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Guidance on Dependence Assessment in SPAR-H

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Abstract: As part of the effort to develop the SPAR-H user guidance, particular attention was paid to the assessment of dependence in order to address user questions about proper application of dependence. This paper presents a discussion of dependence from a psychological perspective and provides guidance on applying this information during the qualitative analysis of dependence to ensure more realistic and appropriate dependence assessments with the SPAR-H method. While this guidance was developed with SPAR-H in mind, it may be informative to other human reliability analysis methods that also use a THERP-based dependence approach, particularly if applied at the human failure event level.

Keywords: human reliability analysis, SPAR-H, dependence, user guidance

1. INTRODUCTION

This paper incorporates and builds upon information provided in Whaley et al. (2011)[1], an Idaho National Laboratory (INL) technical report that provides step-by-step guidance on the use of the Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method (NUREG/CR-6883; Gertman, Blackman, Marble, Byers, & Smith, 2005) for quantifying human failure events (HFEs). A separate paper (Whaley, Kelly, Boring, & Galyean, these proceedings) discusses the process for applying SPAR-H and provides guidance for analysts when plant-specific information is available.

As part of the effort to develop the SPAR-H user guidance, particular attention was paid to the assessment of dependence in order to address recurring user questions. This paper presents a discussion of dependence from a psychological perspective and provides guidance on applying this information during the qualitative analysis of dependence to ensure more realistic and appropriate dependence assessments with the SPAR-H method. While this guidance was developed with SPAR-H in mind, it may be informative to other human reliability analysis (HRA) methods that also use a dependence approach based on A Technique for Human Error Rate Prediction (THERP), particularly if applied at the HFE level.

This paper provides guidance on five issues related to dependence assessment in SPAR-H:

- The psychological causes of dependence,
- Dependence at the HFE level versus dependence at the subtask level,
- When dependence is broken,
- Dependence and performance shaping factors (PSFs), and
- Clarification of the second checker adjustment.

It is important to note that while some of the guidance in this paper is intended to correct improper application of the method (e.g., dependence at the HFE level, and improper use of the second checker adjustment); much of the present guidance is new and has not been evaluated for adaptation into current PRA modeling practice. It is intended that this paper should serve to inform SPAR-H users about issues for consideration when assessing dependence, rather than providing strict, official rules. It is also intended that this guidance should aid analysts in making more thoughtful dependence calculations in order to prevent overuse of dependence adjustments and improper use of the SPAR-H dependence table.

2. WHAT IS DEPENDENCE?

Simply stated, dependence exists when the occurrence of one event affects the likelihood of a second event. In the current context of HRA, dependence exists when the occurrence of one event (typically a hardware or

[1] The Whaley et al. (2011) SPAR-H Step-by-Step Guidance technical report is available for download from the INL website at http://www.osti.gov/energycitations/product.biblio.jsp?query_id=1&page=0&osti_id=1027888.

HFE, but could be a success event) results in a change to the probability of a subsequent HFE. Mathematically for two events "A" and "B" this is simply stated as:

$$P(A \bullet B) = P(A|B) \bullet P(B) \\ = P(B|A) \bullet P(A) \\ \neq P(A) \bullet P(B) \quad (1)$$

In probabilistic risk assessment (PRA) and HRA, dependence can be accounted for either explicitly or implicitly. In modeling hardware failures, dependence can be represented explicitly in fault tree logic (for example) by a support system sub-tree feeding multiple front-line systems. Shared equipment dependence can be modeled by repeating the basic events for that single piece of equipment in multiple fault trees for systems that share that piece of equipment. Other hardware dependencies, such as common maintenance or designs, are modeled implicitly using one of the available common-cause failure (CCF) models (i.e., beta factor, multiple Greek letter, or alpha factor). These CCF models are used to account for dependencies that are not otherwise explicitly included in the PRA or SPAR models.

