1 and HFE2 may overlap in time. The dependency evaluation assesses the impact of occurrence of HFE1 on HFE2.

- **Dependency Relationship**—The dependency relationship describes how the occurrence of HFE1 affects HFE2. This guidance document defines five different dependency relationships: functions or systems, location, personnel, time proximity, and procedures.

- **Dependency Type**—IDHEAS-G describes three types of dependency:

  - Consequential dependency—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. The outcome of the preceding HFE may affect various elements of the subsequent HFE, including HFE definition (e.g., HFE feasibility), critical tasks that must be performed, applicable cognitive failure modes (CFMs), time available to perform the human action, and performance influencing factors (PIFs). The change could also include creating emergent tasks that delay implementation of the subsequent HFE.

  - Cognitive dependency—Cognitive dependency refers to the dependency in the cognitive information for two consecutive HFEs. The cognitive information includes procedures and mental models for detecting information, understanding the situation, making decisions, executing the actions, and coordinating responses of different teams involved.

  - Resource-sharing dependency—The two HFEs share limited resources such as critical tools, staffing, water, or electricity. The resource-sharing dependency could exist in one of two situations: (1) the preceding HFE reduces the resources available for the subsequent HFE, or (2) the HFEs are performed simultaneously using the same resources such that the combination of the resource demands exceeds what is available.

- **Dependency Factor**—The context associated with HFE2 can change due to the occurrence of HFE1 when a dependency relationship and type of dependency exist. Dependency factors are the potential ways that the context can change based on a specific dependency type and dependency relationship combination.

- **Dependency Impact Value, P_d**—This is the value associated with the most likely impacted PIFs for each undiscounted dependency factor. The dependency impact values are grouped into “Low,” “Medium,” and “High” categories according to the potential impact on the screening dependent HEP. Appendix B to this guidance discusses the process used to develop the dependency impact values.

- **Individual HEP**—This is the probability of an HFE evaluated without considering the dependency between HFEs. Some guidance documents may call this the base case, independent, or nondependent HEP.

- **Dependent HEP**—This is the probability of HFE2 after adjusting its individual HEP to account for the impact of dependency. Some guidance documents may call this the adjusted or conditional HEP.

- **Independent HFE Pair (or No Dependency)**—This denotes the situation in which the occurrence of HFE1 has no impact on the probability of HFE2; thus, there is no adjustment to the probability of HFE2.

- **Complete Dependency**—This denotes the situation in which the occurrence of HFE1 will always lead to the occurrence of HFE2; thus, the adjusted probability of HFE2 is 1.0.

1.5 Overview of the IDHEAS Dependency Model

The NRC staff developed a new dependency model as part of IDHEAS-G that is better informed by cognitive and behavioral science. This section briefly summarizes the IDHEAS-G dependency model. Appendix K to NUREG-2198 contains the detailed description of the IDHEAS-G dependency model.

The IDHEAS-G dependency model evaluates dependency at the macrocognitive level. The effect of dependency is modeled in a manner consistent with how individual HFEs are modeled in IDHEAS-G. The IDHEAS-G dependency model consists of three parts: (1) identifying how occurrence of an HFE changes the context of subsequent HFEs, (2) determining how the identified dependency affects the context (e.g., critical tasks, CFMs, PIFs) associated with the subsequent HFEs, and (3) calculating the probability of the subsequent HFE based on the changes to the dependency context. Specifically, changes in context due to the occurrence of the preceding HFE typically deteriorate certain PIFs associated with the subsequent HFE when dependency is present. The impact of the change in context for the subsequent HFE is modeled using additional PIF attributes or increasing the PIF attribute levels in IDHEAS-ECA.

The IDHEAS dependency model advances dependency analysis in that (1) the dependency evaluation explains what factors impact dependency because the evaluation is based on specific context changes due to the occurrence of the preceding HFEs and (2) calculation of dependent HEPs is based on the same factors as those used for calculating individual HEPs.

1.6 Overview of the Guidance Structure

Chapter 1 of this document introduces the concept of the IDHEAS dependency model and includes the purpose, scope, list of related regulatory documents, list of terminology used in the document, and overview of the IDHEAS dependency model.

Chapter 2 presents the guidance for performing the dependency analysis using three steps. Figure 1-1, shown on the next page, provides an overview of the three-step structure. Step 1 is the Predetermination Analysis, which is presented in Section 2.3. It identifies the relationships between HFE1 and HFE2 that can result in dependency and assesses whether the HFEs are independent or completely dependent. If the HFE pair is not independent nor completely dependent and a dependency relationship exists, then the analyst proceeds to Step 2 or Step 3. Step 2 is the Screening Analysis, which is presented in Section 2.4. It is used to perform a quick, rough dependency analysis that results in a screening dependent HEP value. This step can be used for HFEs that were evaluated using IDHEAS-ECA or other HRA methods. Step 2 can be skipped if the analyst does not want a screening result. If Step 2 is performed and the analyst wants a more refined dependency result, Step 3 is the Detailed Analysis, which is presented in Section 2.5. This step calculates dependent HEPs using IDHEAS-ECA and is applicable to HRA applications for which the individual HEPs are calculated using IDHEAS-ECA. Both Step 2 and Step 3 provide dependent HEP values and explain what dependency factors cause the increase in individual HEPs.

Appendix A presents the IDHEAS dependency analysis worksheet that include all three steps described above. Appendix B presents the technical basis for the Screening Analysis. Appendices C and D each present an example of how to perform HRA and dependency analysis using IDHEAS-ECA and this guidance.

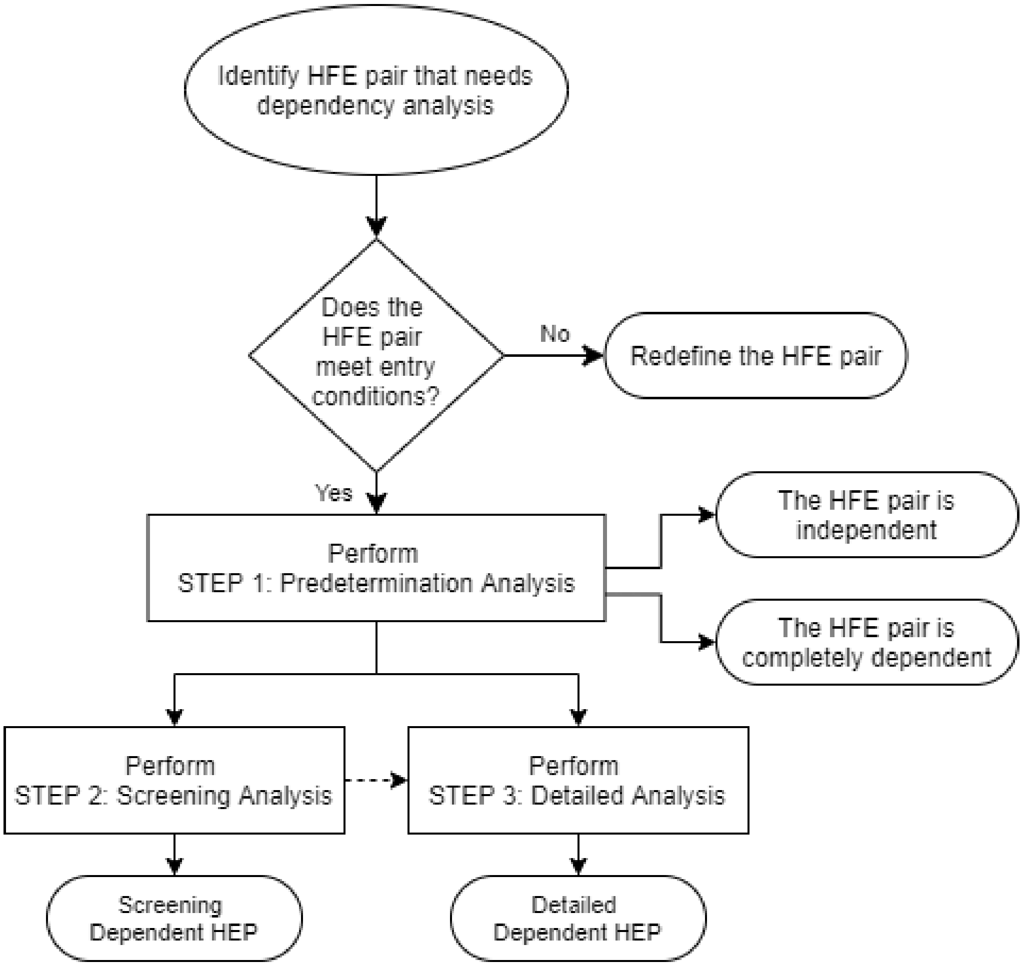


Figure 1-1: Overview of the Dependency Analysis Process

2 DEPENDENCY ANALYSIS GUIDANCE

2.1 Overview of the Dependency Analysis Process

A dependency analysis begins with evaluating the entry conditions. If the entry conditions are met, the analyst proceeds to Step 1, Predetermination Analysis, which will determine whether the HFEs are completely dependent, independent, or require further evaluation. Further evaluation is performed using Step 2, Screening Analysis, or Step 3, Detailed Analysis. Figure 2-1 shows an overview of the dependency analysis process.

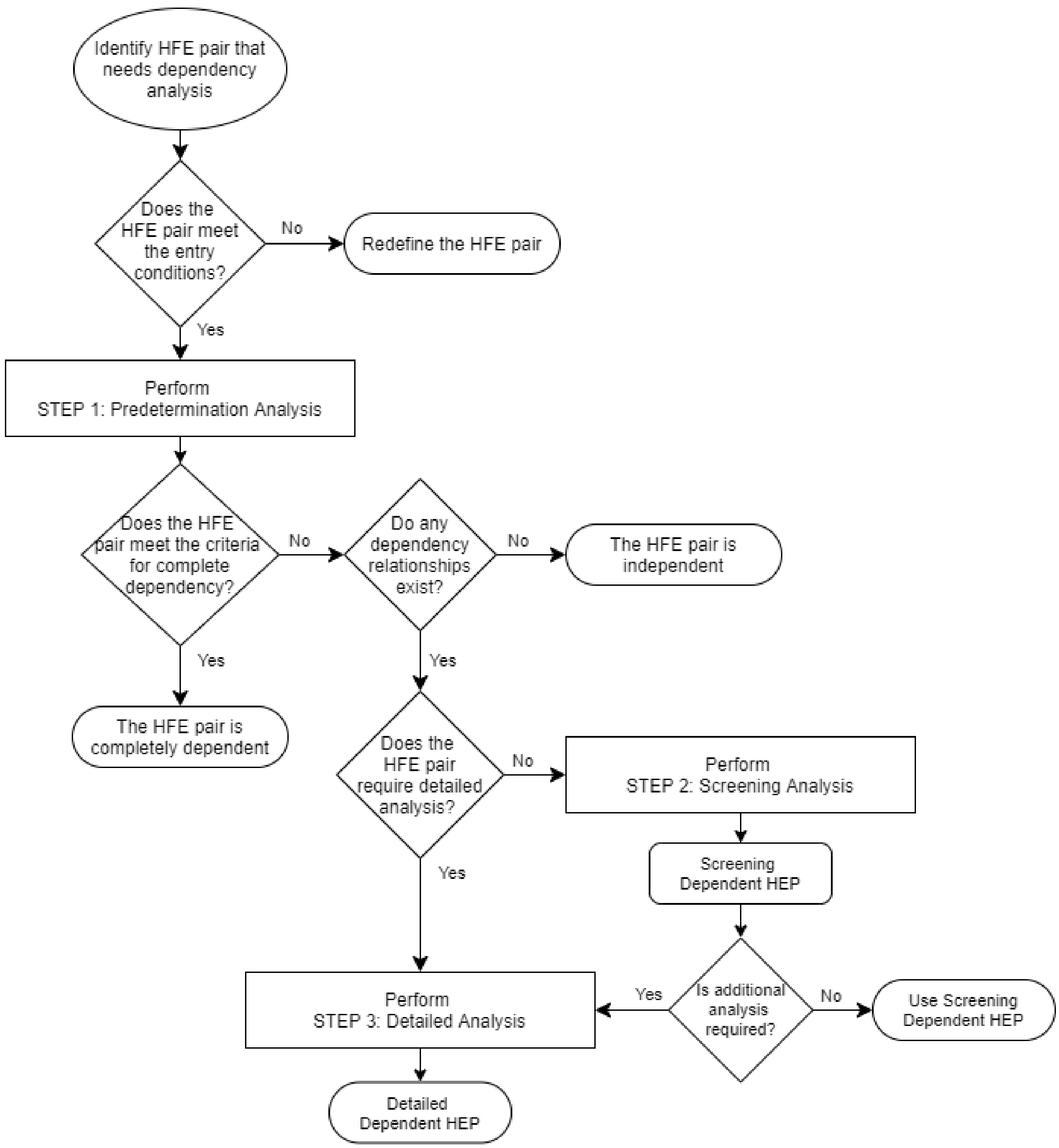


Figure 2-1: Dependency Analysis Process

Step 1 is the Predetermination Analysis. It identifies the relationships between HFE1 and HFE2 that can result in dependency. Step 1 has three possible outcomes:

(1) There is no dependency, so that there is no adjustment to the probability of HFE2, ***OR***

(2) There is complete dependency, so that the adjusted probability of HFE2 is 1.0, ***OR***

(3) One or more relationships exist between the HFEs; thus, the analyst proceeds to Step 2, Screening Analysis, or Step 3, Detailed Analysis.

Step 2 is the Screening Analysis. It should be used in the following situations:

(1) The analyst does not have enough detailed information to assess the impact of dependency on each CFM and PIF in IDHEAS-ECA, ***OR***

(2) Only a quick, rough screening dependent HEP value is needed, ***OR***

(3) The individual HEPs were calculated in another HRA method and cannot be recalculated using IDHEAS-ECA.

The Predetermination Analysis (Step 1) identifies which relationships between the two HFEs are applicable. Thus, the Screening Analysis (Step 2) only needs to evaluate the relationships that were identified as applicable in the Predetermination Analysis. The Screening Analysis identifies a set of potential dependency factors associated with each applicable relationship. Each potential dependency factor represents a unique dependency consideration that has a set of discount factors that can be used to determine whether the potential dependency factor is applicable. The impact of each applicable (undiscounted) dependency factor on the probability of HFE2 is classified into three levels—Low, Medium, and High. Each level has a corresponding screening HEP (P_d). Section 2.4 includes instructions to assist the analyst in determining which dependency factors are applicable and the level of dependency. The adjusted probability of HFE2 is the probabilistic sum of the individual HEP of HFE2 (P_2) and each of the undiscounted dependency impacts (P_d). The outcome of Step 2 is the screening dependent HEP for HFE2.

Step 3 is the Detailed Analysis using IDHEAS-ECA. This step is applicable to HRA applications for which both of the following are true:

(1) The individual HEPs are calculated using IDHEAS-ECA or the analyst has sufficient information to recreate the individual HEPs using IDHEAS-ECA, ***AND***

(2) The specific application requires dependent HEP values and an explanation of what causes the increase in individual HEPs.

The Detailed Analysis (Step 3) identifies additional critical tasks, CFMs, PIFs, PIF attributes, and time availability issues caused by the dependency factors, and then recalculates the probability of HFE2 accounting for the impact of the dependency factors. The outcome of Step 3 is the detailed dependent HEP for HFE2.

2.2 Entry Conditions

The full dependency analysis process in PRA begins by identifying minimal cutsets associated with an initiating event, determining which pairs of HFEs in each cutset require dependency analysis, and evaluating dependency between HFEs in an HFE pair. This guidance is intended to be used to evaluate dependency between HFEs in an HFE pair after the minimal cutsets and HFE pairs requiring analysis have been identified. The entry conditions for applying dependency analysis using this process are as follows:

(1) (a) HFE1 and HFE2 are in the same PRA event sequence or minimal cutset, ***AND***
(b) there are no relevant human action success events between HFE1 and HFE2 in the sequence, ***OR***

(2) 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. These are also called at-initiators and are common at shutdown.

If the conditions in (1) ***OR*** (2) above are met, the analyst may proceed to Step 1, Predetermination Analysis. If neither condition (1) ***OR*** (2) above is met, the analyst is not ready to perform dependency analysis using this process. The following sections discuss additional information that may be useful for meeting the entry conditions.

2.2.1 Assessing Time Sequence

This dependency analysis process is performed for two HFEs with an assumed time sequence, where HFE1 occurs before HFE2. PRA event trees are not necessarily structured sequentially, so the analyst may need additional information to determine the time sequence. If the analyst does not know the order in which HFE1 and HFE2 are performed, or if HFE1 and HFE2 are performed in parallel, dependency modeling may be performed as follows:

- The analyst may evaluate dependency for both time sequences (i.e., the impact of HFE1 occurring first and the impact of HFE2 occurring first) to determine which time order has a larger impact on dependency, ***OR***

- The analyst may assume a time sequence based on the most likely scenario.

2.2.2 Assessing Dependency for More Than Two Human Failure Events

This dependency analysis process is performed for HFE pairs only. Since a minimal cutset can have more than two HFEs, the analyst must break the HFEs into pairs in order to perform the dependency analysis. For example, the analyst can assess the dependency impact of the first HFE that occurs on the second HFE, determine the dependent HEP for the second HFE, and then use the dependent HFE to assess the dependency impact on the third HFE in the sequence. Alternatively, the analyst can choose to group the prior HFEs together into HFE1. In this case, HFE1 will represent several HFEs that occur before HFE2.

2.2.3 Relevant Intervening Successes

If a successful relevant human action occurs between two HFEs, it breaks the dependency between the two HFEs. The word “relevant” means that the successful human action must be related to the other two human actions in a way that impacts dependency. Human actions that share a dependency relationship can usually be considered relevant human actions. Therefore, a successful relevant human action could be an action that is on related systems or functions, occurs close in time with the other actions, is performed by the same personnel, is performed in the same location, or is governed by the same procedures. In most cases, the intervening successful human action will be relevant because it is in the same sequence. However, there could be intervening human actions that are irrelevant because they would not help break an incorrect mental model. For example, some parts of power restoration occur in the main control room (MCR) while others are performed in the field (i.e., outside the MCR). In this case, a successful human action performed in the field may not be relevant to dependency between human actions performed in the MCR.

2.2.4 Determining whether Dependency Analysis Is Necessary

In lieu of completing the dependency analysis, the analyst may choose to perform a sensitivity analysis to determine whether a dependency analysis is needed. Criteria for determining whether a dependency analysis is needed include the following:

- Dependency analysis may not be required if setting the HEP of HFE2 to 1.0 does not affect final PRA result, ***OR***
- In an SDP, dependency analysis may not be required if setting the HEP of HFE2 to 1.0 does not affect the safety significance of the inspection finding, ***OR***
- Dependency analysis may not be required if the minimum joint HEP is applied and the minimum joint HEP for the sequence is larger than the potential dependency effect of HFE2 on the sequence's joint HEP.

2.3 Step 1: Predetermination Analysis

The Predetermination Analysis provides a quick assessment of whether a potential for dependency exists for the HFE pair being evaluated. Each relationship can potentially introduce one or more types of dependency. The outcome of Step 1 is one of the following:

(1) HFE2 is completely dependent on HFE1; thus, the adjusted probability of HFE2 is 1.0, ***OR***

(2) HFE2 is independent of HFE1; thus, the adjusted HEP of HFE2 is equal to the individual HEP of HFE2, ***OR***

(3) One or more dependency relationships exist; thus, the analyst proceeds to either Step 2, Screening Analysis, or Step 3, Detailed Analysis, to obtain the dependent HEP of HFE2.

2.3.1 Descriptions of the Dependency Relationships

This guidance identifies the following five dependency relationships between HFEs:

(1) R1—Functions or Systems

The functions or systems dependency relationship describes when HFE1 and HFE2 are performed using equipment that has the same functions, or equipment that is part of the same system. The same function means that both HFEs are performed with the same intended result, such as to restore core cooling, remove decay heat, or restore power. The same system generally refers to an entire system, including all trains of equipment. However, if trains have different indications, controls, and equipment, some dependency impacts can be discounted.

When the HFEs in an HFE pair are performed using the same functions or systems, failure of the first human action can impact the mental model of the crew or impact the familiarity of the crew in performing the second human action due to cognitive dependency.

When the HFEs in an HFE pair are performed using the same functions or systems, failure of the first human action can increase the complexity of the second action or change the information available for the second action due to consequential dependency.

When the HFEs in an HFE pair are performed using the same functions or systems, failure of the first human action can impact the tools, equipment, or resources available to perform the second human action due to resource-sharing dependency.

(2) R2—Time Proximity

The time proximity dependency relationship describes when HFE1 and HFE2 are performed close in time or the cues for HFE1 and HFE2 are received close in time. For performing actions, close in time means that the actions are performed close enough in time that there is a potential for the first action to impact the time availability for the second action. For receiving cues, close in time means that the cues are received close enough in time that receipt of the second cue could be impacted. Actions for which the time available to perform the actions overlaps should be considered close in time. For example, if the first action takes 2 minutes to perform and must be performed anytime within the first 10 minutes of the scenario, the action should be considered close in time with any other actions that need to be performed in the first 10 minutes because it has the potential to impact the time available to perform the other actions.

When the HFEs in an HFE pair are performed close in time, issues performing the first HFE can reduce the time available or increase the time required to perform the second HFE due to consequential dependency. The ratio of time available (T_a) to perform HFE2 and the time required (T_r) to perform HFE2 is used to estimate the impact of time proximity on dependency. If at least four times more time is available to perform HFE2 than the time required to perform HFE2, the dependency impact of the time proximity relationship on HFE2 is negligible.

When the cues for an HFE pair are received close in time, the cue for the first HFE can mask the cue(s) for the second HFE, or the crew can forget about the second cue while performing the first action due to consequential dependency.

(3) R3—Personnel

The personnel dependency relationship describes when the same personnel perform both HFE1 and HFE2. The same personnel can refer to a single person or a crew, depending on who is responsible for performing the action. For cognition actions, the entire crew or part of the crew may be responsible for decisionmaking because different people are detecting the information and choosing the correct procedure to enter. For execution actions, a single person is often responsible for the action but may direct other people to perform some of the steps in the procedure.

When the HFEs in an HFE pair are both performed by the same personnel, failure of the first human action can cause groupthink or an incorrect mental model that can impact the second HFE due to cognitive dependency. Crews are usually trained together so that they function well as a team. Crews can experience groupthink or a shared incorrect mental model of the situation, which can impact diagnosis (i.e., Detection and Understanding) and Decisionmaking negatively.

When the same personnel perform both HFEs in an HFE pair, failure of the first human action can cause mental fatigue, time pressure, stress, or multitasking that can impact the second HFE due to consequential dependency.

When the same personnel perform both HFEs in an HFE pair, failure of the first human action can cause issues with staffing or resources that can impact the second HFE due to resource-sharing dependency. Reduced staffing can lead to a higher workload than normal or lack of knowledge if experienced members are absent for performing the second action. Staffing issues can result in changes to normal work processes, like suspension of peer checking or direct supervision of human actions.

(4) R4—Location

The location dependency relationship describes when HFE1 and HFE2 are performed in the same location. This relationship can only exist when portions of the human action are performed in the same location. Same location refers to the same room or area when accessibility or habitability is a concern. The same location can be limited to the same physical location of the instrumentation and controls (such as a single panel) when distractions or interference are a concern. For example, the MCR should be considered a single workplace when assessing habitability since noise, smoke, and temperature would impact all inhabitants; however, the MCR could be considered multiple locations when assessing the impact of performing actions at different panels if personnel would not distract or interfere with each other.

When the HFEs in an HFE pair are both performed in the same location, failure of the first human action can cause issues with workplace accessibility, habitability, or distractions that can impact the second HFE due to consequential dependency. Failure of the first human action can cause issues accessing the workplace to perform the second human action or reduce the habitability of the workplace such that it is more difficult to perform the second human action. Issues with excessive temperatures, noise, or visibility can make it more difficult to complete the second action.

If both HFEs are performed in the same location at the same time, performance of the first action can distract the personnel performing the second action. Failure of the first action could result in confusion or troubleshooting that distracts personnel from performing the second action.

(5) R5—Procedure

The procedure dependency relationship describes when HFE1 and HFE2 are both performed using the same procedure. The same procedure can refer to a single procedure or a single part of a multisection or multisheet procedure, like an emergency operating procedure (EOP). If a procedure section has different entry conditions from other parts of the procedure (like independent sections of an operating procedure) or is executed by itself (like a leg of an EOP flowchart), it can generally be considered a different procedure.

When the HFEs in an HFE pair share the same procedure for cognition or execution, failure of the first human action can cause issues entering, understanding, or following the procedure for the second HFE due to cognitive dependency. Failure of the first human action could make the procedure more difficult to follow or cause personnel to misinterpret the procedure when attempting the second human action because the procedure assumes the first action succeeded.

When the HFEs in an HFE pair share the same procedure and there is the potential for an unrecoverable error to occur that is related to the procedure, this dependency relationship results in complete dependency between HFEs in the Predetermination Analysis (Step 1).

2.3.2 Instructions for Performing the Predetermination Analysis

Table 1 is used to perform the Predetermination Analysis (Step 1). The first column identifies the dependency relationship being considered. Each row assesses a single potential dependency relationship. The second (middle) column lists the guidelines used to assess whether the dependency relationship is applicable to the HFE pair being evaluated. The third (last) column documents the yes or no answer to the assessment guideline questions in the second column. If YES is checked in the last column, the dependency relationship is applicable to the HFE pair being evaluated.

The Predetermination Analysis is performed as follows:

(1) Assess complete dependency first. If all of the assessment guideline statements in the first row of Table 1 are met, then the HFE pair is completely dependent, the adjusted probability of HFE2 is set to 1.0, and the dependency analysis is complete. Otherwise, continue assessing each potential dependency relationship between HFEs.

(2) Assess R1, R2, R3, R4, and R5 individually by answering YES or NO to the assessment guideline statements in the middle column of Table 1. Each dependency relationship is evaluated in isolation. For example, when the analyst evaluates “function or systems,” it is irrelevant to the analyst whether the function can be performed by the same or different personnel, at the same or different locations.

(3) If all the answers to the assessment guideline statements are NO, then HFE2 is independent of HFE1. The adjusted probability of HFE2 is equal to its individual HEP and the dependency analysis is complete. Otherwise, continue to the next step.

(4) If one or more answers to the assessment guideline statements are YES, then there is a potential for dependence between HFE1 and HFE2. The analyst may choose to perform Step 2, Screening Analysis, or Step 3, Detailed Analysis. The applicability of Steps 2 and 3 are discussed in the beginning of their respective sections.

Table 1: Predetermination Analysis

Dependency Relationship	Assessment Guidelines	
Complete Dependency	(1) HFE1 and HFE2 use the same procedure, ***AND*** (2) HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), ***AND*** (3) There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2. Note: Opportunity for recovery may exist if there is adequate time to recover, ***AND*** steps are in the procedure to recover, ***AND*** additional personnel outside the crew, such a shift technical advisor (STA), are available to identify the need to recover.	□ YES □ NO
R1— Functions or Systems	(1) HFE1 and HFE2 have the same functions or systems, ***OR*** (2) HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed.	□ YES □ NO
R2— Time Proximity	(1) HFE1 and HFE2 are performed close in time, ***OR*** (2) The cues for HFE1 and HFE2 are presented close in time.	□ YES □ NO
R3— Personnel	(1) HFE1 and HFE2 are performed by the same personnel.	□ YES □ NO
R4— Location	(1) HFE1 and HFE2 are performed at the same location, ***OR*** (2) The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation).	□ YES □ NO
R5— Procedure	(1) HFE1 and HFE2 use the same procedure.	□ YES □ NO

2.4 Step 2: Screening Analysis

The Screening Analysis is applicable when any of the following apply:

(1) There is not enough detailed information to assess the impact of dependency on every CFM and PIF of HFE2 using IDHEAS-ECA, ***OR***

(2) Only a quick, rough screening dependent HEP value is needed for the purpose of the HRA application, ***OR***

(3) The individual HEPs were calculated using another HRA method and cannot be recalculated with IDHEAS-ECA.

2.4.1 Basis for the Screening Analysis Process

The Screening Analysis process is based on the idea that dependency relationships between HFEs can result in one or more dependency factors, and 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 for the dependency factor being assessed, the dependency factor may be discounted. The discounted dependency factor is not considered for further analysis in the Screening Analysis process. If all of the dependency factors for all of the dependency relationships are discounted in the Screening Analysis, there is no impact on the HEP of HFE2 due to dependency using this process. However, that does not mean that the HFEs can be considered independent. The HFEs are still subject to the minimum joint HEP, if applicable. This guidance document does not address how to apply minimum joint HEPs.

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 Analysis process focuses on evaluating the more significant PIF attributes. The Screening Analysis process groups the impact of the most likely affected PIF attributes for each dependency factor into “Low,” “Medium,” and “High” categories according to their impacts on the HEP and assigns a corresponding dependency impact value, P_d. The dependency impact values are based on IDHEAS-ECA. Appendix B describes the process used to develop the dependency impact values.

2.4.2 Instructions for Performing the Screening Analysis

Step 2 is performed using Tables 2.1 through 2.5. There is one table for each of the five dependency relationships. The first column of each table lists the potential dependency factors associated with each dependency relationship. The dependency factors are denoted by capital letters. Each row in the first column is for a single dependency type (cognitive, consequential, or resource-sharing) and dependency relationship combination. The second (middle) column provides example justifications for discounting each dependency factor listed in the first column. The example justifications are labeled with letters corresponding to those used for the associated dependency factor in the first column. The third (last) column presents the impact of the dependency factors and example justifications for selecting a “Low,” “Medium,” or “High” dependency impact.

