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SPAR-H Step-by-Step Guidance

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ABSTRACT

This report provides step-by-step guidance on the use of the Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method for quantifying Human Failure Events (HFEs). The target audience for this document consists of Senior Reactor Analysts (SRAs) and other risk analysts in the U.S. Nuclear Regulator Commission (NRC). This document provides supplemental guidance for analysts when plant specific information is available (e.g., during event and condition assessments), which goes beyond the general guidance provided in existing SPAR-H documentation. This guide is intended to be used in conjunction with the worksheets provided in: "The SPAR-H Human Reliability Analysis Method," NUREG/CR-6883, dated August 2005. Each step in the process of producing a Human Error Probability (HEP) is discussed. These steps are: Step-1, Categorizing the HFE as Diagnosis and/or Action; Step-2, Rate the Performance Shaping Factors; Step-3, Calculate PSF-Modified HEP; Step-4, Accounting for Dependence, and; Step-5, Minimum Value Cutoff. The discussions on dependence describe insights obtained from the supporting psychology literature.

ACKNOWLEDGEMENTS

Most of the information presented in this report on performance shaping factors (PSFs), and how they are interpreted and used in SPAR-H, was taken from an INL report titled: "Guidance on Performance Shaping Factor Assignments in SPAR-H" (INL/EXT-06-11959, draft report dated: November 17, 2006). This report was authored by Ronald L. Boring, April M. Whaley, Tuan Q. Tran, Patrick H. McCabe, Larry G. Blackwood, and Robert F. Buell.

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SPAR-H Step-by-Step Guidance

1. Introduction

The purpose of this report is to provide step-by-step guidance for utilizing the SPAR-H human reliability analysis (HRA) method for quantifying human failure events (HFEs) in the standardized plant analysis risk (SPAR) models. The target audience for this document consists of Senior Reactor Analysts (SRAs) and risk analysts in the U.S. Nuclear Regulator Commission (NRC). This document provides supplemental guidance for analysts when plant specific information is available (e.g., during event and condition assessments), which goes beyond the general guidance provided in existing SPAR-H documentation.

The guidance that follows is provided to aid an analyst in filling-out the SPAR-H worksheets used to estimate human error probabilities (HEPs). SPAR-H is a method for HFE quantification. It does not provide guidance on how to identify or model HFEs, or other aspects of the qualitative HRA needed to support quantification. Therefore, this guide starts with the assumption that the HFE to be quantified has already been identified and is adequately represented in the risk model.

The guidance that follows covers five steps:

- Step-1 (Section 2): Categorizing the HFE as Diagnosis and/or Action
- Step-2 (Section 3): Rate the Performance Shaping Factors
- Step-3 (Section4): Calculate PSF-Modified HEP
- Step-4 (Section 5): Accounting for Dependence
- Step-5 (Section 6): Minimum Value Cutoff

2. Step-1 – Categorizing the HFE as Diagnosis and/or Action

In addition to basic documentation on the HFE and related context, one key decision to be made by the analyst is judging what type of event is being quantified. In the context of SPAR-H, HFEs are categorized as either Diagnosis tasks or Action tasks (or combined Diagnosis and Action). Diagnosis for the purpose of SPAR-H quantification refers to the entire spectrum of cognitive processing, from the very complex process of interpreting information and formulating an understanding of a situation, to the very simple process of just deciding to act.

The bases for the nominal SPAR-H HEP values and for the PSF modifier values are discussed in detail in Boring & Blackman (2007). They explain that the nominal HEP value for the “Action” part of the SPAR-H worksheets (0.001) is based on error rates for simple action implementation, such as pressing a button or turning a dial, and simple slips or lapses in the taxonomy used by (Reason, 1990). Furthermore, “Diagnosis” in SPAR-H is intended to refer to cognitive processing and not to Diagnosis, per se. Most HFEs in the SPAR models involve much more cognition than merely pushing a switch; therefore it is not appropriate to routinely exclude the Diagnosis component from HFE quantification. The only exception where it can be justified that the HFE involves no cognitive activity beyond simple action implementation is when the cognitive aspect is modeled as a separate HFE and only the execution is being considered.

It is a rare situation where Diagnosis is judged to not be a relevant contributor to the overall HEP for HFE in SPAR models. In the context of PRA in general, and SPAR models in particular, there are very few situations where a Diagnosis and an Action are not linked somehow. Action rarely occurs without Diagnosis, but it might be possible to have a Diagnosis that is not followed by an Action. Really the only question here is: is the Diagnosis represented in the PRA or SPAR model as a separate HFE, or is it combined with the Action part into a single-composite HFE?

Therefore, the default modeling in SPAR-H should include both Diagnosis (cognitive processing) and Action (execution). Justification is needed to eliminate one of these elements. This is consistent with the *Good Practices for HRA* (Kolaczkowski et al, 2005), which states that both screening and detailed quantification should include both Diagnosis and Execution components, unless the qualitative HRA "indicate(s) that one of these failure modes predominates the other in such a way that the effect of only one failure needs to be quantified."