Similarly in HRA (and in SPAR-H in particular) dependencies can be accounted for either explicitly or implicitly. An explicit representation of dependence is through common PSF adjustments. If training is poor, stress is high, or available time is short, multiple HFEs could be affected, and this dependence is accounted for by adjusting the appropriate PSFs for each affected HFE. However, there are other potential causes of dependence that are not accounted for through PSFs but which might still need to be included in the final quantification of two or more HFEs in the same sequence or cut set.

2.1. What Causes Dependence?

THERP (Swain & Guttman, 1983) defines dependence as "the situation in which the *probability of failure* [emphasis added] of one task is influenced by whether other tasks were successful or not. The dependence may exist between two tasks performed by one person or between the tasks performed by different persons" (pg 2-6). The THERP HRA method discusses dependence entirely at a subtask level, at the level of pressing buttons and turning switches, and posits that dependence at the subtask level is the rule, rather than the exception; HRA analysts have to justify independence.

The SPAR-H HRA method (Gertman, et al, 2005) has adapted the THERP model of dependence at the HFE level, versus the subtask level at which it is used by THERP. This is an important distinction that will be discussed later. The SPAR-H authors posit that dependence at the HFE level arises from mindset: dependence arises from the knowledge or lack of knowledge of the performer of the second task about the occurrence or effect of a previous task. This dimension of knowledge cuts across the model of human performance, as mental models are updated to coincide with experience, and therefore are impacted by PSFs.

Spurgin (2009) elaborated upon the concept of dependence, declaring that *cognitive connection* between human actions is a crucial criterion for dependence to exist between human actions:

> "If human actions are cognitively connected, then there is likely to be close connection between the events (i.e., strong dependence). Events are cognitively connected when their Diagnosis is connected by the same set of plant indications, or when a procedure couples them. Actions stemming from the same Diagnosis of plant indications are cognitively connected. Under these conditions, if an error is made in detecting, diagnosing, or deciding, then all of the corresponding actions are likely to be erroneous" (p. 66).

In other words, dependence at the HFE level occurs when operators have an incorrect mental model about the situation (or diagnosis of the event) and that incorrect mental model persists across time. Therefore, as dependence arises from mindset, the key to postulating dependence between human actions is postulating a single mindset that spans HFEs.

Psychological research supports this argument. The data/frame theory of sensemaking (Klein, Phillips, Rall, & Peluso, 2007) describes the process of how people make sense of events. People begin the process with a perspective or viewpoint, however minimal, called a *frame* (which includes the concepts of mental model, script, schema, etcetera). Incoming information or *data* is integrated with the existing frame to produce an understanding of the situation. If the data is sufficiently different from what is expected by the frame, the person then investigates to question whether the data or frame is incorrect, and either disregard the data or reframe accordingly (i.e., change the mental model). Frames shape and define what data are relevant, and data can mandate that the frame be changed. A frame functions as a hypothesis about the connections among the data. Incoming data can be integrated into the frame as additional details, or it may prompt questioning the frame and doubting the explanation it provides (which can lead to re-framing).

The data/frame theory of sensemaking provides an explanation for dependence: an operator (or crew) is working within a certain frame that happens to be inappropriate. For the course of actions to be corrected, the mindset must be re-framed. New data must be perceived that are sufficient to cause questioning of the frame and subsequent re-framing. If there are no new data, or the new data are integrated into the existing frame or discounted, then the incorrect frame (mindset) will persist, and the actions taken will continue to be incorrect.

Decision making research also provides support for dependence being caused by mindset. Naturalistic decision making models such as recognition-primed decision making (Klein, 1993) indicate that people match the characteristics of a situation to patterns based on their knowledge and experience. This pattern prescribes actions to address the situation, and this process allows people to make knowledgeable decisions quickly. However, if they match to an incorrect pattern, then subsequent actions are likely to be incorrect. Additional information or feedback is necessary for people to recognize that their actions are not successful.