Table 3 summarizes the results that can be obtained using Tables 2.1 through 2.5, showing the dependency impact that each dependency type and dependency relationship combination can have on HFE2. Analysts may use Table 3 to review the assessment of the dependency factors chosen in the Screening Analysis to ensure they have not missed or double-counted any factors.

The Screening Analysis is performed as follows:

(1) For every dependency relationship assessed as YES in Table 1 as part of the Predetermination Analysis, assess all the potential dependency factors in the first column of the associated Table 2 for that dependency relationship. Each potential dependency factor is assessed individually.

> For example, if R1, Functions or Systems, was assessed as YES in Step 1, the analyst must evaluate all the potential dependency factors associated with R1 presented in Table 2.1. Three dependency type and dependency relationship combinations (R1.1–R1.3) are associated with R1 in Table 2.1. Each of the three dependency type and dependency relationship combinations has two potential dependency factors (A and B). The analyst would evaluate each potential dependency factor (A and B) listed under each dependency type and dependency relationship combination (R1.1–R1.3) in each row of Table 2.1, one at a time.

(2) For each dependency factor being assessed, review the description of a single potential dependency factor in the first column and the corresponding description of the ways that factor can be discounted in the second column. Determine whether it is appropriate to discount the dependency factor. The dependency factor can be discounted if any of the discounting factors associated with that dependency factor apply. The analyst may use additional justifications to discount the dependency factors. If the analyst does not have sufficient information to discount a dependency factor, the potential dependency factor remains undiscounted.

> For example, if the analyst is assessing dependency factor A for the functions or system relationship and cognitive dependency type combination (Table 2.1, row R1.1, factor A), the analyst would review the descriptions labeled A and A/B in the second column to determine whether they apply. If any of the discounting factors labeled A or A/B apply or the analyst has other justifications for why the dependency factor does not apply, dependency factor A for R1.1 can be discounted. The analyst then repeats the process for dependency factor B under R1.1. When assessing the applicability of dependency factor B, the analyst would review the descriptions labeled B and A/B in the second column.
>
> NOTE: When discounting dependency factors, the analyst must only consider the impact of occurrence of HFE1 (failure of the first human action) on the probability of occurrence of HFE2. The analyst must be careful not to count conditions that would have existed without occurrence of HFE1 as dependency impacts. A dependency factor should be discounted if the analyst does not expect the potential dependency factor would result in any changes in context for HFE2; therefore, HFE1 would not impact performance of HFE2.

(3) For every undiscounted dependency factor, use the example justifications in the last column to determine the dependency impact—Low, Medium, or High. The analyst can use additional justification to support their selection. The dependency impact values and example justifications presented in the third column are adapted from the IDHEAS-ECA PIF attributes that are affected by the applicable dependency factors. If the analyst does not have sufficient information to select the most likely dependency impact, the analyst should select "High" as the default dependency impact.

(4) Repeat steps 2 and 3 for each dependency factor that needs to be assessed.

(5) Calculate the 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:

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

<u>NOTE</u>: 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.

Table 2.1: Screening Analysis Guidance for the Functions or Systems Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.	□ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. □ 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. □ 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 the mental model associated with HFE2. □ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	This cognitive dependency affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 □ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** □ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 □ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** □ HFE1 creates a biased mental model or preference for wrong strategies. High: P_d = 3E-1 □ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (i.e., thought process).

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.2 Same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	□ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. □ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on information needed for HFE2. □ B—Personnel have firm information or multiple sources of information that are consistent. □ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	This consequential dependency potentially affects the PIFs for task complexity and information availability and reliability.
		Low: P_d = 1E-2 Task is relatively simple, and one or two of the following apply: □ Cues for detection are less obvious. □ Execution criteria become complicated or ambiguous. □ Potential outcome of the situation assessment becomes more complicated (e.g., multiple states and contexts, not a simple yes or no). □ Decisionmaking criteria become intermingled, ambiguous, or more difficult to assess.
		Medium: P_d = 5E-2 □ More than two items in “Low” are applicable.
		High: P_d =2E-1 One or more of the following apply: □ Cues are masked or must be inferred. □ Detection of the critical information is entirely based on personnel’s experience and knowledge. □ Execution of the critical task requires breaking away from trained scripts. □ HFE1 creates ambiguity associated with assessing the situation for performing HFE2. □ HFE1 creates competing or conflicting goals for decisionmaking of HFE2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.3 Same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	□ A—No shared or no shortage of tools or equipment. □ B—No shared or no shortage of resources. □ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	This resource-sharing dependency potentially affects the PIF for task complexity because the portion of resources HFE2 shares with HFE1, such as power in FLEX events, may be reduced due to HFE1.
		Low: P_d = 2E-3 □ Tool or resource shortage increases task difficulty, such as the following: – high spatial or temporal precision – precise coordination of multiple persons – unusual, unevenly balanced loads, reaching high parts – continuous control that requires dynamic manipulation
		Medium: P_d = 1E-2 □ Complicated or ambiguous execution criteria are present, such as the following: – multiple, coupled criteria – open to misinterpretation
		High: P_d = 5E-2 □ Action execution requires close coordination of personnel at different locations.

Table 2.2: Screening Analysis Guidance for the Time Proximity Dependency Relationship

<table>
<tr><th>Potential Dependency Factors</th><th>Basis for Discounting the Potential Dependency Factor</th><th>Dependency Impact</th></tr>
<tr>
<td>R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency

A. Occurrence of HFE1 reduces the time available or increases the time required for HFE2.</td>
<td>□ A—The ratio of time available to time required, T_a/T_r, for HFE2 is greater than 4; thus, plenty of time is available for HFE2, and dependency due to time proximity is negligible.

□ A—There is no change in the time available and time required for HFE2 due to HFE1.</td>
<td>Use the ratio of T_a to T_r for HFE2 and the chart below to estimate the dependency impact. T_a and T_r are point estimates.

<table>
<tr><th>T_a/T_r</th><th>Dependency Impact</th></tr>
<tr><td>< 1</td><td>1</td></tr>
<tr><td>≥ 1 and < 2</td><td>1E-1</td></tr>
<tr><td>≥ 2 and < 3</td><td>1E-2</td></tr>
<tr><td>≥ 3 and ≤ 4</td><td>1E-3</td></tr>
<tr><td>> 4</td><td>Negligible</td></tr>
</table>
</td>
</tr>
<tr>
<td>R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency

A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.</td>
<td>□ A—The cues for HFE1 and HFE2 do not occur close in time.

□ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitor the cues for HEF2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1).

□ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.</td>
<td>This consequential dependency potentially affects the PIF for task complexity by increasing the difficulty of detecting cues for HFE2.

Low: P_d = 5E-3
□ Detection of the cue demands switching between tasks or needs sustained attention over time.

Medium: P_d = 5E-2
□ Detection of the cue is not directed by alarms or procedures, and personnel need to continuously monitor or actively search for the cue.

High: P_d = 1E-1
□ The cue is masked such that initiating HFE2 is based on personnel’s experience and knowledge.</td>
</tr>
</table>

Table 2.3: Screening Analysis Guidance for the Personnel Dependency Relationship

<table>
<tr><th>Potential Dependency Factors</th><th>Basis for Discounting the Potential Dependency Factor</th><th>Dependency Impact</th></tr>
<tr><td rowspan="4">R3.1 Same personnel leads to cognitive dependency

A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1.

B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at the Three Mile Island nuclear plant (TMI), operators did not put water in because they did not think they needed water).</td><td rowspan="4">□ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since EOPs are symptom based and well trained upon, it is difficult to sustain a wrong mental model).

□ A—The HFEs are not performed by the same person.

□ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the STA can discount A/B if the STA would have reason to review the actions being taken).

□ A/B—Different procedures are used for HFE1 and HFE2.

□ B—Same personnel or crew does not perform diagnosis or decisionmaking for the HFEs.

□ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model).

□ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 AND additional people are available to detect the cues AND adequate time is available to detect the new cues.</td><td>This cognitive dependency potentially affects the PIFs for scenario familiarity, which address the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model.</td></tr>
<tr><td>Low: P_d = 5E-2
□ Parts of the scenario become unfamiliar (e.g., different from what was trained on), OR
□ HFE1 creates a biased mental model or preference for wrong strategies.</td></tr>
<tr><td>Medium: P_d = 1E-1
□ Parts of the scenario become unfamiliar (e.g., different from what was trained on), AND
□ HFE1 creates a biased mental model or preference for wrong strategies.</td></tr>
<tr><td>High: P_d = 3E-1
□ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links (i.e., thought process).</td></tr>
</table>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	□ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. □ B—HFE1 and HFE2 are not performed at the same time. □ 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 □ Mental fatigue increases due to sustained highly demanding cognitive activities, ***OR*** □ Time pressure increases due to perceived time urgency and task load. Medium: P_d = 1E-2 □ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** □ HFE2 does not require complicated diagnosis. High: P_d = 3E-2 □ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** □ HFE2 requires complicated diagnosis.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.3 Same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to SDPs (actual fitness for duty event) or fire events. B. Shared staff requires changes to the work practices for HFE2 (e.g., shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	□ A/B—Staffing is adequate, and good work practices are enforced. □ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but use of the severe accident management guidelines (SAMGs) or fire procedures may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) □ B—Minimum staffing is adequate to complete both tasks without changes to the work practices.	This resource-sharing dependency potentially affects the PIFs for staffing, teamwork and organization factors, and work practices. Work practices, such as peer checking, may change due to lack of adequate staffing. Low: P_d = 2E-3 □ Key staff needed for HFE2 are reduced or untimely due to HFE1, ***OR*** □ Teamwork factors are inadequate, such as knowledge gaps, distributed teams (personnel in multiple locations), dynamic teams (changing team members), or poor team cohesion. Medium: P_d = 1E-2 □ Self-checking or human performance tools (e.g., three-way communication) are not used as trained, ***OR*** □ Peer checking or supervision is ineffective. High: P_d = 5E-2 □ Work scheduling or prioritization is poor.

Table 2.4: Screening Analysis Guidance for the Location Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.1 Same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	□ A—HFE1 has no impact on the workplace.	This consequential dependency potentially affects the PIF for environmental factors.
		Low: P_d = 2E-3 □ HFE1 causes any one of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		Medium: P_d = 5E-3 □ HFE1 causes two or more of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		High: P_d = 2E-2 □ HFE1 significantly impairs the work environment for HFE2, such as by causing excessive heat and humidity, poor visibility, or unstable surface for executing the action.
R4.2 Same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	□ A—HFE1 and HFE2 are not performed at the same time. □ A—Actions can be performed without interference. □ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference).	This consequential dependency potentially affects the PIF for multitasking, interruptions, and distractions due to sharing the same location at the same time.
		Low: P_d = 2E-3 □ Personnel are distracted by the outcome of HFE1.
		Medium: P_d = 5E-3 □ Performance of HFE2 is interrupted by the outcome of HFE1.
		High: P_d = 7E-3 □ Performance of HFE2 is frequently or continuously interrupted by the outcome of HFE1.

Table 2.5: Screening Analysis Guidance for the Procedures Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R5.1 Same procedure leads to cognitive dependency A. Occurrence of HFE1 makes the procedure less applicable for use with HFE2 (i.e., the procedure becomes more confusing or does not match the situation well). For example, EOPs are generally well written because they are used often in training, but use of at-power EOPs at shutdown may be confusing because equipment is not in its normal configuration. Use of procedures during a fire or MCR abandonment situation may not apply as well as when at power. B. Occurrence of HFE1 makes personnel more likely to incorrectly interpret the procedure for use with HFE2 because they are using the same procedure.	□ A/B—Procedure is clear, not confusing, applicable to the situations, and well trained upon. □ A/B—Personnel are trained to use the procedure for the specific situations.	This cognitive dependency potentially affects the PIFs for procedures and guidance and for scenario familiarity due to the effect on personnel's mental model. Low: P_d = 5E-3 □ HFE1 makes the procedure more confusing for personnel to follow. Medium: P_d = 5E-2 □ HFE1 creates a misunderstanding of the situation such that personnel are likely to misinterpret the procedure, ***OR*** □ HFE1 causes unfamiliar elements in the scenario for performing HFE2. High: P_d = 3.5E-1 □ HFE1 creates a mismatched or wrong mental model for HFE2, ***OR*** □ HFE1 creates a bias or preference for wrong strategies, ***OR*** □ HFE1 makes the situation for performing HFE2 extremely rare, such that personnel have no existing mental model for the situation.

Table 3: Summary of the Potential Dependency Factors and 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 T_a/T_r			
		> 4 0.0	≥ 3 and ≤ 4 1E-3	≥ 2 and < 3 1E-2	≥ 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

2.5 Step 3: Detailed Analysis

The Detailed Analysis uses IDHEAS-ECA to calculate the dependent HEP of HFE2 based on how occurrence of HFE1 changes the context associated with performance of HFE2. The Detailed Analysis is applicable to HRA applications for which both of the following are true:

(1) The individual HEPs are calculated using IDHEAS-ECA, or the analyst has sufficient information to recreate the individual HEPs using IDHEAS-ECA, ***AND***

(2) The specific application requires dependent HEP values along with an explanation of what causes the increase in individual HEPs.

2.5.1 Basis for the Detailed Analysis

The Detailed Analysis is based on the IDHEAS dependency model. The IDHEAS dependency model assumes that the occurrence of HFE1 changes the context associated with HFE2 due to the dependency relationships that exist between the HFEs. Each dependency relationship that exists between the HFEs can result in one or more dependency factors. Each dependency factor potentially results in new PIFs and PIF attributes or worsening of the PIF attributes that were originally assessed for the individual HEP of HFE2. The dependent HEP of HFE2 is then calculated using the IDHEAS-ECA software by including the new PIFs and PIF attributes, or by changing the PIF attribute scales.

2.5.2 Instructions for Performing the Detailed Analysis

The Detailed Analysis may be performed after the applicable dependency relationships are determined in the Predetermination Analysis (Step 1), or it may be performed after the screening dependent HEP is determined in the Screening Analysis (Step 2). If the Detailed Analysis is performed after performing the Screening Analysis, the undiscounted dependency factors identified in the Screening Analysis can be used to inform the Detailed Analysis. The Detailed Analysis is performed using Tables 4.1 through 4.5. There is one table for each of the five dependency relationships. The first two columns of Tables 4.1 through 4.5 are the same potential dependency factors and discounting factors from Tables 2.1 through 2.5 for the Screening Analysis. The last column is specific to the Detailed Analysis and lists the CFMs, PIFs, and PIF attributes that can be impacted by the potential dependency factors.

The Detailed Analysis is performed as follows:

(1) If a Screening Analysis was performed, proceed to step 4 below.

(2) For every dependency relationship (R1–R5) assessed as YES in Table 1 as part of the Predetermination Analysis, assess all the potential dependency factors associated with that relationship in the first column of the respective Table 4.1 through 4.5. Each potential dependency factor is assessed individually.

> For example, if R1, Functions or Systems Dependency Relationship, was assessed as YES in Table 1, the analyst must evaluate all the potential dependency factors associated with R1 presented in Table 4.1. Three dependency type and dependency relationship combinations (R1.1–R1.3) are associated with R1 in Table 4.1. There are two potential dependency factors (A and B) for each of the three dependency type and dependency relationship

combinations. The analyst would evaluate each potential dependency factor (A and B) listed under each dependency type and relationship combination (R1.1–R1.3) in each row of Table 4.1, one at a time.

(3) For each potential dependency factor being assessed, review the description of a single potential dependency factor in the first column and the corresponding description of the ways that factor can be discounted in the second column. Determine whether it is appropriate to discount the dependency factor. The analyst may use additional justifications to discount the dependency factors. If the analyst does not have sufficient information to discount a dependency factor, the potential dependency factor remains undiscounted.

NOTE: When discounting dependency factors, the analyst must only consider the impact of occurrence of HFE1 (failure of the first human action) on the probability of occurrence of HFE2. The analyst must be careful not to count conditions that would have existed without occurrence of HFE1 as dependency impacts. A dependency factor should be discounted if the analyst does not expect the potential dependency factor would result in any changes in the context for HFE2; therefore, HFE1 would not impact performance of HFE2.

(4) For every undiscounted dependency factor, use the last column of the respective Table 4.1 through 4.5 to determine which CFMs, PIFs, and PIF attributes are most likely impacted by dependency. Dependency could impact other CFMs, PIFs, and PIF attributes.

NOTE: If the potential consequential dependency due to the time proximity dependency relationship (R2.1) remains undiscounted, the dependency impact on the HEP of HFE2 will be assessed using the IDHEAS-ECA software in step 6 below.

(5) Using the IDHEAS-ECA software, identify any new or changed CFMs, PIFs, and PIF attributes associated with HFE2 that could be impacted by occurrence of HFE1. If HFE2 has multiple critical tasks, review the CFMs for each critical task. If multiple CFMs are potentially impacted, review the PIFs and PIF attributes impacted for each CFM.

For example, the PIF for task complexity has different PIF attributes when it is assessed under the CFM for Detection than under the CFM for Understanding or Decisionmaking.

(6) If the time proximity dependency relationship (R2) is assessed as YES in Table 1 as part of the Predetermination Analysis, evaluate the impact of occurrence of HFE1 on the time available and time required to perform HFE2. If there is an impact, reestimate the probability distributions for the time available and time required.

(7) Enter any changes in CFMs, PIFs, PIF attributes, and time availability using the IDHEAS-ECA software and recalculate the HEP of HFE2. The outcome of the recalculation is the detailed dependent HEP of HFE2.

Table 4.1: Detailed Analysis Guidance for the Functions or Systems Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.	◻ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. ◻ 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. ◻ 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 the mental model associated with HFE2. ◻ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: ◻ SF1—Unpredictable dynamics in known scenarios ◻ SF2—Unfamiliar elements in the scenario ◻ SF3—Scenarios trained on but infrequently performed ◻ SF4—Bias or preference for wrong strategies exists, mismatched mental models

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.2 Same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	□ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. □ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on information needed for HFE2. □ B—Personnel have firm information or multiple sources of information that are consistent. □ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: INF—Information availability and reliability TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ INF1—Information is temporarily incomplete or not readily available □ INF2—Information is unreliable or uncertain □ C4—Detection criteria are highly complex □ C5—Cues for detection are not obvious □ C14—Potential outcome of the situation assessment consists of multiple states and contexts (not a simple yes or no) □ C15—Ambiguity associated with assessing the situation; key information for understanding is cognitively masked □ C16—Conflicting information, cues, or symptoms □ C23—Decision criteria are intermingled, ambiguous, or difficult to assess □ C24—Multiple goals difficult to prioritize (e.g., advantage for incorrect strategies) □ C25—Competing or conflicting goals (e.g., reluctance and viable alternative) □ C35—Long-lasting action, repeated discontinuous manual control (need to monitor parameters from time to time) □ C36—No immediacy to initiate execution; time span between annunciation (decision for execution made) and operation □ C37—Complicated or ambiguous execution criteria □ C39—Unlearn or break away from automaticity of trained action scripts

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.3 Same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	□ A—No shared or no shortage of tools or equipment. □ B—No shared or no shortage of resources. □ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	<u>Potentially affected CFMs</u>: Action Execution <u>Potentially impacted PIFs</u>: PD—Physical demands TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ PD2—High spatial or temporal precision □ PD3—Precise coordination of multiple persons □ PD4—Unusual, unevenly balanced loads (e.g., reaching high parts) □ C34—Continuous control that requires manipulating dynamically □ C37—Complicated or ambiguous execution criteria – multiple, coupled criteria – open to misinterpretation □ C38—Action execution requires close coordination of multiple personnel at different locations

Table 4.2: Detailed Analysis Guidance for the Time Proximity Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency A. Occurrence of HFE1 reduces the time available or increases the time required for HFE2.	□ A—The ratio of time available to time required, T_a/T_r, for HFE2 is greater than 4; thus, plenty of time is available for HFE2, and dependency due to time proximity is negligible. □ A—There is no change in the time available and time required for HFE2 due to HFE1.	Estimate the change in time available, T_a, and time required, T_r, for HFE2. Use the IDHEAS-ECA software to calculate the HEP due to time availability.
R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.	□ A—The cues for HFE1 and HFE2 do not occur close in time. □ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitor the cues for HEF2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1). □ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.	<u>Potentially affected CFMs</u>: Detection <u>Potentially impacted PIFs</u>: TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ C3—Detection demands high attention – need split attention – need sustained attention over time – need intermittent attention □ C5—Cues for detection are not obvious, detection is not directly cued by alarms or instructions, and personnel need to actively search for the information □ C6—No cue or mental model for detection, no rules/procedures/ alarms to cue the detection; detection of the critical information is entirely based on personnel's experience and knowledge

Table 4.3: Detailed Analysis Guidance for the Personnel Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.1 Same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at TMI, operators did not put water in because they did not think they needed water).	□ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since EOPs are symptom based and well trained upon, it is difficult to sustain a wrong mental model). □ A—The HFEs are not performed by the same person. □ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the STA can discount A/B if the STA would have reason to review the actions being taken). □ A/B—Different procedures are used for HFE1 and HFE2. □ B—Diagnosis or decisionmaking for the HFEs are not performed by the same personnel or crew. □ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). □ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND*** adequate time is available to detect the new cues.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ SF1—Unpredictable dynamics in known scenarios □ SF2—Unfamiliar elements in the scenario □ SF3—Scenarios trained on but infrequently performed □ SF4—Bias or preference for wrong strategies exists, mismatched mental models

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	□ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. □ B—HFE1 and HFE2 are not performed at the same time. □ B—Additional personnel are available to perform HFE2.	Potentially affected CFMs: All CFMs Potentially impacted PIFs: MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions PIF attributes that are most likely impacted by the dependency factor: □ MF1—Sustained (> 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) □ MF2—Time pressure due to perceived time urgency □ MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff) □ MT3—Concurrent visual detection and other tasks □ MT4—Concurrent auditory detection and other tasks □ MT5—Concurrent diagnosis and other tasks □ MT8—Concurrently executing action sequence and performing another attention/working memory task □ MT9—Concurrently executing intermingled or interdependent action plans

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.3 Same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to SDPs (actual fitness for duty event) or fire events. B. Shared staff requires changes to the work practices for HFE2 (e.g., shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	□ A/B—Staffing is adequate, and good work practices are enforced. □ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but SAMGs or fires may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) □ B—Minimum staffing is adequate to complete both tasks without changes to the work practices.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: WP—Work process TF—Team and organizational factors STA—Staffing <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ WP1—Lack of practice of self- or cross-verification (e.g., three-way communication) □ WP2—Lack of or ineffective peer checking/supervision □ WP3—Poor work prioritization, scheduling □ TF1—Inadequate team – inadequate teamwork resources (short of personnel, knowledge gaps) – distributed or dynamic teams – poor team cohesion (e.g., newly formed teams, lack of drills/experience together) □ STA1—Shortage of staffing (e.g., key personnel are reduced or temporarily missing, unavailable, or delayed in arrival; staff pulled away to perform other duties)

Table 4.4: Detailed Analysis Guidance for the Location Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.1 Same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	□ A—HFE1 has no impact on the workplace.	Potentially affected CFMs: Detection Action Execution Potentially impacted PIFs: ENV—Environmental factors PIF attributes that are most likely impacted by the dependency factor: □ ENV1—Coldness on action execution □ ENV2—Extreme coldness on action execution requiring high-precision manipulations (e.g., connecting lines to pump, removing air from lines and pumps) □ ENV3—Heat or high humidity □ ENV6—Very low visibility (e.g., heavy smoke or fog) for detecting targets or execution □ ENV9—Slippery surface (e.g., icing)
R4.2 Same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	□ A—HFE1 and HFE2 are not performed at the same time. □ A—Actions can be performed without interference. □ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference).	Potentially affected CFMs: All CFMs Potentially impacted PIFs: MT—Multitasking, interruptions, and distractions PIF attributes that are most likely impacted by the dependency factor: □ MT1—Distraction by other ongoing activities that demand attention □ MT2—Interruption taking away from the main task

Table 4.5: Detailed Analysis Guidance for the Procedures Dependency Relationship

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R5.1 Same procedure leads to cognitive dependency A. Occurrence of HFE1 makes the procedure less applicable for use with HFE2 (i.e., the procedure becomes more confusing or does not match the situation well). For example, EOPs are generally well written because they are used often in training, but use of at-power EOPs at shutdown may be confusing because equipment is not in its normal configuration. Use of procedures during a fire or MCR abandonment situation may not apply as well as when at power. B. Occurrence of HFE1 makes personnel more likely to incorrectly interpret the procedure for use with HFE2 because they are using the same procedure.	□ A/B—Procedure is clear, not confusing, applicable to the situations, and well trained upon. □ A/B—Personnel are trained to use the procedure for the specific situations.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: PG—Procedures, guidance, and instructions SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ PG4—Procedure is ambiguous, confusing □ PG5—Procedure is available but does not match the situation (e.g., needs deviation or adaptation) □ SF2—Unfamiliar elements in the scenario □ SF3—Extremely rarely performed; no existing mental model for the situation □ SF4—Bias or preference for wrong strategies exists, mismatched mental models

2.6 Summary

This chapter presents guidance for applying the IDHEAS dependency model to assess the dependency between two HFEs. The guidance includes three steps: Predetermination Analysis, Screening Analysis, and Detailed Analysis. This guidance provides the flexibility to accommodate different HRA methods and resource availability. The outcome of the Screening Analysis is a screening dependent HEP based on a quick assessment of potentially applicable dependency factors. The outcome of the Detailed Analysis is a detailed dependent HEP that identifies the specific CFMs, PIFs, and PIF attributes impacted by occurrence of the preceding HFE. Both the Screening Analysis and Detailed Analysis provide the dependent HEP of an HFE and identify the dependency relationships between the HFEs, dependency factors, and PIFs impacted by occurrence of the preceding HFE. The qualitative outcomes explain how dependency can affect the probability of an HFE and suggest the dependency effects that can be reduced by eliminating high-impact dependency factors.

3 REFERENCES

1. Xing, J., Y.J. Chang, and J. DeJesus, “The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G),” NUREG-2198, U.S. Nuclear Regulatory Commission, May 2021 (ADAMS Accession No. ML21127A272).

2. U.S. Nuclear Regulatory Commission, “Staff Requirements—Meeting with Advisory Committee on Reactor Safeguards, 2:30 P.M., Friday, October 20, 2006, Commissioners’ Conference Room, One White Flint North, Rockville, Maryland (Open to Public Attendance),” SRM M061020, November 8, 2006 (ADAMS Accession No. ML063120582).

3. Xing, J., J. Chang, and J. DeJesus, “Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA),” RIL 2020-02, U.S. Nuclear Regulatory Commission, January 2020 (ADAMS Accession No. ML20016A481).

APPENDIX A
IDHEAS DEPENDENCY ANALYSIS GUIDANCE WORKSHEETS

The Integrated Human Event Analysis System (IDHEAS) dependency analysis process has three steps: (1) Predetermination Analysis, (2) Screening Analysis, and (3) Detailed Analysis. The analyst performs each step using the guidance in Table 1, Tables 2.1 through 2.5, and Tables 4.1 through 4.5 in Chapter 2 of the main document, respectively.

Appendix A contains six worksheets. The first worksheet is a copy of Table 1 for performing the Predetermination Analysis. The remaining five worksheets combine the information from Tables 2.1 through 2.5 and Tables 4.1 through 4.5 for performing the Screening Analysis and Detailed Analysis:

- Worksheet A.0 is for the Predetermination Analysis.
- Worksheet A.1 is for Relationship R1—Functions or Systems.
- Worksheet A.2 is for Relationship R2—Time Proximity.
- Worksheet A.3 is for Relationship R3—Personnel.
- Worksheet A.4 is for Relationship R4—Location.
- Worksheet A.5 is for Relationship R5—Procedure.

Worksheet A.0 is used to assesses whether the two human failure events (HFEs) under analysis have complete dependency or whether one or more relationships exist between the HFEs. If no dependency relationships exist, the HFEs have no dependency and no further dependency analysis is needed. Any relationships that exist are further assessed for dependency in the Screening Analysis or Detailed Analysis.

Worksheets A.1 through A.5 combine the information from Tables 2.1 through 2.5 for the Screening Analysis with the information in Tables 4.1 through 4.5 for the Detailed Analysis. Each worksheet has four columns that contain the following information:

(1) The first column presents the potential dependency factors for each relationship and dependency type combination.

(2) The second column presents the basis for discounting each of the potential dependency factors.

(3) The third column is for assessing the dependency impact as part of the Screening Analysis.

(4) The fourth column is for assessing the potentially impacted cognitive failure modes (CFMs), performance influencing factors (PIFs), and PIF attributes in Research Information Letter 2020-02, “Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA),” issued February 2020, as part of the Detailed Analysis.