3. Step-2 – Rate the Performance Shaping Factors

Once the HFE has been categorized, the analyst, as part of the supporting qualitative analysis, must identify the salient performance drivers, both positive and negative. This can be supported by reviewing the eight SPAR-H performance shaping factors (PSFs). Each PSF needs to be examined with respect to the context of the HFE to resolve two basic issues. First, is there adequate information to judge the influence of the PSF? Second, does the context for that PSF exert a significant influence on the likelihood of failure for the human operator (i.e., is the PSF a "performance driver")? ONLY those PSFs that have sufficient information to allow an informed judgment and ONLY those PSFs that have been identified as performance drivers should then be evaluated and quantified. Otherwise, the PSF should be assumed to be nominal. If it was not evaluated, or set to Insufficient Information (numerically equivalent to nominal) if there was not enough information available to allow an informed judgment.

The following sections describe the current guidance for the PSF levels in SPAR-H. A later phase of this project is intended to revisit the PSF levels, so some of this information might be revised and additional guidance provided at a later date.

3.1 Available Time

Available time as a PSF term can be misleading. In the assessment of the Available Time PSF, SPAR-H does not look solely at the amount of time that is available for a task. Rather, it looks at the amount of time available relative to the time required to complete the task. In the existing SPAR-H documentation (Gertman et al., 2005) this PSF is evaluated by comparing the time required to the time available. Although the exact definitions for the various PSF levels differ between those for Diagnosis and those for Action, both have a basically consistent definition for the nominal level. Namely, nominal is defined as some extra time is available beyond that minimally required. (Nominal time for Diagnosis is actually defined as "on average, there is sufficient time to diagnose the problem," which implies more than the minimum requirement.) Additionally, while it was not part of the original SPAR-H guidance for this PSF, it is useful to include the *time margin* in this discussion, which is the difference between the required time and the available time (US Nuclear Regulatory Commission, 2009). The point is that the nominal time includes some small but important time margin over the minimum amount of time required. For Diagnosis, the analyst must recognize that the amount of time needed to make a decision (i.e., formulate a diagnosis) is highly dependent on the individual and significant variability among operators should be expected. Hence the nominal time should be assessed in terms of how the average operator is estimated to perform. Another way to look at this is to estimate the time needed by a better-than-average operator (i.e., the minimum time required) and add some small but significant time margin for the nominal time. Figure 1 illustrates the different PSF levels graphically using this concept of time margin.

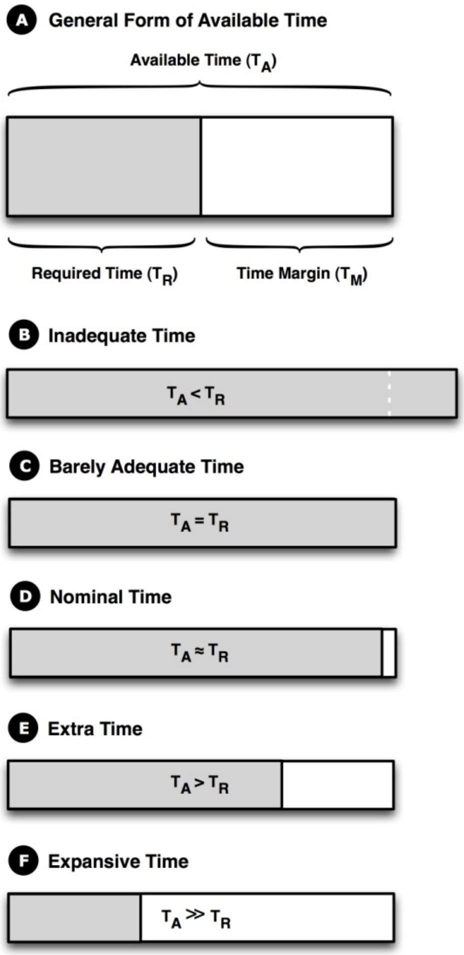

Figure 1. Time Available as a function of the time required and the time margin.

As depicted in Figure 1, this time margin is simply an alternate way to evaluate the Time Available PSF level assignment in SPAR-H:

- *Inadequate Time* (Figure 1b)—the time margin is negative because less time is available than is required.

- *Barely Adequate Time* (Figure 1c)—the time margin is zero because the time available equals the time required.

- *Nominal Time* (Figure 1d)—there is a small time margin because the time available is slightly greater than the time required.

- *Extra Time* (Figure 1e)—the time margin is greater than zero but less than the time required; the time available is greater than the time required.

- *Expansive Time* (Figure 1f)—the time margin exceeds the time required; the time available is much greater than the time required.

While the use of time margins can simplify the assessment of the Time Available PSF, it does not remove the plant and operations expertise required to determine the overall available time and the time required to complete the task. These parameters must also be considered in the context of time required for the Diagnosis and Action parts of a task.

Before a judgment can be made about the effect of time on the HEP, the time issue needs to be reconciled with whatever choice the analyst made on how Diagnosis was treated. As mentioned above, it is only in rare cases that Diagnosis is not factored into the HEP calculation. Therefore, the obvious question here is how the available time is allocated between the event Action and the event Diagnosis.

To apportion the available time between Diagnosis and Action, the analysts should first estimate the nominal time (i.e., the minimum time needed plus some time margin) to perform the action. If there is sufficient time to perform the action, then the available time PSF for the Action is judged to be nominal and the remainder of the time is assigned to the Diagnosis part of the event. This might mean that the available time for Diagnosis is not nominal. Additionally, if a time apportionment is done without specifically estimating the time required for Diagnosis, then time available for Diagnosis is either "nominal" or "barely adequate;" no positive adjustment should be used.