Memory research also provides support for dependence as mindset. Working memory is not, in and of itself, the process by which humans decide what to do about a situation, but it is the underlying framework for conscious thought, and as such is the cognitive foundation for higher-level models such as situation awareness and decision making. There are natural limitations to the capabilities of working memory. Working memory span, referred to as the capacity for storage and processing, has some individual variability, but is generally limited to a number of chunks of information (Baddeley, 2009). This number varies with the person and type of information, but working memory generally has a capacity of about four chunks.

Information can stay active in working memory as long as it is being actively rehearsed, attended to, or cued: remembering over the short term is cue-driven (Nairne, 2002). People tend to forget over time, but research is divided about whether this is due to decay of the information representation or due to changes in cue relevance. Generally, errors in remembering arise when cues change, lose their relevance, or when other information interferes with active rehearsal or attention.

This last point is relevant for dependence. If an operator has an incorrect mindset about the situation, changing the cues or otherwise interfering with his or her maintenance of that inappropriate mental model in active working memory (e.g., via interruptions) can cause the operator to reassess the situation, potentially breaking dependence.

3. GUIDANCE FOR DEPENDENCE ASSESSMENT IN SPAR-H

3.1. Qualitative Analysis of the Context

A qualitative analysis of the context is a prerequisite for dependence assessment. In order to determine whether dependence is present, and if so, to properly characterize the level of dependence, the analyst must assess:

- The sequence of events that has led to this point in the event tree,
- Important plant/equipment status or behavior, and
- The context surrounding the tasks described in the HFE.
  - Performance drivers, PSFs.
  - Causal connections from previous activities and/or equipment issues.

SPAR-H does not provide instructions for qualitative analysis. It is a simplified quantification method and assumes the qualitative analysis has already been conducted, as discussed in Whaley et al. (these proceedings).

For low-power and shutdown (LPSD) conditions, it is especially important that the analyst consider off-normal situations, such as situations without full instrumentation or adequate procedural guidance, as such situations can provide more opportunity for dependence to arise than typical at-power conditions. It is important to clarify here that there is not a different method for assessing dependence for LPSD conditions. However, dependence might be more of a concern for LPSD than for at-power conditions.

3.2. Determine Whether Dependence is Present

The first question to consider is whether dependence is present or not. The guidance in NUREG/CR-6883 specifically states that analysts should first determine whether or not to include a dependence assessment in the analysis.

> "Note that discretion [should be] employed as to whether or not a dependency calculation is warranted. The SPAR-H worksheets have a comments section where analysts indicate whether or not the HEP in question is influenced by preceding diagnoses or actions in that event sequence. When it is not, the dependency calculation should be omitted" (p. 29).

The question analysts should be asking is, "Does a compelling reason exist to indicate that performance of a task is dependent upon a previous task?" If there is not, dependence is not present and should be omitted from the analysis. Note that the analyst is looking for a yes or no answer to the question of whether dependence needs to be modeled; at this point it is premature to consider level of dependence.

This therefore begs the question, what is a compelling reason for performance of a task to be probabilistically dependent upon a previous task? In order to properly answer this question, analysts must consider several factors that are all rooted in human cognition.

3.2.1. Dependence at the HFE vs. Subtask Level

As mentioned above, THERP modeled dependence entirely at a subtask level, at the level of pressing buttons and turning switches, and posited that dependence at the subtask level is the rule, rather than the exception; HRA analysts using THERP for modeling and quantification had to justify independence.

In contrast, SPAR-H models human actions at the level of the composite HFE. At this level of analysis, a single HFE typically comprises multiple *tasks*, each of which contains multiple subtasks. At the HFE level, an uncritical application of THERP-style dependence assessment is not appropriate, as the factors that lead to dependence across HFEs are not the same as those within a task. As discussed previously, dependence at the HFE level occurs when operators have an incorrect mental model about the situation (or diagnosis of the event) and that incorrect mental model persists across time. Therefore, as dependence arises from mindset, the key to postulating dependence between human actions is postulating a single mindset that spans HFEs.