Worksheet A.0 (Table 1): Predetermination Analysis

Relationship	Assessment Guidelines	
Complete Dependency	(1) HFE1 and HFE2 use the same procedure, ***AND*** (2) HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), ***AND*** (3) There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2. Note: Opportunity for recovery may exist if there is adequate time to recover, ***AND*** steps are in the procedure to recover, ***AND*** additional personnel outside the crew, such a shift technical advisor (STA), are available to identify the need to recover.	□ YES □ NO
R1— Functions or Systems	(1) HFE1 and HFE2 have the same functions or systems, ***OR*** (2) HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed.	□ YES □ NO
R2— Time Proximity	(1) HFE1 and HFE2 are performed close in time, ***OR*** (2) The cues for HFE1 and HFE2 are presented close in time.	□ YES □ NO
R3— Personnel	(1) HFE1 and HFE2 are performed by the same personnel.	□ YES □ NO
R4— Location	(1) HFE1 and HFE2 are performed at the same location, ***OR*** (2) The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation).	□ YES □ NO
R5— Procedure	(1) HFE1 and HFE2 use the same procedure.	□ YES □ NO

Worksheet A.1 (Tables 2.1 and 4.1): Dependency Analysis Guidance for Dependency Relationship R1—Functions or Systems

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R1.1 Same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.	☐ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. ☐ 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. ☐ 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 the mental model associated with HFE2. ☐ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	This cognitive dependency potentially affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (i.e., thought process).	Potentially affected CFMs: All CFMs Potentially impacted PIFs: SF—Scenario familiarity PIF attributes that are most likely impacted by the dependency factor: ☐ SF1—Unpredictable dynamics in known scenarios ☐ SF2—Unfamiliar elements in the scenario ☐ SF3—Scenarios trained on but infrequently performed ☐ SF4—Bias or preference for wrong strategies exists, mismatched mental models

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R1.2 Same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	☐ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. ☐ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on information needed for HFE2. ☐ B—Personnel have firm information or multiple sources of information that are consistent. ☐ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	This consequential dependency potentially affects the PIFs for task complexity and information availability and reliability. Low: P_d = 1E-2 Task is relatively simple, and one or two of the following apply: ☐ Cues for detection are less obvious. ☐ Execution criteria become complicated or ambiguous. ☐ Potential outcome of the situation assessment becomes more complicated (e.g., multiple states and contexts, not a simple yes or no). ☐ Decisionmaking criteria become intermingled, ambiguous, or more difficult to assess. Medium: P_d = 5E-2 ☐ More than two items in “Low” are applicable. High: P_d =2E-1 One or more of the following apply: ☐ Cues are masked or must be inferred. ☐ Detection of the critical information is entirely based on personnel’s experience and knowledge. ☐ Execution of the critical task requires breaking away from trained scripts. ☐ HFE1 creates ambiguity associated with assessing the situation for performing HFE2. ☐ HFE1 creates competing or conflicting goals for decisionmaking of HFE2.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: INF—Information availability and reliability TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ INF1—Information is temporarily incomplete or not readily available ☐ INF2—Information is unreliable or uncertain ☐ C4—Detection criteria are highly complex ☐ C5—Cues for detection are not obvious ☐ C14—Potential outcome of the situation assessment consists of multiple states and contexts (not a simple yes or no) ☐ C15—Ambiguity associated with assessing the situation; key information for understanding is cognitively masked ☐ C16—Conflicting information, cues, or symptoms ☐ C23—Decision criteria are intermingled, ambiguous, or difficult to assess ☐ C24—Multiple goals difficult to prioritize (e.g., advantage for incorrect strategies) ☐ C25—Competing or conflicting goals (e.g., reluctance and viable alternative) ☐ C35—Long-lasting action, repeated discontinuous manual control (need to monitor parameters from time to time) ☐ C36—No immediacy to initiate execution; time span between annunciation (decision for execution made) and operation ☐ C37—Complicated or ambiguous execution criteria ☐ C39—Unlearn or break away from automaticity of trained action scripts

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R1.3 Same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	☐ A—No shared or no shortage of tools or equipment. ☐ B—No shared or no shortage of resources. ☐ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	This resource-sharing dependency potentially impacts the PIF for task complexity because the portion of resources HFE2 shares with HFE1, such as power in FLEX events, may be reduced due to HFE1.	Potentially affected CFMs: Action Execution Potentially impacted PIFs: PD—Physical demands TC—Task complexity PIF attributes that are most likely impacted by the dependency factor: ☐ PD2—High spatial or temporal precision ☐ PD3—Precise coordination of multiple persons ☐ PD4—Unusual, unevenly balanced loads (e.g., reaching high parts) ☐ C34—Continuous control that requires manipulating dynamically ☐ C37—Complicated or ambiguous execution criteria – multiple, coupled criteria – open to misinterpretation ☐ C38—Action execution requires close coordination of multiple personnel at different locations
		Low: P_d = 2E-3 ☐ Tool or resource shortage increases task difficulty, such as the following: – high spatial or temporal precision – precise coordination of multiple persons – unusual, unevenly balanced loads, reaching high parts – continuous control that requires dynamic manipulation	
		Medium: P_d = 1E-2 ☐ Complicated or ambiguous execution criteria are present, such as the following: – multiple, coupled criteria – open to misinterpretation	
		High: P_d = 5E-2 ☐ Action execution requires close coordination of personnel at different locations.	

Worksheet A.2 (Tables 2.2 and 4.2): Dependency Analysis Guidance for the Dependency Relationship R2—Time Proximity

<table>
<tr><th>Potential Dependency Factors</th><th>Basis for Discounting the Potential Dependency Factor</th><th>Screening Analysis Dependency Impact</th><th>Detailed Analysis Dependency Impact</th></tr>
<tr>
<td>R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency

A. Occurrence of HFE1 reduces the time available or increases the time required for HFE2.</td>
<td>□ A—The ratio of time available to time required, T_a/T_r, for HFE2 is greater than 4; thus, plenty of time is available for HFE2, and dependency due to time proximity is negligible.

□ A—There is no change in the time available and time required for HFE2 due to HFE1.</td>
<td>Use the ratio of T_a to T_r for HFE2 and the chart below to estimate the dependency impact. T_a and T_r are point estimates.

<table>
<tr><th>T_a/T_r</th><th>Dependency Impact</th></tr>
<tr><td>< 1</td><td>1</td></tr>
<tr><td>≥ 1 and < 2</td><td>1E-1</td></tr>
<tr><td>≥ 2 and < 3</td><td>1E-2</td></tr>
<tr><td>≥ 3 and ≤ 4</td><td>1E-3</td></tr>
<tr><td>> 4</td><td>Negligible</td></tr>
</table>
</td>
<td>Estimate the change in T_a and T_r for HFE2. Use the IDHEAS-ECA software to calculate the HEP due to time availability.</td>
</tr>
</table>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.	□ A—The cues for HFE1 and HFE2 do not occur close in time. □ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitor the cues for HEF2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1). □ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.	This consequential dependency potentially affects the PIF for task complexity by increasing the difficulty of detecting cues for HFE2. Low: P_d = 5E-3 □ Detection of the cue demands switching between tasks or needs sustained attention over time. Medium: P_d = 5E-2 □ Detection of the cue is not directed by alarms or procedures, and personnel need to continuously monitor or actively search for the cue. High: P_d = 1E-1 □ The cue is masked such that initiating HFE2 is based on personnel's experience and knowledge.	<u>Potentially affected CFMs</u>: Detection <u>Potentially impacted PIFs</u>: TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ C3—Detection demands high attention – need split attention – need sustained attention over time – need intermittent attention □ C5—Cues for detection are not obvious, detection is not directly cued by alarms or instructions, and personnel need to actively search for the information □ C6—No cue or mental model for detection, no rules/procedures/ alarms to cue the detection; detection of the critical information is entirely based on personnel's experience and knowledge

Worksheet A.3 (Tables 2.3 and 4.3): Dependency Analysis Guidance for Dependency Relationship R3 - Personnel

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R3.1 Same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at the Three Mile Island nuclear plant, operators did not put water in because they did not think they needed water).	☐ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since emergency operation procedures (EOPs) are symptom based and well trained upon, it is difficult to sustain a wrong mental model). ☐ A—The HFEs are not performed by the same person. ☐ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the shift technical advisor (STA) can discount A/B if the STA would have reason to review the actions being taken). ☐ A/B—Different procedures are used for HFE1 and HFE2. ☐ B—Diagnosis or decisionmaking for the HFEs are not performed by the same personnel or crew. ☐ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). ☐ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND*** adequate time is available to detect the new cues.	This cognitive dependency potentially affects the PIFs for scenario familiarity, which address the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links (i.e., thought process).	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ SF1—Unpredictable dynamics in known scenarios ☐ SF2—Unfamiliar elements in the scenario ☐ SF3—Scenarios trained on but infrequently performed ☐ SF4—Bias or preference for wrong strategies exists, mismatched mental models

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R3.2 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).	☐ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☐ B—HFE1 and HFE2 are not performed at the same time. ☐ 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 ☐ Mental fatigue increases due to sustained highly demanding cognitive activities, ***OR*** ☐ Time pressure increases due to perceived time urgency and task load. Medium: P_d = 1E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 does not require complicated diagnosis. High: P_d = 3E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 requires complicated diagnosis.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ MF1—Sustained (> 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) ☐ MF2—Time pressure due to perceived time urgency ☐ MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff) ☐ MT3—Concurrent visual detection and other tasks ☐ MT4—Concurrent auditory detection and other tasks ☐ MT5—Concurrent diagnosis and other tasks ☐ MT8—Concurrently executing action sequence and performing another attention/working memory task ☐ MT9—Concurrently executing intermingled or interdependent action plans

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R3.3 Same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to significance determination processes (actual fitness for duty event) or fire events. B. Shared staff requires changes to the work practices for HFE2 (e.g., shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	□ A/B—Staffing is adequate, and good work practices are enforced. □ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but use of the severe accident management guidelines or fire procedures may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) □ B—Minimum staffing is adequate to complete both tasks without changes to the work practices.	This resource-sharing dependency potentially affects the PIFs for staffing, teamwork and organizational factors, and work practices. Work practices, such as peer checking, may change due to lack of adequate staffing. Low: P_d = 2E-3 □ Key staff needed for HFE2 are reduced or untimely due to HFE1, ***OR*** □ Teamwork factors are inadequate, such as knowledge gaps, distributed teams (personnel in multiple locations), dynamic teams (changing team members), or poor team cohesion. Medium: P_d = 1E-2 □ Self-checking or human performance tools (e.g., three-way communication) are not used as trained, ***OR*** □ Peer checking or supervision is ineffective. High: P_d = 5E-2 □ Work scheduling or prioritization is poor.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: WP—Work process TF—Team and organizational factors STA—Staffing <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ WP1—Lack of practice of self- or cross-verification (e.g., three-way communication) □ WP2—Lack of or ineffective peer checking/supervision □ WP3—Poor work prioritization, scheduling □ TF1—Inadequate team – inadequate teamwork resources (short of personnel, knowledge gaps) – distributed or dynamic teams – poor team cohesion (e.g., newly formed teams, lack of drills/ experience together) □ STA1—Shortage of staffing (e.g., key personnel are reduced or temporarily missing, unavailable, or delayed in arrival; staff pulled away to perform other duties)

Worksheet A.4 (Tables 2.4 and 4.4): Dependency Analysis for Dependency Relationship R4—Location

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R4.1 Same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	□ A—HFE1 has no impact on the workplace.	This consequential dependency potentially affects the PIF for environmental factors. Low: P_d = 2E-3 □ HFE1 causes any one of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise. Medium: P_d = 5E-3 □ HFE1 causes two or more of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise. High: P_d = 2E-2 □ HFE1 significantly impairs the work environment for HFE2, such as by causing excessive heat and humidity, poor visibility, or unstable surface for executing the action.	Potentially affected CFMs: Detection Action Execution Potentially impacted PIFs: ENV—Environmental factors PIF attributes that are most likely impacted by the dependency factor: □ ENV1—Coldness on action execution □ ENV2—Extreme coldness on action execution requiring high-precision manipulations (e.g., connecting lines to pump, removing air from lines and pumps) □ ENV3—Heat or high humidity □ ENV6—Very low visibility (e.g., heavy smoke or fog) for detecting targets or execution □ ENV9—Slippery surface (e.g., icing)

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R4.2 Same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	□ A—HFE1 and HFE2 are not performed at the same time. □ A—Actions can be performed without interference. □ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference).	This consequential dependency potentially affects the PIF for multitasking, interruptions, and distractions due to sharing the same location at the same time. Low: P_d = 2E-3 □ Personnel are distracted by the outcome of HFE1. Medium: P_d = 5E-3 □ Performance of HFE2 is interrupted by the outcome of HFE1. High: P_d = 7E-3 □ Performance of HFE2 is frequently or continuously interrupted by the outcome of HFE1.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: MT—Multitasking, interruptions, and distractions <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ MT1—Distraction by other ongoing activities that demand attention □ MT2—Interruption taking away from the main task

Worksheet A.5 (Tables 2.5 and 4.5): Dependency Analysis for Dependency Relationship R5—Procedure

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact	Detailed Analysis Dependency Impact
R5.1 Same procedure leads to cognitive dependency A. Occurrence of HFE1 makes the procedure less applicable for use with HFE2 (i.e., the procedure becomes more confusing or does not match the situation well). For example, EOPs are generally well written because they are used often in training, but use of at-power EOPs at shutdown may be confusing because equipment is not in its normal configuration. Use of procedures during a fire or main control room abandonment situation may not apply as well as when at power. B. Occurrence of HFE1 makes personnel more likely to incorrectly interpret the procedure for use with HFE2 because they are using the same procedure.	□ A/B—Procedure is clear, not confusing, applicable to the situations, and well trained upon. □ A/B—Personnel are trained to use the procedure for the specific situations.	This cognitive dependency potentially affects the PIFs for procedures and guidance and for scenario familiarity due to the effect on personnel's mental model. Low: P_d = 5E-3 □ HFE1 makes the procedure more confusing for personnel to follow. Medium: P_d = 5E-2 □ HFE1 creates a misunderstanding of the situation such that personnel are likely to misinterpret the procedure, ***OR*** □ HFE1 causes unfamiliar elements in the scenario for performing HFE2. High: P_d = 3.5E-1 □ HFE1 creates a mismatched or wrong mental model for HFE2, ***OR*** □ HFE1 creates a bias or preference for wrong strategies, ***OR*** □ HFE1 makes the situation for performing HFE2 extremely rare, such that personnel have no existing mental model for the situation.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: PG—Procedures, guidance, and instructions SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: □ PG4—Procedure is ambiguous, confusing □ PG5—Procedure is available but does not match the situation (e.g., needs deviation or adaptation) □ SF2—Unfamiliar elements in the scenario □ SF3—Extremely rarely performed; no existing mental model for the situation □ SF4—Bias or preference for wrong strategies exists, mismatched mental models

APPENDIX B
TECHNICAL BASIS FOR THE SCREENING ANALYSIS

The Screening Analysis is applicable when not enough detailed information is available about the human failure event (HFE) under analysis (referred to as HFE2 in this document) to assess the impact of dependency on the cognitive failure modes and performance influencing factors (PIFs) of HFE2 using Research Information Letter (RIL) 2020-02, “Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA),” issued February 2020, or if the individual human error probabilities (HEPs) were calculated using another human reliability analysis (HRA) method and not enough detailed information is available to recalculate the individual HEPs using IDHEAS-ECA. In the Screening Analysis, the impact of a dependency factor on HFE2 is based on how occurrence of HFE1 (the HFE that occurs before HFE2) changes the event context for HFE2. A dependency factor potentially results in new cognitive failure modes (CFMs), 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 Analysis focuses on evaluating the more significant PIF attributes. The screening process groups the most likely affected PIF attributes for each dependency factor into “Low,” “Medium,” and “High” categories according to their impacts on HEPs and assigns a corresponding dependency impact value for each category. The dependency impact values are used to calculate the screening dependent HEP. The dependency impact values are based on IDHEAS-ECA. This appendix describes the process used to infer the dependency impact values from IDHEAS-ECA.

The authors of this report, referred to as the project team, inferred the screening dependent HEPs in two stages. In the first stage, the project team organized a working group consisting of eight experienced probabilistic risk assessment and HRA analysts from the U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute. The working group had multiple virtual workshops during which the analysts presented and discussed their experience applying the IDHEAS dependency model to six selected examples where dependency analysis was needed to complete an event analysis. The workshop discussions provided the participants with a thorough understanding of the dependency factors and their potential impacts on HFE context. Using the inputs from the workshops, the project team developed the draft dependency guidance. The draft guidance for the Screening Analysis listed PIF attributes that a dependency factor could potentially impact, grouped into “Low,” “Medium,” and “High” impact categories. The analysts applied the draft guidance to their example HFEs and worked with the project team to improve the draft guidance.

In the second stage, the project team inferred the dependency impact values from IDHEAS-ECA, following the principles in the NRC’s expert elicitation guidance “White Paper: Practical Insights and Lessons Learned on Implementing Expert Elicitation,” dated October 13, 2016.[1] The process is summarized below:

1 Xing, J., and S. Morrow, “White Paper: Practical Insights and Lessons Learned on Implementing Expert Elicitation,” U.S. Nuclear Regulatory Commission, October 13, 2016 (Agencywide Documents Access and Management System Accession No. ML16287A734).

(1) Prepare the data and information.

IDHEAS-ECA has two types of PIFs: base PIFs (scenario familiarity, information availability and reliability, and task complexity) and modification PIFs. A PIF has a set of attributes that each describe one way the HEP associated with the PIF can increase. The impacts on the base PIF attributes are represented by HEP values. The impacts on modification PIF attributes are represented by weighting factors. Appendix B to the IDHEAS-ECA report (RIL 2020-02) contains the base HEP values for each of the PIF attributes associated with the three base PIFs and the weighting factors for each of the PIF attributes associated with the modification PIFs. For each dependency factor in the Screening Analysis, the potentially affected PIF attributes and their base HEPs or weighting factors were used as the source data for inferring the dependency impact values.

(2) Infer the dependency impact values.

A dependency factor can affect multiple PIFs and PIF attributes. For each dependency factor, the project team generalized the associated PIF attributes into “Low,” “Medium,” and “High” impact categories. Then the team inferred the dependency impact values using the following considerations:

- The dependency impact values for “Low,” “Medium,” and “High” impact should cover the full range of the HEPs of all the potentially impacted PIF attributes.

- When calculating a HEP using IDHEAS-ECA, the total HEP is a combination of the HEP attributed to the CFMs (and associated PIFs and PIF attributes) and the HEP attributed to time availability. As such, the team used different processes to infer the dependency impact values associated with the HEP attributed to the CFMs and the HEP attributed to time availability.

- The descriptions of the “Low,” “Medium,” and “High” impact categories and the corresponding dependency impact values should be distinguishable from each other. IDHEAS-ECA represents the effect of a modification PIF attribute by modifying the HEP by a weighting factor. The weighting factor was defined as the human error rate caused by a PIF attribute divided by the human error rate when the PIF had no impact. IDHEAS-ECA calculates the HEP of an HFE as the base HEP multiplied by the sum of the applicable PIF attribute weighting factors. The project team members agreed that a base HEP value of 1E-3 would be used to convert a weighting factor to a dependency impact value. For example, if a PIF attribute has a weighting factor of 5, the corresponding dependency impact value would be 5E-3. The base HEP value of 1E-3 in IDHEAS-ECA corresponds to the following example situations:

  – a detection task that is moderately complex, such as having nonstraightforward criteria

  – a straightforward diagnosis with clear procedures or rules

  – simple decisionmaking with a straightforward choice

  – straightforward procedure execution with many steps

NOTE: Using a base HEP value of 1E-3 to convert PIF attribute weights to dependency impact values may result in underestimation of the dependency impact if HFE2 has a base HEP higher than the assumed base HEP value. However, since high base HEP values are for difficult human actions with challenging context, the dependency impact on such HFEs would more likely fall in the "Medium" or "High" impact categories. In these categories, the base PIFs often dominate the dependent HEPs. Thus, the potential underestimation can be subsided.

(3) Infer the dependency impact values attributed to CFMs.

The project team used the following process to infer the dependency impact values attributed to the CFMs into categories for "Low," "Medium," and "High" impact:

- The team discussed the definition of the dependency factor and potential impacts on the HFE context, then verified the list of the potentially affected PIF attributes.

- Each team member individually developed his or her own categorization of "Low," "Medium," and "High" impact as well as the associated dependency impact values.

- Each member took turns presenting his or her inferred dependency impact values along with the justification, followed by team discussion.

- The members reevaluated their individual inferences based on the team discussion and reached the final consensus on the categorization of the "Low," "Medium," and "High" impacts along with the dependency impact values.

(4) Infer the dependency impact values attributed to time availability.

For the Screening Analysis, the ratio of time available (T_a) to perform HFE2 and the time required (T_r) to perform HFE2 is used to estimate the impact of time proximity on dependency. The project team used the IDHEAS-ECA software to estimate the dependency impact values associated with various ratios of time available to time required.

In summary, the team used IDHEAS-ECA to infer the categorization of the dependency impacts and the associated dependency impact values. The screening process assumes that the HFE under analysis is relatively simple and straightforward. This may result in underestimating the dependency impact for complicated, highly challenging human actions. However, the underestimation can be subsided by properly evaluating and selecting the applicable dependency impact category.

APPENDIX C
EXAMPLE 1—APPLYING IDHEAS DEPENDENCY GUIDANCE FOR REACTIVITY CONTROL ISSUES DURING STARTUP

Plant Type: PWR (Westinghouse)

Operation Mode: Startup

Analysis Type: SDP

C.1 Event and Condition Description

This appendix describes an actual event. The operational narrative (Section C.1.1) and the event timeline (Section C.1.2) provide background and basis for the Significance Determination Process (SDP) analysis (Ref. 1). This appendix applies the method in Research Information Letter (RIL) 2020-02, "Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)," issued February 2020 (Ref. 2) to analyze the human actions in the SDP analysis and the guidance in the main body of this document to perform the dependency analysis.

C.1.1 Operational Narrative

On August 19, 2020, operators were conducting a reactor startup at a pressurized-water reactor (PWR) after experiencing a manual reactor trip on August 17, 2020. The operators performed procedure 3-GOP-301, "Hot Standby to Power Operation," and conducted a normal plant startup using control rods. The operating crew included a three-person reactivity team that consisted of a reactor operator at the controls (OATC), a peer checker, and one reactivity senior reactor operator (SRO). The reactivity team was responsible for managing reactivity during the startup. The crew also had a reactor operator (RO), with overall responsibility for plant operations, and a third RO, who provided administrative support (e.g., log keeping, plant announcements). A unit supervisor (US) was responsible for the overall plant activities, and a shift manager (SM) oversaw all crew activities. Also present during the startup was a reactor engineer, who supported the startup by plotting the Source Range Nuclear Instrument (SRNI) inverse count rate (1/M) plot, and a training department observer. Additionally, two assistant operations managers and the site vice president were present in the main control room observing the startup (Ref. 1). In total, 12 individuals were present in the main control room. Three of them were the reactivity team that performed the activities directly related to reactivity control for the startup. The others supported and monitored the startup and performed general activities.

After declaring the reactor critical at 1316 hours, the reactivity SRO gave the OATC the order to perform Step 5.21 of procedure 3-GOP-301 to "raise power to 10^{-8} amps and do not exceed a 1.0 decade per minute (dpm) startup rate (SUR)." However, the OATC did not announce to the rest of the reactivity team or crew his plan to carry out the step. The OATC intended to perform a continuous rod withdrawal of control rod group D until a 0.7 dpm SUR was achieved and stopped. His rationale for 0.7 dpm was that with a steady-state of 0.7 dpm SUR, the power would not double in less than a minute. Had the OATC announced his intentions, both the SM and US stated they would have recommended not taking that action and withdrawing rods in steps and establishing a lower SUR of 0.5 dpm.

The OATC withdrew control bank D for 45 seconds, which was 53 steps until rod motion was stopped when a valid source range (SR) Hi Flux Reactor Protection System (RPS) trip signal was generated, and the reactor automatically tripped. The SUR was greater than 1.0 dpm for the final 25 seconds of the 45 seconds rod pull and reached a maximum indicated value of 3.0 dpm, with an instantaneous SUR of 7.4 dpm at the time of the trip.

No member of the operating crew, nor any of the observers, recognized that the OATC had exceeded the SUR limits of the procedure, or that the plant was approaching an RPS trip threshold, and that the OATC was withdrawing rods continuously. Approximately 20 seconds before the trip, the SR Block Permissive (P-6) came in as expected, and the third RO had been directed to take the procedural actions to deenergize SR High Volts. The third RO announced the expected alarm and had only just opened the procedure before the trip. Note: The same operating crew must properly diagnose the condition using many of the same cues within a relatively short period of time. The large number of observers and operators on shift does make it more likely that someone would diagnose an Anticipated Transient Without Scram (ATWS) before power reached the power range and direct action to be taken.

C.1.2 Event Timeline

Table C-1: Event Timeline

Date/Time	Description **S**: System status or system automatic responses **I**: System or communicated information available to the operators **H**: Human responses **N**: Notes
8/19/2020 ~12:19	**(S)** Reactor startup commenced, SRNI N31 was reading 44 counts per second (cps) and SRNI N32 was reading 36 cps according to plant computer data as determined by the licensee's plant transition report **(S)** Plant startup procedure 3-GOP-301 recorded N31 as the highest reading SRNI at 60 cps for initial count rate in Attachment 1.
After 12:19 during second or third control rod bank withdrawal	**(H)** The reactor OATC on control rods and RO peer checker identified a disparity between N31 and N32 source count levels and discussed with the reactivity SRO and US. The SRO and US discussed the issue with the SM and concurred that SRNIs were trending similarly and were operable. The SM provided direction to the SRO, US, and ROs to continue to monitor SRNI behavior. No additional monitoring criteria were discussed.
12:53	**(S)** Mode 2 entered.
13:19	**(S)** The OATC declared the reactor critical with control rod bank D (CBD) at 83 steps.
~13:22	**(H)** The reactivity SRO directed the OATC not to exceed 1.0 dpm SUR and to raise power in the intermediate range (IR) to a level of 10^{-8} amperes (amps).
13:24:30	**(H)** The OATC initiated a continuous 53-step rod pull from CBD 83 to CBD 136. The OATC was still attempting to withdraw control rods at the time of the automatic reactor trip.
~13:24:47	**(S)** SR and IR SURs reached 0.7 dpm, which was the OATC's intended stop point.

Date/Time	Description **S**: System status or system automatic responses **I**: System or communicated information available to the operators **H**: Human responses **N**: Notes
~13:24:50	**(S, H)** The plant computer data showed 1.0 dpm source range (SR) SUR. OATC and all other operators and observers stated they never saw any SUR meters exceed 0.7 dpm, which was the OATC's intended control rod withdrawal.
~13:24:55	**(S)** The permissive (P-6) light was received. **(N)** The third RO had been directed to deenergize the SRNIs and was standing by to do so. **(H)** Continuous rod withdrawal was still in progress. **(N)** Operators may have been distracted by the P-6 light and evolution to deenergize the SRNIs.
13:25:19	**(S)** An automatic reactor trip was initiated on N31 SR high flux neutron cps at about 76,660 cps. N32 was reading 814 cps (from the plant transition report. Plant computer data indicated the SUR for N31, N35, and N36 was about 3 dpm. The N32 SUR was approximately 1.5 dpm. N31 was 89,421 cps and N32 was at 820 cps according to plant computer data.

The time-dpm plot shown in Figure C-1 reveals some human performance considerations in the event between when the OATC started the control rod withdrawal and the reactor trip (by the RPS):

- The duration is only about 50 seconds. It requires the crew to closely monitor the key parameters.

- The dpm exceeded the OATC's target value (0.7 dpm) at about the 17th second. However, the OATC was still attempting to withdraw control rods at the time of the automatic reactor trip. This indicates that neither the OATC nor any other individual in the main control room was monitoring the dpm shown on the plant computer.

- The OATC never informed the reactivity team of his startup intentions or which key plant parameters to monitor and at what point to stop withdrawing control rods. Thus, the operating crew did not have an opportunity to coach the OATC or to provide backup when the SUR exceeded the intended 0.7 dpm.

- The lit P-6 was expected and occurred at about the 25th second. That, in this event, could distract the operator's attention from the increase of reactivity.

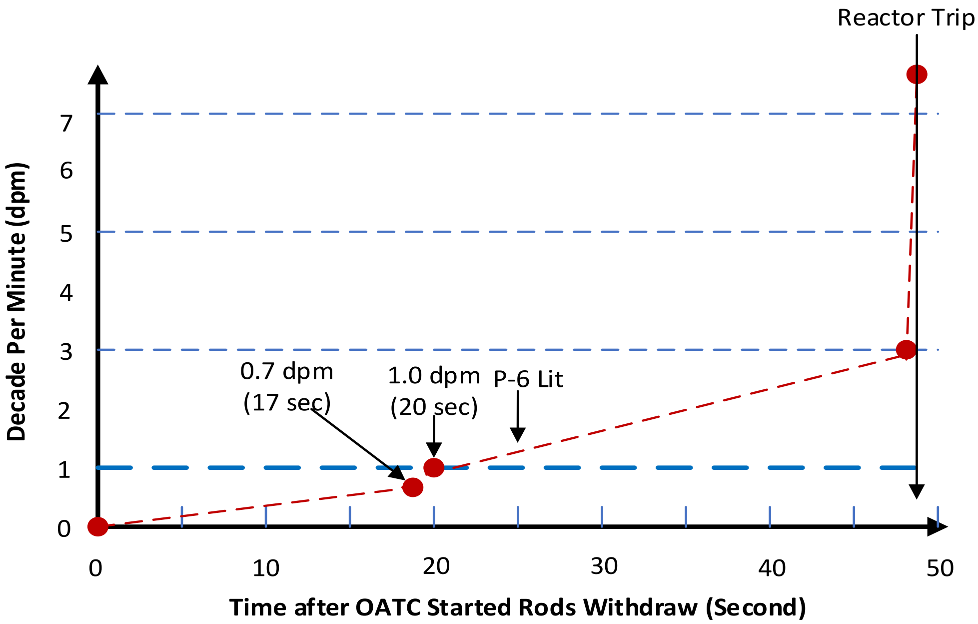


Figure C-3: Time-dpm Plot between Control Rod Withdrawal and Reactor Trip

C.1.3 Identify Human Failure Events

This section starts the human reliability analysis (HRA). Based on the actual event discussed in Sections 1.1 and 1.2, an ATWS event was most representative to calculate the risk associated with the actual event; thus, the SDP analysis assumes that the RPS failed to trip the reactor automatically. The SDP analysis further identified Sequence 17 of the ATWS event tree (shown in Figure C-2) of the U.S. Nuclear Regulatory Commission's standardized plant analysis risk (SPAR) probabilistic risk assessment (PRA) model as the event sequence of interest. The event sequence (Sequence 17) identified three human failure events (HFEs) of interest: manually back up the RPS to trip the reactor, manually trip the reactor, and emergency boration.