There are many influences that can drive the amount of time required and the analyst is cautioned against being too pessimistic by allowing a single influence to affect multiple PSF estimates. For example, a particular action might be very complex, which can extend the amount of time needed to execute that particular action. An analyst might be inclined to then estimate the Time Available PSF as less than nominal *and* also assess the *Complexity* PSF as worse than nominal in the quantification of the Action component of the HFE. This would result in a "double counting" of that particular influence. The analyst should decide whether available time or complexity is the primary performance driver, and model a negative influence of only one of these PSFs. For example, if the primary hurdle for a crew in a particular situation is the fact that they have five minutes in which to act, then the available time is the primary performance driver. If, on the other hand, in a different situation if the primary challenge is that the crew has to deal with multiple system malfunctions, multiple procedures, inexplicable plant response, and multiple indication errors, then the primary performance driver is the complexity of the situation. Analysts should only include a negative assessment of multiple PSFs if there is reason to believe that each of the respective PSFs is a separate performance driver in its own right, and not merely as a side effect of one of the other PSFs. Also note that the two PSFs might influence performance in opposite directions in some situations, with a complex task being performed in the context of a substantial time margin. In such cases, modeling one PSF as a negative driver and the other as a positive driver is justified.

Again, note that the Available Time PSF descriptions for Diagnosis and Action events differ. The presumption is that when necessary, decisions can be made very quickly. However, when judging the nominal time for Diagnosis, the analyst should consider the amount of time needed to make a systematic and thoughtful decision as to the nominal time. That is, what information needs to be gathered and reviewed to support the decision-making process? What permissions or concurrences need to be obtained? The characterizations of the available time PSF for Diagnosis are intended to be best estimate descriptions and are not deliberately conservative. Hence the analyst should likewise make a deliberate effort to be realistic and comprehensive in estimating the nominal time requirement for Diagnosis and not assume there is any conservative margin built into the PSF quantification process as a rationale for not being as thorough as possible. Again, the intent here is not to simply assume the time required is only the (virtually instantaneous) time needed to decide upon a course of action, it also includes the observation of indicators, the gathering of information, processing of the information and any group interactions (among team members or between supervisor and subordinate).

Once the time required has been estimated, it is then compared to the time available to quantify the Available Time PSF. Again, the intent is to be realistic and make a best estimate of this time window. However, uncertainty pervades this process and it should be recognized that hard and fast discrimination among the different PSF Levels (in particular, among Nominal Time, Extra Time, and Expansive Time) is not feasible.

Therefore, the analyst is cautioned against relying on overly precise estimates that lead to threshold effects from the Available Time PSF. The description of Extra Time (for Diagnosis) in Gertman et al., 2005) is between 1 and 2 times nominal time *AND* greater than 30 minutes. The 30-minute criterion should be evaluated in the context of the time required for Action (i.e., after accounting for the Action portion). Therefore, if the time available is estimated in the 25 to 30 minute range, then the PSF (for Diagnosis) should be assigned the Nominal level despite the fact that it would otherwise meet the criterion for Extra Time (i.e., be 2 times nominal). Use of the time margin described above might help reduce the over literal reliance on the 30 minute criterion.

Note that the Available Time PSF does not consider aspects of perceived time pressure by the operator or crew. Actual and perceived time pressure induces stress and should therefore be considered under the Stress/Stressor PSF.

3.2 Stress/Stressors

Stress (and level of arousal) has been broadly defined and used to describe negative as well as positive motivating factors in predicting human performance. However, stress as used in SPAR-H specifically refers to the level of undesirable conditions and circumstances that impede the operator in completing a task. Stress can include mental stress, excessive workload, or physical stress such as that imposed by environmental factors. Consequently, stress could manifest on both Diagnosis and Action performance. Environmental factors, often referred to as stressors, such as excessive heat, noise, poor ventilation, or radiation, can induce stress in a person and affect mental or physical performance. It is important to note that the effect of stress on performance is curvilinear—that is, some small amount of stress can enhance performance, and in the context of SPAR-H should be considered nominal, while high and extreme levels of stress will negatively affect human performance. It is the degradation of performance that is the key point when assigning high or extreme stress levels. Typically, this will occur when the context of a situation deviates from what is anticipated (leading to confusion, uncertainty, fear or overloading the capabilities of the human operator). Situations that are expected, even though they might result in some anxiety in the human operators, should be judged nominal. Remember, some enhanced level of stress can be good in that it can help the operators stay focused. The analyst is cautioned against being too analytical in assigning a stress level. Even if we could predict the specific individual subjected to the context of interest (which we can’t), everyone handles stress a little differently. Therefore, the focus here (for High or Extreme Stress) is on those situations outside of what the operator(s) have experienced or trained for.

Levels for the stress PSF in SPAR-H are:

- *Extreme*—a level of disruptive stress in which the performance of most people will deteriorate drastically, the so-called stress performance cliff. This is likely to occur when the onset of the stressor is sudden and the stressing situation persists for long periods. This level is also associated with the feeling of threat to one's physical well-being or to one's self-esteem or professional status, and is considered to be qualitatively different from lesser degrees of high stress (e.g., catastrophic failures can result in extreme stress for operating personnel because of the potential for radioactive release).