What this means for dependence assessment in SPAR-H is that groups of tasks that are considered as a whole (i.e., at the HFE level), do not readily lend themselves to a routine, THERP-style assumption of dependence. At the HFE level, unless two HFEs are cognitively connected (as by an incorrect mental model of the situation), there is probably no dependence. When dependence does exist, it can be broken if operators receive information from any source that is sufficient to cause them to correct their diagnosis or mental model of the event.

In fact, it might be argued that HFEs tend to be, by definition, independent of one another. The subtasks that comprise an HFE might be considered dependent subtasks; however, the boundaries between HFEs mark the logical points where dependence is broken.

At the HFE Level, *independence* is more likely; dependence is the exception rather than the rule. Analysts should still consider whether it is present, however. Independence should not be assumed without first asking the question and considering the context of the situation. Instead, analysts should first justify why dependence is present, and then determine dependence level. Additional guidance for assigning dependence level is not available at this time, though the authors hope that a future project that will address this issue. For now, analysts should not feel constrained by the dependence level table in SPAR-H. It was designed to identify situations in which there is likely to be an unchanged mindset. Analysts should allow themselves some flexibility in using the table, and if they can justify a different level than the one prescribed by the table, they should feel free to use the level they believe is warranted by the situation and document their assumptions.

3.2.2. Breaking Dependence

Is there anything that can be said to guarantee independence at the HFE level? Long periods of time? Different crews? Possibly, but long time periods or different crews do not necessarily guarantee independence. Organizational culture or mindset can lead to dependence over different crews and long periods of time.

However, if anything can break dependence, it is *quality of information*. As described in the discussion of cognition and human psychology above, information is key to disrupting dependence between human actions. This information can come in the form of new or additional cues from the system, a new perspective from a different crew member or personnel outside the crew, or feedback that the current approach is not working. The source of the information does not matter. For new information to break dependence, it must be sufficient to change the situation assessment, to change the operator's understanding of the situation. Such a change breaks dependence. This also means that if new information is discounted or rationalized away, it will not have an impact on any dependence between human actions.

3.2.3. How to Determine whether Dependence is Present

Given the above discussion, how does an analyst identify when dependence is present at the HFE level, given that independence seems to be the rule at this level? Dependence arises from mindset, from a person's interpretation of the context. This understanding provides a script for behavior, and anything that disrupts the script can break dependence. For example, a procedure, an alarm, an interruption, a new cue, a shift change, another event, or even a restroom break—anything new that causes people to look at the situation with a fresh perspective can break dependence.

Simply having two or more HFEs together in a sequence or cut set does not make them dependent. A psychological basis must exist (the HFEs must be psychologically connected). Analysts should review the situation and context carefully and consider, for example, the following factors:

- Time (to allow forgetting and emptying of working memory),
- Location (introducing new information, potentially interrupting the script),
- Same person or crew (allows for mindset to develop), and
- Cues (stimulate the human to think differently).

All these aspects should be considered within the framework of the accident scenario context (e.g., simply having the same person, close in time, no additional cues, etc., does not necessarily mean dependence is present).

Also, analysts should be alert to a situation that produces a cut set with two HFEs, which are separated by a success. The success will not be evident in the cut set, but will be seen by following the sequence in the event tree. The presence of the success could indicate a break in the mindset of the operators.

In a normal or familiar situation, with good procedures, no compelling reason for dependence exists. Some compelling reasons that can cause dependence (this list is not exhaustive):

- No feedback,
- Misleading feedback,
- Masking of symptoms,
- Disbelieving indications,
- Incorrect situation assessment or understanding of the event in progress,
- Situation mimics an often-experienced sequence,
- Situation triggers a well-rehearsed, well-practiced response, and
- Time demand, workload, and task complexity (such that a slip, lapse, or mistake is more likely).

All these factors serve to instill or reinforce a mindset in the operator.

It is expected that the qualitative analysis and resulting context and operational story would help to identify the existence of compelling reasons for dependence. The analyst should be on the lookout for situations in which operators develop an incorrect mindset about the situation and identify ways in which that mindset can be corrected to break dependence.