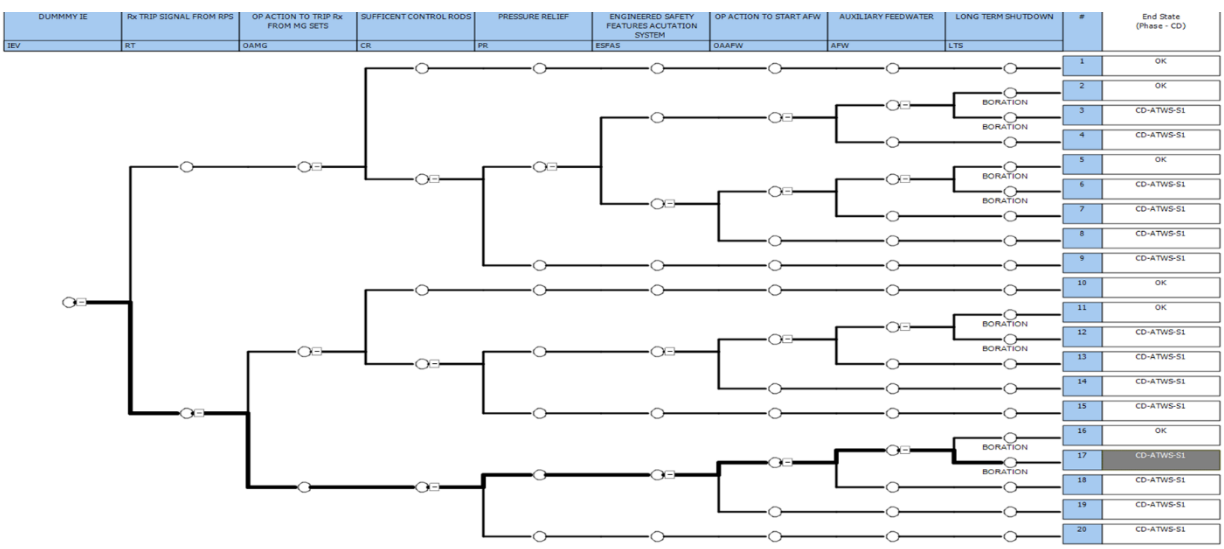


Figure C-4: The Event Sequence of the Analysis

C.1.4 Analysis Assumptions/Boundary Conditions

The assumptions of this analysis include the following:

- Since a reactor startup was in progress in accordance with 3-GOP-301, Revision 53, the following equipment was in service: both primary power-operated relief valves (PORVs) were in service and unblocked, and the motor-driven startup feedwater pump (a credited auxiliary feedwater (AFW) source) was in service and lined up to feed both steam generators. Therefore, the basic events PPR-MOV-FC-535, PORV 1 (PCV-456) BLOCK VALVE 535 CLOSED DURING POWER, and PPR-MOV-FC-536, PORV 2 (PCV-455A) BLOCK VALVE 536 CLOSED DURING POWER were set to FALSE since the valves were open, and AFW-XHE-XMSTART, OPERATOR FAILS TO START AFW GIVEN NO SIGNAL was set to FALSE since the AFW system was already in service.

- All rod motion was assumed to stop at the time the RPS actuation did or should have occurred. If the RPS failed and the operator continued to withdraw control rods, less time would be available, which could result in a higher human error probability (HEP).

- The RPS has three levels of protection for a continuous rod withdrawal casualty: SR high flux, IR high flux, and power range low range high flux trips. Both SR and IR trips only require one trip signal of two available channels to cause a scram.

- The recovery action for performing a manual backup of the RPS to trip the reactor would require operators to diagnose the condition. The milestone that the crew was looking for was 10^{-8} amp in the IR. It would be expected that this cue would cause the operator to stop shimming out and to shim rods in the control rods to level reactor power and draw attention to other plant parameters, including the SUR. Diagnosis of an ATWS should be clearly obvious and credited operator actions directed and taken (i.e., attempt to manually trip the reactor, initiate auxiliary feedwater, and initiate emergency boration). As additional cues become available, and with the crew size and number of observers present, the probability of diagnosing the condition increases. Recovery actions could still be performed from the control room and provide mitigation even if performed late. (Note: The quantitative review conservatively did not consider recovery.)

- In the actual event, the SR SUR indication for N32 was lagging N31, IR SUR channel N35, and IR SUR channel N36. This false indication could confuse operators. However, N32 SUR was less than 1.5 dpm at the time of the scram, compared to the 3.0 dpm shown on the other three indicators. The differences would help the operator to diagnose the problem.

- Unique elements of the SR continuous rod withdrawal in this analysis include no temperature moderation, more positive moderator temperature coefficient, Xenon not at equilibrium since less than 50 hours since the shutdown, the systems designed to mitigate an ATWS not in service (e.g., ATWS mitigation system actuation circuitry[1] and

[1] The ATWS mitigation system actuation circuitry is designed to meet the requirement in Title 10 of the *Code of Federal Regulations* 50.62(b), which states, "Each pressurized water reactor must have equipment from sensor output to final actuation device, that is diverse from the reactor trip system, to automatically initiate the auxiliary (or emergency) feedwater system and initiate a turbine trip under conditions indicative of an ATWS. This equipment must be designed to perform its function in a reliable manner and be independent (from sensor output to the final actuation device) from the existing reactor trip system."

engineered safety features actuation system), minimal decay heat loading, and the AFW system already in service for startup.

C.1.5 Identify Scenario Context

This section discusses the overall context applied to the scenario for analysis. This analysis incorporates the crew's performance and the component failures affecting scenario reliability from the actual event into the scenario context, the same as the practice for SDP analysis.

C.1.5.1 Environment and Situation Context

The environment and situation context includes the following factors: • Location accessibility and habitability • Workplace visibility • Noise in workplace and communication pathways • Cold/heat/humidity • Resistance to physical movement

All actions were performed in the main control room. No perceived environmental factors affected crew performance.

C.1.5.2 System Context

System context includes the following factors: • System and instrumentation and control transparency to personnel • Human-system interfaces • Equipment and tools

The senior operators knew that N32 was lagging behind N31 but still decided to proceed with the startup. In addition, 3-GOP-301 directed reactor engineers to collect and calculate inverse count rate data using a single designated SRNI. The reactor engineer used N32. The senior operators misunderstood that the reactor engineer used both N31 and N32 to calculate the inverse count rate. In the actual event, N31 tripped the reactor with an SR high flux neutron cps at about 76,660 cps, while N32's reading was only 814 cps at the time of reactor trip. Besides N32, all the other human-system interfaces were normal. No information transparency issue existed and no special equipment or tools were needed.

C.1.5.3 Personnel Context

Personnel context includes the following factors: • Staffing • Procedures, guidelines, and instructions • Training • Teamwork and organizational factors • Work processes

There were no issues associated with staffing. However, issues exist related to procedures, training, teamwork and organization, and work processes.

<u>Staffing</u>: Staffing was sufficient to perform the required tasks. The plant staff in the main control room included the following:

- a three-person reactivity team, including the OATC, a peer checker, and one reactivity SRO, who were responsible for managing reactivity during the startup
- an RO, who was responsible for plant general operation
- a third RO, who provided administrative support (e.g., log keeping, plant announcements)
- a US, who was responsible for overall plant activities
- an SM, who oversaw all crew activities
- a reactor engineer, who supported the startup by plotting the SRNI inverse count rate (1/M)
- a training department observer
- two assistant operations managers and the site vice president, who observed the startup

Procedures: The revised procedure 3-GOP-301 directed reactor engineers to collect and calculate inverse count rate data using a single designated SRNI instead of two SRNIs as called for in the previous version of the procedure.

The following descriptions based on the inspection report indicate issues with teamwork (TF), training and experience (TE), and work practices (WP):

- The crew and observers present failed to diagnose the condition before the scram; this issue was not limited to one operator. The same crew would have to diagnose and take required operator actions as plant conditions changed. Groupthink was observed in this organization with respect to the operability of the SRNI N32 the following day, so it cannot be ruled out here. However, the numerous additional cues that would present themselves as the event progressed (power entering the intermediate and power ranges, PORVs lifting, steaming to the condenser, and AFW flows increasing) would likely break the dependency, particularly later in the event, given the number of crew and observers present. (Note: This factor was represented in the SPAR model through the HEP adjustments considering dependency.)

- Related to command and control, the Onsite Review Group (ORG) members did not understand that the current revision of procedure 3-GOP-301 directed reactor engineers to collect and calculate inverse count rate data using a single designated SRNI. Those members assumed the reactor startup was compared to inverse count rate data using both SRNIs. Unaware that the procedure used only a single SRNI to calculate the inverse count rate, the ORG decided to restart the plant with an inoperable SRNI.

- Related to training and command and control, two of the three members of the reactivity team and the Unit Supervisor had never conducted a reactor startup using control rods rather than boron dilution to establish a steady-state SUR less than 1.0 dpm and then leveling at 10^{-8} amp in the IR. It was known that this was the first startup for the reactivity SRO since he had recently qualified, but it was not recognized that neither the OATC (a qualified RO for 8 years) nor the Unit Supervisor had ever performed this evolution in the plant. The SM thought he had paired an experienced RO with an inexperienced SRO.

- Related to training and work practices, the OATC never informed the reactivity team of his startup intentions or which key plant parameters to monitor and at what point to stop withdrawing control rods. Thus, the operating crew did not have an opportunity to coach the OATC or to provide backup when the SUR exceeded the intended 0.7 dpm. Also, operators did not follow fundamental principles to ensure they understood the expected plant response for actions (i.e., take actions, observe plant response, and stop if the expected plant response was not achieved). The OATC did not know how much rod motion was needed to establish a steady 0.7 dpm SUR and did not recognize that not "seeing" a 0.7 dpm for such an extended rod withdrawal was an abnormal system response.

- Required just-in-time training was conducted for the startup crew the afternoon before the startup. All members of the crew attended, with the exception of the RO and the reactor engineer. A tabletop walkthrough of the startup procedure was performed, emphasizing three-way communications. However, simulator training was only performed for the turbine synchronization to the grid and not the startup and power ascension. The training crew was also unaware that the OATC had never performed this evolution in the plant.

- Procedure 3-GOP-301, "Hot Standby to Power Operation," Revision 53, Step 5.21, required operators to establish a steady-state SUR of 1.0 dpm or less while raising power to and stabilizing at 10^{-8} amp on intermediate-range nuclear instruments (IRNIs). In addition, "Precautions and Limitations," Step 4.14, stated the SUR should not be permitted to exceed a steady-state value of 1.0 dpm below the Point of Adding Heat (POAH). Contrary to the procedure, operators failed to follow Step 5.21 and continuously withdrew control bank D from 83 steps to 136 steps over a 45-second period, resulting in a SUR in excess of 1.0 dpm for approximately the last 25 seconds of the rod pull on both IRNI and SRNI reaching a maximum displayed value of 3.0 dpm. This action added excessive reactivity, which resulted in an automatic reactor trip on SR high flux of 10^5 cps.

- In Procedure 3-GOP-301, the caution statement before Step 5.16.3 stated, "Excessive boration/dilution rates and rod motion shall be avoided." Additionally, the caution statement in procedure OP-AA-103-1000, "Reactivity Management," Revision 13, Section 3.7, stated, "Inadequate reactivity control has the potential to cause core damage. As a result, licensed operators are responsible for conservative, deliberate reactivity control, in accordance with approved procedures, to prevent challenging the integrity of the fuel cladding or the RCS pressure boundary." Contrary to the procedure, the operating crew failed to adequately control reactivity additions, and the OATC performed an excessive continuous rod withdrawal of 53 steps for 45 seconds, which resulted in a SUR greater than 3 dpm and a SR high flux RPS trip. This was a reactivity addition of 270 percent mille (pcm), which was 130 pcm in excess of that necessary to achieve a 1.0 dpm SUR.

- Procedure OP-AA-100-1000, "Conduct of Operations," Revision 25, Attachment 5, Section 3.2, stated the OATC was responsible for monitoring for the effects of primary reactivity manipulations on the unit (control rods, boration, dilution, and turbine control system adjustments). Contrary to the procedure, the OATC did not adequately monitor key reactor parameters for the effects of continuously withdrawing the control rods while raising power to 10^{-8} amp. Specifically, the OATC did not recognize plant response (SRNIs, IRNIs, and associated SURs) was not as expected and outside procedural limits and did not appropriately stop withdrawing control rods. The OATC was attempting to withdraw control rods when the RPS actuation occurred.

- Procedure OP-AA-100-1000, "Conduct of Operations," Revision 25, Attachment 4, Section 3.3, stated that the command and control SRO, or Unit Supervisor, was expected to stay in a position of oversight for all control room activities, remain fully involved, and assert authority when standards were not being maintained. Contrary to the procedure, the Unit Supervisor did not assert authority to ensure the OATC withdrawing the control rods maintained a SUR less than 1.0 dpm. Specifically, no communications were conducted to understand how the OATC intended to withdraw control rods, and the US did not ensure how the reactivity team (reactivity SRO, OATC, and RO peer checker) intended to adequately monitor key parameters during the power increase to 10^{-8} amp.

- Procedure OP-AA-100-1000, "Conduct of Operations," Rev. 25, Attachment 4, Section 3.1, stated that licensed operators were responsible for complying with the conditions of their license and intervening in system or component operation as necessary. Contrary to the procedure, the reactivity SRO, OATC peer checker, US, RO, administrative third RO, and SM each had an opportunity to recognize and respond to the following conditions:

  – The OATC was continuously withdrawing control rods for 45 seconds.

  – Key plant parameters, which were clearly displayed in the control room, were greater than procedural limits and rapidly approaching the RPS trip limit.

- Procedure OP-AA-103-1000, Revision 13, stated that no significant discrepancies exist between reactor power level indicators and indirect power indications such as turbine first-stage pressure. If significant discrepancies exist, power ascension shall cease until the situation is investigated. Approval of the operations director/manager was required to resume power ascension. Contrary to the procedure, reactor startup was continued with a deviation between SRNI channels N31 and N32 with an increasing magnitude as the startup progressed. The OATC and his peer checker identified the deviation as a concern to the reactivity SRO, who then discussed the concern with the US and SM. The SROs determined the current deviation to be acceptable and directed the OATC and his peer checker to continue the startup and monitor N32.

C.1.5.4 Task Context

Task context includes the following factors:
• Information availability and reliability • Scenario familiarity • Multi-tasking, interruptions and distractions • Task complexity • Mental fatigue • Time pressure and stress • Physical demands

An information reliability issue in the event was that the indicator SRNI N32 that the operator relied on for reactivity control provided a misleading indication. The licensee conducted a reactor startup and entered Mode 2 with SRNI N32 and its associated SR high flux RPS trip channel inoperable. Before the reactivity reached critical during the startup, it was noted that SRNI channels N31 and N32 were deviating by approximately 1.0 decade. As the startup progressed, this deviation continued to increase. During the continuous rod withdrawal, plant computer data showed that SRNI N32 SUR was also lagging the other three SUR indications (i.e., IRNI channels N35 and N36 and SRNI N31). At the time of the trip, SUR was 3.0 dpm on three channels and 1.5 dpm on SRNI N32. It was possible that some operators may have been confused by this or focused on this incorrect indication. The ORG members did not understand that the current revision of procedure 3-GOP-301, "Hot Standby to Power Operation," directed reactor engineers to collect and calculate inverse count rate data using a single designated SRNI, instead of two SRNIs as specified in the previous version of the procedure. The reactor engineer used N32 to calculate the single count rate.

C.2 Analyzing Human Failure Events

This analysis includes three HFEs. HFE1 is to manually backup the RPS in responding to an RPS signal that did not cause an automatic reactor trip. HFE2 is to shim in the control rod in responding to the IR reaching 10^{-8} amp. HFE3 is performing an emergency boration in responding to the pressurizer power-operated relief valves (PORVs) open after neither HFE1 nor HFE2 has been performed. The cues to perform HFE1 and HFE2 occurred almost simultaneously. PZR PORV open, the cue to performing an emergency boration, occurred a few minutes after the RPS signal occurred. Figure C-3 shows a timeline of an HFE for the discussion.

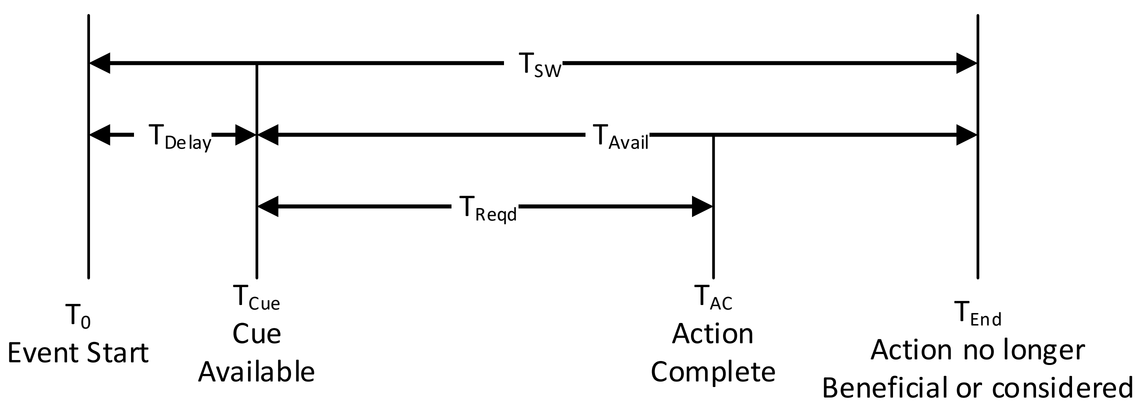


Figure C-5: Event Timeline Diagram

Where,

T_{SW}: System time window. The beginning to the end of the time window of an HFE.

T_{Delay}: The time from the event occurring to the time that the cue related to the event was available to the crew.

T_{Avail}: The time available for the crew to respond.

T_{Reqd}: The time required (or needed) for the crew to respond to the event, including diagnosis and actions.

T_0: The beginning of T_{SW}. Usually, the time when the event occurred. Reactor trip is a common point for T_0 in many PRAs.

T_{Cue}: The time the cue become available to the crew

T_{AC}: The time the required mitigation action is complete.

T_{End}: The time when crew actions (the HFE of analysis) are no longer beneficial or no longer considered. “No longer beneficial” means that if the action is not completed by T_{End}, the HFE is assumed to have failed. “No longer considered” means that if the decision to perform the action has not been made by T_{End}, the operator would no longer consider implementing the action. Therefore, the HFE is assumed to have failed.

C.2.1 HFE1—Manually Backup Reactor Protection System (RPS-XHE-XE-SIGN)

C.2.1.1 Define Human Failure Event

HFE1 starts at the reactivity reaching the RPS setpoint, but the reactor fails to trip automatically. The RPS fails to trip the reactor automatically under four different conditions, as shown in Figure C-4. The four situations are divided into two categories: with and without the presence of an RPS signal. The category of without an RPS signal is assumed to have an HEP of 1.0 (certainly fail) because the ATWS initiating event is initiated by the operator excessively withdrawing the control rod. Without an RPS signal, the operator would not notice the reactivity has exceeded the RPS setpoint. As a result, the HEP of RPS-XHE-XE-NSIGNL (operators manually trip reactor with RPS failure and no RPS signal present) was equal to one.

RPS-XHE-XE-SIGN (operators manually trip the reactor with RPS failure and RPS signal present) has the RPS signal to alert the operator. In this analysis, RPS-XHE-XE-SIGN represents HFE1. The condition of performing RPS-XHE-XE-SIGN is that after excessively withdrawing the control rod, the rod triggered the RPS signal, but the control rods failed to insert into the core automatically. The reactivity team would need to detect the RPS signal, evaluate that the RPS signal is valid, and decide on and then perform the RPS backup actions to trip the reactor. An RPS signal is expected to accompany an automatic reactor trip. When there is no automatic reactor trip, the operators would evaluate whether the RPS signal is valid.

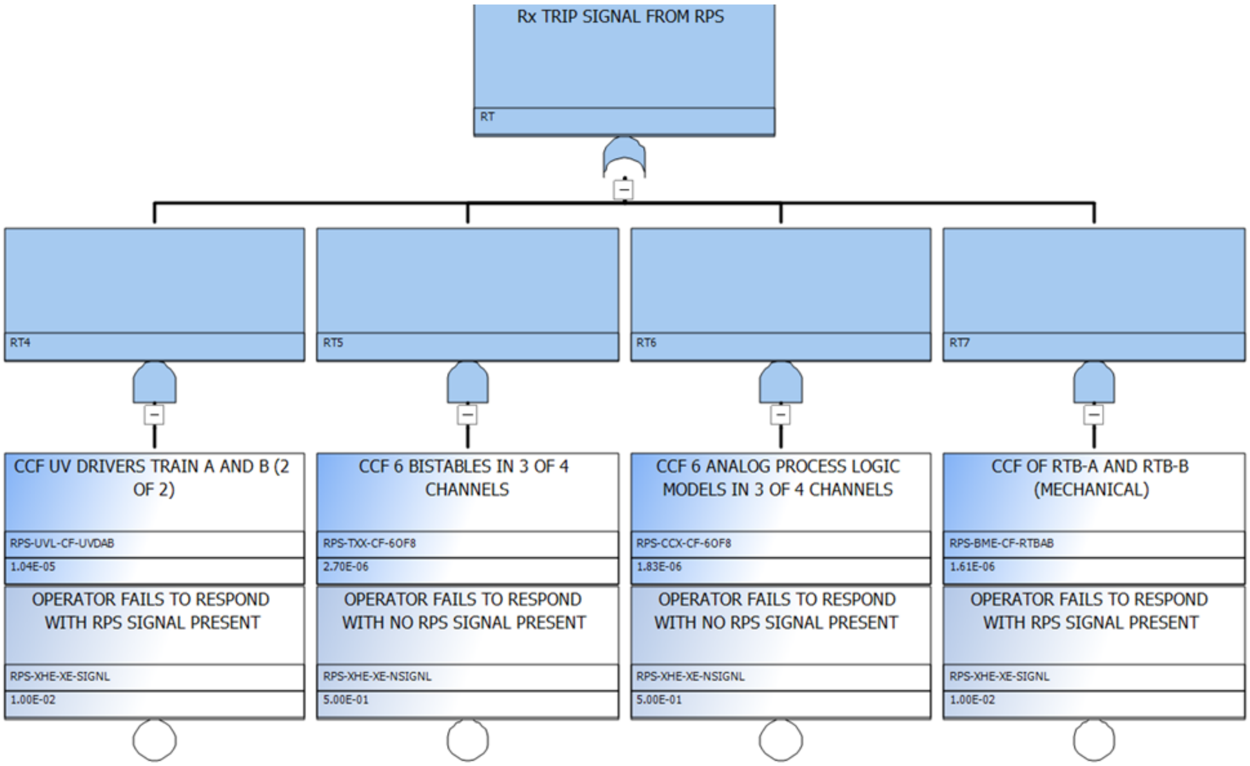


Figure C-6: The Fault Tree to Manually Backup the RPS

<u>Analysis Timeline</u>

The following summarizes the key parameters that characterize HFE1:

- T_0: The RPS signal triggered (but did not trip the reactor automatically).
- T_{Cue}: The time the RPS signal occurred.
- T_{AC}: The OATC manually trips the reactor.
- T_{End}: The time that PZR PORVs lifted open, which is a cue to another human action. If the operator has not decided to trip the reactor before T_{End}, this analysis assumed that the operator would not trip the reactor afterward (i.e., the action is no longer considered).
- T_{SW}: 3 minutes, from T_0 (RPS signal) to T_{end} (PZR PORVs open).
- T_{Delay}: There is no time delay because the cue (RPS signal) and the event (exceeded RPS setpoint) occurred almost at the same time.
- T_{Avail}: 3 minutes, same as T_{SW}.
- T_{Reqd}: 1 minute. In this analysis, T_{Reqd} is defined as the time that the operator needs to decide to trip the reactor before PZR PORVs open. The time to diagnose the RPS signal to trip the reactor manually is estimated as 1 minute. Once the operator decides to trip the reactor before PZR PORVs open, this analysis assumes that the operator will

manually trip the reactor regardless of changes in plant status (e.g., PZR PORVs' statuses).

Error Recovery Opportunities

No error recovery is credited because of the short amount of time available for this HFE.

C.2.1.2 Task Analysis and Critical Task Identification

The reliability of RPS-XHE-XE-SIGN is modeled by a time-critical task that requires performing all five macrocognitive functions. The Detection function is to detect the RPS signal. The Understanding function is to understand that an ATWS event is ongoing (i.e., the RPS signal is valid). The Decisionmaking function is to decide to trip the reactor immediately. In this analysis, the reactivity team was inexperienced in the startup of the reactor. When encountering the situation in which the RPS failed to trip the reactor automatically, it is suspected that the OACT would seek input on the response action instead of tripping the reactor right away. The Action Execution function is to trip the reactor manually. The Interteam function is the coordination between the reactivity team and the operating team. Since all five macrocognitive functions are performed for this critical task, all five CFMs must be evaluated for this critical task.

All the activities occur in the main control room. Manually tripping the reactor in this situation is an immediate action on which personnel are frequently trained. A challenge is to diagnose that the RPS signal is valid. Human reliability is affected by the crew's lack of awareness of plant status, as discussed in Section C.1.5 with respect to scenario context, and the justifications to the performance influencing factor (PIF) attributes as discussed in Section C.2.1.3.

C.2.1.3 Estimate Human Error Probability

HEP(RPS-XHE-XE-SIGN) = 9.26E-02
P_c = 9.11E-02
P_t = 1.6E-03

C.2.1.3.1 Calculate P_c

HEP(Detection, with recovery): 4.02E-03
Task: Detect the RPS signal is ON

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: The reactivity team did not question or back up the OATC. The US and SM did not back up or question the reactivity addition team. The reactor engineer was not involved in the N32 operability issue.

- Staffing: STA4: Inappropriate staff assignment

  Justification: The OATC, reactivity SRO, and US had never performed this evolution on the plant.

- Training and Experience: TE5: The operator is inexperienced

  Justification: The reactivity SRO recently qualified for the first startup. The OATC and US had never actually performed this evolution on the plant before. The just-in-time training did not cover this step in the procedure because the experience gap was not recognized.

- Training and Experience: TE7: Inadequate training or experience with sources of information

  Justification: The OATC, reactivity SRO, and US were qualified but not experienced for this type of startup.

- Team Factors: TF2: Poor command and control

  Justification: The OATC never communicated his plan to perform the step in the startup procedure. The order to do the step was clearly communicated. None of the qualified operators or observers ever questioned the OATC actions.

- Work Practices: WF2: Lack of or ineffective peer-checking or supervision

  Justification: The SRO, OATC peer checker, US, and SM failed to provide any meaningful supervision during the step.

- Work Practices: WF5: Lack of or ineffective instrumentation for safety issue monitoring and identification

  Justification: N32 SR power level indication and N32 SUR meters were lagging and, in fact, inoperable. This placed a confusing and ineffective meter in the middle of the key parameters being monitored. It is likely a number of the crew members locked onto these confusing indications.

- Multitasking, Interruption, and Distraction: MT1: Distraction by other ongoing activities that demand attention

  PIF Attribute (1–10): 5

  Justification: The P-6 interlock and deenergizing SR high volts alarm and procedural steps came in about 20 seconds before the scram and diverted much of the crew’s attention to that activity and indication.

- Multitasking, Interruption, and Distraction: MT4: Concurrent auditory detection and other tasks

  PIF Attribute (1–10): 5

  Justification: The control rod withdrawal audio signal and SR counts audio indications overlapped and may have reduced sensitivity to the sound of rods being withdrawn continuously for 50 seconds.

HEP(Understanding, with recovery): 4.42E-02
Task: Understand an ATWS event is ongoing
Recovery Factor(Understanding): 1

- Scenario Familiarity: SF4: Bias or preference for wrong strategies exists, mismatched mental models

Justification: The entire operating crew was in the improper mindset and was not critically evaluating key reactivity plant parameters. The crew accepted and possibly relied upon invalid and confusing indications, which may lead to questioning the validity of subsequent cues and not taking action.

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: See the justification in Detection.

- STA4: Inappropriate staff assignment

  Justification: See the justification in Detection.

- Team Factors: TF2: Poor command and control

  Justification: See the justification in Detection.