- *High*—a level of stress higher than the nominal level (e.g., instruments with anomalous readings or unexpected alarms; loud, continuous noise impacts ability to focus attention on the task; the consequences of the task represent a threat to plant safety). This level basically encompasses any situation where there is a perceived threat that can result in significant health or financial consequences (such as loss of the plant).

- *Nominal*—the level of stress that is conducive to good performance. Also, this level should be assigned whenever stress is judged to not be a performance driver.

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level. Note that *Insufficient Information* is quantified with the same value as Nominal.

It is important to note that stress is not independent of other PSFs. Often stress results from limited time, high complexity, poor procedures, poor training, poor work processes, or poor crew dynamics. However, the analyst should make an effort to avoid any "double counting" of specific influencing factors. If time constraints are being accounted for in the Available Time PSF, then the effect of time on the Stress/Stressors PSF should be minimized (note that other details of the context, not explicitly accounted for in other PSFs might still need to be accounted for in the Stress/Stressors PSF). While high or extreme stress does increase the probability of an error, it does not guarantee failure; people can and have succeeded during high-stress scenarios.

The key to assigning a level to this PSF is the distinction between high and extreme stress. Extreme stress is qualitatively different from high stress, and is likely to occur if a problem is prolonged, such as multiple equipment failures, if the crew has had prolonged difficulties controlling plant parameters, or in situations where there is a severe threat to personnel or plant safety.

3.3 Complexity

Complexity refers to how difficult the task is to perform in the given context; it considers both the task and the environment. The more difficult the task is to perform, the greater the chance for human error. Similarly, the more ambiguous the task is, the greater the chance for human error. Complexity also considers the mental effort required, such as performing mental calculations, memory requirements, understanding the underlying model of how the system works, and relying on knowledge instead of training, practice or procedures. Complexity can also refer to physical efforts required, such as physical actions that are difficult because of complicated patterns of movements.

In general, a task with greater complexity requires greater skill and comprehension to successfully complete. Multiple variables are usually involved in complex tasks. Concurrent Diagnosis of multiple events and execution of multiple actions at the same time is more complex than diagnosing and responding to single events.

The levels used for complexity in SPAR-H are:

- *Highly Complex*—very difficult to perform. There is much ambiguity in what needs to be diagnosed or executed. Many variables are involved, with concurrent diagnoses (or actions). For example, an unfamiliar equipment line-up is required that involves defeating interlocks on valves.

- *Moderately Complex*—somewhat difficult to perform. There is some ambiguity in what needs to be diagnosed or executed. Several variables are involved, perhaps with some concurrent diagnoses (or actions). For example, an atypical system startup is executed requiring the manual connection of backup power supplies.

- *Nominal*—not difficult to perform. There is little ambiguity. An easily managed number of variables or inputs are involved. The organization of information or execution of steps is relatively straightforward with little potential for confusion. Also, nominal should be chosen when this PSF is judged as not being a performance driver.

- *Obvious Diagnosis*—Diagnosis becomes greatly simplified. There are times when a problem becomes so obvious that it would be difficult for an operator to misdiagnose. The most common and usual reason for this is that validating and/or convergent information becomes available to the operator. Such information can include automatic actuation indicators or additional sensory information, such as smells, sounds, or vibrations. When such a compelling cue is received, the complexity of the diagnosis for the operator is reduced. There are three characteristics needed to qualify a diagnosis as obvious. First, the situation needs to be relatively simple, a single event only. Second, the indications need to be clear and unambiguous. Third, it needs to be something the operators have experienced before (at least in training). An example that might fit this profile is an uncomplicated turbine trip, where a single cause results in multiple but consistent indicators and alarms, and the operators have seen it in the training simulator.

  Note that there is no *obvious action* PSF level assignment available to the analyst. Easy to perform actions are encompassed in the nominal complexity rate.

- *Insufficient information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level.

A crew or operator’s understanding of the situation can influence complexity. If the crew does not have an adequate understanding of the nature of the problem, solving it becomes more complex, as the plant parameters often do not respond as expected. Key to assigning a level for this PSF is determining how challenging the situation is to the operator/crew. Obviously, complexity is a relative issue. As with all other PSFs, there is the potential to double-count the effects of complexity. To a well-trained and experienced operator/crew, a particular situation might be simple, whereas for those poorly trained or inexperienced it might be very complex. As a general rule, the analyst should avoid double-counting the effects of a PSF. If the Experience/Training PSF is assessed negatively, the analyst should avoid including the effects of experience/training in the Complexity PSF.

3.4 Experience/Training

This PSF refers to the experience and training of the operator(s) involved in the task. Included in this consideration are years of experience of the individual or crew, and whether or not the operator/crew has been trained on the type of accident, the amount of time passed since training, the frequency of training, and the systems involved in the task and scenario. Another consideration is whether or not the scenario is novel or unique (i.e., whether or not the crew or individual has been involved in a similar scenario, in either a training or an operational setting). Specific examples where training might be deficient are guidance for bypassing engineered safety functions, guidance for monitoring reactor conditions during reactivity changes, and guidance for monitoring plant operation during apparently normal, stable conditions for the purpose of promoting the early detection of abnormalities. Levels used for this PSF in SPAR-H are:

- *Low*—less than 6 months of relevant experience and/or training. This level of experience/training does not provide the level of knowledge and deep understanding required to adequately perform the required tasks, does not provide adequate practice in those tasks, or does not expose individuals to various abnormal conditions.