3.2.4. Additional Guidance

The type of human action involved in the HFEs under consideration matters. The type of error made in the first (or previous) HFE makes a difference. Simply knowing that the first HFE in a sequence or cut set occurred is not sufficient for considering dependence in quantifying a second HFE; the analyst needs to understand why the first HFE occurred. For example, if the first error was a slip or lapse (and the operator has a correct understanding of the situation), then a subsequent error is NOT more likely, meaning the HFEs are independent. However, if the first error was a mistake (the operator has an incorrect understanding of the situation), then a subsequent error is more likely, unless additional information is interjected into the situation that causes the operator to reassess the situation assessment.

It is also important to recognize that the above guidance will only work when analysts have this kind of information, such as in event or condition assessments. In base PRA modelling, this type of information is not likely to be available.

3.3. Determine Whether a Dependence Adjustment Should Be Included In the Analysis

Given the above guidance, once the analyst has determined that dependence is present, there are some additional considerations to take prior to including a dependence correction in the analysis. It may be appropriate for the analyst to not include a dependence adjustment in the analysis, despite believing dependence to be present. In particular, this may be the case if the reasons for dependence are already accounted for in the PSF adjustments.

3.3.1. Dependence and PSFs

The practice of including a dependence assessment in HRA analyses is an attempt to account for and quantify the influence of human actions on one another. A common practice in HRA methods, as exemplified by SPAR-H, is to account for the factors that affect human behavior through PSFs, such as availability of time, complexity, and stress. The PSFs used vary by method, but all PSFs attempt to characterize the context of the situation in which the human action occurs. "Dependence" as it is used in SPAR-H reflects the influence of a prior human action where this influence has not already been accounted for through one or more PSFs. Therefore, if the influence of previous actions on subsequent actions is already fully accounted for in the PSF adjustments that have been made, an additional dependence correction is not necessary.

Many discussions of dependence (including THERP) cite increased stress, time pressure, and complexity as causes of dependence between HFEs. However, in SPAR-H, these factors have already been accounted for in the PSF multipliers. Additional dependence correction is not usually warranted (i.e., the HFEs are conditionally independent because the influence of the PSFs has already been taken into account) and must be justified—e.g., the analyst must explain that the PSF adjustments leave residual dependence that should be modeled.

Therefore, if the reason(s) why the analyst believes that dependence is present include reduced time available or increased time pressure, increased stress, increased complexity (e.g., the situation is now physically more complicated to recover from), or any other reason that is addressed in the PSF adjustments, then an additional dependence calculation is not appropriate.

However, if the influences include:

- Misdiagnosis/situation assessment error (e.g., operators have an incorrect understanding of the event in progress and this leads them to take a path of actions that is not appropriate for the situation);
- Situation awareness issues;
- Organizational or cultural mindset/beliefs/biases;
- Cognitive biases, heuristics, mental shortcuts; or
- Any other reason NOT already accounted for in the PSF adjustments.

Then an additional dependence correction is appropriate in SPAR-H.

3.4. Determine Dependence Level

In determining the *level* (i.e., degree) of dependence, SPAR-H adapts from THERP the factors of same person/crew, close/not-close in time, same/different location, and presence/absence of additional cues. SPAR-H also adapts the same dependence levels used in THERP: zero, low, moderate, high, and complete.

Guidance for this step is not available at this time. However, the authors hope that future development work will produce guidance that includes descriptions of the dependence levels and discussion of factors to consider when assigning dependence level. For now, analysts should not feel constrained by the dependence level table in SPAR-H. It was designed to identify situations in which there is likely to be an unchanged mindset. Analysts should allow themselves some flexibility in using the table, and if they can justify a different level than the one prescribed by the table, they should feel free to use the level they believe is warranted by the situation.

3.4.1. Clarification of the Second-Checker Dependence Adjustment

In the SPAR-H dependency table, there are instructions for what is known as the "second checker" adjustment:[2]

> "When considering recovery in a series, e.g., 2nd, 3rd, or 4th checker: If this error is the 3rd error in the sequence, then the dependency is at least moderate. If this error is the 4th error in the sequence, then the dependency is at least high" (p. A-7)."