HEP(Decisionmaking, with recovery): 4.42E-02
Task: Decide to immediately trip the reactor manually
Recovery Factor(Decisionmaking): 1

- Scenario Familiarity: SF4: Bias or preference for wrong strategies exists, mismatched mental models

  Justification: The entire operating crew was in the improper mindset and was not critically evaluating key reactivity plant parameters. The crew accepted and possibly relied upon confusing indications, which may lead to questioning the validity of subsequent cues and not taking action.

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: See the justification in Detection.

- Staffing: STA4: Inappropriate staff assignment

  Justification: See the justification in Detection.

- Team Factors: TF2: Poor command and control

  Justification: See the justification in Detection.

HEP(Action Execution, with recovery): 1.00E-04
Task: Manually trip the reactor
Recovery Factor(Action Execution): 1

Manually tripping the reactor is a simple action performed inside the main control room. There is no PIF affecting operator reliability. The lowest Action Execution basic HEP of 0.0001 should be applied.

HEP(Interteam, with recovery): 1.00E-03
Task: Coordinate between the reactivity team and operating team on the decision to manually trip the reactor
Recovery Factor(Interteam): 1

The reactivity team and the operating team were in the main control room. There is no PIF affecting Interteam coordination. The lowest Interteam basic HEP of 0.001 should be applied.

C.2.1.3.2 Calculate P_t

The uncertainty distributions of the time required and time available are modeled using the normal distribution. The mean and 95th percentile for the time required is 1 and 1.5 minutes, respectively, and 3 and 4 minutes, respectively, for the time available. The calculated P_t is 1.6E-03.

Time Required Distribution Type: Normal Distribution Mean = 1 minute 95th Percentile = 1.5 minutes	Time Available Distribution Type: Normal Distribution Mean = 3 minutes 95th Percentile = 4 minutes

C.2.1.4 Uncertainty Analysis

The time available in the analysis is the time of the PZR PORV opening. The time should be estimated by a thermal-hydraulic analysis. Without performing a detailed thermal-hydraulic analysis, the time available distribution used in the analysis could have significant effects on HEP. In this analysis, P_c and P_t (9E-2 and 7E-2, respectively) have about equal contributions to the total HEP. Instead of the estimated 3 and 4 minutes for the mean and 95th percentile of time available, using 5 and 7 minutes for the mean and 95th percentile would result in a P_t of 1.7E-3. That is a factor of 4 reduction in P_t.

This analysis assumes that the PZR PORV opening is the end of the time window. In reality, the PZR PORV opening could be a redundant cue to the operators to trip the reactor manually. In this case, a factor of 2 could be applied to the Detection cognitive failure mode (CFM). That would reduce 2E-3 from the overall HEP.

Based on the above discussion, an optimistic analysis that does not model the Decisionmaking CFM and uses 5 and 7 minutes for the mean and 95th percentile of time available would result in a total HEP of 5.1E-2.

C.2.2 HFE2—Shim in Control Rod (OAMG-XE-CRIN)

C.2.2.1 Define Human Failure Event

HFE2 is the second opportunity for the operator to reduce reactivity manually. The cue of HFE2 is the IR reaching 10^{-8} amp, which would occur about 10 to 15 seconds after the RPS signal. Procedure 3-GOP-301 instructs the operator to level power at 10^{-8} amp. Reaching 10^{-8} amp in the IR reading is a milestone of the startup process. The reactivity team would monitor this parameter closely. Once the operator realizes that an ATWS is ongoing, he or she can choose from three options to control the reactivity: (1) manually trip the reactor by opening breakers to the motor-generator set (RPS-XHE-XM-OAMG), (2) open RPS trip breakers locally (OAMG-XE-BRKLOC), and (3) manually insert control rods for 60 seconds (OAMG-XE-CRIN), as shown in Figure C-5. This analysis does not consider the first two options (RPS-XHE-XM-OAMG and OAMG-XE-BRKLOC) because they are performed only if the RPS trip breakers fail mechanically. Thus, the performance deficiencies identified in this analysis do not affect the HEPs of these two actions. The SDP analyzes the elevated risk associated with the identified performance deficiencies. Because RPS-XHE-XM-OAMG and OAMG-XE-BRKLOC are not affected by the identified performance deficiencies in the special inspection (Ref. 1), this analysis does not discuss these two HFEs but only analyzes shimming the control rods into the core (OAMG-XE-CRIN), representing the top event OAMG in the event tree shown in Figure C-1.

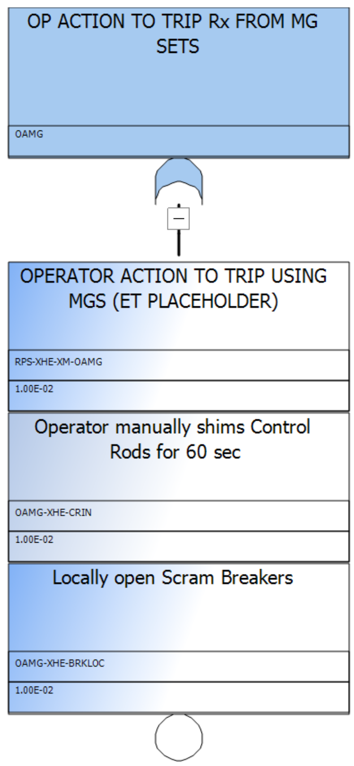


Figure C-7: Fault Tree of the Second Operator Defense

OAMG-XE-CRIN requires the operators to manually insert control rods for 60 seconds after perceiving the IR reaching 10^{-8} amp when following procedure 3-GOP-301. The procedure instructs the operator to monitor and level the IR power at 10^{-8} amp. Common factors affect the reliability of HFE1 and HFE2. However, the cues of HFE1 and HFE2 and the ways to detect the cues are different. The cue of HFE1 is the RPS signal alarm. The detection requires the operator's awareness of the alarm occurrence. The cue of HFE2 is the IR indicator. Procedure 3-GOP-301 instructs the operators to monitor the IR indication closely.

Analysis Timeline

The following summarizes the key parameters that characterize HFE1:

- T_0: The time at which IR reaches 10^{-8} amp.
- T_{Cue}: Same as T_0.
- T_{AC}: The OATC manually inserts control rods for 60 seconds.
- T_{End}: The time after which the action is no longer considered. PZR PORVs lifting open is a strong cue to break the cognition. If the operator has not decided to insert the control

rods before PZR PORVs open, this analysis assumed that the operator would not consider inserting the control rods afterward.

- T_{SW}: 3 minutes, from T_0 to T_{End}.
- T_{Delay}: There is no time delay because that the cue (10^{-8} amp) occurs at T_0.
- T_{Avail}: 3 minutes, same as T_{SW}.
- T_{Reqd}: 0.5 minutes. T_{Reqd} is the time operators decide to insert the control rods without making any errors. The 60-second action time is not included in T_{Reqd} because T_{End} is defined as the action no longer considered, instead of no longer being beneficial.

Error Recovery Opportunity

No error recovery is credited for this HFE because of the short time window for cognition (3 minutes before PZR PORVs open).

C.2.2.2 Task Analysis and Critical Task Identification

OAMG-XE-CRIN is represented by a critical task that requires performing all five macrocognitive functions. The Detection function is to detect that the IR is reaching 10^{-8} amp. The Understanding function is to understand that an ATWS event occurred. The Decisionmaking function is to decide to shim in the control rods to maintain the IR at 10^{-8} amp. The Action Execution function is to manually trip the reactor by manually inserting the control rods into the core. The Interteam function is the coordination between the reactivity team and the operating team. Since all five macrocognitive functions are performed for this critical task, all five CFMs must be evaluated for this critical task.

Operator action OAMG-XE-CRIN (operators failed to manually insert control rods for 60 seconds) is that the operator manually drives the control rods into the core using the rod control system. This action needs to be taken quickly following event initiation (i.e., within minutes) to limit the pressure transient. Successful action provides 72 steps (negative reactivity) from the lead bank, which is equivalent to 1 minute of insertion. The cue to perform OAMG-XE-CRIN is the IR reaching 10^{-8} amp, at which point procedure 3-GOP-301 orders to level power at 10^{-8} amp.

If the operator pays attention to the IR and notices its value exceed 10^{-8} amp, it would be expected that this cue would cause the operator to stop shimming out and start to shim rods in to attempt to level power (arresting the control rod withdrawal). Observing the IR would also draw the operator's attention to other plant parameters, including SURs. Diagnosis of an ATWS should be clearly obvious and credited operator actions directed and taken (i.e., attempt to manually trip the reactor, and initiate AFW and emergency boration).

The probability of diagnosing the condition would increase as additional cues become available and with the crew size and number of observers. Recovery actions could still be performed from the control room and provide mitigation even if performed late. (Note: The quantitative evaluation conservatively did not consider recovery.)

C.2.2.3 Estimate Human Error Probability

HEP(ECA, independent) = 1.16E-01
P_c = 1.16E-01
P_t = 1.35E-04

C.2.2.3.1 Calculate P_c

The PIFs affecting HFE1 and HFE2 are similar. Except for the PIF attribute WF5 (lack of or ineffective instrumentation for safety issue monitoring and identification,) all PIF attributes applied to the Detection CFM of HFE1 apply to the diagnosis CFM of HFE2. HFE1 and HFE2 have the same PIF attributes for the Understanding and Decisionmaking CFMs, except that TF2 (poor command and control) is identified for the Understanding CFM of HFE2. The reasons for selecting the PIF attributes are discussed below.

HEP(Detection, with recovery): 4.02E-03
Task: Monitor the IR indication
Recovery Factor(Detection): 1

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: The reactivity addition team did not question or back up the OATC and US. The SM did not back up or question the reactivity addition team. The reactor engineer was not involved in the N32 operability issue.

- Staffing: STA4: Inappropriate staff assignment

  Justification: The OATC, reactivity SRO, and US had never performed this evolution on the plant.

- Training and Experience: TE5: The operator was inexperienced

  Justification: The reactivity SRO was recently qualified for the first startup. The OATC and US had never actually performed this evolution on the plant before. The just-in-time training did not cover this step in the procedure because the experience gap was not recognized.

- Training and Experience: TE7: Inadequate training or experience with sources of information

  Justification: The OATC, reactivity SRO, and US were qualified but not experienced for this type of startup.

- Team Factors: TF2: Poor command and control

  Justification: The OATC never communicated his plan for performing the step in the startup procedure. The order to do the step was clearly communicated. None of the qualified operators or observers ever questioned the OATC actions.

- Work Practices: WF2: Lack of or ineffective peer-checking or supervision

Justification: The SRO, OATC peer checker, US, and SM failed to provide any meaningful supervision during the step.

- Work Practices: WF5: There was a lack of or ineffective instrumentation for safety issue monitoring and identification.

  Justification: The N32 SR power level indication and N32 SUR meters were lagging and, in fact, inoperable. This placed a confusing and ineffective meter in the middle of the key parameters being monitored. It is likely a number of the crew members locked onto these confusing indications.

- Multitasking, Interruption, and Distraction: **MT1: Distraction by other ongoing activities that demand attention

  PIF Attribute Status (1–10): 5

  Justification: The P-6 interlock and deenergizing SR high volts alarm and procedural steps came in about 20 seconds before the scram and diverted much of the crew's attention to that activity and indication.

- Multitasking, Interruption, and Distraction: **MT4: Concurrent auditory detection and other tasks

  PIF Attribute Status (1–10): 5

  Justification: The control rod withdrawal audio signal and SR counts audio indications overlapped and may have reduced sensitivity to the sound of rods being withdrawn continuously for 50 seconds.

- No base PIF is selected. The lowest Detection HEP of 0.0001 should be applied.

HEP(Understanding, with recovery): 7.02E-02
Task: Understand an ATWS event is ongoing
Recovery Factor(Understanding): 1

- Scenario Familiarity: SF4: Bias or preference for wrong strategies exists, mismatched mental models

  Justification: The entire operating crew was in the improper mindset and was not critically evaluating key reactor plant parameters. The crew accepted and possibly relied upon invalid and confusing indications, which may lead to questioning the validity of subsequent cues and not taking action.

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: See the justification in Detection.

- Staffing: STA4: Inappropriate staff assignment

  Justification: See the justification in Detection.

- Team Factors: TF2: Poor command and control

Justification: See the justification in Detection.

- Mental Fatigue, Stress, and Time Pressure: MF2: Time pressure due to perceived time urgency

  Justification: Due to the elevated startup rate, the operator at the control reaches to procedure setpoint (10^{-8} amp) much sooner than anticipated. That caused a sense of urgency to respond to the situation.

HEP(Decisionmaking, with recovery): 4.42E-02
Task: Decide to shim in control rods
Recovery Factor(Decisionmaking): 1

- Scenario Familiarity: SF4: Bias or preference for wrong strategies exists, mismatched mental models

  Justification: The entire operating crew was in the improper mindset and was not critically evaluating key reactor plant parameters. The crew accepted and possibly relied upon invalid and confusing indications, which may lead to questioning the validity of subsequent cues and not taking action.

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: See the justification in Detection.

- Staffing: STA4: Inappropriate staff assignment

  Justification: See the justification in Detection.

- Team Factors: TF2: Poor command and control

  Justification: See the justification in Detection.

HEP(Action Execution, with recovery): 1.00E-04
Task: Shim in control rods to the core
Recovery Factor(Action Execution): 1

Manually inserting control rods into the reactor is a simple action performed inside the main control room. There are no perceived PIFs affecting operator reliability. The lowest Action Execution basic HEP of 0.0001 should be applied.

HEP(Interteam, with recovery): 1.00E-03
Task: Coordinate between the reactivity team and the operation team
Recovery Factor(Interteam): 1

The reactivity team and the operating team were in the main control room. There are no perceived PIFs affecting Interteam coordination. The lowest Interteam basic HEP of 0.001 should be applied.

C.2.2.3.2 Calculate P_t

The uncertainty distributions of the time required and time available are modeled using the normal distribution. The mean and 95th percentile for the time required is 0.5 and 1 minute, respectively, and 3 and 4 minutes, respectively, for the time available. The calculated P_t is 1.35E-04.

Time Required Distribution Type: Normal Distribution Mean = 0.5 minute 95th Percentile = 1 minute	Time Available Distribution Type: Normal Distribution Mean = 3 minutes 95th Percentile = 4 minutes

C.2.2.4 Uncertainty Analysis

The SDP analysis applies the operator behavior observed in the actual event and represented by the PIF attributes. Because of the nature of the actual event, the specified PIF attributes for the P_c calculations are not expected to be significant factors contributing to uncertainty. The model uncertainty (the uncertainty associated with the IDHEAS-ECA method) is out of the scope of this discussion. The parameter values used to calculate P_t could have a significant impact on uncertainty. The time-required and time-available distributions in the analysis are gross estimates. Simulator observation to collect data to assess the distributions of time required and time available would provide more accurate estimates.

C.2.3 HFE3—Perform Emergency Boration (CVC-XHE-XM-BORATION)

C.2.3.1 Define Human Failure Event

After failing to manually trip the reactor in responding to the RPS system failure (HFE1) and the failure of the operators to manually insert rods in the IR reaching 10^{-8} amp in accordance with the startup procedure (HFE2), the operators would receive the following additional cues: the reactor is exceeding the point of adding heat and the primary temperature is increasing rapidly, indicated power is exceeding the IR high flux trip setpoint, indicated power is exceeding the power range low power high flux trip setpoint, indicated power is exceeding the licensed power limits, and indicated power is exceeding the power range high flux trip setpoint. The next significant cue would be the PZR PORV opening due to the rapid plant heatup because of the increasing power. It would be a strong cue for the operator to perform emergency boration. The final cues would be the AFW system flow rates increasing to remove decay heat, the primary plant temperature reaching equilibrium approximately 50–60 degrees Fahrenheit above the operating temperature bands, and indicated power stabilizing at approximately 7-percent power (AFW decay heat removal capacity).

Emergency Operating Procedure (EOP) EOP-0 instructs the operator to enter EOP FR-S1 (response to nuclear power generation/ATWS), which directs operators to perform emergency boration in FR-S1 step 4. The action is performed from the main control room. It is estimated (Ref. 3) that the time from PZR PORV opening to core damage is about 1 hour. Emergency boration would be needed to cool the plant to restore temperature and shut down and cool down the plant by removing the excess reactivity due to the rods. Note that HFE1 or HFE2 could also be performed as directed by EOP-0 once the operator recognizes that an ATWS is in progress. The “response not obtained” column for EOP-0 directs that HFE1, HFE2, and HFE3 should all be performed. EOP-0 contains an instruction for HFE1 and HFE2, and FR-S1 includes the instruction for HFE3. More than one of the HFEs may be performed simultaneously.

Once the PZR PORV is open, with reactor power stabilizing in the power range and temperature stabilizing high of the normal operating bands, given the crew size and number of observers, the probability of diagnosing the condition increases significantly. The action to use emergency boration to control the reactivity may be performed early in the event if EOP-0 was entered. The actions would be performed from the control room to provide mitigation even if performed late. (Note: The quantitative evaluation conservatively did not consider error recovery to credit the additional cues available to performing emergency boration.)

Analysis Timeline

The following summarizes the key parameters that characterize HFE1:

- T_0: The time when PZR PORV opens.
- T_{Cue}: Same as T_0.
- T_{AC}: The time when the emergency boration started.
- T_{End}: The time when core damage occurred.
- T_{SW}: 60 minutes. The 60 minutes to core damage is a conservative estimate based on a Westinghouse analysis (Ref. 3).
- T_{Delay}: There is no time delay.
- T_{Avail}: 60 minutes, same as T_{SW}.
- T_{Reqd}: 10 minutes. In this analysis, T_{Reqd} is defined as the time the operators need to line up the system for emergency boration and the time to add enough borated water to the primary system to compensate for the excess reactivity added by the control rods and to cool the primary system back to normal analyzed bands (long-term shutdown function).

Error Recovery Opportunities

No error recovery is credited because of the short amount of time available for this HFE.

C.2.3.2 Task Analysis and Critical Task Identification

CVC-XHE-XM-BORATION is represented by a critical task that requires performing all five macrocognitive functions. The Detection function is to detect that the PZR PORV is open. The Understanding function is to understand that an ATWS event is ongoing. The Decisionmaking function is to decide to perform emergency boration. The Action Execution function is to perform emergency boration. The Interteam function is the coordination between the reactivity team and the operating team on implementing the emergency boration. All the system information, actions, and communication for the HFE occur within the main control room. Since all five macrocognitive functions are performed for this critical task, all five CFMs must be evaluated for this critical task.

C.2.3.3 Estimate Human Error Probability

HEP(CVC-XHE-XM-BORATION) = 8.50E-03
HEP($P_{c's}$) = 8.50E-03
HEP(P_t) = 0.00E00

C.2.3.3.1 Calculate P_c

HFE3 shares many PIF attributes with HFE1 and HFE2. These shared PIF attributes are considered as common factors associated with the human-induced initiating event instead of dependency effects on HFE3 resulting from HFE1 and HFE2. Once the PZR PORV opens, the operators have about 1 hour to complete emergency boration. The cue and the 1-hour time available are credited to not include SF4 (bias or preference for wrong strategies exists, mismatched mental models) for the CFMs of Understanding and Decisionmaking. The PIF attributes identified for the CFMs are discussed below.

HEP(Detection, with recovery): 4.02E-03
Recovery Factor(Detection): 1

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: The reactivity addition team did not question or back up the OATC. The US and SM did not back up or question the reactivity addition team. The reactor engineer was not involved in the N32 operability issue.

- Staffing: STA4: Inappropriate staff assignment

  Justification: The OATC, reactivity SRO, and US had never performed this evolution on the plant.

- Training and Experience: TE5: The operator is inexperienced

  Justification: The reactivity SRO recently qualified and this was his first startup. The OATC and US had never actually performed this evolution on the plant before. The just-in-time training did not cover this step in the procedure because the plant management did not recognize the experience gap.

- Training and Experience: TE7: Inadequate training or experience with sources of information

  Justification: The OATC, reactivity SRO, and US were qualified but not experienced for this type of startup.

- Team Factors: TF2: Poor command and control

  Justification: The OATC never communicated his plan to perform the step in the startup procedure. The order to do the step was clearly communicated. None of the qualified operators or observers ever questioned the OATC actions.

- Work Practices: WF2: Lack of or ineffective peer-checking or supervision

  Justification: The SRO, reactivity team peer checker, US, and SM failed to provide any meaningful supervision during the step.

- Work Practices: WF5: Lack of or ineffective instrumentation for safety issue monitoring and identification

  Justification: The N32 SR power level indication and N32 SUR meters were lagging and, in fact, inoperable. This placed a confusing and ineffective meter in the middle of the key parameters being monitored. It is likely a number of the crew members locked onto these confusing indications.

- Multitasking, Interruption, and Distraction: **MT1: Distraction by other ongoing activities that demand attention

  PIF Attribute Status (1–10): 5

  Justification: The P-6 interlock and deenergizing SR high volts alarm and procedural steps came in about 20 seconds before the scram and diverted much of the crew's attention to that activity and indication.

- Multitasking, Interruption, and Distraction: **MT4: Concurrent auditory detection and other tasks

  PIF Attribute Status (1–10): 5

  Justification: The control rod withdrawal audio signal and SR counts audio indications overlapped and may have reduced sensitivity to the sound of rods being withdrawn continuously for 50 seconds.

- The lowest Detection basic HEP of 0.0001 should be applied.

HEP(Understanding, with recovery): 1.70E-03
Recovery Factor(Understanding): 1

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: Not provided.

- Staffing: STA4: Inappropriate staff assignment

  Justification: Not provided.

- Team Factors: TF2: Poor command and control

  Justification: Not provided.

- The lowest Understanding basic HEP of 0.001 should be applied.

HEP(Decisionmaking, with recovery): 1.70E-03
Recovery Factor(Decisionmaking): 1

- Staffing: STA2: Lack of backup or lack of peer check or cross-checking

  Justification: Not provided.

- Staffing: STA4: Inappropriate staff assignment

  Justification: Not provided.

- Team Factors: TF2: Poor command and control

  Justification: Not provided.

- The lowest Decisionmaking basic HEP of 0.001 should be applied.

HEP(Action Execution, with recovery): 1.00E-04
Recovery Factor(Action Execution): 1

- The lowest Action Execution basic HEP of 0.0001 should be applied.

HEP(Interteam, with recovery): 1.00E-03
Recovery Factor(Interteam): 1

- The lowest Interteam basic HEP of 0.001 should be applied.

C.2.3.3.2 Calculate P_t

The uncertainty distributions of the time required and time available are modeled using the normal distribution. The mean and 95th percentile for the time required is 10 and 20 minutes, respectively, and 60 and 70 minutes, respectively, for the time available. The calculated P_t is zero.

Time Required Distribution Type: Normal Distribution Mean = 10 minutes 95th Percentile = 20 minutes	Time Available Distribution Type: Normal Distribution Mean = 60 minutes 95th Percentile = 70 minutes

C.2.3.4 Uncertainty Analysis

SDP analyses apply the performance deficiencies of hardware, software, and human performance identified in the plant event or condition of interest to the analysis. In this event analysis, the performance deficiencies of the operating crew in the actual event are incorporated into the analysis, as in the practice of SDP analyses. The PIF attributes and time assessment specified by the analysts are based on the specific plant condition, specific scenario, and specific crew. The inspectors used plant logs and event reports and interviewed plant operators to develop their SDP analysis, which is replicated in this documentation. Therefore, given the quality of the information collection process and the requirements of an SDP analysis, the uncertainty about the estimated HEP associated with the parameter values entered by the analysts is assessed to be minimum. The main uncertainty could be the uncertainty associated with the IDHEAS-ECA method, which is outside the scope of this discussion.

C.3 Dependency Analysis

The dependency between HFE1 and HFE2 is assessed. HFE1 and HFE2 are combined (HFE1&2) to assess their dependency on HFE3 because HFE1 and HFE2 occurred at about the same time. Therefore, this analysis includes two dependency relations: HFE1 on HFE2, and HFE1&2 on HFE3. Each dependency analysis is a complete dependency analysis that includes evaluation of the entry condition, Predetermination Analysis, Screening Analysis, and Detailed Analysis. Table C-2 summarizes the dependency effects on HFE2 and HFE3. The HEPs values in Table C-2 were assessed using the IDHEAS dependency model.

Table C-2: Independent, Screening Dependent, and Detailed Dependent HEPs of HFE2 and HFE3

	Individual (Independent) HEP	Dependent HEP by Screening Analysis	Dependent HEP by Detailed Analysis
HFE2	0.12	0.25	0.15
HFE3	8.5E-3	1.1E-2	9.9E-3

C.3.1 HFE1 (Backup RPS) and HFE2 (Shim in Control Rods)

C.3.1.1 Entry Condition

Evaluation

☒ (a) HFE1 and HFE2 are in the same PRA event sequence or minimal cutset, ***AND*** (b) there are no relevant human action success events between HFE1 and HFE2 in the sequence. ***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. These are also called at-initiators and are common at shutdown.

Result

Proceed to Step 1, Predetermination Analysis.

Additional Considerations

- Assessing Time Sequence: HFE1 and HFE2 occur in sequence. HFE1 precedes HFE2.
- Assessing Dependency for More Than Two HFEs: The dependency between HFE1 and HFE2 is assessed. HFE1 and HFE2 are combined (HFE1&2) to assess their dependency on HFE3.
- Relevant Intervening Successes: No intervening success.
- Determining whether Dependency Analysis Is Necessary: Yes.

C.3.1.2 Predetermination Analysis

Assessment Result

☐	HFE2 is completely dependent on HFE1; thus, the adjusted probability of HFE2 is 1.0.
☐	HFE2 is independent of HFE1; thus, the adjusted HEP of HFE2 is equal to the individual HEP of HFE2.
☒	One or more dependency relationships exist; thus, the analyst proceeds to either Step 2, Screening Analysis, or Step 3, Detailed Analysis, to obtain the dependent HEP of HFE2.

Assessment Details

Relationship	Assessment Guidelines	
Complete Dependency	☒ HFE1 and HFE2 use the same procedure, ***AND*** ☐ HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), ***AND*** ☒ There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2. **Justification:** HFE1 is failing to respond to the RPS signal. The procedure is not a likely source of the failure.	☐YES ☒NO
R1— Functions or Systems	☒ HFE1 and HFE2 have the same functions or systems, ***OR*** ☐ HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed. **Justification:** HFE1 and HFE2 are about reactivity control.	☒YES ☐NO
R2— Time Proximity	☒ HFE1 and HFE2 are performed close in time, ***OR*** ☒ The cues for HFE1 and HFE2 are presented close in time. **Justification:** The cues for HFE1 and HFE2 are about 10 to 15 seconds apart.	☒YES ☐NO
R3— Personnel	☒ HFE1 and HFE2 are performed by the same personnel. **Justification:** HFE1 and HFE2 are performed by the reactivity team.	☒YES ☐NO
R4— Location	☒ HFE1 and HFE2 are performed at the same location, ***OR*** ☐ The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation). **Justification:** HFE1 and HFE2 are performed in the main control room.	☒YES ☐NO

Relationship	Assessment Guidelines	
R5—Procedure	☒ HFE1 and HFE2 use the same procedure.	☒YES ☐NO

C.3.1.3 Screening Analysis

The Predetermination Analysis identified dependencies include all types of dependencies (R1 to R5). The total increased error probability as the result of the dependency effect is 0.15. The individual (independent) HEP is 0.12. Therefore, the total HEP with dependency effects is 0.25 (= 1 – (1 – 0.15)(1 – 0.12)). The sections below discuss the individual P_d values, which are as follows:

- P_d(R1—Functions or Systems) = 5.0E-2
- P_d(R2—Time Proximity) = 5.2E-2
- P_d(R3—Personnel) = 5.0E-2
- P_d(R4—Location) = 2.0E-3
- P_d(R5—Procedure) = 0.0E00

C.3.1.3.1 R1—Functions or Systems

Assessment Result

The probabilistic sum of P_d(R1) = 5.0E-2.

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Use of the same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of	☐ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. **Justification:** HFE1 created an ATWS scenario. HFE2 (shimming in control rods) is not trained under ATWS. ☐ 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. ☐ A/B—There is no cognitive link (similar thought process) between the two HFEs; thus, occurrence of HFE1 has no impact on scenario familiarity	This cognitive dependency potentially affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☒ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
the situation associated with HFE2.	or the mental model associated with HFE2. ☐ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (i.e., thought process).
R1.2 Use of the same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	☐ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. ☒ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on information needed for HFE2. **Justification:** IR reaching 10^{-8} amp is not affected by RPS signal. ☐ B—Personnel have firm information or multiple sources of information that are consistent. ☐ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	This consequential dependency potentially impacts the PIFs for task complexity and information availability and reliability.
		Low: P_d = 1E-2 Task is relatively simple, and one or two of the following apply: ☐ Cues for detection are less obvious. ☐ Execution criteria become complicated or ambiguous. ☐ Potential outcome of the situation assessment becomes more complicated (e.g., multiple states and contexts, not a simple yes or no). ☐ Decisionmaking criteria become intermingled, ambiguous, or more difficult to assess.
		Medium: P_d = 5E-2 ☐ More than two items in "Low" are applicable.
		High: P_d =2E-1 One or more of the following apply: ☐ Cues are masked or must be inferred. ☐ Detection of the critical information is entirely based on personnel's experience and knowledge. ☐ Execution of the critical task requires breaking away from trained scripts. ☐ HFE1 creates ambiguity associated with assessing the situation for performing HFE2. ☐ HFE1 creates competing or conflicting goals for decisionmaking of HFE2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.3 Use of the same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	☒ A—No shared or no shortage of tools or equipment. ☒ B—No shared or no shortage of resources. **Justification:** No special tool is needed for HFE2. No shared resources between HFE1 and HFE2. ☐ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	This resource-sharing dependency potentially impacts the PIF for task complexity because the portion of resources HFE2 shares with HFE1, such as power in FLEX events, may be reduced due to HFE1.
		Low: P_d = 2E-3 ☐ Tool or resource shortage increases task difficulty, such as the following: – high spatial or temporal precision – precise coordination of multiple persons – unusual, unevenly balanced loads, reaching high parts – continuous control that requires dynamic manipulation
		Medium: P_d = 1E-2 ☐ Complicated or ambiguous execution criteria are present, such as the following: – multiple, coupled criteria – open to misinterpretation
		High: P_d = 5E-2 ☐ Action execution requires close coordination of personnel at different locations.