- *Nominal*—more than 6 months of relevant experience and/or training. This level of experience/training provides an adequate amount of formal schooling and instruction to ensure that individuals are proficient in day-to-day operations and have been exposed to abnormal conditions. Also, this level should be assigned if the analyst judges Experience/Training to not be a performance driver.

- *High*—extensive experience; a demonstrated master. This level of experience/training provides operators with extensive knowledge and practice in a wide range of potential scenarios. Good training makes operators well prepared for possible situations.

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level.

If Training/Experience has been judged to be a performance driver, then this PSF might also include the quality of the training provided. If the simulator training does not match plant response, training might be judged as low. If the training does not cover the given situation, training might be judged as low, as would be the case if training were incomplete or incorrect. If the training for a particular situation is infrequently conducted, to the extent that important skills and concepts are not regularly rehearsed and refreshed, training might be considered low. Note that the threshold of 6 months of experience and/or training for the Low level should not be viewed as a firm rule; an activity that is well trained over five months may find the operator more qualified than one which is infrequently trained over multiple years.

Extensive experience and training does reduce the likelihood of error, but people can and have made errors despite being highly trained. Also, note that training and experience are considered here in the aggregate. Consequently, low experience might be offset by good training (and vice versa).

3.5 Procedures

This PSF refers to the existence and use of formal operating procedures for the tasks under consideration. Use of procedures and the assignment of a PSF level for Procedures can apply to either Diagnosis or Action (or both). Past problems seen in event investigations involving procedures include situations where procedures give wrong or inadequate information regarding a particular control sequence. Another problem that has been cited is ambiguity in procedure steps. PSF levels differ somewhat, depending on whether the activity is a Diagnosis activity or an Action. In situations where multiple transitions between procedures are required to support a task or group of tasks, SPAR-H suggests that the analyst adjust the PSF for complexity accordingly. If the procedures themselves are problematic, then the analyst should assess the procedures and determine whether they should be assigned an “Incomplete” or “Available, but poor” rating. However, as with all PSFs in SPAR-H, a prerequisite to evaluating this PSF quantitatively is the qualitative determination of whether or not Procedures are in fact a performance driver for the subject HFE. Levels used for this PSF in SPAR-H are:

- *Not Available*—the procedure needed for a particular task or tasks in the event is not available. However, this level should be used only if the analyst judges that the lack of procedures materially affects the error probability. If the analyst judges the Procedures PSF not to be a performance driver, then the Nominal level should be selected even though procedures might not be available.

- *Incomplete*—information is needed that is not contained in the procedure or procedure sections; sections or task instructions (or other needed information) are absent.

- *Available, but Poor*—a procedure is available but it is difficult to use because of factors such as formatting problems, ambiguity, or such a lack in consistency that it impedes performance.

- *Nominal*—procedures are available and enhance performance, or the analyst judges this PSF as not a performance driver.

- *Diagnostic/Symptom Oriented*—diagnostic procedures assist the operator/crew in correctly diagnosing the event. Symptom-oriented procedures (sometimes called function-oriented procedures) provide the means to maintain critical safety functions. These procedures allow operators to maintain the plant in a safe condition, without the need to diagnose exactly what the event is, and what needs to be done to mitigate the event. There will be no catastrophic result (i.e., fuel damage) if critical safety functions are maintained. Therefore, if either diagnostic procedures (which assist in determining probable cause) or symptom-oriented procedures (which maintain critical safety functions) are used, there is less probability that human error will lead to a negative consequence. This being said, if the symptom-based procedure is found to be inaccurate or awkwardly constructed, then the Procedures PSF should be negatively rated.

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives then assign this PSF level.

This PSF assesses the quality of procedures and other reference documents or information available to operators. If there is no procedure to cover the situation, then procedures are not available. The distinction between the levels “Incomplete” and “Available but poor” can be difficult to make, but generally, if a procedure is missing important information, it is “Incomplete.” If the procedure contains incorrect or inaccurate information, if it allows for or directs improper actions, or if it is difficult to use or understand, then it is “Available but poor.”

Contemporary control room operating procedures are written to be diagnostic or symptom oriented. There may be the temptation to credit this level automatically for the Procedures PSF. This has the effect of lowering the HEP by a factor of 10. The assignment of “Diagnostic/symptom oriented” for the Procedures PSF should only be undertaken when there is clear evidence that the procedures will quickly help the operators diagnose a situation that would otherwise be difficult or would take considerable additional effort to diagnose without particular procedural guidance. This is the exception, not the rule.

3.6 Ergonomics/HMI

Ergonomics refers to the equipment, displays and controls, layout, quality, and quantity of information available from instrumentation, and the interaction of the operator/crew with the equipment to carry out tasks. Aspects of the human-machine interface (HMI) are included in this category. The adequacy or inadequacy of computer software is also included in this PSF. Examples of poor ergonomics might be found in the panel design layout, annunciator designs, and labeling. Plant instrumentation generally corresponds to the Diagnosis aspect of crew performance, while plant controls correspond to the Action aspect.

When considering the panel design layout, event investigations at U.S. commercial nuclear facilities have shown that when necessary plant indications are not consolidated in one location, it is difficult for an operator to monitor all such indications to properly control the plant. If there is evidence that this is the case, a negative PSF value should be assigned.