Further explanation is available in the SPAR-H document:

> "Adjust the level of dependency if a second, third, or fourth checker is being modeled as part of recovery. For example, if the event is the third basic event (second checker) in the sequence, dependency must be no less than moderate; if it is the fourth event (third or fourth checker), the dependency must be no less than high. *If there is a compelling reason for less dependence, do not apply the rule, but document the reason in the block above the rule*" [emphasis added] (p. 62).

There has been confusion about when this rule should be applied, and it appears that it is being applied in situations it was not intended to address. The rule was adapted from THERP, where it applies to recovery subtasks within an HFE. Thus, in SPAR-H, the second, third, and fourth checker adjustment applies ONLY when all of the following apply:

- A second, third, or fourth checker of an action is being modeled as part of a recovery,
- The second, third, or fourth checker is standing over the shoulder of the operator, checking work, and
- The relationship between the operator and the checker(s) is important in creating the psychological basis. For example, if the second checker and the operator know each other well, trust each other, and the second check does not use a form, then dependence is likely.

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[2] The use of second checkers is a plant-specific practice and is not contained in the SPAR models. The analyst will have to determine the specific practices in use that affect the condition or event under consideration.

The purpose of the second checker adjustment is to encourage the analyst to question the rigor of the work processes and associated documentation for the checking. To clarify further, in a sequence or cut set from a SPAR model, it is rare that the second HFE in the sequence serves as a second check of the first HFE (the authors cannot think of an example when this would be the case, but we cannot rule it out).

It is important that analysts understand this point: *merely because the HFE is the second, third, or fourth HFE in a sequence or cut set does not mean that the "second checker" rule applies.* Furthermore, the SPAR-H guidance allows analyst flexibility in applying this rule, granting permission for them to justify a lower level of dependence if they feel the situation warrants it. So, generally speaking, unless the events being modeled are recoveries with "independent" checkers as described above, the "second checker" rule will not apply.

4. EXAMPLE: A LOSS OF INVENTORY EVENT

A loss of inventory event (LOI) occurred at a pressurized-water nuclear power plant that can serve as an example of proper dependence assessment. This event occurred during shutdown; the vessel head was detensioned in preparation for removal. Reactor coolant system (RCS) level had been restored to below vessel flange, after going to mid-loop to install cold-leg nozzle dams. At this point, an electrical transient caused by main generator voltage regulator testing caused a relief valve in the letdown system to open and stay open. This created a pathway from the RCS to a hold-up tank, and RCS level dropped about 15 inches (2,000 gallons). Operators recognized problem and isolated RCS within 17 minutes.

During the significance determination process (SDP), the NRC evaluated this event to determine the conditional core damage probability (CCDP) of the event. The dominant cut set is shown in Figure 1.