C.3.1.3.2 R2—Time Proximity

<u>Assessment Result</u>

The probabilistic sum of $P_d(R2) = 5.0E\text{-}2$.

<u>Assessment Details</u>

<table>
<tr><th>Potential Dependency Factors</th><th>Basis for Discounting the Potential Dependency Factor</th><th>Dependency Impact</th></tr>
<tr>
<td>R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency

A. Occurrence of HFE1 reduces the time available or increases the time required for HFE2.</td>
<td>☐ A—The ratio of the time available to the time required, T_a/T_r, for HFE2 is greater than 4; thus, plenty of time is available for HFE2, and dependency due to time proximity is negligible.

☒ A—There is no change in the time available and time required for HFE2 due to HFE1.</td>
<td>Use the ratio of T_a to T_r for HFE2 and the chart below to estimate the dependency impact. T_a and T_r are point estimates.

<table>
<tr><th>T_a/T_r</th><th>Dependency Impact</th></tr>
<tr><td>☐ < 1</td><td>1</td></tr>
<tr><td>☐ ≥ 1 and < 2</td><td>1E-1</td></tr>
<tr><td>☐ ≥ 2 and < 3</td><td>1E-2</td></tr>
<tr><td>☐ ≥ 3 and ≤ 4</td><td>1E-3</td></tr>
<tr><td>☐ > 4</td><td>Negligible</td></tr>
</table>
</td>
</tr>
<tr>
<td>R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency

A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.</td>
<td>☐ A—The cues for HFE1 and HFE2 do not occur close in time.

☐ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitoring the cues for HEF2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1).

☐ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.</td>
<td>This consequential dependency impacts the PIF for task complexity by increasing the difficulty of detecting cues for HFE2.<hr>Low: P_d = 5E-3
☐ Detection of the cue demands switching between tasks or needs sustained attention over time.<hr>Medium: P_d = 5E-2
☒ Detection of the cue is not directed by alarms or procedures, and personnel need to continuously monitor or actively search for the cue.<hr>High: P_d = 1E-1
☐ The cue is masked such that initiating HFE2 is entirely based on personnel's experience and knowledge.</td>
</tr>
</table>

C.3.1.3.3 R3—Personnel

Assessment Result

$P_d(R3) = 5.2E-2$

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.1 Use of the same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at the Three Mile Island nuclear plant (TMI), operators did not put water in because they did not think they needed water).	☐ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since EOPs are symptom-based and well trained upon, it is difficult to sustain a wrong mental model). ☐ A—The HFEs are not performed by the same person. ☐ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the shift technical advisor (STA) can discount A/B if the STA would have reason to review the actions being taken). **Justification:** Additional people in the main control room during the actual event did not seem helpful for monitoring IR. ☐ A/B—Different procedures are used for HFE1 and HFE2. ☐ B—Same personnel or crew does not perform diagnosis or decisionmaking for the HFEs. ☐ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). ☒ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND***	This cognitive dependency potentially affects the PIFs for scenario familiarity, which address the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☒ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links (i.e., thought process).

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
	adequate time is available to detect the new cues.	
R3.2 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).	☒ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☐ B—HFE1 and HFE2 are not performed at the same time ☐ 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 ☐ Mental fatigue increases due to sustained highly demanding cognitive activities, ***OR*** ☐ Time pressure increases due to perceived time urgency and task load.
		Medium: P_d = 1E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☒ HFE2 does not require complicated diagnosis.
		High: P_d = 3E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 requires complicated diagnosis.
R3.3 Use of the same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to SDPs (actual fitness for duty event) or fire events. B. Using shared staff requires changes to the work practices for HFE2 (e.g.,	☒ A/B—Staffing is adequate, and good work practices are enforced. ☒ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but use of the severe accident management guidelines (SAMGs) or fire procedures may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) ☒ B—Minimum staffing is adequate to complete both tasks	This resource-sharing dependency potentially affects the PIFs for staffing, teamwork and organizational factors, and work practices. Work practices, such as peer checking, may change due to lack of adequate staffing.
		Low: P_d = 2E-3 ☐ Key staff needed for HFE2 are reduced or untimely due to HFE1, ***OR*** ☐ Teamwork factors are inadequate, such as knowledge gaps, distributed teams (personnel in multiple locations), dynamic teams (changing team members), or poor team cohesion.
		Medium: P_d = 1E-2 ☐ Self-checking or human performance tools (e.g., three-way communication) are not used as trained, ***OR***

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	without changes to the work practices. **Justification:** HFE1 and HFE2 can be completed with minimum staffing.	☐ Peer checking or supervision is ineffective.
		High: P_d = 5E-2 ☐ Work scheduling or prioritization is poor.

C.3.1.3.4 R4—Location

Assessment Result

P_d(R4) = 2.0E-3

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.1 Use of the same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	☒ A—HFE1 has no impact on the workplace.	This consequential dependency potentially affects the PIF for environmental factors.
		Low: P_d = 2E-3 ☐ HFE1 causes any one of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		Medium: P_d = 5E-3 ☐ HFE1 causes two or more of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		High: P_d = 2E-2 ☐ HFE1 significantly impairs the work environment for HFE2, such as by causing excessive heat and humidity, poor visibility, or unstable surface for executing the action.
R4.2 Use of the same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with	☐ A—HFE1 and HFE2 are not performed at the same time. ☐ A—Actions can be performed without interference.	This consequential dependency potentially affects the PIF for multitasking, interruptions, and distractions due to sharing the same location at the same time.
		Low: P_d = 2E-3 ☒ Personnel are distracted by the outcome of HFE1.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	**Justification:** HFE2 was performed after the RPS signal. The crew could be distracted by the RPS signal. ☐ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference). **Justification:** HFE2 requires constant monitoring of IR.	Medium: P_d = 5E-3 ☐ Performance of HFE2 is interrupted by the outcome of HFE1. High: P_d = 7E-3 ☐ Performance of HFE2 is frequently or continuously interrupted by the outcome of HFE1.

C.3.1.3.5 R5—Procedure

<u>Assessment Result</u>

P_d(R5) = 0.0E00

<u>Assessment Details</u>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R5.1 Use of the same procedure leads to cognitive dependency A. Occurrence of HFE1 makes the procedure less applicable for use with HFE2 (i.e., the procedure becomes more confusing or does not match the situation well). For example, EOPs are generally well written because they are used often in training, but use of at-power EOPs at shutdown may be confusing because equipment is not in its normal configuration. Use of procedures during a fire or main control room abandonment situation may not apply as well as when at power. B. Occurrence of HFE1 makes personnel more likely to incorrectly interpret the procedure for use with HFE2 because they are using the same procedure.	☒ A/B—Procedure is clear, not confusing, applicable to the situations, and well trained upon. ☐ A/B—Personnel are trained to use the procedure for the specific situations.	This cognitive dependency potentially affects the PIFs for procedures and guidance and for scenario familiarity due to the effect on personnel's mental model. Low: P_d = 5E-3 ☐ HFE1 makes the procedure more confusing for personnel to follow. Medium: P_d = 5E-2 ☐ HFE1 creates a misunderstanding of the situation such that personnel are likely to misinterpret the procedure, ***OR*** ☐ HFE1 causes unfamiliar elements in the scenario for performing HFE2. High: P_d = 3.5E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2, ***OR*** ☐ HFE1 creates a bias or preference for wrong strategies, ***OR*** ☐ HFE1 makes the situation for performing HFE2 extremely rare, such that personnel have no existing mental model for the situation.

C.3.1.4 Detailed Analysis

The dependency relations of R1.1, R2.2, R3.1, R3.2, and R4.2 are not discounted by the Screening Analysis. The Detailed Analysis on dependency will only analyze these items. The sections below document the Detailed Analysis. The detailed dependency analysis added "SF3—Scenarios trained on but infrequently performed," which applied to the detecting CFM. The dependent HEP from the Detailed Analysis is 0.15. In comparison, the independent HEP is 0.12. Therefore, the dependency effect on HEP is 3E-2 based on the Detailed Analysis.

C.3.1.4.1 R1—Functions or Systems

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Use of the same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.	☐ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. ☐ 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. ☐ 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 the mental model associated with HFE2. ☐ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	Potentially affected CFMs: All CFMs Potentially impacted PIFs: SF—Scenario familiarity PIF attributes that are most likely impacted by the dependency factor: ☐ SF1—Unpredictable dynamics in known scenarios ☐ SF2—Unfamiliar elements in the scenario ☒ SF3—Scenarios trained on but infrequently performed **Justification:** HFE2 has never been trained in the condition of an RPS signal with a failure to trip the reactor. The condition could affect detection. The cue of the P-6 light lit occurred in the same time window, but the operator expected the P-6 to be lit. ☐ SF4—Bias or preference for wrong strategies exists, mismatched mental models

C.3.1.4.2 R2—Time Proximity

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.	☐ A—The cues for HFE1 and HFE2 do not occur close in time. ☐ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitor the cues for HFE2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1). ☒ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.	<u>Potentially affected CFMs</u>: Detection <u>Potentially impacted PIFs</u>: TC—Task complexity <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ C3—Detection demands high attention – need split attention – need sustained attention over time – need intermittent attention ☐ C5—Cues for detection are not obvious, detection is not directly cued by alarms or instructions, and personnel need to actively search for the information ☐ C6—No cue or mental model for detection, no rules/procedures/alarms to cue the detection; detection of the critical information is entirely based on personnel’s experience and knowledge

C.3.1.4.3 R3—Personnel

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.1 Use of the same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at TMI, operators did not put water in because they did not think they needed water).	☒ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since EOPs are symptom based and well trained upon, it is difficult to sustain a wrong mental model). ☐ A—The HFEs are not performed by the same person. ☐ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the STA can discount A/B if the STA would have reason to review the actions being taken). ☐ A/B—Different procedures are used for HFE1 and HFE2. ☐ B—Same personnel or crew does not perform diagnosis or decisionmaking for the HFEs. ☐ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). ☒ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND*** adequate time is available to detect the new cues.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: SF—Scenario familiarity <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ SF1—Unpredictable dynamics in known scenarios ☐ SF2—Unfamiliar elements in the scenario ☐ SF3—Scenarios trained on but infrequently performed ☐ SF4—Bias or preference for wrong strategies exists, mismatched mental models

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	☒ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☒ B—HFE1 and HFE2 are not performed at the same time. ☐ B—Additional personnel are available to perform HFE2.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ MF1—Sustained (> 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) ☐ MF2—Time pressure due to perceived time urgency ☐ MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff) ☐ MT3—Concurrent visual detection and other tasks ☐ MT4—Concurrent auditory detection and other tasks ☐ MT5—Concurrent diagnosis and other tasks ☐ MT8—Concurrently executing action sequence and performing another attention/working memory task ☐ MT9—Concurrently executing intermingled or interdependent action plans

C.3.1.4.4 R4—Location

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.2 Use of the same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	☐ A—HFE1 and HFE2 are not performed at the same time. ☐ A—Actions can be performed without interference. ☐ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference).	Potentially affected CFMs: All CFMs Potentially impacted PIFs: MT—Multitasking, interruptions, and distractions PIF attributes that are most likely impacted by the dependency factor: ☒ MT1—Distraction by other ongoing activities that demand attention ☐ MT2—Interruption taking away from the main task **Note:** MT1 was identified as affecting detection in the independent HEP calculation. The effects of MT1 remain on the Detection CFM only, not the other CFMs.

C.3.1.5 Uncertainty Analysis

With the individual HEP of 0.12 for HFE2, the dependent HEPs calculated by the Detailed Analysis and Screening Analysis are 0.15 and 0.25, respectively. In comparison, using the dependency model of the fire HRA method (Ref. 4) would result in a dependency level of "High."[2] That results in 0.56 of the dependent HEP of HFE2. Therefore, the dependency effects, calculated by subtracting the individual HEP from the combined HEP, are 0.03, 0.13, and 0.44 using the Detailed Analysis, Screening Analysis, and fire HRA method, respectively.

C.3.2 HFE1&2 and HFE3

The cues of HFE1 (RPS signal) and HFE2 (IR reaching 10^{-8} amp) are only separated by about 15 seconds. Their action times are less than or close to 1 minute. In comparison, after HFE1 and HFE2 occurred, the reactor coolant system (RCS) would heat up and generate multiple vivid symptoms to cue the operator to perform emergency boration (HFE3). The T_{End} of HFE3 is core damage that occurs about 60 minutes after the RPS signal. The short time between HFE1 and HFE2 and the relatively long separation in time between HFE1&2 and HFE3 justifies the grouping of HFE1 and HFE2 on the assessment of dependency effects on HFE3.

2 The assessment uses the statuses of the following parameters: Intervening success (No), Crew (Same), Cognitive (Different), Cue demand (sequential), Location (same), Sequential timing (0–15 minutes), and Stress (neither high nor moderate).

C.3.2.1 Entry Condition

Evaluation

☒ (a) HFE1&2 and HFE3 are in the same PRA event sequence or minimal cutset, ***AND*** (b) there are no relevant human action success events between HFE1 and HFE2 in the sequence. ***OR***

☒ The initiating event is caused by human action and is analyzed as the first HFE, such that the subsequent HFEs need to be assessed for dependency. These are also called at-initiators and are common at shutdown.

Result

Proceed to Step 1, Predetermination Analysis.

Additional Considerations

- Assessing Time Sequence: HFE1&2 and HFE3 occur in sequence. HFE1&2 precedes HFE3.
- Assessing Dependency for More Than Two HFEs: The dependency between HFE1 and HFE2 is assessed. HFE1 and HFE2 are combined (HFE1&2) to assess their dependency on HFE3.
- Relevant Intervening Successes: No intervening success
- Determining whether Dependency Analysis Is Necessary: Yes

C.3.2.2 Predetermination Analysis

Assessment Result

☐	HFE2 is completely dependent on HFE1; thus, the adjusted probability of HFE2 is 1.0.
☐	HFE2 is independent of HFE1; thus, the adjusted HEP of HFE2 is equal to the individual HEP of HFE2.
☒	One or more dependency relationships exist; thus, the analyst proceeds to either Step 2, Screening Analysis, or Step 3, Detailed Analysis, to obtain the dependent HEP of HFE2.

Assessment Details

Relationship	Assessment Guidelines	
Complete Dependency	☐ HFE1&2 and HFE3 use the same procedure, ***AND*** ☐ HFE1&2 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), ***AND*** ☒ There is no opportunity to recover from the issue with the procedure between HFE1&2 and HFE3.	☐YES ☒NO
R1—Functions or Systems	☒ HFE1&2 and HFE3 have the same functions or systems, ***OR*** ☐ HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed. **Justification:** HFE1 and HFE2 are about reactivity control.	☒YES ☐NO
R2—Time Proximity	☒ HFE1&2 and HFE3 are performed close in time, ***OR*** ☐ The cues for HFE1&2 and HFE3 are presented close in time. **Justification:** Failure of HFE1 and HFE2 would quickly heat up the RCS and require performing HFE3.	☒YES ☐NO
R3—Personnel	☒ HFE1&2 and HFE3 are performed by the same personnel. **Justification:** HFE1, HFE2, and HFE3 are performed by the reactivity team.	☒YES ☐NO
R4—Location	☒ HFE1 and HFE2 are performed at the same location, ***OR*** ☐ The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation). **Justification**: HFE1, HFE2, and HFE3 are performed in the main control room.	☒YES ☐NO
R5—Procedure	☐ HFE1&2 and HFE3 use the same procedure. **Justification:** HFE1 and HFE2 are directed by EOP-0. HFE3 is directed by FR-S1.	☐YES ☒NO

C.3.2.3 Screening Analysis

This analysis groups HFE1 and HFE2 (discussed in Sections C.2.1 and C.2.2) and represents them by a single HFE to analyze the combined dependency effects of HFE1 (manually backup RPS) and HFE2 (shim in control rod) on HFE3 (perform emergency boration). Because IDHEAS dependency worktables use “HFE1” and “HFE2” for the dependency discussion, to be consistent with the IDHEAS dependency worktables, after this point, “HFE1” represents the

combination of old HFE1 and old HFE2 (i.e., the combination of manually backup RPS and shim in control rod), and HFE2 represents the old HFE3 (i.e., perform emergency boration).
The Predetermination Analysis identified four types of dependency (R1 to R4). The total increased error probability as the result of the dependency effect is 2.0E-3. The independent HFE is 8.5E-3. The total HEP with dependency effects is 1.1E-2 (= 8.5E-3 + 2.0E-3). The sections below discuss the individual P_ds, which have the following values:

- P_d(R1—Functions or Systems) = 0.0E00
- P_d(R2—Time Proximity) = 0.0E00
- P_d(R3—Personnel) = 2.0E-3
- P_d(R4—Location) = 0.0E00

C.3.2.3.1 R1—Functions or Systems

Assessment Result

The probabilistic sum of P_d(R1) = 0.0E00.

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Use of the same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; 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.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of	☒ A—The staff is trained in HFE2 in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. **Justification:** The staff is trained for emergency boration (HFE2 here) to respond to the RCS heatup symptoms. HFE1 caused the symptoms in this analysis. ☒ 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. **Justification:** The staff is trained on emergency boration (HFE2 here) to respond to the RCS heatup symptoms regardless of the causes of the heatup.	This cognitive dependency potentially affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
the situation associated with HFE2.	☐ 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 the mental model associated with HFE2. ☐ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (i.e., thought process).
R1.2 Use of the same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	☒ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. **Justification:** HFE1 is on the RPS breaker and control rods. HFE2 is on the boration system. ☒ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on information needed for HFE2. **Justification:** RCS heatup symptoms are not affected by HFE1. ☐ B—Personnel have firm information or multiple sources of information that are consistent. ☐ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	This consequential dependency potentially impacts the PIFs for task complexity and information availability and reliability. Low: P_d = 1E-2 Task is relatively simple, and one or two of the following apply: ☐ Cues for detection are less obvious. ☐ Execution criteria become complicated or ambiguous. ☐ Potential outcome of the situation assessment becomes more complicated (e.g., multiple states and contexts, not a simple yes or no). ☐ Decisionmaking criteria become intermingled, ambiguous, or more difficult to assess. Medium: P_d = 5E-2 ☐ More than two items in “Low” are applicable. High: P_d =2E-1 One or more of the following apply: ☐ Cues are masked or must be inferred. ☐ Detection of the critical information is entirely based on personnel’s experience and knowledge. ☐ Execution of the critical task requires breaking away from trained scripts. ☐ HFE1 creates ambiguity associated with assessing the situation for performing HFE2. ☐ HFE1 creates competing or conflicting goals for decisionmaking of HFE2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.3 Use of the same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	☒ A—No shared or no shortage of tools or equipment. ☒ B—No shared or no shortage of resources. **Justification:** No special tool is needed for HFE1 and HFE2. ☐ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	This resource-sharing dependency potentially impacts the PIF for task complexity because the portion of resources HFE2 shares with HFE1, such as power in FLEX events, may be reduced due to HFE1.
		Low: P_d = 2E-3 ☐ Tool or resource shortage increases task difficulty, such as the following: – high spatial or temporal precision – precise coordination of multiple persons – unusual, unevenly balanced loads, reaching high parts – continuous control that requires dynamic manipulation
		Medium: P_d = 1E-2 ☐ Complicated or ambiguous execution criteria are present, such as the following: – multiple, coupled criteria – open to misinterpretation
		High: P_d = 5E-2 ☐ Action execution requires close coordination of personnel at different locations.

C.3.2.3.2 R2—Time Proximity

Assessment Result

The probabilistic sum of P_d(R2) = 0.0E00.

Assessment Details

<table>
<tr><th>Potential Dependency Factors</th><th>Basis for Discounting the Potential Dependency Factor</th><th>Dependency Impact</th></tr>
<tr>
<td>R2.1 Close time proximity in performing HFE1 and HFE2 leads to consequential dependency

A. Occurrence of HFE1 reduces the time available or increases the time required for HFE2.</td>
<td>☐ A—The ratio of time available to time required, T_a/T_r, for HFE2 is greater than 4; thus, plenty of time is available for HFE2, and dependency due to time proximity is negligible.

☒ A—There is no change in the time available and time required for HFE2 due to HFE1.</td>
<td>Use the ratio of T_a to T_r for HFE2 and the chart below to estimate the dependency impact. T_a and T_r are point estimates.

<table>
<tr><th>T_a/T_r</th><th>Dependency Impact</th></tr>
<tr><td>☐ < 1</td><td>1</td></tr>
<tr><td>☐ ≥ 1 and < 2</td><td>1E-1</td></tr>
<tr><td>☐ ≥ 2 and < 3</td><td>1E-2</td></tr>
<tr><td>☐ ≥ 3 and ≤ 4</td><td>1E-3</td></tr>
<tr><td>☐ > 4</td><td>Negligible</td></tr>
</table></td>
</tr>
<tr>
<td>R2.2 Close time proximity in receiving the cues for HFE1 and HFE2 leads to consequential dependency

A. Cues for HFE1 and HFE2 occur close in time such that the cue for HFE2 is likely to be masked or forgotten by the time that HFE2 needs to be performed.</td>
<td>☐ A—The cues for HFE1 and HFE2 do not occur close in time.

☒ A—Personnel are trained to identify the need for HFE2 given the occurrence of HFE1 (e.g., personnel are dedicated to monitoring the cues for HEF2 or procedures specifically direct personnel to look for the cues for HFE2 after HFE1).

☒ A—The cues remain available and salient, and there is adequate time to perform the action such that personnel could identify the cues and perform the task later without impact.</td>
<td>This consequential dependency potentially impacts the PIF for task complexity by increasing the difficulty of detecting cues for HFE2.

Low: P_d = 5E-3
☐ Detection of the cue demands switching between tasks or needs sustained attention over time.

Medium: P_d = 5E-2
☐ Detection of the cue is not directed by alarms or procedures, and personnel need to continuously monitor or actively search for the cue.

High: P_d = 1E-1
☐ The cue is masked such that initiating HFE2 is based on personnel’s experience and knowledge.</td>
</tr>
</table>

C.3.2.3.3 R3—Personnel

Assessment Result

$P_d(R3) = 2.0E-3$

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.1 Use of the same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at TMI, operators did not put water in because they did not think they needed water).	☐ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since EOPs are symptom based and well trained upon, it is difficult to sustain a wrong mental model). ☐ A—The HFEs are not performed by the same person. ☒ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the STA can discount A/B if the STA would have reason to review the actions being taken). **Justification:** Additional people in the main control room in combination with new vivid cues are expected to break the cognitive dependency if it exists. ☐ A/B—Different procedures are used for HFE1 and HFE2. ☐ B—Same personnel or crew does not perform diagnosis or decisionmaking for the HFEs. ☐ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). ☒ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND*** adequate time is available to detect the new cues.	This cognitive dependency potentially affects the PIFs for scenario familiarity, which address the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: $P_d = 5E-2$ ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: $P_d = 1E-1$ ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. High: $P_d = 3E-1$ ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links (i.e., thought process).

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	☐ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☐ B—HFE1 and HFE2 are not performed at the same time. ☐ 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 ☐ Mental fatigue increases due to sustained highly demanding cognitive activities, ***OR*** ☒ Time pressure increases due to perceived time urgency and task load. **Justification:** Emergency boration is the last barrier before core damage.
		Medium: P_d = 1E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 does not require complicated diagnosis.
		High: P_d = 3E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 requires complicated diagnosis.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.3 Use of the same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to SDPs (actual fitness for duty events) or fire events. B. Using shared staff requires changes to the work practices for HFE2 (e.g., shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	☐ A/B—Staffing is adequate, and good work practices are enforced. ☒ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but use of the SAMGs or fire procedures may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) ☒ B—Minimum staffing is adequate to complete both tasks without changes to the work practices. **Justification:** HFE1 and HFE2 can be completed with minimum staffing.	This resource-sharing dependency potentially affects the PIFs for staffing, teamwork and organizational factors, and work practices. Work practices, such as peer checking, may change due to lack of adequate staffing. Low: P_d = 2E-3 ☐ Key staff needed for HFE2 are reduced or untimely due to HFE1, ***OR*** ☐ Teamwork factors are inadequate, such as knowledge gaps, distributed teams (personnel in multiple locations), dynamic teams (changing team members), or poor team cohesion. Medium: P_d = 1E-2 ☐ Self-checking or human performance tools (e.g., three-way communication) are not used as trained for, ***OR*** ☐ Peer checking or supervision is ineffective. High: P_d = 5E-2 ☐ Work scheduling or prioritization is poor.

C.3.2.3.4 R4—Location

<u>Assessment Result</u>

P_d(R4) = 0.0E00

<u>Assessment Details</u>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.1 Use of the same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	☒ A—HFE1 has no impact on the workplace.	This consequential dependency potentially affects the PIF for environmental factors.
		Low: P_d = 2E-3 ☐ HFE1 causes any one of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		Medium: P_d = 5E-3 ☐ HFE1 causes two or more of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		High: P_d = 2E-2 ☐ HFE1 significantly impairs the work environment for HFE2, such as by causing excessive heat and humidity, poor visibility, or unstable surface for executing the action.
R4.2 Use of the same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	☐ A—HFE1 and HFE2 are not performed at the same time. ☒ A—Actions can be performed without interference. ☒ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference). **Justification:** HFE2 is cued by multiple symptoms relating to plant heatup.	This consequential dependency potentially affects the PIF for multitasking, interruptions, and distractions due to sharing the same location at the same time.
		Low: P_d = 2E-3 ☐ Personnel are distracted by the outcome of HFE1.
		Medium: P_d = 5E-3 ☐ Performance of HFE2 is interrupted by the outcome of HFE1.
		High: P_d = 7E-3 ☐ Performance of HFE2 is frequently or continuously interrupted by the outcome of HFE1.

C.3.2.4 Detailed Analysis

The R3.2 is the only dependency relation not discounted from the Screening Analysis. Therefore, the Detailed Analysis only assesses the effects of R3.2. The sections below document the Detailed Analysis. The detailed dependency analysis added "MF2—Time pressure due to perceived time urgency” to all CFMs. The dependent HEP from the Detailed Analysis is 9.9E-3. In comparison, the independent HEP is 8.5E-3. The dependent HEP from the Screening Analysis is 1.1E-2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	☐ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☒ B—HFE1 and HFE2 are not performed at the same time. ☐ B—Additional personnel are available to perform HFE2.	Potentially affected CFMs: All CFMs Potentially impacted PIFs: MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions PIF attributes that are most likely impacted by the dependency factor: ☐ MF1—Sustained (> 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) ☒ MF2—Time pressure due to perceived time urgency ☐ MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff) ☐ MT3—Concurrent visual detection and other tasks ☐ MT4—Concurrent auditory detection and other tasks ☐ MT5—Concurrent diagnosis and other tasks ☐ MT8—Concurrently executing action sequence and performing another attention/working memory task ☐ MT9—Concurrently executing intermingled or interdependent action plans

C.3.2.5 Uncertainty Analysis

With the individual HEP of 8.5E-3 for HFE3, the dependent HEPs calculated by the Detailed Analysis and the Screening Analysis are 9.9E-3 and 1.1E-2, respectively. In comparison, using the dependency model of the fire HRA method (Ref. 4) would result in a dependency level of low or moderate.[3] That results in a value of 5.8E-2 and 1.5E-1 of the dependent HEP of HFE3 for the low level and the moderate level of dependency, respectively. Therefore, the dependency effects, calculated by subtracting the individual HEP from the combined HEP, are 1.4E-3, 2.5E-3, 5.0E-2, and 1.4E-1 using the Detailed Analysis, Screening Analysis, and fire HRA method (low dependency and moderate dependency), respectively.

C.4 Summary

This appendix demonstrates the application and documentation of the IDHEAS-ECA method, with an emphasis on dependency analysis. A complete dependency process was performed, including evaluation of the entry condition, Predetermination Analysis, Screening Analysis, and Detailed Analysis. The IDHEAS dependency method uses the same generic categories that are used by the dependency models as the first layer to identify the potential dependency categories. This identification takes place during the Predetermination Analysis. The IDHEAS dependency model provides more detailed guidance in the Screening Analysis and Detailed Analysis to determine the dependency mechanisms causing dependence. The additional layers are beneficial to reduce conservatism in assessing dependency effects.

The dependency analysis examined a sequence of three HFEs. The uncertainty discussions in the dependency analyses compare the dependency effects assessed by the Screening Analysis, Detailed Analysis, and fire HRA method. The results show that the dependency impacts on HEP assessed by the Detailed Analysis are less than those in the Screening Analysis, which, in turn, are less than those in the fire HRA method. These results are expected. The IDHEAS dependency model guides the analysts to identify the dependency mechanisms more specifically than with the fire HRA method. This capability enables analysts to account for the dependency effects of the identified dependency mechanisms.