Examples of poor annunciator designs have been found where only a single acknowledge circuit is used for all alarms, which increases the probability that an alarm might be cleared before it is recognized. A problem also exists when alarms have set points that are very close to the nominal value for a parameter. Additionally, alarm set points that do not correspond to the current mode of operation (e.g., at-power set points triggering alarms during low power) can result in a high number of inappropriate or nuisance alarms that may distract the operator or cause him or her to overlook relevant alarms.

Examples of poor labeling include instances where labels are temporary, informal, or illegible. Multiple names used for the same piece of equipment can cause confusion and create ambiguity in communication. Job performance aids can also be considered a special case of ergonomics. However, in SPAR-H, if the job performance deficiency is related to a procedure, then the preferred means of evaluating the situation is to apply this information to the Procedures PSF, as opposed to the Ergonomics PSF. For example, if the procedure does not match the equipment to be used, then the equipment-procedure deficiency should be noted in the Procedures, not the Ergonomics, PSF.

During low power and shutdown (LPSD) plant operations, certain information is assumed for the nominal ergonomics case. For Boiling Water Reactors this includes availability of reactor coolant system (RCS) level instrumentation and residual heat removal (RHR) system instrumentation. For Pressurized Water Reactors, this includes the availability of RHR system instrumentation, the availability of RCS temperature instrumentation, and the availability of RCS level instrumentation.

Levels of the Ergonomics/HMI PSF in SPAR-H are:

- *Missing/Misleading*—the required instrumentation fails to support Diagnosis or post Diagnosis behavior, or the instrumentation is inaccurate (i.e., misleading). Required information is not available from any source (e.g., instrumentation is historically so unreliable that operators ignore the instrument, even if it is registering correctly at the time). Note that this PSF level also includes failed and faulty instrumentation and indications.

- *Poor*—the design of the plant negatively impacts task performance (e.g., poor labeling, needed instrumentation cannot be seen from a work station where control inputs are made, or poor computer interfaces).

- *Nominal*—the design of the plant supports correct performance, but does not enhance performance or make tasks easier to carry out than typically expected (e.g., operators are provided useful labels; the computer interface is adequate and learnable, although not easy to use). Again, as with all PSFs, the nominal level should be assigned whenever the analyst judges the PSF as not a performance driver.

- *Good*—the design of the plant positively impacts task performance, providing needed information and the ability to carry out tasks in such a way that lessens the opportunities for error (e.g., easy to see, use, and understand computer interfaces; instrumentation is readable from workstation location, with measurements provided in the appropriate units of measure).

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level.

Included in Ergonomics and HMI is the quality and quantity of information available from displays and gauges, control sensitivity and panel layout, usability of tools and quality of materials, and control accessibility, among others. If instrumentation is inaccurate, incomplete, missing, or unavailable, then HMI is “Missing/Misleading.” Issues such as poor panel displays or layouts, inadequate control sensitivity or accessibility are best assessed as “Poor.” Note that although a typical control room console may not meet usability criteria of being intuitive or easy to use, the extensive training and experience of the crew allows them to interact with the system in an effective manner. They are able to get the information they need to monitor and diagnose plant states, and they are able to control all necessary parameters. Any deficiency in this basic functionality should be considered “Poor” or “Missing/Misleading.”

3.7 Fitness for Duty

Fitness for duty refers to whether or not the individual is physically and mentally suited to the task at hand. Issues that might degrade Fitness for Duty include fatigue, sickness, drug use (legal or illegal), overconfidence, personal problems, and distractions. Fitness for duty includes factors associated with individuals, but not related to training, experience, or stress (which are covered by other PSFs). Levels used in SPAR-H are:

- *Unfit*—the individual is unable to carry out the required tasks, due to illness or other physical or mental incapacitation (e.g., having an incapacitating stroke).

- *Degraded Fitness*—the individual is able to carry out the tasks, although performance is negatively affected. Mental and physical performance can be affected if an individual is ill, such as having a fever. Individuals can also exhibit degraded performance if they are inappropriately overconfident in their abilities to perform. Other examples of degraded fitness include experiencing fatigue from long duty hours; taking cold medicine that leaves the individual drowsy and inattentive; or being distracted by personal bad news (such as news of a terminal illness diagnosis of a loved one).

- *Nominal*—the individual is able to carry out tasks; no known performance degradation is observed. Nominal should also be used when the analyst judges the PSF as not a performance driver.

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level.

Fitness for Duty encompasses much more than fatigue, such as impairment due to drugs (prescription, over-the-counter, or illegal) or alcohol, distraction due to personal or family issues, whether a person is physically or mentally capable of performing a task, or boredom. These issues are rarely documented in event reports, however; so, the most common Fitness for Duty issue cited is fatigue.

Time of day plays a role in Fitness for Duty. For example, it is not unusual for persons to become drowsy in the early afternoon, after lunch. For individuals accustomed to a night shift, cognitive functioning in the early hours of the morning is poorer than during the day. In circumstances such as this, a PSF assignment of “Degraded Fitness” might be appropriate. The type of task a person is working on also influences fitness for duty: it is well documented that people are bad at extended vigilance or monitoring tasks. Performance typically drops after about 30 minutes of continuous monitoring.