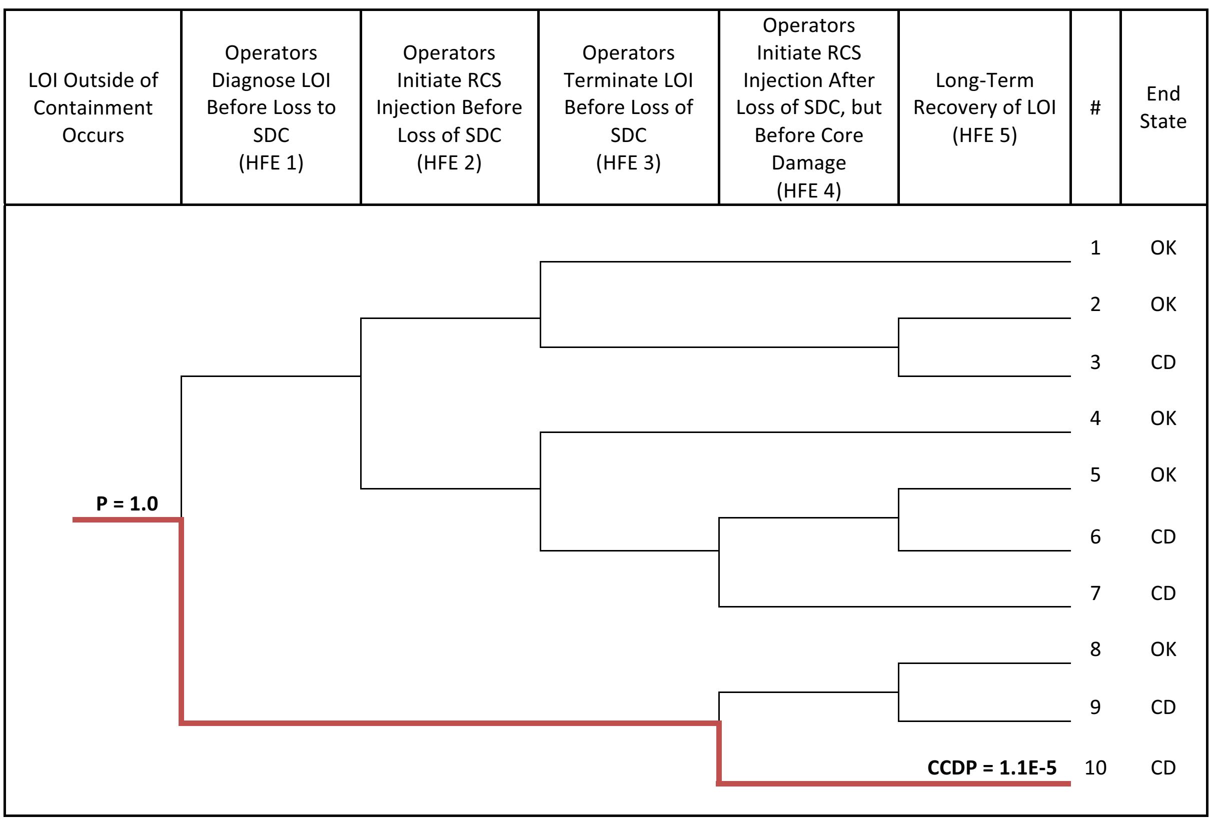

Figure 1. Dominant Sequence of LOI SDP Example

In the dominant cut set, there are two HFEs under evaluation. First, operators must diagnose the loss of inventory event prior to the loss of shutdown cooling SDC (HFE 1). If operators fail, they have 70 minutes to initiate RCS injection to prevent core damage (HFE 4).

In evaluating this sequence, the question of dependence arises on HFE 4. The context of the scenario surrounding HFE 4 is as follows: if operators fail to diagnose the loss of inventory (e.g., they disbelieve their indications of dropping RCS level), once the level drops to a certain point, the residual heat removal pumps will start to cavitate and alarms will go off. This new information is enough to force the operators to reassess their understanding of the situation and recognize the LOI.
Therefore, in this sequence, start of RCS injection is *independent* of the prior failure to diagnose the LOI, because the new, *salient* cues change the situation such that the LOI is recognized. There should be no dependence correction on HFE 4, as dependence is zero.

5. CONCLUSIONS

Due to requests for guidance from SPAR-H users, an effort was made to develop enhanced SPAR-H user guidance above and beyond the guidance available in NUREG/CR-6883. In this effort, particular attention was paid to the assessment of dependence in order to address user questions about proper application of dependence and to correct improper use of dependence adjustments. This paper presented a discussion of dependence from a psychological perspective and provided guidance on applying this information during the qualitative analysis of dependence to ensure more realistic and appropriate dependence assessments with the SPAR-H HRA method. This guidance covered the psychological causes of dependence, clarification of dependence at the HFE versus subtask level, identified when dependence is broken, explained proper use of dependence with PSF ratings, and clarified the second checker adjustment. While this guidance was developed with SPAR-H in mind, it may be informative to other HRA methods that also use an approach to dependence based on THERP.

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