C.5 References

1. U.S. Nuclear Regulatory Commission, "Turkey Point Units 3 and 4—Special Inspection Report 05000250/2020050 and 05000251/2020050," December 9, 2020 (Agencywide Documents Access and Management (ADAMS) Accession No. ML20344A126).

2. Xing, J., Y.J. Chang, and J. DeJesus, "Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)," RIL 2020-02, U.S. Nuclear Regulatory Commission, January 2020 (ADAMS Accession No. ML20016A481).

3. André, G.R., G.G. Ament, R.D. Ankney, C.F. Doumont, P.J. Kotwicki, T.J. Matty, and E.M. Monahan, "WOG Risk-Informed ATWS Assessment and Licensing Implementation Process," WCAP-15831-NP-A, Revision 2, Westinghouse, August 2007 (ADAMS Assession No. ML072550560).

4. Julius, J., J. Grobbelaar, K. Kohlhepp, B. Hannaman, B. Najafi, E. Collins, S. Cooper, K. Hill, J. Forester, and S. Hendrickson, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," EPRI-1019196/NUREG-1921, Electric Power Research Institute/U.S. Nuclear Regulatory Commission, November 2009 (ADAMS Accession No. ML093350494).

[3] A low-level dependency is assessed using the statuses of the following parameters: Intervening success (No), Crew (Same), Cognitive (Different), Cue demand (sequential), Location (same), Sequential timing (30–60 minutes), and Stress (neither high nor moderate). The dependency level is moderate if the Stress is changed to high or moderate.

APPENDIX D
EXAMPLE 2—APPLYING IDHEAS DEPENDENCY GUIDANCE FOR A STUCK-OPEN PRESSURIZER SPRAY VALVE

Plant Type: PWR (Westinghouse)
Operation Mode: Power Operation
Analysis Type: ASP

D.1 Event and Condition Description

This appendix provides an example using the method described in Research Information Letter (RIL) 2020-02, “Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS ECA),” issued February 2020, for analysis and documentation, including dependency analysis. The analysis was based on an accident sequence precursor (ASP) (Ref. 1) analysis. Sections D.1.1 and D.1.2 describe the actual event. Sections D.1.3, D.1.4, and D.1.5 discuss the event sequence, the assumptions, and the scenario context for the analysis, respectively.

D.1.1 Operational Narrative

On September 4, 2020, main control room operators for a pressurized-water reactor (PWR) completed a planned power reduction from 100-percent to 92-percent reactor power in preparation for main turbine valve testing. As reactor coolant system (RCS) pressure reached 2,235 pounds per square inch gauge (psig), one pressurizer (PZR) spray valve (2-NRV-163) began to close as expected; however, the other spray valve (2-NRV-164) unexpectedly opened fully. The operators could not close the failed-open spray valve and subsequently manually tripped the reactor due to lower RCS pressure. RCS pressure continued to decrease below the safety injection (SI) actuation setpoint, resulting in an automatic SI actuation.

All automatic actions in response to the SI signal occurred as expected. These included that all control rods inserted fully; all auxiliary feedwater (AFW) pumps started and supplied the steam generators, and all emergency core cooling system (ECCS) components operated as required. In addition, both emergency diesel generators started automatically. However, they remained unloaded because offsite power remained available throughout the event. The steam dump values removed decay heat, and the ECCS was secured manually. Due to high RCS pressure resulting from the SI actuation, the PZR power-operated relief valves (PORVs) cycled seven times before operators secured PZR spray and terminated SI. The cause of the failed PZR spray valve 2-NRV-164 was foreign material from the control air supply stuck in the positioner spool valve. The operator could not manually close 2-NRV-164. In this event, the operators followed the instructions in E-0 (the emergency operating procedure for a reactor trip and safety injection) to stop reactor coolant pumps (RCPs) 23 and 24 to stop the PZR spray flow and tripped an additional RCP (22) when the RCS pressure continued to decrease.

D.1.2 Event Timeline

The licensee event report of the actual event gives the event timeline summarized below (Ref. 2).

Table D-2: Event Timeline

Date/Time	Description **S**: System status or system automatic responses **I**: System or communicated information available to the operators **H**: Human responses **N**: Notes
9/4/2020	**(S)** Unit 2 was operating at 100-percent power. **(H)** The Unit 2 control room operators were preparing to perform main turbine stop and control valve testing.
16:06	**(H)** The operators placed the initial set of PZR backup heaters into service in preparation for a planned power reduction to support testing. After the heaters were energized, PZR spray valve(s) 2-NRV-163 (reactor coolant loop #3 to PZR spray control valve) and 2-NRV-164 (reactor coolant loop #4 to PZR spray control valve) were modulating to control PZR pressure.
20:35	**(H)** The operators began to lower reactor power in accordance with 2-OHP-4021-011-001, Attachment 2, "Power Reductions Between 89 percent and 100 percent."
22:04	**(I)** Operators reported completing the planned power reduction, and Unit 2 was stable at 92-percent reactor power.
22:37	**(S)** PZR spray valves 2-NRV-163 and 2-NRV-164 closed together as expected in response to a lowering PZR pressure.
22:38	**(S)** Both PZR spray valves began to open upon a valid open signal.
22:39	**(S)** RCS pressure reached 2,235 psig, and 2-NRV-163 began to close, as 2-NRV-164 continued to travel fully open.
22:42	**(I)** The control room received an annunciator, "Pressurizer Pressure Low Deviation Backup Heaters On." **(H)** The operators discovered that 2-NRV-164 was fully open with 0-percent demand and entered procedure 2-0HP-4022-IFR-001, "Instrument Failure Response," and determined that 2-NRV-164 could not be closed using the control board or digital controls on the alarm log panel. In accordance with procedure immediate actions, operators performed a manual trip of the reactor. The operators entered procedure 2-0HP-4023-E-0, "Reactor Trip or Safety Injection." RCPs 23 and 24 were removed from service following verification of E-0 immediate actions. SI was actuated automatically after RCS pressure was lowered below the setpoint (1,815 psig). **(S)** All automatic actions in response to the SI signal occurred as expected. These actions include that the SI signal initiates a reactor trip (this may have already occurred); starts the diesel generators; opens the boron injection tank isolation valves and the centrifugal charging pump (CCP) refueling water storage tank (RWST) suction valves; and starts the CCPs, the SI pumps, and the residual heat removal pumps. In addition, isolation valves on the volume control tank discharge, charging line, and CCP minimum flow lines close. A safety injection signal will also initiate main feedwater isolation, actuate the auxiliary feedwater system, isolate control room ventilation, actuate an essential service water pump, initiate containment ventilation isolation, and produce a phase A containment isolation signal, which results

Date/Time	Description **S**: System status or system automatic responses **I**: System or communicated information available to the operators **H**: Human responses **N**: Notes
	in the closure of the majority of the automatic containment isolation valves, isolating all nonessential process lines. **(S)** Following the trip, Unit 2 was supplied with offsite power. All control rods fully inserted. The auxiliary feedwater pumps started and operated as expected. All ECCS components and containment isolation operated as required. Both emergency diesel generators started automatically and remained on standby. The condenser steam dump valves removed decay heat, and the ECCS was secured. **(H)** During SI termination, RCP 22 was removed from service due to continued lowering RCS pressure caused by the failed-open PZR spray valve 2-NRV-164. Afterward, RCS pressure recovered to normal pressure and remained stable.

D.1.3 Identify and Define the Human Failure Events

This section discusses the analysis of the risk associated with the actual event described in Sections D.1.1 and D.1.2. The risk is assessed by assuming that a random crew in the same event may fail to respond properly, leading to core damage. The analysis uses ASP practices to assess the risk using the NRC's probabilistic risk assessment (PRA) model for the plant. The ASP analysis (Ref. 3) identified that the most likely core damage sequence of the PRA model was in the event tree of inadvertent SI actuation. Figure D-1 shows the event tree. The event sequence of interest is Sequence 5, which includes two human failure events (HFEs): terminate SI and initiate high-pressure recirculation. This appendix analyzes the two HFEs and the dependency effects of terminating SI (HFE1) on initiating high-pressure recirculation (HFE2).

The event sequence starts with an SI signal that triggers an automatic reactor trip. The operators' procedure path is to enter E-0 cued by the reactor trip, then transfer to appropriate procedures. The procedure to terminate SI is ES-1.1, and the procedure to perform high-pressure recirculation is ES-1.3. The following E-0 steps are relevant to this event sequence:

- Step 15: Check the statuses of PZR PORVs, PZR block valves, and spray valves:
  - PZR PORVs and block valves:
    1. If RCS pressure is less than 2,335 psig and any PORV is open, then manually close the opened PZR PORVs.
    2. If the PORV cannot be closed, then close the PZR block valves.
    3. If the block valves cannot be closed, then transfer to E-1, "Loss of Reactor or Secondary Coolant."

– PZR spray valves (including the procedure instruction on handling PZR spray valves' statuses because the actual event was initiated by a PZR spray valve stuck open; the risk analysis includes the situation's effects on operator performance):

1. If RCS pressure is less than 2,260 psig then close all spray valves.

2. If any spray valve cannot be closed, stop RCPs 23 and 24 to stop the spray flow.

3. If RCS pressure continues to decrease, then stop another RCP.

- Step 20: Transition to ES-1.1 to terminate SI flow if RCS subcooling, secondary heat sink, RCS pressure, and PZR level met the specified criteria. The key criterion in this event is that the RCS pressure needs to be stable or rising.

- Step 31 (last step in E-0): Return to Step 14 to diagnose the event again.

- Foldout page: Transfer to ES-1.3 when RWST water level reaches 30 percent.

If the scenario progresses to an unisolable loss-of-coolant accident (LOCA) before the SI is terminated, then the SI should not be terminated. The operator would transfer to E-1 (LOCA procedure) from E-0. E-1 instructs the operator to use either cold-leg recirculation (ES-1.3) or hot-leg recirculation (ES-1.4) to cool the reactor. The following are the related E-1 instructions:

- Foldout page: Transfer to ES-1.3 when RWST water level reaches 30 percent.
- Step 13: Transfer to ES-1.3 when RWST water level reaches 30 percent.
- Step 19: Transfer to ES-1.4 when the event has lasted 7 hours.

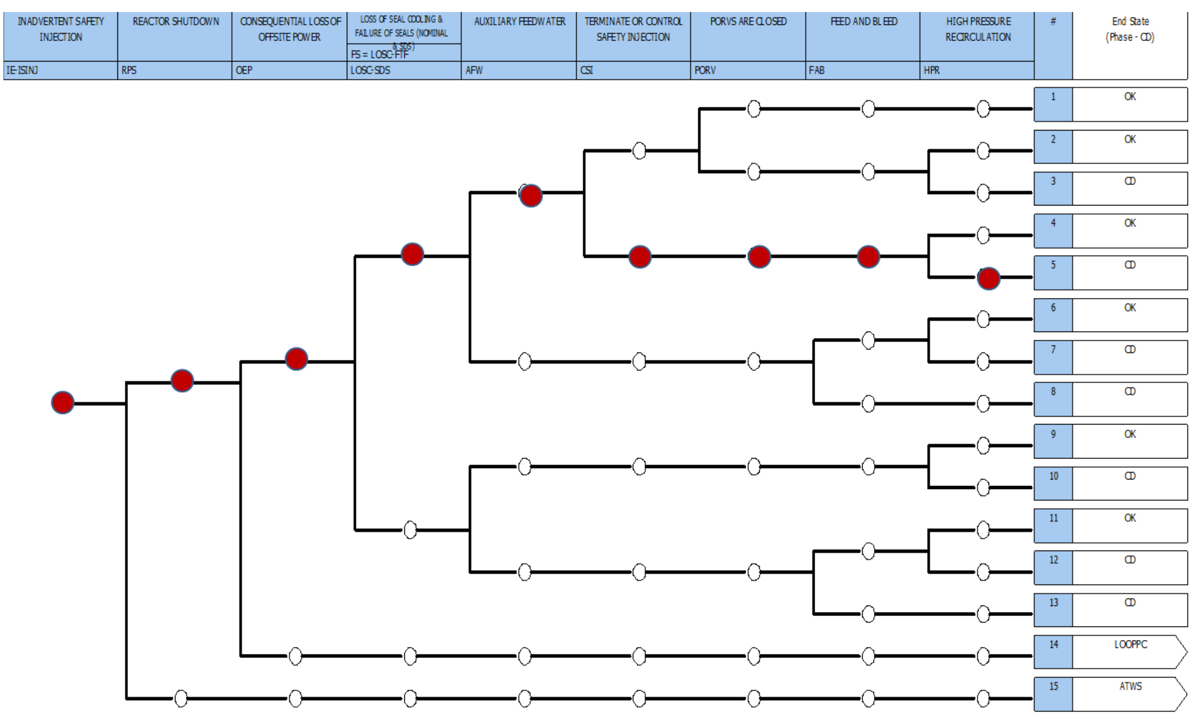


Figure D-8: The Event Sequence of the Analysis

Based on the analysis assumptions (discussed in Section D.1.4), the operators are most likely using cold-leg recirculation (ES-1.3) in Sequence 5. ES-1.3 serves to ensure there is sufficient water level in the sump to perform cold-leg recirculation. Therefore, after entering ES-1.3 when the RWST water level reaches 30 percent, ES-1.3 instructs the operators not to initiate a cold-leg recirculation until the RWST water level is further decreased to 20 percent.

D.1.4 Analysis Assumptions

This section discusses the assumptions applied to the analysis of the two HFEs (terminate SI and initiate high-pressure recirculation) shown in Sequence 5 in Figure D-1. Because the purpose of this appendix is to demonstrate application of the IDHEAS-ECA method and dependency model, the analysis did not follow a rigorous human reliability analysis (HRA) process, which requires significant effort to collect data for the analysis (e.g., talk-through, walkthrough, simulation observations). Instead, the parameter values used in the analysis are based on assumptions. This appendix explicitly states the assumptions supplemented with the information available in the final safety analysis report. The uncertainty analysis section for each HFE discusses the important factors affecting the uncertainty of the HFE's human error probability (HEP) estimate. The same section includes a sensitivity analysis to show the range of uncertainty impacts.

<u>Assumptions related to the system behavior affecting RWST water level</u>

Immediately after the reactor trip, CCPs inject water from the RWST into the RCS. Without operator intervention, the PZR would eventually be filled with water. The water would be purged out of the RCS through either PZR PORVs or safety valves, or both. As a result, the RWST inventory would continue to reduce until the CCPs stop. RWST water level reaching 30 percent is the procedure cue to transfer to ES-1.3 to initiate cold-leg recirculation. This analysis applies the following assumptions to calculate the time to reach this RWST water level:

- Sequence 5 includes no operator action or automatic function to control CCP flow rates.
- Initially, two CCPs inject water into the RCS at their designed flow rate (150 gallons per minute (gpm) per pump, as given in the final safety analysis report) until the PZR is filled with water.
- Two PZR PORVs are stuck open when the PZR is filled with water. After this point, the leakage flow rate changed to the maximum flow rate allowed by the PORVs (i.e., 420 gpm per PORV).[1]
- The PZR water level initially is at 55 percent. The total PZR volume is 1,800 cubic feet (ft^3).
- The RWST water level initially is at 95 percent. The RWST is a cylindrical tank with height and internal diameters of 31 and 48 feet, respectively, as given in the final safety analysis report. That is equivalent to a maximum capacity of 420,000 gallons (at 100-percent water level). The plant normally maintains the RWST water level at 95 percent, which is about 399,000 gallons.

The following shows the timing calculations.

[1] A CCP's maximum flow rate is 550 gpm, which is sufficient to provide the 420 gpm maximum flow rate of a PZR PORV.

Calculation: The time from reactor trip to when the PZR is filled with water

The PZR total volume is 1,800 ft^3 initially, and 55 percent of the volume is initially water; the other space is filled with steam. The total designed flow rate of two CCPs is 300 gpm. Therefore, the time for the PZR to be filled with water is 20.2 minutes (= 1,800 $ft^3 \times$ 7.48 gallons per $ft^3 \times 0.45 \div$ 300 gpm).

Calculation: The time from when the PZR is filled with water to the RWST water level reaching 30 percent

After the PZR is filled with water, two PZR PORVs are assumed to have failed open and remain open. This changes the combined CCP flow rate from the designed flow rate (300 gpm in total) to the maximum flow rate of the two PORVs (840 gpm in total). The time from the PZR being filled with water to the RWST water level reaching 30 percent is found by calculating the RWST inventory available between 30 percent and 95 percent, subtracting the water lost to fill the steam volume of the PZR, then dividing by the flow rate through the two PORVs. The calculated time is 318 minutes {= [420,000 gallons $\times$ (0.95 – 0.3) – 1,800 $ft^3 \times 0.45 \times$ 7.48 gallons per ft^3] $\div$ 840 gpm)}.

Calculation: The time from the reactor trip to the RWST water level reaching 30 percent

The total time is 338 minutes (= 20.2 + 318 minutes), based on the calculations above.

Assumptions related to the time available to terminate SI

The time available for the operator to terminate SI is 338 minutes (5.6 hours). The time window starts at the reactor trip and ends at the RWST water level reaching 30 percent.

Assumptions related to the time required to terminate SI

The operators’ procedure path to terminate SI starts at E-0, then at E-0, Step 20, transfers to ES-1.1. In ES-1.1, Step 2 instructs the operator to stop all but one CCP and place the CCP in NEUTRAL status. Steps 3 to 11 instruct the operators to check and align the plant configuration to ensure the ECCS is not needed. Therefore, the time required to terminate SI is the time to complete the procedure path (from E-0, Step 1, to ES-1.1, Step 11). The estimated time required is 15 minutes.

Assumptions related to the time available to initiate high-pressure recirculation

The most likely procedures that instruct the operators to perform high-pressure recirculation in Sequence 5 are E-0 and E-1. They provide two options for high-pressure recirculation:

- Transfer to ES-1.3 when the RWST water level reaches 30 percent, based on E-0 and E-1.
- Transfer to ES-1.4 when the LOCA event has lasted 7 hours, based on E-1.

Based on the above analysis, the RWST water level would reach 30 percent before 7 hours in a LOCA event. Therefore, the timing assessment for initiating high-pressure recirculation is based on cold-leg recirculation.

Once entering ES-1.3, and once the RWST water level reaches 30 percent, the procedure instructs the operators to wait until the RWST water level further decreases to 20 percent to initiate cold-leg recirculation. This requirement ensures that the containment sump has sufficient water level for cold-leg recirculation. This analysis assumes the following:

- The CCPs' injection flow rate remains the same (840 gpm in total).
- When the RWST water level decreases to 5 percent, the CCPs will fail due to cavitation. This time point serves as the end of the time window for high-pressure recirculation.

Based on the above assumptions, the RWST water level decreases from 30 percent to 20 percent in 50 minutes (= 420,000 gallons × 0.1 ÷ 840 gpm). The operators are expected to monitor the RWST water level closely when the level is between 20 percent and 30 percent. The water level decreases from 20 percent to 5 percent in 75 minutes (= 420,000 gallons × 0.15 ÷ 840 gpm). Because the diagnosis takes no time for HFE2, 75 minutes are available for actions, and this time is used to calculate P_t.

<u>Assumptions related to the time required to initiate high-pressure recirculation</u>

The operators enter ES-1.3 when the RWST water level reaches 30 percent, but they have to wait until the level decreases to 20 percent to initiate the cold-leg recirculation. Because the diagnosis is straightforward and takes no time, this analysis only uses action time to calculate P_t. The action instruction is on Step 6, which contains 21 substeps. The estimated time required for action is 12 minutes.

D.1.5 Identify Scenario Context

D.1.5.1 Environment and Situation Context

Environment and Situation context includes the following factors: • Work location accessibility and habitability • Workplace visibility • Noise in workplace and communication pathways • Cold/heat/humidity • Resistance to physical movement

All actions were performed in the main control room. No perceived environmental factors would affect crew performance.

D.1.5.2 System Context

The system context includes the following factors: • System and instrumentation and control transparency to personnel • Human-system interfaces • Equipment and tools

The human-system interface was normal. No information transparency issue was perceived, and no special equipment and tools were needed.

D.1.5.3 Personnel Context

Personnel context includes the following factors: • Staffing • Procedures, guidelines, and instructions • Training • Teamwork and organizational factors • Work processes

Operators were well trained to respond to the scenario. The operators' responses in the actual event demonstrated adequate knowledge, skills, and abilities to respond to an inadvertent SI actuation transient. In addition, terminating SI and initiating cold-leg recirculation were transferred from either E-0 or E-1. The operators received routine simulator training on E-0 and E-1. The procedures provided clear instructions to handle the event.

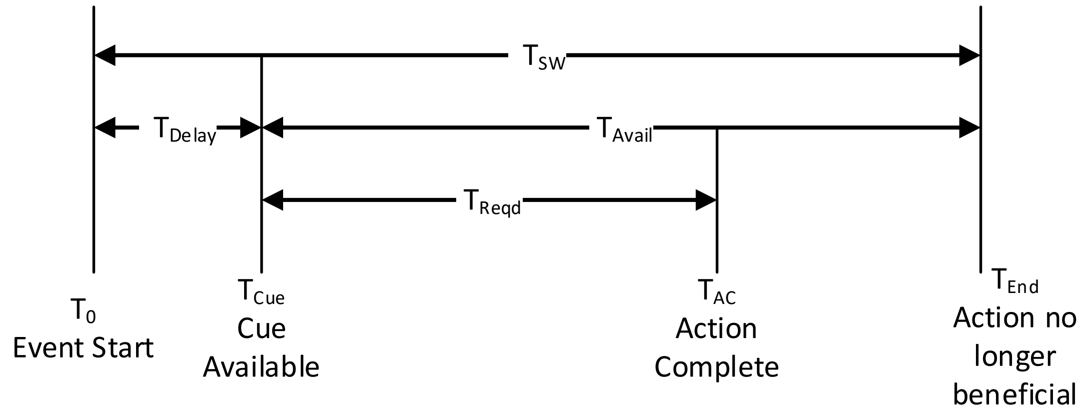
D.1.5.4 Task Context

Task context includes the following factors: • Information availability and reliability • Scenario familiarity • Multi-tasking, interruptions and distractions • Task complexity • Mental fatigue • Time pressure and stress • Physical demands

The event was an unexpected SI actuation event. All indications for the operators to diagnose the plant abnormality and verify actions were functioning properly. All tasks (detecting cues, understanding the situation, decisionmaking, and executing the action) on the two HFEs were instructed by procedures. A human performance consideration is that the cold-leg recirculation could be performed until more than 5 hours after the reactor trip. Fatigue could affect the performance, assuming that the same crew handles the whole scenario.

D.2 Human Failure Event Analysis

The event sequence of interest is an inadvertent SI actuation without complications. Sections D.2.1 and D.2.2 discuss HFE1 (terminate SI) and HFE2 (initiate cold-leg recirculation), respectively. Figure D-2 shows a timeline representation of an HFE for the discussion.



Where,

T_{SW}: System time window. The beginning to the end of the time window of an HFE.

T_{Delay}: The time from the event occurring to the time that the cue related to the event is available to the crew.

T_{Avail}: The time available for the crew to respond.

T_{Reqd}: The time required (or needed) for the crew to respond to the event, including diagnosis and actions.

T_0: The beginning of T_{SW}. Usually, T_0 is when the event occurs that requires the operator response.

T_{Cue}: The time at which the cue become available to the crew.

T_{AC}: The time at which the required mitigation action is complete.

T_{End}: The time after which the crew actions (the HFE of analysis) are no longer beneficial to the scenario.

Figure D-9: Timeline Diagram

D.2.1 HFE1—Terminate SI (XHE-CSI)

D.2.1.1 Define Human Failure Event

The following summarizes the key parameters that characterize HFE1:

- T_0: The time at which the reactor trips.
- T_{Cue}: The time at which reactor trip indications occurred.
- T_{AC}: The time at which the operator completed ES-1.1, Step 11, to ensure the ECCS is not needed.
- T_{End}: The time at which the RWST water level reaches 30 percent.
- T_{SW}: 338 minutes (see Section D.1.4).

- T_{Delay}: 0 minutes (= $T_{Cue} - T_0$).

- T_{Avail}: 338 minutes. A constant value of 338 minutes is used to calculate P_t. Section D.2.1.4 discusses the uncertainty analysis.

- T_{Reqd}: 15 minutes (see Section D.1.4). A normal distribution, with a mean of 15 minutes and a standard deviation of 4 minutes, represents the uncertainty distribution of the time required.

Error Recovery Opportunities

A recovery factor of 10 is applied to all the cognitive failure modes (CFMs) of the analysis to credit the extended time available (338 minutes), compared to the time required (15 minutes). The justification is that as the scenario progresses, more plant indications and symptoms would be available to support the diagnosis and decision to terminate SI. If the operators mistakenly transferred to a wrong procedure or performed actions incorrectly, the plant symptoms and extended time available provide opportunities and time to turn the scenario around. The recovery factor of 10 was determined based on the analyst's judgment. At the time of this analysis, IDHEAS-ECA has not provided quantitative guidance to credit error recovery. Once the guidance is available, the readers should refer to the guidance to assess the error recovery factor.

D.2.1.2 Task Analysis and Critical Task Identification

HFE1 is modeled by a critical task with three CFMs: Detection, Understanding, and Action Execution.

- The Detection CFM is about the reliability to detect the alarms and indications required to initiate the diagnosis process and to follow the procedure path.

- The Understanding CFM is about the reliability to follow the procedure path correctly (i.e., enter E-0, Step 1, then at E-0, Step 20, transfer to ES-1.1, Step 1, then implement ES-1.1 until Step 11 (ensure ECCS is not needed)). Depending on the scenario tempo and the operators' pace in following the procedures, the operators may need to loop between E-0, Step 14, and E-0, Step 31, until the plant condition is met to transfer to ES-1.1. The Understanding CFM is also about not transferring to wrong procedures. A recovery factor of 10 is applied (discussed with respect to error recovery opportunities in Section D.2.1.1) to credit that the operators could return to the correct procedure path in time after entering a wrong procedure.

- This analysis excludes the Decisionmaking CFM. The justification is that once the operators understood that the event was an inadvertent SI actuation, the procedure instructs the operators to enter ES-1.1 to terminate SI. E-0 provides only one option (enter ES-1.1) to the operator. There is no foreseeable reason that the operator would not follow the procedure instruction.

- The Action Execution CFM is about the reliability to perform ES-1.1, Step 1, to ES-1.1, Step 11 (ensure ECCS is not needed).

- This analysis excludes the Interteam CFM because the same crew performs all activities.

D.2.1.3 Estimate Human Error Probability

HEP(P_c + P_t) = 2.10E-04
HEP($P_{c's}$) = 2.10E-04
HEP(P_t) = 0.00E00

D.2.1.3.1 Calculate P_c

HEP(Detection, with recovery): 1.00E-05
Recovery Factor(Detection): 10

- HEP(Detection): Scenario Familiarity: SF0: No impact
- HEP(Detection): Task Complexity: C0: No impact

HEP(Understanding, with recovery): 1.00E-04
Recovery Factor(Understanding): 10

- HEP(Understanding): Scenario Familiarity: SF0: No impact
- HEP(Understanding): Information Completeness and Reliability: INF0: No impact
- HEP(Understanding): Task Complexity: C0: No impact

HEP(Action Execution, with recovery): 1.00E-04
Recovery Factor(Action Execution): 10

- HEP(Action Execution): Scenario Familiarity: SF0: No impact

- HEP(Action Execution): Task Complexity: C31: Straightforward procedure execution with many steps

Justification: Complete ES-1.1, Step 1, to ES-1.1, Step 11, to terminate ECCS flow.

D.2.1.3.2 Calculate P_t

The time required and time available parameters are shown below. The calculated P_t is zero.

Time Required Distribution Type: Normal Distribution Mean = 15 minutes Standard Deviation = 4 minutes	Time Available Distribution Type: Constant Value = 338 minutes

D.2.1.4 Uncertainty Analysis

The main uncertainty factors contributing to the reliability of HFE1 are the estimates of the time available and the error recovery factor.

Two factors determine the time available to terminate SI: RWST water level reaching 30 percent, and the scenario developing into an unisolable loss of coolant accident (LOCA). Both factors have a large uncertainty. The time that RWST water reaches 30 percent is calculated based on the following assumptions: (1) two CCPs inject water into the RCS by withdrawing water from the RWST at the CCPs' designed flow rate until the PZR is filled with water, (2) two PORVs failed open when the PZR is filled with water, and the CCPs' injection flow rate increases to the maximum flow rate of the two PZR PORVs, and (3) there is no human action or automatic control of the CCP flow rate throughout the scenario. These assumptions involve great uncertainty about the time that the RWST water level reaches 30 percent.

The other factor affecting the time available is whether and when the scenario developed into an unisolable LOCA before the SI was terminated. If the scenario becomes an unisolable LOCA (e.g., stuck-open safety valves or combinations of stuck-open PORVs and unable to close PZR block valves), the operators will not isolate SI. Instead, the operators would transfer to E-1, which instructs the operators to wait until the RWST water level reaches 30 percent to transfer to ES-1.3 to initiate cold-leg recirculation. Table D-2 shows the calculated P_t corresponding to when the scenario developed into an unisolable LOCA. The table uses the same time required distribution (a normal distribution with a mean of 15 minutes and a standard deviation of 4 minutes) for the calculation. The shortest time (20.2 minutes) is when the PZR is full of water. The results show that P_t is comparable to or greater than P_c if the scenario developed into an unisolable LOCA within 30 minutes after the reactor trip.