3.8 Work Processes

Work Processes refer to aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies. How work is planned, communicated, and executed can affect individual and crew performance. If planning and communication are poor, then individuals might not fully understand the work requirements. Work Processes include consideration of coordination, command, and control. Work Processes also include any management, organizational, or supervisory factors that may affect performance. Examples seen in event investigations are problems due to information not being communicated during shift turnover, as well as communication with maintenance crews and auxiliary operators.

The shift supervisor also plays a major role in Work Processes. Instances where the shift supervisor gets too involved in the specifics of the event—in contrast to maintaining a position of leadership in the control room—would indicate a breakdown in Work Processes.

Conditions with effects adverse to quality are also included in the Work Processes category, as are problems associated with a safety-conscious work environment. This includes retaliation by management against allegations as it pertains to a failure event under investigation. For example, the analyst must decide whether utility management actions against maintenance staff have any bearing on a particular control room action or maintenance action under evaluation. If the analyst believes there is such evidence, then the appropriate negative level for Work Processes PSF might be assigned.

Additionally, any evidence obtained during the review of an operating event indicating inter-group conflict or indecisiveness (e.g., between engineering and operations), or an uncoordinated approach to safety, is evaluated in SPAR-H as a Work Process problem. Schisms between operators and management are also considered Work Process problems.

SPAR-H does directly acknowledge potential problems between the regulator and licensee as they might affect operator and crew performance. It is assumed that problems in communication or adherence to enforcement actions or notices are indicative of Work Process problems.

Finally, inadequacies in the utility corrective action program (CAP), such as failure to prioritize, failure to implement, failure to respond to industry notices, or failure to perform root cause analyses as required by regulation, are considered in SPAR-H as a Work Process issues. Because there are so many potential areas of concern within the Work Process category that influence assignment of a PSF level, the analyst is directed to provide as much information as possible in the worksheet space provided, listing the reasons for assigning a particular Work Processes PSF level.

Levels used for this PSF in SPAR-H are:

- *Poor*—performance is negatively affected by the work processes at the plant (e.g., shift turnover does not include adequate communication about ongoing maintenance activities; poor command and control by supervisor(s); performance expectations are not made clear).

- *Nominal*—performance is not significantly affected by work processes at the plant, or work processes do not appear to play an important role (e.g., crew performance is adequate; information is available, but not necessarily proactively communicated). The analyst should select nominal when the PSF is judged as not a performance driver.

- *Good*—work processes employed at the plant enhance performance and lead to a more successful outcome than would be the case if work processes were not well implemented and supportive (e.g., good communication; well-understood and supportive policies; cohesive crew).

- *Insufficient Information*—if you do not have sufficient information to determine if this is a performance driver or to choose among the other alternatives, assign this PSF level.

Work Processes is a “catch-all” PSF, encompassing organizational and management issues, cultural issues, safety culture, communications, crew dynamics, work planning and scheduling, supervision, conduct of work, and problem identification and resolution. The assignment of “Poor” or “Good” should follow from clear indications that aspects of work processes degraded or enhanced performance. For example, simply having a crew that communicates well is not sufficient reason to credit “Good” for Work Processes. If, on the other hand, good communication clearly helped to quickly diagnose an event at the plant, it would be appropriate to credit Work Processes as “Good.” Because so many factors are encompassed under Work Processes, it might be possible that a particular situation both features positive and negative aspects of the same PSF. In such cases, the most dominant factor should be considered as the main weighting factor. Precedence may be given to factors that degraded performance in such cases.

4. Step-3 – Calculate PSF-Modified HEP

Once the PSFs levels have been assigned, then the final HEP is simply the product of the nominal HEP and the PSF multipliers. When Diagnosis and Action are combined into a single HFE, the two HEPs are calculated separately and then summed to produce the composite HEP. The analyst should note that HEPs are probabilities of the union of Diagnosis and Action and should be calculated accordingly. The SPAR-H documentation in (Gertman et al., 2005) does not limit the probability of the union of Diagnosis and Action, meaning it is possible to have a value exceeding 1.0. However, if the two probabilities are small, then the Rare-Event approximation (i.e., the simple arithmetic sum) is acceptable. In the event that a combined Diagnosis and Action HEP approaches or exceeds 1.0, the following equation should be applied:

$$HEP(Diagnosis+Action) = HEP(Diagnosis) + HEP(Action) - [HEP(Diagnosis) \times HEP(Action)]$$

If multiple PSFs have been judged to negatively impact an HEP, then there is the possibility that the final individual HEP might be greater than one. If this is the case, then an *adjusted* PSF is calculated and used in the formula provided in the worksheets:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot \left(PSF_{composite} - 1\right) + 1}$$

where $NHEP$ is the respective nominal HEP for Diagnosis and Action and $PSF_{composite}$ is the product of the PSF level multipliers. This formula will ensure that the individual Diagnosis and Action HEP values do not exceed a probability limit of 1.0.

5. Step-4 – Accounting for 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 human failure event, but could be a success event) results in a change to the probability of a subsequent human failure event. Mathematically for two events “A” and “B” this is simply stated as:

$$
\begin{aligned}
P(A*B) &= P(A|B) * P(B) \\
&= P(B|A) * P(A) \\
&\neq P(A) * P(B)
\end{aligned}
$$

In 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.