Table D-3: P_t of HFE1 (Terminate SI) versus the Time the Scenario Developed into an Unisolable LOCA

Time (min)	20.2	28	30	338
P_t	9.7E-2	5.8E-4	8.8E-5	0

D.2.2 HFE2—High-Pressure Recirculation (XHE-HPR)

D.2.2.1 Define Human Failure Event

The following summarizes the key parameters in analyzing HFE2:

- T_0: The time that RWST water level reaches 30 percent.
- T_{Cue}: The time that the indication of RWST water level reaches 30 percent.
- T_{AC}: The time that the operator completed ES-1.3, Step 16, to initiate cold-leg recirculation, including isolating the RWST from the recirculation path.
- T_{End}: The time that the RWST water level reaches 5 percent, assuming the RWST inventory decrease rate is the maximum flow rate of the two PZR PORVs.
- T_{SW}: 125 minutes. This includes 50 minutes for the RWST water level to decrease from 30 percent to 20 percent, and 75 minutes to decrease from 20 percent to 5 percent.
- T_{Delay}: 0 minutes (= $T_{Cue} – T_0$).
- T_{Avail}: 125 minutes. However, only 75 minutes are used to calculate P_t because the diagnosis and decision would take less than 50 minutes, and the operators cannot start the actions until 50 minutes after T_0.
- T_{Reqd}: 12 minutes, the time to perform the action portion of the procedure (i.e., ES-1.3, Step 6, which has 21 substeps). This analysis uses a normal distribution with a mean of 12 minutes and a standard deviation of 3 minutes to represent the T_{Reqd} uncertainty.

D.2.2.2 Task Analysis and Critical Task Identification

HFE2 is modeled by a critical task with four CFMs: Detection, Understanding, Decisionmaking, and Action Execution, as discussed below:

- Detection CFM: This CFM concerns the reliability of detecting the RWST water level and the parameters essential to implement ES-1.3 until Step 6.
- Understanding CFM: This CFM concerns the reliability of being able to correctly follow ES-1.3. Specifically, ES-1.3, Step 4, checks that the RWST water level is less than 20 percent, and Step 5 checks that the containment sump water level is greater than the minimum recirculation water level. The assessment of the two steps leads to the understanding that the condition is ready for cold-leg recirculation.
- Decisionmaking CFM: Once the operators conclude that the plant conditions are ready for cold-leg recirculation, even though ES-1.3 instructs the operator to initiate cold-leg recirculation, this analysis considers that performing cold-leg recirculation would cause high radiation in the auxiliary building. This consideration could potentially cause the operator to decide to delay the implementation of cold-leg recirculation. The Decisionmaking CFM addresses the reliability of making this decision.
- Action Execution CFM: This concerns the reliability of performing ES-1.3, Step 6, which has 21 substeps, to implement cold-leg recirculation.
- Interteam CFM: This analysis does not include the Interteam CFM because all activities are performed by the same crew.

The T_0 of HFE2 will not start until more than 5 hours after the reactor trip. This analysis assumes the same crew responds to the event from the beginning. This assumption justifies applying the performance influencing factor (PIF) attribute MF5 (long working hours (> 4 hours) with highly cognitively demanding tasks) of the PIF "Mental Fatigue, Stress, and Time Pressure" to all the modeled CFMs.

Error Recovery Opportunities

This analysis applies an error recovery factor of 2 for the action CFM because the indications for action effectiveness are available and timely, and there is a relatively long time available (75 minutes) compared to the time required (12 minutes). No error recovery is credited for the other CFMs because the RWST water level is the only indication for the diagnosis of HFE2.

D.2.2.3 Estimate Human Error Probability

HEP(P_c + P_t) = 3.50E-03
HEP($P_{c's}$) = 3.50E-03
HEP($P_{t)}$ = 0.00E00

D.2.2.3.1 Calculate P_c

HEP(Detection, with recovery): 1.50E-04
Recovery Factor(Detection): 1

- HEP(Detection): Mental Fatigue, Stress, and Time Pressure: MF5: Long working hours (> 4 hours) with highly cognitively demanding tasks

  Justification: The HFE is started more than 5 hours after the reactor trip.

HEP(Understanding, with recovery): 1.50E-03
Recovery Factor(Understanding): 1

- HEP(Understanding): Mental Fatigue, Stress, and Time Pressure: MF5: Long working hours (> 4 hours) with highly cognitively demanding tasks

  Justification: The HFE is started more than 5 hours after the reactor trip.

HEP(Decisionmaking, with recovery): 1.10E-03
Recovery Factor(Decisionmaking): 1

- HEP(Decisionmaking): Mental Fatigue, Stress, and Time Pressure: MF5: Long working hours (> 4 hours) with highly cognitively demanding tasks

  Justification: The HFE is started more than 5 hours after the reactor trip.

HEP(Action Execution, with recovery): 7.50E-04
Recovery Factor(Action Execution): 2

- HEP(Action Execution): Task Complexity: C31: Straightforward procedure execution with many steps

  Justification: Perform ES-1.3, Step 6.

- HEP(Action Execution): Mental Fatigue, Stress, and Time Pressure: MF5: Long working hours (> 4 hours) with highly cognitively demanding tasks

  Justification: The HFE is started more than 5 hours after the reactor trip.

D.2.2.3.2 Calculate P_t

The time required and time available parameters are shown below. The calculated P_t is zero.

Time Required Distribution Type: Normal Distribution Mean = 12 minutes Standard Deviation = 3 minutes	Time Available Distribution Type: Constant Mean = 75 minutes

D.2.2.4 Uncertainty Analysis

The analysis shows that performing cold-leg recirculation is a high-reliability task. The HEP contribution is all from P_c. That contribution is reasonable because of the extended time available for the Detection, Understanding, Decisionmaking and Action Execution CFMs of HFE2 compared to the time required. An uncertainty factor is the inclusion of the

Decisionmaking CFM because of potential radiation effects even though ES-1.3 does not consider radiation to implement a cold-leg recirculation.

D.3 <u>Dependency Analysis</u>

This section documents the dependency analysis to assess the dependency effect of HFE1 (terminate SI) on HFE2 (high-pressure recirculation). In the discussion, a checked check box (☒) indicates that the corresponding criteria are satisfied. An unchecked check box (☐) indicates that the criteria are not satisfied. This section discusses a complete dependency analysis process, including evaluation of the entry condition (Section D.3.1), Predetermination Analysis (Section D.3.2), Screening Analysis (Section D.3.3), and Detailed Analysis (Section D.3.4). Section D.3.5 discusses the overall dependency analysis. The IDHEAS dependency analysis guidance worksheets are used to document the analysis. Each of the following subsections start with the assessment results, followed by assessment details.

D.3.1 Entry Condition

<u>Result</u>

Proceed to Predetermination Analysis (Section D.3.2).

<u>Evaluation</u>

☒ (a) HFE1 and HFE2 are in the same PRA event sequence or minimal cutset, ***AND*** (b) there are no relevant human action success events between HFE1 and HFE2 in the sequence. ***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. These are also called at-initiators and are common at shutdown.

<u>Additional Considerations</u>

- Assessing Time Sequence: HFE1 and HFE2 occur in sequence. HFE1 precedes HFE2.
- Assessing Dependency for More Than Two HFEs: Not applicable.
- Relevant Intervening Successes: No intervening success.
- Determining whether Dependency Analysis Is Necessary: Yes.

D.3.2 Predetermination Analysis

<u>Assessment Result</u>

☐	HFE2 is completely dependent on HFE1; thus, the adjusted probability of HFE2 is 1.0.
☐	HFE2 is independent of HFE1; thus, the adjusted HEP of HFE2 is equal to the individual HEP of HFE2.
☒	One or more dependency relationships exist; thus, the analyst proceeds to either Step 2, Screening Analysis, or Step 3, Detailed Analysis, to obtain the dependent HEP of HFE2.

Assessment Details

Relationship	Assessment Guidelines	
Complete Dependency	☒ HFE1 and HFE2 use the same procedure, ***AND*** ☐ HFE1 is likely to occur because of issues associated with the common procedure (such as having an ambiguous or incorrect procedure), ***AND*** ☐ There is no opportunity to recover from the issue with the procedure between HFE1 and HFE2. **Justification:** (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 HEF2 are different. The common procedure is not a likely cause of dependency.	☐YES ☒NO
R1— Functions or Systems	☒ HFE1 and HFE2 have the same functions or systems, ***OR*** ☒ HFE1 and HFE2 have coupled systems or processes that are connected due to automatic responses or resources needed. **Justification:** HFE1 and HFE2 use the same system (ECCS) for different functions. HFE1's function is to control RCS inventory. HFE2 provides core cooling.	☒YES ☐NO
R2— Time Proximity	☐ HFE1 and HFE2 are performed close in time, ***OR*** ☐ The cues for HFE1 and HFE2 are presented close in time.	☐YES ☒NO
R3— Personnel	☒ HFE1 and HFE2 are performed by the same personnel. **Justification:** HFE1 and HFE2 are assumed to be performed by the same crew.	☒YES ☐NO
R4— Location	☒ HFE1 and HFE2 are performed at the same location, ***OR*** ☐ The workplaces for HFE1 and HFE2 are affected by the same condition (such as low visibility, high temperature, low temperature, or high radiation). **Justification:** HFE1 and HFE2 are performed in the main control room. No environmental factors are expected to affect the reliability of HFE1 and HFE2.	☒YES ☐NO
R5— Procedure	☒ HFE1 and HFE2 use the same procedure. **Justification:** HFE1 and HFE2 could share the same procedure (E-0).	☒YES ☐NO

D.3.3 Screening Analysis

The Predetermination Analysis identified that dependency could exist in R1 (Functions or Systems), R3 (Personnel), R4 (Location), and R5 (Procedure). This Screening Analysis only assesses dependency in these four relationships. The total error probability as a result of the dependency effect is 2E-3. The following are the dependency effects on HEP (P_d):

- P_d(R1) = 0.0
- P_d(R3) = 2E-3
- P_d(R4) = 0.0
- P_d(R5) = 0.0

With the individual HEP of 3.5E-3 calculated for HFE2 (discussed in Section D.2.2.3), the combined HEP with dependency effects, based on the Screening Analysis, is 5.5E-3.

Sections D.3.3.1 to D.3.3.4 discuss the analyses of R1, R3, R4, and R5, respectively. Note that the dependency analysis identified mental fatigue as a dependent factor that was already considered in the individual HEP calculation (discussed in Section D.2.2.3). Therefore, including the effects in the Screening Analysis is a double count. Nevertheless, the Screening Analysis identifies fatigue effects to compare the numerical difference between the Screening Analysis and Detailed Analysis on the same consideration.

D.3.3.1 R1—Functions or Systems

<u>Assessment Result</u>

The probabilistic sum of P_d(R1) = 0.0.

<u>Assessment Details</u>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.1 Use of the same functions or systems leads to cognitive dependency A. Occurrence of HFE1 leads to the scenario or parts of the scenario being different from what was typically trained on; thus, the scenario associated with HFE2 becomes less familiar. (Note: Occurrence of HFE1 alters the scenario for	☐ A—HFE2 was trained on in the scenarios in which HFE1 occurs (e.g., Feed & Bleed is the last action after others fail), so there is no unfamiliarity due to HFE1. ☒ B—HFE2 is well trained in various scenarios such that personnel are unlikely to develop a wrong mental model due to the occurrence of HFE1. **Justification:** HFE2 is a LOCA, a routinely trained scenario.	This cognitive dependency potentially affects the PIF for scenario familiarity, which addresses the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model. Low: P_d = 5E-2 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
HFE2; thus, HFE1 causes some level of unfamiliarity with HFE2.) B. Occurrence of HFE1 leads to an incorrect or biased mental model of the situation associated with HFE2.	☒ 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 the mental model associated with HFE2. **Justification:** HFE1 and HFE2 are for different objectives based on different cues. ☐ B—There are opportunities between the HFEs to break the incorrect mental model, such as multiple crews or diverse cues.	Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies.
		High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links between HFE1 and HFE2 (i.e., thought process).
R1.2 Use of the same functions or systems leads to consequential dependency A. Occurrence of HFE1 makes HFE2 more complex because the systems, indications, or controls for HFE2 may be incorrect, misunderstood, or in a different status due to occurrence of HFE1. B. Occurrence of HFE1 makes the information for diagnosis or decisionmaking for HFE2 less timely or less trusted (e.g., personnel discount indications or cues for HFE2 due to inadequate training on the unusual or unexpected scenario created by HFE1 or early termination of information collection).	☐ A—No common equipment (e.g., different trains), different interfaces, and different indications and controls. ☒ A/B—Occurrence of HFE1 does not impact the information or cues used for HFE2, so there is no impact on the information needed for HFE2. **Justification:** RWST water level is always available and accurate in this analysis. ☐ B—Personnel have firm information or multiple sources of information that are consistent. ☐ A/B—Occurrence of HFE1 is obvious, and personnel are trained to diagnose HFE2 given occurrence of HFE1.	This consequential dependency potentially impacts the PIFs for task complexity and information availability and reliability.
		Low: P_d = 1E-2 Task is relatively simple, and one or two of the following apply: ☐ Cues for detection are less obvious. ☐ Execution criteria become complicated or ambiguous. ☐ Potential outcome of the situation assessment becomes more complicated (e.g., multiple states and contexts, not a simple yes or no). ☐ Decisionmaking criteria become intermingled, ambiguous, or more difficult to assess.
		Medium: P_d = 5E-2 ☐ More than two items in "Low" are applicable.
		High: P_d =2E-1 One or more of the following apply: ☐ Cues are masked or must be inferred. ☐ Detection of the critical information is entirely based on personnel's experience and knowledge. ☐ Execution of the critical task requires breaking away from trained scripts. ☐ HFE1 creates ambiguity associated with assessing the situation for performing HFE2. ☐ HFE1 creates competing or conflicting goals for decisionmaking of HFE2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R1.3 Use of the same functions or systems leads to resource-sharing dependency A. Shared tools or equipment leads to shortage of tools or equipment needed for HFE2. B. Shared resources (e.g., water, power, or offsite resources such as fire trucks) lead to inadequate resources or increased complexity for HFE2.	☒ A—No shared or no shortage of tools or equipment. ☒ B—No shared or no shortage of resources. **Justification:** No special tool is needed for HFE2. No shared resources between HFE1 and HFE2. ☐ A/B—There is adequate time to perform the actions sequentially using the shared tools, equipment, or resources.	This resource-sharing dependency potentially impacts the PIF for task complexity because the portion of resources HFE2 shares with HFE1, such as power in FLEX events, may be reduced due to HFE1.
		Low: P_d = 2E-3 ☐ Tool or resource shortage increases task difficulty, such as the following: – high spatial or temporal precision – precise coordination of multiple persons – unusual, unevenly balanced loads, reaching high parts – continuous control that requires dynamic manipulation
		Medium: P_d = 1E-2 ☐ Complicated or ambiguous execution criteria are present, such as the following: – multiple, coupled criteria – open to misinterpretation
		High: P_d = 5E-2 ☐ Action execution requires close coordination of personnel at different locations.

D.3.3.2 R3—Personnel

<u>Assessment Result</u>

P_d(R3) = 2E-3

<u>Assessment Details</u>

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.1 Use of the same personnel leads to cognitive dependency A. Same person performs the two HFEs; thus, the person may incorrectly interpret the situation for	☒ A—Training and experience rule out the possibility of misinterpreting the situation (e.g., since emergency operating procedures (EOPs) are symptom based and well trained upon, it is difficult to sustain a wrong mental model).	This cognitive dependency potentially affects the PIFs for scenario familiarity, which address the mental model. Scenario familiarity is applicable when something is wrong with the mental model and no diverse methods are available to correct the wrong mental model.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
HFE2 due to occurrence of HFE1. B. Same personnel or crew makes diagnosis or decisionmaking in the two HFEs; thus, personnel may experience groupthink, which causes a biased or incorrect mental model for HFE2 (e.g., during the accident at the Three Mile Island nuclear plant, operators did not put water in because they did not think they needed water).	**Justification:** HFE2 is a LOCA, a design-basis event that operators are routinely trained on. ☐ A—The HFEs are not performed by the same person. ☐ A/B—Additional people are available to break groupthink or question the interpretation of the situation (e.g., presence of the shift technical advisor (STA) can discount A/B if the STA would have reason to review the actions being taken). **Justification:** Additional plant staff may be available, but this is not assumed in this analysis. ☒ A/B—Different procedures are used for HFE1 and HFE2. **Justification:** HFE1 and HFE2 are completely different diagnoses (different cues, different objectives). Even though they share the same E-0, their main activities are in different procedures (ES-1.1 and ES-1.3). ☐ B—Work process independence factors are used that could break groupthink or the wrong mental model (e.g., monitoring of the critical function status trees could provide a way to break the wrong mental model). ☐ B—New cues before HFE2 (from procedures, indications, or success of other human actions) can break down the wrong mental model from occurrence of HFE1 ***AND*** additional people are available to detect the cues ***AND*** adequate time is available to detect the new cues.	Low: P_d = 5E-2 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***OR*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. Medium: P_d = 1E-1 ☐ Parts of the scenario become unfamiliar (e.g., different from what was trained on), ***AND*** ☐ HFE1 creates a biased mental model or preference for wrong strategies. High: P_d = 3E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2 due to close cognitive links (i.e., thought process).
R3.2 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	☐ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. **Justification:** Simulator training never requires the crew to wait for more than 5 hours before performing cold-leg recirculation (HFE2). The	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

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
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).	mental fatigue is different in training than in actual events. ☐ B—HFE1 and HFE2 are not performed at the same time ☐ B—Additional personnel are available to perform HFE2. ☒ B—The condition stated in first column for B does not apply to the analysis. **Justification:** The analyst added this item. The IDHEAS-ECA dependency model allows the analysts to add justifications to exclude the dependency considerations indicated in the first column.	actions or when both actions are performed in parallel. Low: P_d = 2E-3 ☒ Mental fatigue increases due to sustained highly demanding cognitive activities, ***OR*** ☐ Time pressure increases due to perceived time urgency and task load. Medium: P_d = 1E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 does not require complicated diagnosis. High: P_d = 3E-2 ☐ Same personnel perform HFE1 and HFE2 in parallel, ***AND*** ☐ HFE2 requires complicated diagnosis.
R3.3 Use of the same personnel leads to resource-sharing dependency A. Reduced staffing or missing key members results in higher workload than in training or lack of key knowledge needed. This would generally only apply to SDPs (actual fitness for duty event) or fire events. B. Using shared staff requires changes to the work practices for HFE2 (e.g., shortcuts, no peer checking or supervision) to accommodate shortage of staffing due to occurrence of HFE1.	☒ A/B—Staffing is adequate, and good work practices are enforced. ☒ A/B—Staffing, workload, and work practices are similar to training situations. (EOPs are trained upon using minimum staffing, but use of the severe accident management guidelines or fire procedures may require additional personnel, shortcuts, or use of personnel outside what is normally trained upon.) ☒ B—Minimum staffing is adequate to complete both tasks without changes to the work practices. **Justification:** HFE1 and HFE2 can be completed with minimum staffing.	This resource-sharing dependency potentially affects the PIFs for staffing, teamwork and organizational practices, and work practices. Work practices, such as peer checking, may change due to lack of adequate staffing. Low: P_d = 2E-3 ☐ Key staff needed for HFE2 are reduced or untimely due to HFE1, ***OR*** ☐ Teamwork factors are inadequate, such as knowledge gaps, distributed teams (personnel in multiple locations), dynamic teams (changing team members), or poor team cohesion. Medium: P_d = 1E-2 ☐ Self-checking or human performance tools (e.g., three-way communication) are not used as trained for, ***OR*** ☐ Peer checking or supervision is ineffective. High: P_d = 5E-2 ☐ Work scheduling or prioritization is poor.

D.3.3.3 R4—Location

Assessment Result

$P_d(R4) = 0.0$

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R4.1 Use of the same location leads to consequential dependency A. HFE1 degrades the work environment for HFE2 (e.g., reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, noise).	☒ A—HFE1 has no impact on the workplace.	This consequential dependency potentially affects the PIF for environmental factors.
		Low: P_d = 2E-3 ☐ HFE1 causes any one of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		Medium: P_d = 5E-3 ☐ HFE1 causes two or more of the following to exist for HFE2: reduced workplace accessibility or habitability, abnormal heat or cold, reduced visibility, or noise.
		High: P_d = 2E-2 ☐ HFE1 significantly impairs the work environment for HFE2, such as by causing excessive heat and humidity, poor visibility, or unstable surface for executing the action.
R4.2 Use of the same location and time leads to consequential dependency A. HFE1 and HFE2 use the same workplace at the same time such that HFE1 may interfere with or cause distractions in the performance of HFE2 (e.g., fire response may make noise and cause distractions that impact HFE2, smoke may affect personnel's judgment or stress level).	☐ A—HFE1 and HFE2 are not performed at the same time. ☒ A—Actions can be performed without interference. ☐ A—HFE2 is straightforward and does not require sustained attention (thus, it is resistant to interference).	This consequential dependency potentially affects the PIF for multitasking, interruptions, and distractions due to sharing the same location at the same time.
		Low: P_d = 2E-3 ☐ Personnel are distracted by the outcome of HFE1.
		Medium: P_d = 5E-3 ☐ Performance of HFE2 is interrupted by the outcome of HFE1.
		High: P_d = 7E-3 ☐ Performance of HFE2 is frequently or continuously interrupted by the outcome of HFE1.

D.3.3.4 R5—Procedure

Assessment Result

$P_d(R5) = 0.0$

Assessment Details

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Screening Analysis Dependency Impact
R5.1 Use of the same procedure leads to cognitive dependency A. Occurrence of HFE1 makes the procedure less applicable for use with HFE2 (i.e., the procedure becomes more confusing or does not match the situation well). For example, EOPs are generally well written because they are used often in training, but use of at-power EOPs at shutdown may be confusing because equipment is not in its normal configuration. Use of procedures during a fire or main control room abandonment situation may not apply as well as when at power. B. Occurrence of HFE1 makes personnel more likely to incorrectly interpret the procedure for use with HFE2 because they are using the same procedure.	☒ A/B—Procedure is clear, not confusing, applicable to the situations, and well trained upon. ☒ A/B—Personnel are trained to use the procedure for the specific situations.	This cognitive dependency potentially affects the PIFs for procedures and guidance and for scenario familiarity due to the effect on personnel's mental model.
		Low: P_d = 5E-3 ☐ HFE1 makes the procedure more confusing for personnel to follow.
		Medium: P_d = 5E-2 ☐ HFE1 creates a misunderstanding of the situation such that personnel are likely to misinterpret the procedure, ***OR*** ☐ HFE1 causes unfamiliar elements in the scenario for performing HFE2.
		High: P_d = 3.5E-1 ☐ HFE1 creates a mismatched or wrong mental model for HFE2, ***OR*** ☐ HFE1 creates a bias or preference for wrong strategies, ***OR*** ☐ HFE1 makes the situation for performing HFE2 extremely rare, such that personnel have no existing mental model for the situation.

D.3.4 Detailed Analysis

The IDHEAS worktables for detailed dependency analysis identify a list of PIF attributes for each dependency relation to facilitate the identification of the PIF attributes representative for the dependency effects. This Detailed Analysis did not identify any PIF attribute in the worktable for the Detailed Analysis of R3.2 representative of the dependency effect (i.e., fatigue). However, the individual HFE analysis (Section D.2.2.3) included some of the dependency effects because the HFEs were analyzed in the context of Sequence 5. The individual analysis identified the PIF attribute MF5 as representative of the dependency effects and included MF5 in the individual HEP calculation (Section D.2.2.3). IDHEAS dependency analysis permits the analysts to use the PIF attributes not listed in the worktables to represent the dependency effects. Therefore, the individual HEP of HFEs (3.5E-3, calculated in Section D.2.2.3) is the same as the HEP with dependency effects. MF5 is the PIF attribute representing the dependency effects.

Removing MF5 from the HEP of HFE2 resulted in a HEP of 2.6E-3, representing the reliability of performing cold-leg recirculation without the dependency effect (i.e., a long waiting time). Therefore, 9E-4 (= 3.5E-3 – 2.6E-3) is the dependency effect calculated by the Detailed Analysis. In comparison, the screening dependency analysis resulted in a 2E-3 increase in HEP.

The detailed dependency analysis is developed based on the Screening Analysis discussed in Section D.3.3 that identified a potential dependency in the category of R3.2 (Use of the same personnel leads to consequential dependency). The following is the worktable for detailed dependency analysis for R3.2.

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
R3.2 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).	☐ A—Workload is similar to training situations and occurs within a single shift, so no increase in stress, time pressure, or mental fatigue. ☐ B—HFE1 and HFE2 are not performed at the same time ☐ B—Additional personnel are available to perform HFE2.	<u>Potentially affected CFMs</u>: All CFMs <u>Potentially impacted PIFs</u>: MF—Mental fatigue, stress, and time pressure MT—Multitasking, interruptions, and distractions <u>PIF attributes that are most likely impacted by the dependency factor</u>: ☐ MF1—Sustained (> 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) ☐ MF2—Time pressure due to perceived time urgency ☐ MF3—Lack of self-verification due to rushing task completion (speed-accuracy tradeoff) ☒ MF5—Long working hours (> 4 hours) with highly cognitively demanding tasks **Note**: The analyst added MF5 to the list. ☐ MT3—Concurrent visual detection and other tasks

Potential Dependency Factors	Basis for Discounting the Potential Dependency Factor	Dependency Impact
		☐ MT4—Concurrent auditory detection and other tasks ☐ MT5—Concurrent diagnosis and other tasks ☐ MT8—Concurrently executing action sequence and performing another attention/working memory task ☐ MT9—Concurrently executing intermingled or interdependent action plans

D.3.5 Uncertainty Analysis

The analysis identified two scenarios that the operators failed to terminate before the RWST water level reached 30 percent. The two scenarios have different contexts that could result in different uncertainty assessments.

The first scenario is that the scenario does not progress to an unisolable LOCA before the RWST water level reaches 30 percent. With more than 5 hours available to isolate SI and all needed components available, it is inconceivable that the operators failed to terminate SI. It is difficult to identify the dependency mechanisms without knowing the likely causes of failing to terminate SI. An instructor at the NRC's Technical Training Center stated that the only cause the instructor could think of was the crew being disabled. The instructor's comments point to the limitation on the scope and reliability of the existing HRA techniques.

The second scenario is that the operators failed to isolate SI before the scenario developed into an unisolable LOCA. Once the operators discovered that the LOCA was unisolable, the operators would transfer to E-1 and wait until the RWST water level reaches 30 percent to transfer to ES-1.3 for cold-leg recirculation. This scenario context is consistent with the dependency analysis in this appendix. A consideration is that the timing of scenario development into an unisolable LOCA could significantly affect the HEP of HFE1. Section D.2.1.4 provides a sensitivity analysis on the variation of the HEP of HFE1.

D.4 Summary

This appendix demonstrates the application and documentation of the IDHEAS-ECA method, with emphasis on the dependency analysis. A complete dependency process was performed, including evaluation of the entry condition, Predetermination Analysis, Screening Analysis, and Detailed Analysis. The IDHEAS dependency method uses the same generic categories that are used by the dependency models in current practice as the first layer to identify the potential dependency categories. This identification is in the Predetermination Analysis. The IDHEAS dependency model provides more guidance in the Screening Analysis and Detailed Analysis to determine the mechanisms causing dependence. The additional layers are beneficial to reduce conservatism in assessing dependency effects.

This analysis calculated that the HEPs contributed by the dependency effects are 9E-4 and 2E-3. Applying the dependency model in the fire HRA (Ref. 4) would result in a low-level dependence[2] with a dependency contribution to HEP of about 5E-2.

The analysis also identified a technical challenge in applying dependency analysis that may need to consider different scenarios that fall in the same PRA event sequence. In addition, the minimum joint HEP issue would be a technical item to consider. The joint HEP of HFE1 and HFE2 in this analysis is 7.4E-7 (= 2.1E-4 × 3.5E-3), based on the detailed dependency analysis. The minimum joint HEP is outside the scope of this appendix. This appendix does not discuss the topic further but identifies the issue for the analysts' awareness.

D.5 References

1. U.S. Nuclear Regulatory Commission, "Accident Sequence Precursor (ASP) Program," last updated June 22, 2021 (https://www.nrc.gov/about-nrc/regulatory/research/asp.html).

2. Indiana Michigan Power, "Donald C. Cook Nuclear Plant Unit 2, Manual Reactor Trip and Automatic Safety Injection Due to Failed Open Pressurizer Spray Valve," Licensee Event Report 316-2020-002, November 2, 2020 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML20311A129).

3. Hunter, C., "Final ASP Analysis—Precursor: D.C. Cook Nuclear Plant, Unit 2, Manual Reactor Trip and Automatic Safety Injection Due to Failed Open Pressurizer Spray Valve," Licensee Event Report 316-2020-003, U.S. Nuclear Regulatory Commission, February 8, 2021 (ADAMS Accession No. ML21035A236).

4. Julius, J., J. Grobbelaar, K. Kohlhepp, B. Hannaman, B. Najafi, E. Collins, S. Cooper, K. Hill, J. Forester, and S. Hendrickson, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," EPRI-1019196/NUREG-1921, November 2009 (ADAMS Accession No. ML093350494).

[2] Evaluated based on the following parameter settings: Intervening success (No), Crew (Same), Cognitive (Different), Cue demand (sequential), Location (Same), Sequential time (> 60–120 minutes), and Stress (High or moderate).