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. At the HFE level, which typically involves multiple tasks, 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. 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.

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.

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.

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 higher level of the HFE.

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 still in development and not available at this time. 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.

In order to determine whether dependence is present between HFEs, 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 accident scenario,
- Important plant/equipment status and performance, and
- The context surrounding the tasks described in the HFE.
    - Performance drivers, PSFs.
    - Causal connections from previous activities and/or equipment issues.

For 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 full-power conditions. In full-power situations, instrumentation and procedures may serve as additional cues to aid the operator in diagnosing the situation and breaking out of an incorrect mindset, thus breaking dependence. 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.

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.

5.1 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:[a]

> “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).”

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

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.

It is a question of 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.

6. Step-5 – Minimum Value Cutoff

In past applications of HRA in general, and SPAR-H in particular, questions have arisen concerning extremely small HEPs. Basically, the question is: how small can an HEP (or combination of HEPs in a sequence or cut set) become before it becomes unrealistic and unbelievable? As HEPs become smaller and smaller, the associated potential failure mechanisms become more and more incredible (but not impossible). At what point does the calculated HEP fall below the likelihood of very incredible (but possible) failure mechanisms, which are *not* being accounted for in the calculated failure probability?

This concept can be illustrated with a simple example. Based on the well known Framingham Heart Study, the average rate of death from a heart attack in men ages 40–50 is about 10^{-6}/hr. Consequently, for calculated HEPs in the range of 10^{-2} to 10^{-4}, the contribution to the failure probability from incredible events like heart disease is insignificant and can be ignored. However, if a calculated HEP is in the range of 10^{-6} or lower, now the contribution to the total failure probability from death caused by heart disease is a significant contributor and needs to be accounted for in the HEP quantification. Or more specifically, how is a human error probability of 10^{-6} credible, when the probability of that operator becoming incapacitated (from a heart attack) is 10^{-6}?

When HEPs are being pushed down to the 10^{-6} range (literally, one in a million), failure mechanisms that would otherwise be judged to be insignificant contributors to the total failure probability and consequently could be ignored, now become relatively important contributors that need to be included in the HEP estimate. There exist a virtually infinite number of potential failure mechanisms; as probabilities become smaller and smaller, more and more of these incredible failure scenarios become relevant to the failure modeling. It is for this reason that the lower bound on a single HEP in SPAR-H is suggested to be 10^{-5}.

For situations where there is extensive time available or other extenuating circumstances that would support a very low HEP, the validity of very low probabilities would require estimating the likelihood of the operators committing an error that was simply not recoverable. The concern then is not one of: given enough time, surely the operators would eventually get it right, but what is the chance (1 in a million?) that a mistake is made that prevents further efforts at getting it right? The TMI accident is an example where many hours were available but still mistakes were made. Empirical evidence suggests that HEPs in such a low range can only be associated with highly repetitive, highly skilled actions, such as weapons disassembly. Again, more thought and research are needed to provide a basis for extremely low HEP estimates. A recent report that explores this issue further is (EPRI, 2010).

The analyst should understand that typical post-initiator HEPs are expected to be in the range of 0.1 to 10^{-4} (see section 5.3.3.8, page 5-17 of NUREG-1792; Kolaczkowski, Forester, Lois, & Cooper, 2005).

The *Good Practices for HRA* document (Kolaczkowski,et al., 2005) does not address the issue of a lower bound on a single HEP, but recommends a joint HEP lower bound of 1E-5 for sequences or cut sets containing more than one HFE. After conferring with the authors of the *Good Practices* document, it is clear that this lower bound was motivated principally by concerns about dependence among HFEs in a cut set. Essentially, it was included to ensure that analysts consider dependence between HFEs in a cut set or sequence, but was not intended to constitute a hard and fast lower limit. It is permissible that a joint HEP be lower than 10^{-5} if there is a good basis for little or no dependence among the HFEs appearing in the sequence or cut set.

7. References

Boring, R. L., & Blackman, H. S. (2007). "The origins of the SPAR-H method's performance shaping factor multipliers," *Proceedings of the Joint 8th IEEE Conference on Human Factors and Power Plants and 13th Annual Workshop on Human Performance/Root Cause/Trending/Operating Experience/Self Assessment*, August, 2007, Monterey, CA, 177-184.

Electric Power Research Institute, *Establishing Minimal Acceptable Values for Probabilities of Human Failure Events: Practical Guidance for Probabilistic Risk Assessment*, Interim Report, EPRI-TR-1021081, October 2010.

Gertman, D., Blackman, H., Marble, J., Byers, J., & Smith, C. (2005). *The SPAR-H Human Reliability Analysis Method*, NUREG/CR-6883, US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC.

Kolaczkowski, A., Forester, J., Lois, E., & Cooper, S. (2005). *Good Practices for Implementing Human Reliability Analysis*, NUREG-1792, US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC.

Spurgin, A. (2009). *Human Reliability Assessment Theory and Practice*, Boca Raton, FL: Taylor and Francis Group, LLC.

Swain, A. D., & Guttman, H. E. (1983). *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, Final Report*, NUREG/CR-1278, US Nuclear Regulatory Commission, Washington, DC.

US Nuclear Regulatory Commission/Electrical Power Research Institute. (2009). *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines, Draft Report, NUREG-1921,* US Nuclear Regulatory Commission, Washington, DC